PHYSIOLOGICAL AND MATCH PERFORMANCE CHARACTERISTICS OF FIELD HOCKEY PLAYERS

By

Vikki Leslie

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Abstract

This thesis aimed to examine the physiological and match performance characteristics of field hockey players in relation to age, sex and playing standard. The relationship between the physiological and match performance characteristics of players was also investigated.

In Chapter 4, the physiological characteristics of 159 elite male international U16, U18, U21 and senior (mean±*S.E*. age, 15±*0.1*; 16.9±*0.2*; 20.1±*0.2* and 24.9±*0.7* years respectively) players were profiled. Seventy-seven players completed a series of lab tests including: treadmill VO_{2peak}, repeated 10 x 6 s cycle ergometer sprints, maximum blood lactate concentration and running economy during submaximal treadmill running. Eighty-two players completed a 15 m sprint and a multi-stage fitness test. Field test characteristics of successful (went on to compete at senior international level) and unsuccessful (did not compete beyond junior international level) players were compared. Directly determined VO_{2peak} was not different when squads were compared (U16 *vs*. U18 *vs*. U21 *vs*. senior; 58.7±*0.9* *vs*. 60.5±*0.8* *vs*. 60.9±*0.9* *vs*. 59.7±*0.9*; $ml.kg^{-1}.min^{-1}$; $P>0.05$). Successful U21 players were faster over 15 m than unsuccessful U21 players (successful U21 *vs*. unsuccessful U21; 2.37±*0.02* *vs*. 2.44±*0.02*; s; $P<0.05$). These findings suggest that a high peak oxygen uptake of approximately 60 $ml.kg^{-1}.min^{-1}$ is a prerequisite for elite male hockey players from at least U16 level onwards. Sprint speed may be a key factor determining progression from junior to senior international level.

Chapter 5 examined the match performance characteristics of male U16 (16.0±0.3 years, n=8), U18 (17.8±0.1 years, n=14) and senior (25.7±0.6 years, n=16) elite level players. Players wore a non-differential GPS device (SPI Elite, GPSports, Australia) during at least one full match. Duration, distance covered, mean speed and maximum speed were obtained for the total match and the 1st and 2nd halves. Match activities were analysed in absolute terms and also relative to an individual's maximal speed. Results showed players from all age groups covered similar total distances (5385.0±*315.7*; 6608.4±*317.9*; 6260.4±*296.2*, m, U16 *vs*. U18. *vs*. senior, $P>0.05$) at similar mean speeds (8.0±*0.2* *vs*. 8.1±*0.3* *vs*. 7.6±*0.1*, $km.h^{-1}$, U16 *vs*. U18. *vs*. senior, $P>0.05$) and the majority of the movements completed by players could be categorised as low-moderate intensity (<14.5 $km.h^{-1}$) during match play (87.6 %, 86.7 % and 87.8 % for U16, U18 and senior players respectively). All age groups demonstrated fatigue during the second half of a match, but senior players exhibited the highest decrement in high intensity activity (>14.5 $km.h^{-1}$). Results from this study suggest that the activities associated with elite level hockey competition are predominantly low intensity. Similar demands are placed on elite players from U16 to senior level. Age-related differences in exercise metabolism are likely to account for differences in the fatigue profiles of high intensity activity over the course of a game.

Using the same methodology as Chapter 5, Chapter 6 sought to profile the match performance characteristics of elite female U16 (16.2±*0.1* years, n=7), U18 (17.6±*0.2* years,

n=5) and senior (24.5±*0.8* years, n=15) players. Amongst female players there were no differences between age groups in the distance covered (4962.3±*295.1 vs*. 5202.5±*155.5 vs*. 5581.1±*208.8* m, U16 *vs*. U18 *vs*. senior, *P*>0.05) the mean speed (23.3±0.6 vs. 23.5±0.7 vs. 24.3±0.3 $km.h^{-1}$, U16 *vs*. U18 *vs*. senior, *P*>0.05) during a match. While senior females completed more high intensity movement (>14.5 $km.h^{-1}$) than U16 players (5.0±*0.8 vs*. 7.5±*0.6* %, *P*<0.05), there were no other differences in the match activity profiles between age groups (analysed in absolute and relative terms). Senior females demonstrated a reduction in the amount of high intensity activity during the second half of a match. These results suggest that, similar to elite male hockey, elite female competition predominantly involves activity that can be classified as low-moderate intensity. The decrement in high intensity activity during the second half of a match in senior players may be related to performing significantly more high intensity bouts over the course of a game than younger players.

In Chapter 7, the relationship between the physiological and performance characteristics of 26 university level female players (20.8±0.5 years) was examined. The distance travelled during games in terms of low (0-6 $km.h^{-1}$), moderate (6-14.5 $km.h^{-1}$) and high intensity (>14.5 $km.h^{-1}$) movements was examined. Players also completed the Yo-Yo Intermittent Recovery Test level 1 (YYIRT), the Interval Shuttle Run Test (ISRT), the Multi-Stage Fitness Test (MSFT) and a laboratory assessment of speed at 4 $mmol.L^{-1}$ blood lactate concentration and a VO_{2max} test. The total distance covered during a match was associated with VO_{2max}, speed at 4 $mmol.L^{-1}$, YYIRT, ISRT and MSFT performance (Pearson's correlation coefficients; 0.58; 0.67; 0.67; 0.61; 0.58, respectively, *P*<0.05 in all cases). Mean speed was also related to VO_{2max}, speed at 4 $mmol.L^{-1}$, YYIRT, ISRT and MSFT (Pearson's correlation coefficients: 0.58; 0.71; 0.61; 0.62; 0.54 respectively, *P*<0.05 in all cases). The amount of high intensity activity, which may be an indicator of the quality of match performance was most closely associated with VO_{2max}, YYIRT and ISRT (Pearson's correlation coefficients: 0.60; 0.60; 0.54 respectively, *P*<0.01 in all cases). These results suggest that player performance during a match is related to their physiological characteristics. Such characteristics can be examined using both field and laboratory tests.

Chapter 8 examined the physiological, skill and match performance characteristics of three different competitive levels of female field hockey players. The players were recruited from the 1^{st} (n=13), 2^{nd} (n=10) and 3^{rd} (n=16) teams of Loughborough University Ladies Hockey Club. Players completed field based physiological assessments (YYIRT, ISRT, MSFT and 5,10, 20 and 30 m sprints) and a field based hockey specific dribbling test. Laboratory measures included treadmill VO_{2max} and a submaximal speed lactate test. Results from comparisons between teams did not indicate any differences based on any physiological or match performance parameters (*P*>0.05 in all cases). Superior dribbling skill, as assessed during a hockey-specific skill test, discriminated 1^{st} team from 2^{nd} and 3^{rd} team players (2.58±*0.22 vs*. 4.43±*0.28* and 3.90±*0.27* s, *P*<0.01, 1^{st} *vs.* 2^{nd} and 1^{st} *vs.* 3^{rd}). These results suggest that skill is crucial to determining success in competitive field hockey.

Based on the investigations outlined above it appears a relatively high maximal oxygen uptake is a prerequisite for elite level players from junior to senior levels, although it probably does not distinguish between playing standards. In contrast both short distance speed and skill would seem to discriminate between different standards of field hockey performance. Therefore, in order to succeed at the elite level of field hockey players must possess a certain degree of speed, aerobic power and hockey specific dribbling ability. In terms of match play, it would appear that the demands placed on elite junior and senior players during match play are very similar and this observation may explain why a relatively high aerobic power is required even at junior level. Match performance (in particular with respect to high intensity activities) may be different between elite and sub-elite players and because there appears to be a strong link between physiological and match performance characteristics, laboratory and field based assessments may be used to provide an indication of a player's likely physical performance during a match.

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Preface

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Chapter 1. Introduction

Field hockey is an intermittent sport played by males and females of all ages around the world. Despite the popularity of the game, relatively little is known about the physiological and match performance characteristics of field hockey players. A more detailed understanding of the characteristics and of the demands placed upon players could benefit the training of players and aid the identification and development of individuals with the potential to progress to elite levels of competition and ultimately perhaps to international level.

Some past studies have sought to examine the physiological profiles of field hockey participants (e.g. Withers *et al*., 1977; Withers *et al*., 1981; Ready *et al*., 1986; Reilly and Bretherton, 1986), however the majority of this research is dated and its relevance to the current version of the game is questionable as the surface on which the game is played (water-based, artificial) and a number of rule changes (repeated substitutions) have altered patterns of play and the demands on players. In addition, there is very little literature pertaining to the development of the physiological characteristics and match demands on young hockey players. Whilst an attempt to bridge this gap has been made in recent years with several studies examining the characteristics of young Dutch hockey players (Elferink-Gemser *et al*., 2004; Elferink-Gemser, 2005; Elferink-Gemser *et al*., 2006), the focus on the physiological characteristics of players in these studies was limited and made no comparison with adult data.

In particular, there is a dearth of information regarding match performance in field hockey. Due to the inherent unpredictability of such sports, quantifying and evaluating the activity of players during game play has proved problematic. Previous studies have attempted to profile the match activity patterns of field hockey using video time-motion analysis techniques (Lothian and Farrally, 1994; Boddington *et al*., 2002; MacLeod *et al*., 2007; Spencer *et al*., 2004), however, such methods are time-consuming and the classification of movements is very subjective. The advent of automated video-tracking and global positioning systems provides an objective measure of activity during match play. Whilst there are practical and financial limitations to the use of automated video tracking systems (e.g. ProZone) in field hockey, global positioning systems (GPS) offer a more portable and affordable method for examining activity during matches. While non-differential GPS has been shown to be a valid and objective method for assessing the movement patterns occurring during competitive field hockey (MacLeod *et al*., 2009), to date this technology has not been utilised to profile the match performance characteristics of field hockey players.

While some data concerning the match performance characteristics of field hockey players is available, there is no research on the activity patterns of young players during a match, or how activity profiles may change as players age. Understanding the age-associated demands placed on players during competition can help to structure and specify training programmes and can highlight the characteristics necessary for high quality match performance.

To summarise, currently there is a lack of research examining the physiological and match performance characteristics of field hockey players, particularly with reference to young players. This thesis aims to address this gap in the literature by profiling the physiological and performance characteristics of field hockey players in relation to age, sex and playing standard. The relationship between physiological and performance characteristics will also be examined to determine whether attributes measurable in the field and laboratory are related to physical performance during a game.

The remainder of this thesis will be presented as follows:

- **Chapter 2**: presents a review of the relevant literature; focussing on the existing information available regarding hockey match analysis; assessment of physiological and performance characteristics in intermittent sports players and the effect age may have on physiological characteristics associated with competitive match performance.
- **Chapter 3**: details the procedures, equipment and statistical analyses adopted for the collection and analysis of data.

- **Chapter 4**: Provides a cross-sectional analysis of the physiological characteristics of male international U16, U18, U21 and senior field hockey players.
- **Chapters 5 & 6**: Using GPS match analysis, the match performance characteristics of male and female elite U16, U18 and senior field hockey players were examined.
- **Chapter 7:** A series of laboratory and field based assessments were used to determine the relationship between physiological and match performance characteristics of female field hockey players.
- **Chapter 8:** The physiological, skill and match performance characteristics of female field hockey players from three different competitive standards are compared.
- **Chapter 9**: Provides a general overview and interpretation of the results from the five previous experimental chapters and discusses the implications of the research findings.

Chapter 2. Literature Review

2.1. Introduction

The purpose of this chapter is to provide a theoretical basis for the original research contained within this thesis. Findings and methodologies from a range of studies relevant to the theme of the physiological and performance characteristics of junior and senior field hockey players will be presented. The review of literature will focus on three principle topics. Firstly, the physical and metabolic demands of competitive field hockey will be examined. The subsequent sections will describe methodologies commonly adopted for the assessment of physiological and performance characteristics of players. The final section will discuss growth and maturation and the impact these processes have on the physiological characteristics associated with hockey performance.

2.2. Physical and Metabolic Demands of Competitive Field Hockey

Team sports such as soccer, rugby and hockey can be classified as intermittent sports and are characterised by repetitive bouts of high intensity activity interspersed with variable periods of rest or exercise of low to moderate intensity (e.g. walking, jogging) (Maughan and Gleeson, 2004). Activity patterns during matches are predominantly unpredictable and large variation exists between players and from match to match. Multiple factors such as the level of the opposition and the tactical approach can clearly influence the demands placed on players and hence their activities during match play. Limited research has focussed on hockey, with much of the existing match analysis research focussing on soccer. Whilst the patterns of activity in soccer have been investigated to some extent, there is a dearth of information regarding activity patterns in field hockey.

Hockey matches are 70 min in duration and players have been reported to complete around 1000 changes in activity (approximately once every 4 s) (Lothian and Farrally, 1992) with female players reported to cover up to 9.5 km (Gabbett, 2010) over the course of a match. Based on the literature, the majority of activity may be classified as low intensity in nature with periods of high intensity superimposed. A video-based time-motion analysis study of female hockey players in the 1990s reported 78% of match time comprised of low intensity activities (walking, standing and jogging) and 22% of the match spent involved in high intensity activity (jogging backwards/sideways, cruising, cruising backward/sideways, sprinting and hockey related activities) (Lothian and Farrally 1992; 1994). However, more recent studies suggest that an even higher proportion of time is spent engaged in low intensity activities. Several studies have found players to spend >90% of a match in low to moderate intensity activities with as little as 3-8% of time spent in high intensity activities (Boddington *et al*., 2002; Spencer *et al*., 2004; MacLeod *et al*., 2007, Gabbett, 2010). Inconsistencies in the measurement techniques and activity classifications make direct comparisons between studies difficult. However, these investigations highlight the importance of well developed aerobic and anaerobic energy systems to the elite hockey player.

2.2.1 Aerobic Energy Production in Field Hockey

Field hockey is an intermittent team sport which is aerobically demanding (Reilly and Borrie, 1992). Direct measurement of metabolic responses in sports such as hockey have proved impractical as such measurements are likely to interfere with normal play. Replicating the demands of such sports in the laboratory has also proved difficult due to the inherent unpredictable changes in match tempo and the demands placed on players. An indirect estimation of the physiological demands placed on players during competition can be obtained by monitoring heart rate responses. In elite female hockey players mean heart rate values of around 170 $beats.min^{-1}$ have been reported (Lothian and Farrally, 1992; MacLeod *et al*., 2007). Elite men have been shown to have an average heart rate of around 160 $beats.min^{-1}$ during a match with 64% of total match time spent at intensities eliciting a heart rate of >75% HR_{max} (Boyle *et al*., 1994; Johnston *et al*., 2004).

Using heart rate and VO_2 data collected during treadmill running in the laboratory it is possible to produce individual regression equations which describe the relationship between heart rate and oxygen consumption. Such equations can then be applied to the heart rate data obtained during competitive play to provide an estimation of energy expenditure. Research using this methodology has shown elite male players exercise at a mean relative intensity of 78% VO_{2max} during a match with an energy expenditure of 74.2

$KJ.min^{-1}$ (Boyle *et al*., 1994), whilst females players reportedly expend on average 55.3 $KJ.min^{-1}$ during a game (Lothian and Farrally, 1992).

2.2.2. Anaerobic Energy Production in Field Hockey

Whilst field hockey may be viewed as a largely aerobic activity, lower intensity periods are punctuated by brief, intense bouts of activity (Reilly and Borrie, 1992). Video-based match analysis of elite male and female players suggests players spend around 6-8% of a match engaged in 'high intensity' activities, completing on average 30 and 24 sprints, respectively, over the course of a game (Spencer *et al*., 2004; MacLeod *et al*., 2007). The mean sprint duration in field hockey has been reported to be between 1.8-3.1 seconds (Lothian and Farrally, 1994; Spencer *et al*., 2002; Spencer *et al*., 2004; MacLeod *et al*., 2007). Although these sprints make up only a small portion of total match play, such activities are often crucial to the outcome of a match (Di Salvo *et al*., 2009). Therefore an appreciation of the metabolic demands of such sprint exercise is important to understanding the demands placed on players during match-play.

Numerous studies have examined the energy system contribution during maximal sprint exercise, typically investigating metabolic responses to sprints of 6 to 30 s in duration. However, as previously noted, such sprint durations are considerably longer than the average 2-3 s sprints observed during competitive hockey. During a 3 s sprint, it is estimated that the majority (55%) of energy is derived from PCr degradation, 32% from anaerobic glycolysis, 10% from ATP store with a small (3%) aerobic contribution (Spencer *et al*., 2005).

In the laboratory, ATP stores have been shown to decrease minimally (8-16%) during 6 s sprint exercise (Boobis *et al*., 1982; Gaitanos *et al*., 2003; Dawson *et al*., 1997). Furthermore, after an intense period of first half soccer play, ATP concentrations were shown to fall by only 3% (Krustrup *et al*., 2006). However, following intense activity in the second half, ATP was 14% lower than resting values (Krustrup *et al*., 2006), which may suggest that repeated bouts of high intensity activity have a cumulative effect on ATP depletion over the course of a match. From these studies it would appear that muscle ATP is largely preserved during short term maximal exercise.

Muscle PCr concentrations are thought to be large enough to sustain maximal sprinting for around 5 s (Newsholme, 1986). However, the contribution of other energy systems to ATP supply prevent PCr stores from being depleted completely during short-term maximal exercise. Krustrup and colleagues (2006) examined changes in PCr concentration during soccer matches. Muscle biopsies were obtained at rest and after periods of intense activity which included fast running (>18 $km.h^{-1}$) and sprinting (>25 $km.h^{-1}$). Compared with resting values (88*±2* $mmol.kg^{-1}$.d.w.), PCr was significantly depleted after intense activity periods in the first and second halves (76*±3* and 67*±3* $mmol.kg^{-1}$.d.w. respectively) (Krustrup *et al*., 2006). However, resynthesis of PCr has been reported to be as high as 0.5 $mmol.kg^{-1}.d.w.s^{-1}$ and as biopsy samples in the aforementioned study were collected 15-30 s after cessation of exercise, PCr values reported may not reflect the true extent of PCr depletion during high intensity match activities.

Early work examining the glycolytic contribution to short term high intensity exercise suggested that anaerobic glycolysis was activated only after PCr stores were fully depleted (Margaria *et al.*, 1964). However, more recently it has become clear, primarily from measurements of muscle and blood lactate, that the glycolytic pathway plays a substantial role in energy production during sprint-type activities. Muscle lactate values of around 40 $mmol.kg^{-1}$.d.w. have been reported after 6 s maximal sprint cycling (Dawson *et al.*, 1997) and net increases of 4 $mmol.kg^{-1}$.d.w. in muscle lactate have been found following 1.28 s of maximal/near maximal electrical stimulation (50 Hz) (Hultman and Sjoholm, 1983). In field hockey, post-match blood lactate values of 5.6 $mmol.L^{-1}$ have been reported (Ghosh *et al.*, 1991) which are similar to the 5-6 $mmol.L^{-1}$ measured in soccer players following intense match activity (Krustrup *et al.*, 2006). In the same study, individual muscle lactate concentrations of over 29 $mmol.kg^{-1}$.d.w. were observed after intense periods of play in the first and second half (Krustrup *et al.*, 2006). Therefore based on studies examining short term maximal exercise in the laboratory and the high blood lactate and moderate muscle lactate concentrations reported during match-play, it would appear that the rate of anaerobic glycolysis is high for short periods of time during high intensity efforts associated with intermittent team sports.

2.2.3. Repeated Sprints

Whilst the previous section highlighted the metabolic changes that occur during single maximal or near maximal effort sprints, field-based team sports such as hockey are characterised by repeated periods of high intensity activity. On average, elite level male and female players are reportedly required to sprint approximately once every 2 min during competitive play (Spencer *et al*., 2004; MacLeod *et al*., 2007). Match analysis of field hockey therefore suggests that sprints of 2-3 seconds in duration occur, on average, every 2 minutes. With such short duration bouts of high intensity activity punctuated by considerable recovery periods, it is doubtful that such sprint profiles would impact negatively on match performance. Balsom *et al*. (1992) demonstrated that during 15 x 40 m sprints separated by either 30, 60 or 120 s recovery, performance was not affected until the 3rd, 7th and 11th sprint respectively. However, the 40 m distances examined are likely to be greater than those typically observed during competitive field hockey. In the same study the initial 15 m initial acceleration period of the 40 m sprint was examined and was shown to only be affected during the shortest (30 s) recovery period with sprint time increasing from a mean of 2.58 s (sprint 1) to 2.78 s (sprint 15) (Balsom *et al*., 1992a). A subsequent study demonstrated that 40 x 15 m sprints could be repeated every 30 s without any decrement in performance. Whilst conversely, repeated 30 and 40 m sprint times increased significantly with the same 30 s recovery period (Balsom *et al*., 1992b). Therefore based on this evidence, the average 120 s recovery period observed between short duration sprints during competitive play would appear to be sufficient to maintain sprint performance throughout a match. However, the argument above is based on mean match data. In reality, the frequency of sprints completed, sprint duration and the recovery time between sprints varies from player to player and can depend on the period of match observed. Large standard deviations for the number of sprints completed over the course of a game have been reported for elite male (30±14; Spencer *et al*., 2004) and female (24±12; MacLeod *et al*., 2007) hockey players, highlighting individual differences in the demands placed on players. Spencer and colleagues (2004) also noted a considerable range in maximal sprint duration (1.5-10.0 s) amongst players. High intensity periods during a match may require players to complete several sprints in quick succession with limited recovery. The only study to date specifically examining repeated sprints during a single game defined 'repeated sprint' activity as a minimum of 3 sprints with a mean recovery duration between sprints of less than 21 s (Spencer *et al.*, 2004). This criteria was met on 17 occasions during an international match. On average players completed 4 sprints during a 'repeated sprint' bout with a mean recovery time of 14.9 s between sprints (Spencer *et al.*, 2004). Therefore, whilst expressing sprint/high intensity activities as averages over the course of a game may prove useful for illustrating work to rest ratios, it is clear that such methods do not properly represent the intermittent high intensity nature of team based sports such as field hockey. Understanding the metabolic effects of performing repeated maximal or near maximal efforts is important in recognising the competitive demands placed on players and is crucial in the optimisation of training.

2.3 Assessment of Physiological Characteristics

2.3.1. Introduction

The previous section provided an introduction to the physical and metabolic demands associated with competitive field hockey. From the available evidence, it appears that well developed aerobic and anaerobic metabolic pathways are important for successful competition. Laboratory-based protocols of such characteristics have been well-documented elsewhere (e.g. Gore, 2000; Eston and Reilly, 2001), however, such methodologies may not be viable when a whole team of players is to be tested, therefore the following section will focus on field-based assessments which are frequently used in the physiological assessment of intermittent sports players.

2.3.2 Field-Based Assessment of Physiological Characteristics

Whilst physiological testing of athletes in the laboratory may provide accurate assessment of an athlete's maximal and submaximal exercise performance, such tests are time consuming, require specialised equipment and trained personnel. Field-based tests offer an alternative to laboratory assessments and can be easily conducted by coaching/support staff permitting testing of an entire squad within a relatively short time period. When considering which field test to use, there are a number of factors to consider. Firstly it is important to select a test which will measure variables specific to the sport in question. In addition, to ensure results from the test are providing quality, dependable information on the athlete(s) tested, the test must be valid, reliable and objective.

For a test to be considered valid it must provide appropriate, useful and meaningful results. The validity of a field test does not refer to the test itself, but to the interpretation of the results. Test validity can be established using criterion validity and/or construct validity. Criterion validity requires assumptions of the test to be tested against an established method (e.g. laboratory VO_{2max}) (Thomas *et al.*, 2005). If field test results are shown to correlate with an established measure, it is said to have criterion validity. Construct validity refers to the ability of a test to discriminate between groups of athletes of different standards.

The reliability of a test refers to the consistency of results obtained from the test, either on the same day (repeatability) or over several days (reproducibility). Results from a test are comprised of two components: the true score (the portion of the test result which reflects an individual's true performance) and the error score (reflecting the part of the test result which may be influenced by additional factors e.g. environmental conditions, test familiarity or motivation). The reliability is therefore effectively a measure of the error associated with the test. The error is typically interpreted using the coefficient of variance (CV) where a large CV generally indicates poor test reliability. The following sections will examine three field tests commonly used amongst intermittent sport players.

2.3.3. Multi-stage Fitness Test

A number of attempts have been made to develop field-based assessments of VO_{2max} with protocols requiring participants to cover as much distance as possible in a given time (e.g. Cooper *et al*., 1970) or to cover a set distance in as short a time as possible (e.g. Getchell *et al*., 1977; Ramsbottom *et al*., 1987). Obvious drawbacks to such protocols are that they are almost maximal from onset and require participants to pace themselves throughout the test (Shepard, 1984). During the 1980s however, a progressive maximal multi-stage test for estimation of VO_{2max} was developed (Léger and Lambert, 1982). Participants were required to repeatedly run 20 m shuttles at a pace dictated by audio signals from a tape/CD player. The aim of the test is to complete as many 20 m runs as possible (i.e. to exhaustion). Test performance can then be used to predict VO_{2max}. Initially the test consisted of participants completing repeated 20 m runs with the speed increased by 0.5 $km.h^{-1}$ every 2 minutes (Léger and Lambert, 1982). Test stages were later modified to last 1 minute (i.e. 0.5 $km.h^{-1}$

increment every 60 s) as this was deemed more suitable for use with younger participants (Léger *et al*., 1988). Further development of the test by Ramsbottom and colleagues (1988) has led to the commercial availability of the Multi-Stage Fitness Test (MSFT) with it becoming the most commonly used field test for prediction of VO_{2max} (Cooper *et al*., 2005).

Early work on the MSFT claimed the test to be valid and reliable for prediction of VO_{2max} in adults with a test-retest correlation of r=0.92 (standard error of the estimate [S.E.E.] 2.0 $ml.kg^{-1}.min^{-1}$) (Léger and Lambert, 1982). Using backward extrapolation of the O_2 recovery curve obtained at the end of the MSFT, it was demonstrated that VO_{2max} could be predicted from the maximal speed obtained during the test (r=0.84, S.E.E. 5.4 $ml.kg^{-1}.min^{-1}$) (Léger *et al*., 1980). Further, Léger and colleagues (1988) found the adapted 1 minute stage protocol was reliable in both children (r=0.89) and adults (r=0.95), with no differences between test-retest performances (P>0.05). In the same cohort, VO_{2max} could be predicted from test performance in adults (r=0.90, S.E.E. 4.7 $ml.kg^{-1}.min^{-1}$) and in children using an age-specific equation (r=0.71, S.E.E. 5.9 $ml.kg^{-1}.min^{-1}$). The validity of the MSFT as a test for predicting VO_{2max} was supported further with findings that VO_{2max} predicted from the MSFT correlated highly with laboratory treadmill assessment of VO_{2max} (r=0.92, P<0.01) (Ramsbottom *et al*., 1988).

Whilst the previous examinations of the MSFT have used statistical tests such as correlation coefficients to examine the reliability and validity of the MSFT, such statistical procedures have received criticism for primarily providing an indication of a relationship between two variables rather than an indication of agreement (Bland and Altman, 1986; Nevill, 1996). Alternatively, 95 % limits of agreement is a statistical test proposed to provide a more robust indication of the absolute reliability of a test (see Bland and Altman, 1986). A recent examination of the repeatability and validity of the MSFT using 95 % limits of agreement reported conflicting results with those which had adopted less appropriate statistical analyses. Contradicting much of the existing MSFT literature, Cooper *et al.*, (2005) concluded that the MSFT did not provide valid predictions of VO_{2max}, and whilst it was repeatable, the MSFT routinely underestimated VO_{2max} when compared to laboratory assessments. From these results, the authors highlighted the need for exercise scientists to ensure that appropriate statistical methods are adopted when examining and reporting the validity and repeatability of commonly used tests (Cooper *et al.*, 2005).

From research in soccer, it appears that the MSFT may be limited in terms of test performance differentiating between players from different competitive standards. In soccer players, MSFT performance was not significantly different between academy players (contracted to a professional soccer club) and recreationally active soccer players (from a university population) with estimated MSFT VO_{2max} values of 57.4±*4.7* vs. 54.3±*5.1* $ml.kg^{-1}.min^{-1}$ respectively (Edwards *et al.*, 2003). Similarly, when MSFT performance of three varying standards of soccer player (professional, high-level amateur and low-level amateur) were compared, there were no differences between level of competition (P>0.05) (Lemmink *et al.*, 2004). It has been argued that the continuous maximal protocol of the MSFT bears little relevance to the intermittent nature of team sports such as soccer and field hockey (Lemmink *et al.*, 2004; Svesson and Drust, 2005) and may explain its lack of discriminatory power between players of differing standards. However, further investigation is required to establish the relationship between MSFT performance and performance during intermittent team sports.

2.3.4. Interval Shuttle Run Test

High level performance in intermittent sports such as hockey, soccer and rugby requires players to perform high intensity running and sprinting but also have the ability to recover during lower intensity activities (Lemmink *et al*., 2004). In order to assess this 'interval endurance capacity' (Lemmink and Visscher, 2003), the Interval Shuttle Run Test (ISRT) (Lemmink *et al*., 2000) was developed. To more closely replicate the demands placed on intermittent games players, creators of the ISRT modified the MSFT in 3 ways: (i) the initial running speed of the ISRT is higher than that of the MSFT (10 $km.h^{-1}$ vs. 8.0 $km.h^{-1}$) (ii) the ISRT running speed increases more rapidly up to 13 $km.h^{-1}$ than in the MSFT (1 $km.h^{-1}$ every 90 s vs. 0.5 $km.h^{-1}$ every 60 s) (iii) unlike the MSFT, the ISRT is not a continuous maximal test, instead, every 30 s of running is punctuated with 15 s of walking.

Investigations of the reliability of the ISRT have shown high relative reliability with ICCs of 0.90 (Lemmink *et al*., 2000) and 0.98 (Lemmink *et al*., 2004). The relationship between ISRT and laboratory VO_{2max} has been examined in male soccer players (Lemmink and Visscher, 2003) and female field hockey players (Lemmink and Visscher, 2006). Results demonstrated moderate correlations between performance in the ISRT and treadmill VO_{2max} (r=0.77, $P<0.05$) (Lemmink and Visscher, 2003) and ISRT performance and cycle ergometer VO_{2max}

(r=0.74, $P<0.01$) (Lemmink and Visscher, 2006). Based on correlation and regression analyses of the ISRT and several laboratory based tests (VO_{2max}, 10 s cycle sprint, 30 s cycle sprint) the authors concluded that during the ISRT energy is supplied predominantly by the aerobic energy system, with anaerobic energy sources also required due to the intermittent nature of the test (Lemmink and Visscher, 2006).

In order to establish construct validity of the ISRT, soccer players from three competitive levels (professional, high level amateur and low level amateur) completed the ISRT. Professional players completed more runs on the ISRT than either high or low level amateurs ($P<0.05$) however there were no difference between the performances of high and low level amateurs ($P>0.05$) (Lemmink *et al.*, 2004). However, as the authors noted, future investigations of the construct validity of the ISRT should include comparisons of ISRT performance and measure of competitive performance such as moderate and high intensity activities during match play (Lemmink *et al.*, 2004).

2.3.5. Yo-Yo Intermittent Recovery Test

Like the ISRT, the Yo-Yo Intermittent Recovery Test level 1 (YYIRT) (Bangsbo, 1994) was developed to replicate the intermittent nature of team sports with the aim of assessing an athlete's ability to repeatedly perform intense exercise and the ability to recover from high intensity activities. The test itself consists of repeated 20 m runs at increasing speed with each 20 m run punctuated with a 10 s active recovery period. The test is maximal and is deemed complete when the participant reaches volitional exhaustion or can no longer keep pace with the audio CD (Krustrup *et al*., 2003). Since its introduction, the YYIRT has been researched extensively in terms of reliability, validity, physiological response and relationship with match performance characteristics.

Investigations of the YYIRT have shown the test to have a reasonably high reliability. Krustrup and colleagues (2003) found no differences in test performance when the test was repeated after 7 days (Pearson correlation coefficient r=0.98, $P<0.05$; CV 4.9%). Similarly, Thomas *et al*., (2006) measured the test-retest reliability, reporting an intraclass correlation coefficient of r=0.95 ($P<0.01$) with a CV of 8.7%. Examination of the relationship between YYIRT and VO_{2max} has provided mixed results. A weak relationship of r=0.46 ($P<0.05$) has been reported between YYIRT performance and laboratory assessed VO_{2max} in amateur soccer players (Castagna *et al*., 2006). Conversely, stronger correlation coefficients of between 0.71 and 0.87 ($P<0.05$) have been demonstrated in several studies examining the relationship between YYIRT performance and VO_{2max} (Krustrup *et al*., 2003; Thomas *et al*., 2006; Rampinini *et al*., 2010). In addition, based on the analysis of 141 individuals, Bangsbo and colleagues (2008) obtained a correlation coefficient of 0.70 ($P<0.05$) between YYIRT and VO_{2max}.

Several studies have found YYIRT performance to discriminate between soccer players from different competitive levels. Top class soccer players (from an elite Italian team competing in the UEFA Champions League) have been shown to cover 11% more distance during the YYIRT than players of a moderate standard (playing professionally in the top Danish league)

(Mohr *et al*., 2003). More recently, a study reported similar findings with professional male soccer players performing around 20% better than amateur players (Rampinini *et al*., 2010).

Performance in intermittent team sports is difficult to quantify, however, match analysis techniques (discussed in the section 2.4) are often used to provide a measure of physical performance during competitive game-play. Correlations between YYIRT and match variables in professional male soccer players have shown significant relationships between performance in the YYIRT and the total distance covered during a match (r=0.53, $P<0.05$) and the sum of high speed running and sprinting (r=0.58, $P<0.05$) (Krustrup *et al*., 2003). The amount of high intensity running completed during a match is often considered a measure of the quality of soccer performance (Bangsbo, 1994) and importantly, YYIRT performance has been shown to correlate with high intensity running in professional male players (r=0.71, $P<0.05$) (Krustrup *et al*., 2003). Similar results were reported in elite female soccer, with YYIRT performance related to the distance covered (r=0.56, $P<0.05$) and the amount of high intensity activity (r=0.76, $P<0.01$) recorded during a match (Krustrup *et al*., 2005).

2.3.6. Field Test Summary

A review of the present literature suggests that the MSFT, ISRT and YYIRT all have potential applications in the physiological assessment of field hockey players. Performance in the YYIRT and ISRT appears to discriminate between players of different competitive levels which means these tests may have an important role in the assessment and selection of players. However, the majority of existing research has involved soccer players' performance, therefore the role of such tests in field hockey is yet to be determined. Similarly, there is a paucity of information regarding the relationship between performance in these field tests and performance during competitive match play, particularly with regard to the MSFT and ISRT. Again, hockey-specific investigations of field test performance and match activity profiles which establish the roles of such tests in assessing the physiological and performance characteristics of field hockey players have not been undertaken.

2.4. Assessment of Match Performance Characteristics

2.4.1. Introduction to Match Analysis

The importance of quantifying the physical demands placed on intermittent sports players has become increasingly recognised. Information obtained from match analyses can be used to provide valuable feedback to players and coaches with application in training regimes, fitness assessment and player selection (Roberts *et al*., 2006). Match analysis can give an indication of the physiological demands of match play, for example, total distance covered during a game can provide an indication of the overall exercise intensity of match play (Reilly, 1996). Such measures can then be broken down into discrete actions (e.g. walking, jogging, running, sprinting) for each individual player. Match activities of a player can then be presented according to type, duration, % match time, distance or frequency (Reilly, 1996).

Many of the existing time-motion analyses conducted amongst intermittent games players have used manual video-based methods to examine physical performance during competitive play. Whilst such methods have provided important information regarding activity profiles for field hockey, soccer and rugby players, there are a number of drawbacks and limitations associated with such methodologies. This method of analysis can prove time and labour intensive (Bloomfield *et al*., 2004); video footage recorded during a match is played back and each movement of a player is manually coded against reference values of specific movements obtained during calibration processes. This subjective classification of activities means there is potential for human error in the interpretation of individual movements. Video-based time-motion analysis is also often limited to observing a single player during a match. Even in situations where multiple players can be assessed, the amount of detail involved in the analysis means the time taken to produce comprehensive analyses is lengthy and not compatible with the intense competitive schedules of elite sport (Carling *et al*., 2008).

Within the last decade, technological advances have permitted the development of new systems to assess match performance characteristics of intermittent games players, including semi-automated camera methods (Di Salvo *et al*., 2007; Rampinini *et al*., 2007) and global positioning systems (GPS) (Edgecomb and Norton, 2006; MacLeod et al., 2009). These systems not only permit the simultaneous assessment of multiple players, but also provide objective measures of match activity. Whilst there is no "gold-standard" method for determining the movement pattern of players during matches, these methods must be valid, reliable and objective in order to provide accurate and meaningful data (Carling *et al*., 2008). Whilst automated video methods (e.g. ProZone and AMISCO Pro) have become popular among many of the English Premiership soccer clubs, financial constraints and the lack of mobility of such systems limits their use in sports such as field hockey. Global positioning systems potentially offer a more financially accessible and portable option to such automated systems. The following section will examine the available literature pertaining to GPS as a tool for assessing match performance characteristics.

2.4.2. Global Positioning Systems

Global positioning systems were initially designed for military use, but have increasingly become utilised as a method to assess activity patterns in intermittent sports (Larsson, 2003). The system uses 27 orbiting satellites, each equipped with an atomic clock, which synchronises with the clock of a GPS receiver on the earth's surface. Information on the exact time is constantly sent to the GPS receiver (at the speed of light) and by comparing the time of the satellite to that of the receiver, the signal travel (or lag) time can be deduced (Larsson, 2003). Multiplying the lag time by the speed of light establishes the distance of the receiver from the satellite. Using trigonometry, the exact position and altitude of the GPS receiver can then be determined by calculating the distance to at least four of the orbiting satellites (Larsson, 2003). Until the 1990s, the US Department of Defence included a deliberate error in the GPS signal. Since 2000, the deliberate error has been reduced, permitting increased accuracy of the system and thereby enabling its use in the sport setting (MacLeod et al., 2009).

Larsson (2003) highlighted several characteristics integral to the development of a sports-specific GPS receiver capable of providing measurements of sufficient accuracy and precision. In order to obtain such data, a nine channel (at least) GPS receiver with a sufficiently large memory capacity to store data on position, cumulative distance and speed should be used. Additionally, such a device should include a computer interface to enabling downloading and analysis of data. A receiver must have the capability to connect to a differential receiver and must have clear visibility to the sky (Larsson, 2003). Differential GPS equipment consists of two separate GPS receivers; one based at a station whose precise geographic coordinates are known and the other can be mobile in the field (Gao, 2001). Use of differential systems is not always practical, particularly in the assessment of sports performance. Where access to a secondary, fixed receiver is not possible or practical, non-differential systems can be used. In recent years, manufacturers (e.g. GPSports, Australia; Catapult, Australia) have developed a number of devices for use in intermittent team sports. Such devices have become widely used by a number of different sports including soccer, rugby league and Australian rules football. Despite GPS analysis becoming increasingly common during training and competition, few studies have examined the reliability and validity of non-differential GPS technology in intermittent sports.

Edgecomb and Norton (2006) were amongst the first to examine the reliability and validity of commercially available non-differential sports GPS. Using Australian rules football players, the validity of GPS (SPI 10, GPSports, Australia) in determining the distances covered by players during match-play was assessed by players completing a pre-determined course, with the actual distance measured using a calibrated trundle wheel. Intratester reliability were examined during triplicate trials of the circuit. The accuracy and reliability of the system was found to be relatively high with a 4.8 % error rate in measuring total distance covered. The technical error of measurement (TEM), which can be described as a measure of precision (defined as the standard deviation of repeated measurements taken independently of one another) (Pederson and Gore, 1996) was reported as 5.5 %. The author's concluded that GPS could confidently be used in competition and/or training with the acknowledgement that true distances are likely to be overestimated by <7 % (Edgecomb and Newton, 2006). More recently, MacLeod and colleagues (2009) sought to assess the validity of non-differential GPS (SPI Elite, GPSports, Australia) for measuring player movement patterns during field hockey. A protocol designed to replicate activity patterns of competitive hockey was used to examine the validity of a GPS system by comparing GPS measures of distance and speed with the actual distance and speed as determined by a calibrated trundle wheel and timing gates, respectively. The mean distance recorded by the GPS was 6821 m and the mean speed was 7.0 $km.h^{-1}$ compared with the actual distance and speed of 6818 m and 7.0 $km.h^{-1}$. The authors reported a high correlation between GPS speed and speed measured using timing gates ($r=0.99$, $P<0.001$) and a mean difference and 95 % limits of agreement of 0.0±0.9 $km.h^{-1}$. Together these results suggest that using non-differential GPS to assess performance characteristics during match-play is a valid method and can provide essential, objective feedback to players and coaches

2.4.3. Match Analysis Summary

Much of the existing literature regarding activity profiles during intermittent sport has focussed on soccer. At present, nearly all the analyses of competitive field hockey have utilised video-based time-motion analysis, which lacks objectivity. In addition, comparisons of video-based, semi-automated and GPS match analysis methods have demonstrated large differences between the absolute distances covered, thus any comparison of data from analyses using differing methods should be treated with caution (Randers et al., 2010). With the development of techniques which are faster and permit multiple players to be monitored simultaneously, it is hoped that future match analyses of field hockey will adopt more objective methods which provide more insight into the performance of players during competitive matches.

2.5. Growth and Maturation

2.5.1. Overview of Growth and Maturation

Several chapters in this thesis will involve child and/or adolescent participants, it is therefore crucial to have an understanding of the impact growth and maturation can have on the metabolic, physiological and performance characteristics of an individual. Firstly it is important to differentiate and define the processes of growth and maturation. Growth refers to a change in size of an individual and is the result of three cellular processes; an increase in cell number (hyperplasia); an increase in cell size (hypertrophy) and an increase in extracellular substances (accretion) (Malina *et al*., 2004). Maturation is the process of becoming mature or the progress toward the mature state (Malina *et al*., 2004). Central to maturation are two components: timing and tempo. Timing refers to the point at which a specific maturational event occurs (e.g. attainment of menarche, peak height velocity) while tempo refers to the rate at which maturation progresses (Baxter-Jones and Sherar, 2007). Growth and maturation are related and both impact upon physical performance (Beunen and Malina, 1996).

2.5.2. Growth, Maturation and Exercise Metabolism

Growth and maturation mark a period of significant change in the metabolic profile of an individual and are associated with changes (often improvements) in many physiological performance measures including aerobic and anaerobic power (Armstrong and Welsman, 2007). Whilst much of this change can be attributed to maturity-associated changes in body size and composition, changes in endocrinology and the metabolic characteristics of muscle tissue during growth and maturation are also likely to impact upon the physiological responses to exercise and training. For example, it is often reported that children are better adapted to aerobic exercise, due to a heavier reliance on oxidative metabolism and reduced glycolytic activity compared to adults (Boisseau and Delamarche, 2000). Important factors to consider when examining the development of the hormonal and metabolic responses to exercise include changes in; muscle fibre type; energy stores; skeletal muscle enzymes and substrate utilisation. However, because investigations of such characteristics are typically invasive, ethical and methodological limitations have justifiably restricted research in younger populations.

2.5.2.1. Muscle Fibre Type

The influence of maturation of skeletal muscle fibre type composition may explain some of the age-associated variation seen in energy metabolism when children/adolescents are compared with adults. The muscle biopsy technique offers a direct method for investigating metabolism *in vivo*, however, it is an extremely invasive technique and therefore few studies have directly investigated the muscle fibre characteristics of young people.

An early biopsy study of Swiss children took samples from the vastus lateralis of thirteen 6 year-old boys and girls (Bell *et al*., 1980). The authors reported muscle tissue to be comprised of 58.8 % type I fibres (Bell *et al*., 1980). After comparing these results with the % type I fibres found in older boys (54.8 %, Eriksson *et al*., 1973), male and female athletes (50.2 %, Costill *et al*., 1976) and trained adult males (54.8 %, Gollnick *et al*., 1973) the authors concluded that the muscle fibre composition of children was in agreement with those reported in older children and adults (Bell, 1980).

In contrast to this, several subsequent studies have reported a higher proportion of type I fibres in children and adolescents, with the proportion decreasing as individuals get older. Oertel (1988) conducted an autopsy study using the vastus lateralis of 113 males and females aged from 1 week to 20 years. Results demonstrated that while the proportion of type I fibres increased during the first 2 years of life, the percentage of type I fibres of some 15-20 year olds tended to be less than in younger subjects. A second autopsy study (Lexell *et al*., 1992) sampled whole vastus lateralis muscle from 22 previously healthy males aged 5-37 years. The authors concluded that the proportion of type II fibres significantly increased from the age of 5 years (~35%) to the age of 20 years (~50%). This change in the fibre type composition of the muscle was attributed to transformation of type I fibres to type II fibres, rather than a decrease in the number of type I fibres within the muscle (Lexell *et al*., 1992).

Whilst these studies provide a cross-sectional insight into the muscle fibre changes that occur during growth and maturation, a number of factors including genetic variation and the degree of muscle use can influence muscle fibre composition (Gollnick *et al*., 1973; Gollnick *et al*., 1972). Longitudinal examination of the alterations in fibre types that occur with age would help determine to what extent these changes occur.

Glenmark and colleagues (1992) biopsied the vastus lateralis of 55 males and 28 females aged 16 years, and then at 27 years. In the female subjects, there were no significant changes in the fibre types, however, there was a tendency for an increase in type I fibres and a decrease in type II fibres with age (Glenmark *et al*., 1992; Glenmark *et al*., 1994). Conversely, in males there was a significant decrease in type I and a significant increase in type II fibres between 16 and 27 years of age (Glenmark *et al*., 1992; Glenmark *et al*., 1994).

The higher proportion of type I fibres in children/adolescents is thought to disappear during late adolescence (Fournier *et al*., 1982) and could explain, at least in part, the “immature” glycolytic system often reported in young people. Magnetic resonance imaging (MRI) techniques have been used in adults to determine muscle fibre distributions (Houmard *et* *al*., 1995; Kuno *et al*., 1988). The use of these techniques in younger populations could provide a non-invasive alternative for investigating the development of human muscle.

2.5.2.2. Energy Stores

Intramuscular stores of ATP are limited and alone can support maximal exercise for no more than 2 seconds. At the onset of exercise, hydrolysis of phosphocreatine (PCr) occurs almost instantaneously to resynthesise ATP. Phosphocreatine is rapidly depleted during very heavy exercise, therefore at least in the short term, glycogenolysis and glycolysis are required to maintain high intensity activity (Spriet, 2006). Endogenous stores of ATP, PCr and glycogen are therefore very important during exercise of a high intensity nature and age-related variation in these stores may effect the ability to produce and sustain such efforts.

The pioneering investigations of Eriksson and colleagues in the 1970s (Eriksson *et al*., 1971a; Eriksson *et al*., 1973; Eriksson and Saltin 1974; Eriksson, 1980) reported that ATP stores were not age-dependent, with values for 11-16 year old boys (~5 $mmol.kg^{-1}$ wet weight of muscle) similar to 4.8 $mmol.kg^{-1}$ wet weight of muscle reported in trained adult men (Karlsson *et al*., 1972). Similarly, examination of resting PCr levels in boys aged 11.6, 12.6, 13.5 and 15.5 years were found to be comparable with adult values (Eriksson and Saltin, 1974). Thus the evidence would suggest that muscle stores of ATP and PCr do not differ between children, adolescents and adults (Boisseau and Delamarche, 2000).

Liver and muscle glycogen stores are thought to be lower in children than adults (Bougnères, 1988; Schiffrin and Cole, 1989). Obvious limitations make determination of hepatic glycogen levels difficult and therefore knowledge is scarce, however, a review by Boisseau and Delamarche (2000) highlights the differences between infant (~15 g) and adult (~100 g) stores. The central nervous system in children has higher glucose uptake than in adults (4 vs. 1 $mg.kg.min^{-1}$ respectively) and this has led to speculation in children that glycogen depletion could occur as a consequence (Bougnères, 1988; Schiffrin and Cole, 1989). However, this has been shown to not be the case, and young adolescents can exercise at ~60% VO_{2max} for more than 120 min without developing hypoglycaemia (Eriksson *et al*., 1971b; Martinez and Haymes, 1992).

Resting muscle glycogen concentrations of young boys have been shown to be 50-60% of adult levels (Eriksson *et al*., 1971a; Eriksson *et al*., 1973), reaching values comparable with those reported for adults by around 16 years of age (Eriksson and Saltin, 1974). A study comparing muscle glycogen content of boys aged 11.6, 12.6, 13.5 and 15.5 years reported concentrations of 54, 70, 69 and 87 $mmol.kg^{-1}$ wet weight glucose units respectively (Eriksson and Saltin, 1974). During exercise, glycogen concentration was found to decrease in relation to age with utilisation in the oldest boys being three times higher than in the younger boys, suggesting a greater glycolytic contribution in the older participants (Eriksson and Saltin, 1974).

2.5.2.3. Skeletal Muscle Enzymes

The body of existing evidence suggests that during childhood there is a greater reliance on oxidative metabolism during exercise, with an increasing glycolytic contribution with age. Differences in skeletal muscle enzyme content or activity may account for the child-adult differences in energy metabolism during exercise.

Limited investigations have focussed on differences in tricarboxylic acid (TCA) cycle enzymes. Citrate synthase activity has been shown to be similar between children and adults (Haralambie, 1982) and the activity of the TCA rate-limiting enzyme α-ketogluterate dehydrogenase has been shown to be 25% higher in adults than in children (Kaczor *et al.*, 2005). However, when α-ketogluterate dehydrogenase values were corrected for total protein content, there were no significant differences between age groups (Kaczor *et al.*, 2005). Analyses of oxidative enzyme activity in the skeletal muscle of children, adolescents and adults have shown higher levels of succinate dehydrogenase, isocitrate dehydrogenase, NADP-isocitrate dehydrogenase, fumerase and malate dehydrogenase in children than in adults (Fournier *et al.*, 1982; Eriksson *et al.*, 1973; Haralambie, 1982). However, as children age, this enhanced oxidative metabolism appears to decline, with reductions of 22% and 29% in citrate synthase and fumerase activities between 6 and 17 years (Berg and Keul, 1988). The adult-child differences in ratio of phosphofructokinase (PFK) to isocitrate dehydrogenase (ICDH) found in skeletal muscle are perhaps indicative of the higher oxidative metabolism of children. Phosphofructokinase to ICDH ratios of 0.844 and 1.633 have been reported in children and adults respectively (Haralambie, 1982) suggesting greater pyruvate oxidation in young people, thus indicating that the ability to utilise aerobic pathways may be age-dependent.

Although some attention has been paid to the oxidative enzymes, most of the published research relating to age-related changes in muscle enzyme activity have focused on enzymes involved in PCr degradation (i.e. creatine kinase) or glycolytic (e.g. PFK, LDH and aldolase) pathways. Amongst the first to illustrate the child-adult differences in glycolytic capacity were Eriksson *et al.*, (1973), who described the activity of the rate-limiting glycolytic enzyme phosphofructokinase (PFK) in 11-13 year old boys to be 50% less than that of adults. Berg and Keul (1988) demonstrated that resting activities of creatine kinase and several glycolytic enzymes all increased from adolescence into young adulthood with mean increases of 45%, 51% and 57% in pyruvate kinase, aldolase and LDH respectively. A recent study by Kaczor and co-workers (2005) reported similar findings from abdominal muscle samples; the creatine kinase activity of children (3-11 years) was 28% less than that of adults (29-54 years) and adults displayed more than four times the LDH activity of children. It has been speculated that this lower glycolytic flux through LDH may partially explain the lower blood lactate levels often observed during exercise in children.

These limited data concerning age-related changes in the enzyme activity and content of skeletal muscle are generally characterised by small sample sizes and should be interpreted with caution. The literature appears to suggest that children have higher oxidative enzyme activity than adults which then decreases during adolescence with a concurrent increase in glycolytic enzyme activity. Differences between adolescents and adults are less apparent and further investigation is required.

2.5.2.4. Hormonal Responses

Hormones regulate many of the body's processes, including energy metabolism. During exercise insulin, glucagon and catecholamine (adrenaline and noradrenaline) levels are largely responsible for substrate availability and utilisation, although other hormones (e.g. growth hormone and cortisol) and cytokines (i.e. interleukin-6) may also influence metabolism. Changes in the levels of these substances as individuals grow and mature may therefore result in differences in substrate utilisation during exercise (Riddell, 2008).

2.5.2.5. Substrate Utilisation

The respiratory exchange ratio (RER), calculated from VCO_2/VO_2 measured at the mouth, is often used as an estimate of CO_2 production and O_2 utilisation at the cellular level. The ratio can be used to assess the relative contribution of lipid and carbohydrate as substrates; an RER of 0.7 indicates exclusive utilisation of lipid while 1.00 indicates 100% carbohydrate contribution. Because protein can make a (small) contribution to energy provision, RER can also be corrected for protein oxidation from nitrogen secretion in urine and sweat (Lemon and Nagle, 1981). Measurement of RER can be difficult as participants must be exercising at steady-state, below the "ventilatory anaerobic threshold" to prevent the influence of non-respiratory CO_2 (from the buffering of lactate) affecting RER values.

Based on RER measurements made during treadmill walking, Robinson (1938) was the first to observe increased carbohydrate utilisation with age. The mean values of the groups increased from 0.87 in the youngest boys (6 years) to 0.95 in men (63 years). Robinson speculated the younger participants may have experienced a greater depletion in carbohydrate stores during the 15 hour fast preceding the exercise and therefore had limited endogenous carbohydrate to fuel the muscular work (Robinson, 1938). Subsequent work by Morse and colleagues (1949) also reported RER to increase with age. Since this early work, several additional studies have reported lower RER values in boys than in adolescents and men during exercise at the same relative (Asano and Hirakiba, 1984; Enyde *et al*., 1989) and absolute (Rowland *et al*., 1987) intensities.

Fewer studies have compared the substrate utilisation of girls and women. Martinez and Haymes (1992) reported lower RER values for girls (8-10 years) during 30 minute treadmill running at 70% VO_{2max}, than for women (20-32 years). This observation led the authors to conclude that girls rely more on fat utilisation and less on carbohydrate metabolism during treadmill running at the same relative intensity. However, the authors reported no significant differences in RER when the same group of participants exercised at the same absolute intensity (Martinez and Haymes, 1992). In contrast, a later study reported no maturity-related differences in substrate utilisation when girls (9-13 years) and women (20-31 years) undertook 40 min cycling at 63 % VO_{2max} (Rowland and Rimany, 1995). However, the authors reported that 77% of the women and 45% of the girls were exercising above their "ventilatory anaerobic threshold", which means, for reasons cited previously, these results should be treated with caution.

Blood parameters can also be indicative of fuel utilisation during exercise. Mobilisation of fat from peripheral stores results in an increase in plasma free fatty acid (FFA) and glycerol levels. Several studies have reported no differences in the exercise-induced changes in FFAs and glycerol between girls and women (Martinez and Haymes, 1992) or between boys and adolescents or adults (Eriksson *et al.*, 1971b; Wirth *et al.*, 1978; Lehman *et al.*, 1982). Conversely, other authors found prepubertal boys to have a higher fat contribution during exercise than adults, based on a higher FFA turnover per minute per litre of oxygen utilised (Delamarche *et al.*, 1992). In a subsequent study with male and female participants (8.5-11 years) following a similar protocol, comparable FFA and glycerol findings were reported, with no differences based on sex (Delamarche *et al.*, 1994).

More recently, Timmons *et al.*, (2003) compared substrate utilisation of early pubertal boys (10 years) and men (22 years) using ^{13}C stable isotope methodology. During 60 min of cycling exercise at 70% VO_{2max}, boys utilised around 70% more fat and 23% less carbohydrate than men. Using similar protocols, these authors later reported fat oxidation of 12 year old participants to be more than twice that of those aged 14 years in both girls (Timmons *et al.*, 2007a) and boys (Timmons *et al.*, 2007b).

Because the degree of fat oxidation during exercise has consequences for both health and performance, determining the intensity at which maximal fat oxidation occurs has been a focus of several recent investigations. Recently, Stephens *et al.*, (2006) reported maximal fat oxidation rates to be higher in prepubertal boys compared with pubertal boys. These finding were expanded when Riddell *et al*., (2008) adopted a longitudinal approach to assessing maximal fat oxidation and the intensity at which it occurs (fat_{max}). These authors measured maximal fat oxidation in prepubertal (Tanner stage 1) boys with repeated assessments throughout puberty. Compared with men, prepubertal boys had a higher relative maximal fat oxidation (4.2 vs. 8.6 mg.kg.lean body mass^{-1}.min^{-1}, respectively) that decreased with progression through puberty, reaching levels found in men during the final stages of puberty (Riddell *et al*., 2008). Fat_{max} was shown to occur at around 56% and 31% VO_{2peak} in prepubertal boys and untrained men, respectively, and again decreased with maturation (Riddell *et al*., 2008). These studies demonstrate an age-dependent effect of lipid metabolism, with high rates of lipid metabolism at considerably higher exercise intensities than found in adult populations. This means that the intensity which elicits carbohydrate as the predominant fuel source is higher in children than in adults, however, an “adult-like metabolic profile” appears to develop between mid-late puberty and is complete by the end of puberty (Stephens *et al*., 2006).

2.6 Literature Review Summary

The aim of this chapter was to provide a theoretical basis for the experimental chapters of this thesis. An overview of the existent literature relating to the demands of field hockey, the assessment of player characteristics and the impact of growth and maturation on hockey performance.

In the subsequent chapters, the theoretical implications of the existing literature and the relevant methodologies proposed by previous studies will provide a basis for the investigation of the physiological and performance characteristics of field hockey players with relation to age, sex and playing standard.

Chapter 3. General Methods

3.1 General Introduction

This chapter details the methodological procedures used to collect the data for this thesis. Where appropriate, individual chapters will detail any deviation from the methods described here. All laboratory testing was conducted in the Loughborough University Paediatric Exercise Physiology Laboratory. Field tests were conducted predominantly on the Loughborough University waterbased hockey pitch, but facilities outside the University were also used when necessary. Match analysis data were collected from hockey matches at various locations in the UK, Belgium and Azerbaijan. The Loughborough University Ethical Committee approved all procedures described prior to data collection. All researchers involved with testing of participants under-18 years of age were Criminal Records Bureau approved prior to involvement.

This chapter is organised into 5 sections; the first section describes how participants were recruited to take part in the research. The remaining 4 sections detail the laboratory, field, match analysis and statistical procedures used.

3.2 Participant Recruitment

The participants who volunteered to take part in the research described in this thesis were recruited from junior and senior England international squads and Loughborough University Hockey Clubs. International players became involved with the research via direct liaising with coaching and administrative staff at England Hockey, the national governing body for hockey in England. Loughborough University coaches were contacted regarding players' participation. In all cases, players were provided with an information pack detailing the rationale for the research, the specific requirements, procedures and techniques involved and any possible risks and discomforts associated with participation. Volunteers (and parents/guardians for participants under 18 years) were also given a verbal explanation of the procedures, emphasising that they were under no obligation to participate and could withdraw from the study at any time without providing reason. Participant consent/assent (and parental consent where applicable) were obtained before testing began. Individuals were also asked to complete a health history questionnaire to highlight any existing or potential health issues.

3.3 Laboratory Procedures

3.3.1. Anthropometric Assessment

Height was determined to the nearest 0.1 cm using a stadiometer (Holtain Ltd., Crmych, UK). Participants stood with heels together and the heels, buttocks and upper portion of the back against the stadiometer. The head was placed in the Frankfurt plane; with the orbitale (lower edge of the eye socket) in the same horizontal plane as the tragion (the notch superior to the tragus of the ear). The participant took a deep breath, maintaining the Frankfurt plane with heels firmly on the ground as the measurer applied gentle upward lift and firmly placed the measuring board onto the head, compressing the hair as far as possible. Measurement of height was taken before the participant exhaled. Body mass was measured to the nearest 0.1 kg using a calibrated balance beam (Model 3306ABV, Avery industrial Ltd. Leicester, UK).

Skinfold measurements were made at four sites on the right hand side of the body using a Harpenden skinfold calliper (Gaiam Ltd. Warwickshire, UK) and recorded to the nearest 0.1 mm. The triceps measurement was made on the midline of the posterior surface of the arm, midway between the acromiale and radiale. Biceps were measured on the midline of the anterior surface of the arm, midway between the acromiale and radiale. The subscapular skinfold was taken at a point 2 cm laterally and obliquely downward from the subscapulare (the undermost tip of the inferior angle of the scapula) at a 45^{o} angle. The iliac crest measurement (also known as suprailliac) was made at the centre of the skinfold raised immediately above the iliocristale (the point of the iliac crest there the line of the mid-axilla meets the ilium on the longitudinal axis of the body). Sites were measured in triplicate with the median of the three values used for data analysis. All anthropometric measures and reporting of results (i.e. expressed as sum of skinfolds) were made in accordance with the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Marfell-Jones *et al.,* 2006).

3.3.2 Submaximal Treadmill/Speed Lactate Test

Participants involved in laboratory tests completed a submaximal treadmill test to determine submaximal VO_2 (running economy) and to provide a whole blood lactate profile during incremental exercise. Participants began running at a moderate speed of 8 km.h^{-1} on the treadmill (RUNRACE, Technogym, Gambettola, Italy). Treadmill speed was increased by 1 km.h^{-1} every 4 min. Heart rate was monitored throughout the test and recorded during the final minute of each stage (Polar A3, Kempele, Finland). During the final minute of each 4 min stage, expired air was collected and a rating of perceived exertion was recorded (Borg, 1982). Expired air samples were collected in Douglas bags and were subsequently analysed for oxygen and carbon dioxide content using a parametric oxygen analyser and an infra-red carbon dioxide analyser (Series 1400, Servomex, Crowborough, East Sussex, UK). The volume of expired air was measured using a dry gas meter (Harvard Apparatus, Edenbridge, Kent, UK). At the end of each 4 min stage participants stepped from the treadmill for approximately 30 s to permit a finger prick blood sample to be obtained. Prior to each sample, the finger was wiped using an isopropyl alcohol swab (Sterets, Medlock Medical, Oldham, UK). Blood samples were obtained using a single-use lancet (Unistick 3 Extra, Owen Mumford, Oxford, UK) and were collected in 300 µl EDTA microvettes (CB 300, Sarstedt, Numbrect, Germany). Samples were immediately analysed for whole blood lactate concentration (YSI 2300 Stat Plus, Yellow Springs, Ohio, USA). Participants then resumed running on the moving treadmill 1 km.h^{-1} faster than the previous stage. Treadmill speed was increased (by 1 km.h^{-1} every 4 min) until whole blood lactate concentration exceeded 4 mmol.L^{-1}.

3.3.3 Assessment of Maximal Oxygen Uptake

Using results from the submaximal test, a running speed that elicited a heart rate of approximately 170-180 beats.min^{-1} was selected for the duration of the maximal test. Participants began the test at the pre-determined speed and at a gradient of 3 % which was increased by 2 % every 3 min until the participant indicated he/she could continue for only 60 s longer (protocol adapted from Taylor *et al.*, 1955). Heart rate was monitored throughout the test (Polar A3, Kempele, Finland). During the final minute of each 3 min stage and during the last 60 s of the test, heart rate was recorded, expired air was collected and RPE recorded. Douglas bags were analysed for oxygen and carbon dioxide content (Series 1400, Servomex, Crowborough, East Sussex, UK) and volume (Harvard Apparatus, Edenbridge, Kent, UK). The test continued to volitional exhaustion. Attainment of VO_{2max} was in accordance with the criteria suggested by the British Association of Sport and Exercise Sciences; a plateau in VO_2 of <2 ml.kg^{-1}.min^{-1} or 3 % (following an increase in work intensity); an RER of ≥1.15; a HR_{max} of within ±10 beats.min^{-1} or an RPE of 19 or 20 at volitional exhaustion (Cooke, 2001).

3.4 Field Test Procedures

All field tests took place outdoors, either on Astroturf or waterbased hockey surfaces. Participants all wore suitable clothing and footwear for the tests. Each field testing session consisted of an anthropometric assessment, a maximal test (either the Multi-Stage Fitness Test, the Yo-Yo Intermittent Recovery Test level 1 or the Interval Shuttle Run Test), timed sprints and a dribble test. During maximal tests, participants wore a heart rate monitor

(Team System, Polar, Kempele, Finland). During subsequent field testing sessions, players completed the remaining maximal tests only. A minimum of 24 hours was permitted between maximal tests.

3.4.1. Anthropometric Assessment

Height was determined using the same protocol as laboratory assessment, however, a portable statiometer was used during field testing (Leicester, Seca, Birmingham, UK). Body mass was measured to the nearest 0.1 kg using portable scales (Seca 770, Seca, Birmingham, UK).

3.4.2. Multi-Stage Fitness Test

The Multi-Stage Fitness Test (MSFT) is a maximal test designed to provide a field-based assessment of maximal aerobic power (Ramsbottom *et al.,* 1988). The test consists of repeated 20 m runs at an increasing pace determined by bleeps from an audio CD (Multi-Stage Fitness Test, National Coaching foundation, 1998). The frequency of the audio signals meant that the running speed was increased by approximately 0.5 km.h^{-1} every minute from a starting speed of 8.0 km.h^{-1}. The test ended when the participant could no longer keep pace with the bleeps (i.e. failed to meet the 20 m line on two consecutive occasions) or reached volitional exhaustion. The level and shuttle reached was recorded as the individuals score, and was converted to distance covered (m) for analysis.

3.4.3. Interval Shuttle Run Test

The Shuttle Run Test (ISRT) is designed to measure interval endurance capacity (Lemmink *et al.,* 2000). A schematic of the course for the ISRT is shown in figure 3.1. Players were required to run back and forth between the two 20 m lines in time with bleeps omitted from a pre-recorded CD (ISRT, ProMotion, Grogingen, 2000). Frequency of the signals from the CD increased so that running speed was increased by 1 km.h^{-1} every 90 s from a starting speed of 10 km.h^{-1} and then by 0.5 k.m.h^{-1} from 13 km.h^{-1}. Each 90 s interval was divided into two 45 s periods where players ran for 30 s and then walked for 15 s. During the walking periods, participants walked back and forth within the 8 m 'walking area' (figure 3.1), ensuring they had returned to the 20 m line before the next bout of running began. Players were instructed to complete as many 20 m runs as possible. The test ended once a player reached volitional exhaustion or was unable to reach the marker placed 3 m before the 20 m line (figure 3.1) on two consecutive occasions. The number of completed 20 m runs was recorded as the participants' score.

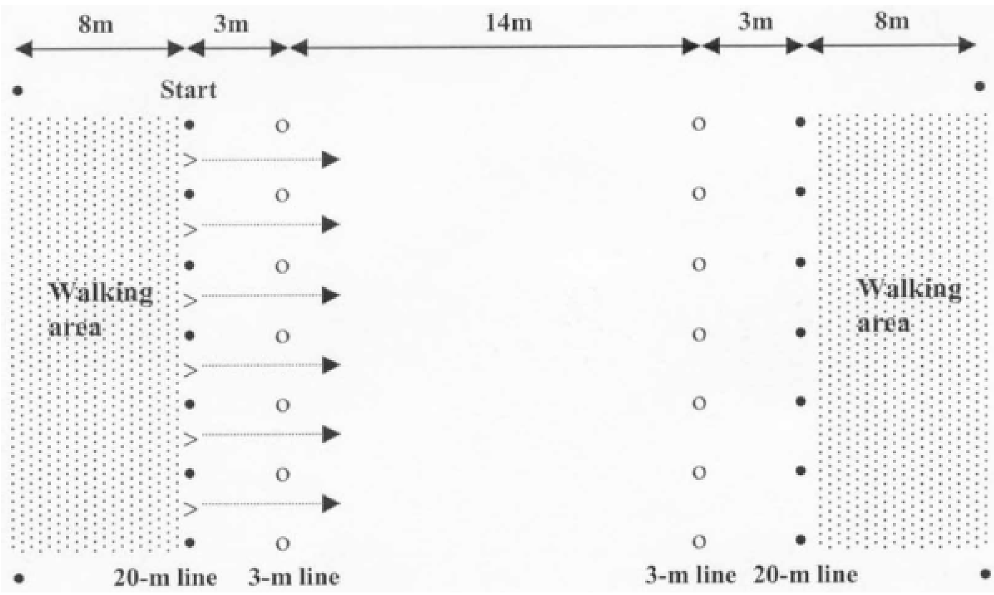

Figure 3.1: Layout of Interval Shuttle Run Test (ISRT) (Elferink-Gemser *et al.,* 2004).

3.4.4. Yo-Yo Intermittent Recovery Test

The Yo-Yo Intermittent Recovery Test (YYIRT) is designed to assess an individual's capacity to carry out intermittent exercise leading to maximum activation of the aerobic system (Bangsbo, 1994). The YYIRT set-up is shown in figure 3.2. Participants were required to complete repeated 2 x 20 m runs back and forth between the two 20 m lines at progressively faster speeds as controlled by audio signals from a pre-recorded CD (The Yo-Yo Intermittent Recovery Test, Bangsbo Sport). The YYIRT Level 1 consisted of 4 running bouts at 10-13 km.h^{-1} (0-160 m) followed by 7 runs at 13.5-14 km.h^{-1} (160-440 m), thereafter the test continued in a stepwise fashion of 0.5 km.h^{-1} speed increments after every 320 m of running. Between each 40 m running bout, players had a 10 s active recovery period of 2 x 5 m jogging. The test continued until the participant reached volitional exhaustion or could no longer keep pace with the bleeps (i.e. did not make the 20 m line on two consecutive occasions). The distance covered (m) was recorded as the test score.

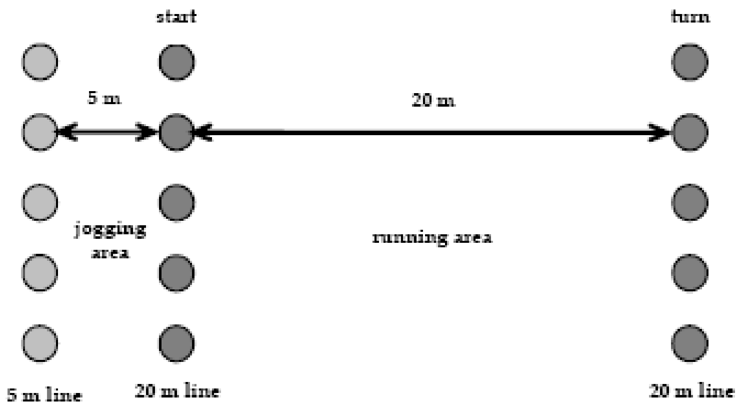

Figure 3.2: Layout of the Yo-Yo Intermittent Recovery Test (YYIRT).

3.4.5. Slalom Sprint and Dribble Test

The Slalom Sprint and Dribble Test (SlalomSDT) was developed to provide a measure of slalom sprint and dribble performance of field hockey players (Lemmink *et al.,* 2004). Players began the test with both feet behind line A (figure 3.3) and were instructed to begin the test when ready. The participant sprinted around the 12 cones, finishing on line B, whilst carrying a hockey stick. After the sprint, players were permitted approximately 5 min recovery. Once recovered, the player completed the course again, only this time dribbling a ball around the 12 cones. In both instances, it was ensured that both the player's feet went around the outside of the cones. If the player lost control of the ball whilst dribbling, the second part of the test was repeated. Participants were timed accurately to 0.01 s using wireless infra-red timing gates (Speedtrap 2, Brower Timing Systems, Utah, USA) positioned at the start and finish lines. Slalom sprint, slalom dribble and the difference between the dribble and sprint times (Δ slalom time) were recorded for each player. The Δ slalom time was used as an index of players' dribbling ability.

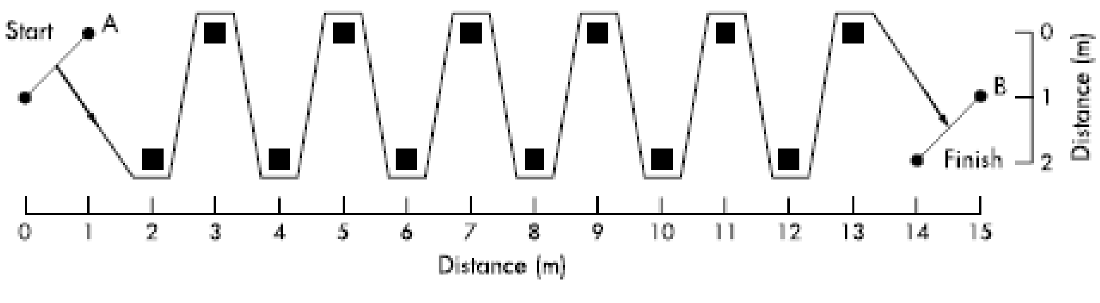

Figure 3.3: The SlalomSDT course (Lemmink *et al.,* 2004). Solid squares represent cones 12 inches in height. Solid circles at the start and finish lines denote the position of infra-red timing gates.

3.4.6. Timed Sprints

Participants completed timed sprints over 5, 10, 20 and 30 m. Players started with a foot on the start line and accelerated maximally through the timing gates. The first timing gate was placed 1 m in front of the start line to minimise the likelihood of a part of the body other than the torso breaking the infra-red beam. The subsequent gates were placed at 6, 11, 21 and 31 m from the start line. Players completed the sprints at least twice and the fastest time for each split was recorded. Times were measured accurately to the nearest 0.01 s using a wireless infra-red timing system (Speedtrap 2, Brower Timing Systems, Utah, USA).

3.5 Match Analysis

To provide an indication of the demands placed on players during competitive hockey, participants wore a Global Positioning System (GPS) unit (SPI Elite, GPSports, Canberra, Australia) during at least one hockey match.

3.5.1 SPI Elite

The GPS device was small (91 x 45 x 21 mm) and light (75 g). To permit normal movement and minimise any disruption to game-play, the device was worn in a harness on the players' back (figure 3.4). The frequency logging rate of the devices is 1 Hz, with the units communicating with orbiting satellites on a second by second basis to provide information on the players' position. These data were then used to provide information regarding the speed and distances covered by individual players over the course of a match.

Figure 3.4: (a) SPI Elite GPS Unit (b) GPS unit as worn during competitive hockey.

3.5.2 Team AMS Software

Data from the GPS units were downloaded onto a computer and analysed using Team AMS software (Version 1.2.1.12, GPSports, Canberra, Australia). The speed categories used for analysis of match data are shown in table 3.1. Data were analysed for the minimum, mean and maximum speeds, the total distance covered, the distance covered in each activity category and the % time spent in each activity category. Only time spent playing was analysed: i.e. if a player was substituted, the data recorded when the player was not on the pitch was ignored. Each spell was analysed individually - if a player was substituted several times during either half, the individual spells were used to provide a total for the first and second halves. The low-moderate speed categories used were comparable with those of previsou match analysis investigations (e.g. Mohr *et al*., 2003 and Krustrup *et al*., 2005). However the categorisation of sprint activities in previous analyses were deemed too high for the participants involved within the current thesis. Typical examples of sprint categories in the literature include over ~25 $km.h^{-1}$ (Krustrup *et al.*, 2005, Di Salvo *et al.*, 2009) or >30 $km.h^{-1}$ (Mohr *et al.*, 2003). Due to the inclusion of junior, as well as senior male and female players in the current analyses, speeds of > 19.0 $km.h^{-1}$ were deemed to better reflect the high intensity activity profiles of players.

Table 3.1: GPS match analysis speed categories.

Speed	Description	Intensity
0 - 3.0 $km.h^{-1}$	Standing	Low
3.1 - 6.0 $km.h^{-1}$	Walking	
6.1 - 10.0 $km.h^{-1}$	Jogging	Moderate
10.1 - 14.5 $km.h^{-1}$	Running	
14.6 - 19.0 $km.h^{-1}$	Fast Running	High
≥19.1 $km.h^{-1}$	Sprinting	

3.6 Statistical Analyses

A number of statistical analyses were used to analyse the data collected for this thesis, including; Pearson product moment correlation coefficient, paired sample t-test, independent sample t-test, one-way ANOVA, two-way ANOVA with repeated measures on one factor and *post hoc* Tukey tests. Analyses were conducted using Statistical Package for Social Scientists (SPSS, versions 14-16). A more detailed description of the procedures used are provided in each experimental chapter. Unless otherwise stated, data are presented as the mean and standard error of the mean (mean±*S.E.*). In all cases, significance was accepted at $P<0.05$.

Chapter 4. Characteristics of Elite Junior and Senior Male Field Hockey Players: a Cross-Sectional Analysis

4.1. Introduction

Despite field hockey's global popularity, little is known about the physiological characteristics required for elite level play, or how these develop in elite players from junior to senior level. Such insight is important in talent detection, identification, development and selection of players. While it has been suggested that to compete at hockey's highest level players must possess certain physiological, psychological, technical and tactical characteristics (Elferink-Gemser*,* 2005), these are yet to be clearly defined. To date, the physiological requirements of hockey have perhaps received most attention in the literature. Previous profiling of senior male international players suggests that a maximal aerobic power of approximately 60 $ml.kg^{-1}.min^{-1}$ is necessary to compete at elite level (Withers *et al.,* 1977; Boyle *et al.,* 1994; Spencer *et al.,* 2004). However the development of aerobic power and other performance related variables from junior to senior level have not previously been examined. Understanding which characteristics are favourable for success in hockey can allow identification of promising players at an early age, providing opportunities for talented young players to improve and progress to achieve their potential.

This study therefore sought to profile the characteristics of elite under-16 (U16), under-18 (U18), under-21 (U21) and senior male international field hockey players using physiological, anthropometric and field test data collected between 1993 and 1995. Data were analysed with three primary aims; firstly to describe the physiological characteristics of elite hockey players; secondly to conduct a cross-sectional analysis of data from the different age groups to examine the development of such characteristics from junior to senior level and finally, to discriminate, based on measured variables, attributes which may determine the successful progression of players from junior to senior international level.

4.2. Methods

4.2.1. Participants

One hundred and fifty-nine male U16, U18, U21 and senior England International field hockey players were assessed between 1993 and 1995 as part of a sports science support programme. In 2009 the playing record of all the players tested in 1993-5 was re-examined to establish which players had played at senior international level. Loughborough University Ethical Committee and England Hockey approval was gained prior to testing. Seventy-seven players completed anthropometric, physiological and field test assessment. A further eighty-two players completed field test assessment only.

4.2.2. Anthropometric Measurements

Height (Holtain Ltd., Crmych, UK), body mass (Model 3306ABV, Avery industrial Ltd., Leicester, UK) and 4-site skinfold thickness measurements (bicep, tricep, subscapular and suprailliac) were recorded in accordance with standard laboratory procedures (see page 39) to obtain a sum of skinfolds.

4.2.3. Physiological Assessment

Peak oxygen uptake (VO_{2peak}) was determined directly via a continuous uphill treadmill protocol (adapted from Taylor *et al.,* 1955). Submaximal running economy and blood lactate concentrations were determined during 4 minute stages of treadmill running at 3 or 4 increasing intensities. During the final minute of each 4 minute stage expired air was collected to determine oxygen consumption (VO_2). Heart rate was monitored throughout the test and recorded during the final minute of each stage. Duplicate thumb prick blood samples were obtained at the end of the minute for subsequent fluorimetric analysis for whole blood lactate concentration (Maughan, 1982). Repeated sprint performance was assessed using a friction loaded cycle ergometer (Model 864, Monark, Varberg, Sweden). Participants completed 10 x 6 s sprints separated by 30 s passive recovery (applied load = 55 g x kg^{-1} body mass). For each of the ten sprints, peak power output (the highest recorded output during the 6 s) (PPO) and mean power output (averaged over the 6 s) (MPO) were obtained. The sit and reach test (Wells and Dillon, 1952) was used to assess players' lower back and hamstring flexibility.

4.2.4. Field Tests

Performance in field tests was used to assess speed and provide an indirect estimation of peak aerobic power. Fifteen metre sprints between electronic timing gates provided an indication of sprint performance. For indirect assessment of VO_{2peak}, participants completed the 20 m Multi-Stage Fitness Test (MSFT) (Ramsbottom *et al.,* 1988).

4.2.5. Comparison of Successful and Unsuccessful Players

In an attempt to identify characteristics which may contribute to determining a junior players' progression to senior level, players from U16, U18 and U21 squads were classed as "successful" or "unsuccessful". Successful players were those who by 2009 had represented England at senior international level, while unsuccessful players did not compete internationally beyond U16, U18 or U21 level. Due to small numbers in the laboratory tests, comparison of successful and unsuccessful players was only possible with respect to 15 m sprint and MSFT results.

4.2.6. Statistical Analyses

For cross-sectional analysis of player characteristics from U16 to senior level, means for each squad were compared (U16 *vs.* U18 *vs.* U21 *vs*. senior) using a one-way ANOVA with subsequent *post hoc* Tukey test. Where comparisons were limited to two groups (e.g. higher velocities during submaximal running; successful *vs.* unsuccessful players) independent sample t-tests were used. Two-way repeated measures ANOVA was used to examine performance in the repeated cycle sprint test. When significant interactions were detected, means were compared using a *post hoc* Tukey test. Paired sample t-tests were used to compare laboratory and MSFT VO_{2pek} results. To assess criterion validity of the MSFT as an indirect assessment of VO_{2peak} in each age group, the Bland and Altman 95% limits of agreement were employed (Bland and Altman, 1986). The data were tested for heteroscedascity by plotting the absolute difference against the mean and computing the correlation (Atkinson and Nevill, 1998). All data are presented as the mean and standard error of the mean (mean±*S.E.*) and significance was accepted at $P<0.05$.

4.3. Results

4.3.1. Anthropometric Assessment

The physical characteristics of participants are given in table 4.1. Under-16 players were shorter and lighter than U21 and senior players ($P<0.05$). Under-18 players were lighter than senior players ($P<0.05$). Sum of 4 skinfolds was not different between squads ($P>0.05$).

4.3.2. Physiological Assessment

Directly determined VO_{2peak} ($L.min^{-1}$) increased with age (table 4.2) but there were no differences between the squads when VO_{2peak} was corrected for body mass ($ml.kg^{-1}.min^{-1}$) ($P>0.05$) (table 4.2). Senior players had lower maximal heart rate (HR_{max}) values than all other squads ($P\leq0.05$) (table 4.2). There were no differences in flexibility between squads. Speed at 4 $mmol.L^{-1}$ blood lactate was higher in the senior and U21 players than U16 players

(*P*<0.05) (table 4.2). It should be noted that several players' (U16 n=2; U18 n=3; U21 n=2) blood lactate did not exceed 4 mmol.L^{-1} during the submaximal test. These players are excluded from the results presented for treadmill speed at 4 mmol.L^{-1} (table 4.2).

Senior players had a more economical submaximal oxygen consumption (VO_2) than U16 and U18 players at every speed (*P*<0.05) assessed (figure 4.1). Under-21 players were more economical than U16 players at every speed (*P*<0.05) and U18 players at 3.5 m.s^{-1} (figure 4.1).

Results from the cycle ergometer repeated sprint tests are presented in figures 4.2 and 4.3. Peak and mean power outputs remained unchanged for the 10 sprints in the U16 and U18 players (*P*>0.9 in all cases). In U21 players, PPO and MPO decreased (compared to sprint 1) in sprints 4-10 (P<0.05). Senior players' PPO and MPO were lower in sprints 9 and 10 than in sprint 1 (*P*<0.05). There were no differences in PPO or MPO between U16 and U18 players (*P*>0.05) or between U21 and senior players (*P*>0.05) during any of the sprints. Senior and U21 players maintained a higher a PPO than U16 players during the 10 sprints (*P*<0.05). Senior and U21 players had higher PPO than U18 players during sprints 1-4 (*P*<0.05) and 1-3 (*P*<0.05) respectively. Seniors had higher MPO values than U16 players in all sprints (*P*≤0.001) and higher values than U18 players in sprints 1-4 (*P*<0.05). Under-21 players had higher MPO than U16 and U18 players in sprints 1-9 (*P*≤0.01) and 1-3 (*P*<0.05) respectively.

4.3.3. Field Tests

Mean (*±S.E.*) 15 m sprint times for the U16, U18, U21 and senior squads were 2.58*±0.02*; 2.45*±0.03*; 2.30*±0.02*; 2.39*±0.02*; s respectively. Under-16 players were slower over 15 m than all other age groups (P<0.05). Under-21 players were faster than U18 players (P<0.05). Using equations based on adult runners, senior and U21 players obtained higher VO_{2peak} values in the MSFT than U18 and U16 players (P<0.01). Performance in the MSFT underestimated VO_{2peak} when compared with laboratory measured VO_{2peak} in U16 (51.5*±0.8* vs. 58.0*±1.4* ml.kg^{-1}.min^{-1}; n=15; P<0.001) and U18 (54.8*±1.1* vs. 60.1*±0.8* ml.kg^{-1}.min^{-1}; n=9; P<0.01) players. There were no differences between MSFT predicted VO_{2peak} and laboratory assessed VO_{2peak} in senior (59.3*±1.0* vs. 59.2*±0.9* ml.kg^{-1}.min^{-1}; n=18; P>0.05) or U21 (60.2*±0.6* vs. 60.9*±0.9* ml.kg^{-1}.min^{-1}; n=14; P>0.05) players. Figure 4.4 shows the mean difference and 95 % limits of agreement (LOA) for laboratory and MSFT VO_{2peak} of U16, U18, U21 and senior players. The data did not show any heteroscedasticity.

4.3.4. Comparison of successful and unsuccessful players

Examination of the playing record of junior players showed that 15% of U16, 19% of U18 and 48% of U21 players eventually went on to play at senior international level. At U16, U18 and U21 level no differences in MSFT performance were evident when successful and unsuccessful players were compared (P>0.05) (table 4.3). At U21 level, 15 m sprint performance discriminated between successful and unsuccessful players (P<0.05) (table 4.3).

Table 4. 1: Physical characteristics of participants (mean±*S.E.*)

	U16 n=27	U18 n=12	U21 n=14	Senior n=24	Statistical Analyses
Age (years)	15.0±*0.1*	16.9±*0.2*	20.1±*0.2*	24.9±*0.7*	Sen vs. U21; U18; U16 *P*<0.001 U21 vs. U18; U16 *P*<0.01 U18 vs. U16 *P*<0.05
Height (cm)	170.8±*1.5*	174.1±*1.9*	178.0±*1.9*	178.8±*1.0*	Sen vs. U16 *P*<0.001 U21 vs. U16 *P*<0.01
Body Mass (kg)	61.3±*2.0*	64.2±*3.3*	71.3±2.0	75.3±*1.4*	Sen vs. U16; U18 *P*<0.01 U21 vs. U16 *P*<0.01
Sum of 4 Skinfolds (mm)	26.5±*1.1*	24.3±*1.4*	24.9±*0.8*	27.6±*1.1*	ns.

Table 4.2: Physiological characteristics of elite U16, U18, U21 and Senior male field hockey players (n) (mean±*S.E.*)

	U16		U18		U21		Senior		Statistical analyses
VO_{2peak} (L.min^{-1})	3.6±*0.1*	(27)	3.9±*0.2*	(12)	4.3±*0.1*	(14)	4.5±*0.1*	(24)	Sen vs. U18 *P*=0.01 Sen vs. U16 *P*<0.001 U21 vs. U16 *P*<0.01
VO_{2peak} (ml.kg^{-1}.min^{-1})	59.0±*0.9*	(27)	60.5±*0.7*	(12)	60.9±*0.9*	(14)	59.8±*0.8*	(24)	ns.
MSFT Predicted VO_{2peak} (ml.kg^{-1}.min^{-1})	51.5±*0.8*	(15)	54.8±*1.1*	(9)	60.2±*0.6*	(14)	59.3±*1.0*	(18)	Sen vs. U18 *P*<0.01 Sen vs. U16 *P*<0.001 U21 vs. U18 *P*<0.01 U21 vs. U16 *P*<0.001
HR_{max} (beats.min^{-1})	202±*1*	(26)	200±*2*	(10)	200±*2*	(14)	192±*2*	(23)	Sen vs. U21 *P*<0.05 Sen vs. U18 *P*=0.05 Sen vs. U16 *P*<0.001
Speed at 4 mmol.L^{-1} Whole Blood Lactate (m.s^{-1})	3.4±*0.1*	(23)	3.6±*0.1*	(9)	4.0±*0.1*	(11)	3.8±*0.1*	(23)	Sen vs. U16 P<0.05 U21 vs. U16 P≤0.001
Flexibility (cm)	11±*1*	(27)	12± 2	(12)	16±*2*	(14)	12±*2*	(24)	ns.

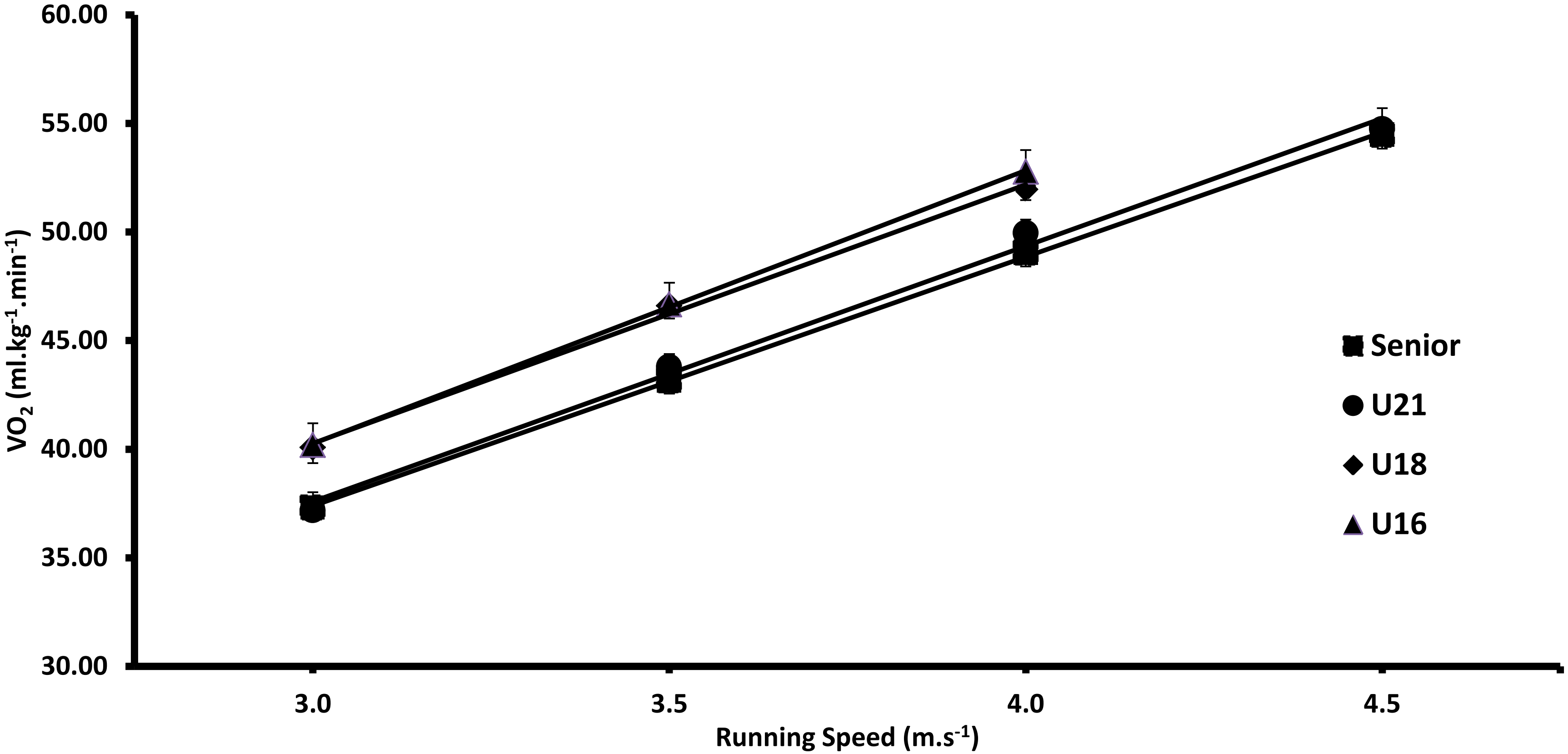

Figure 4.1: Submaximal VO_2 (running economy) of U16, U18, U21 and Senior international hockey players.

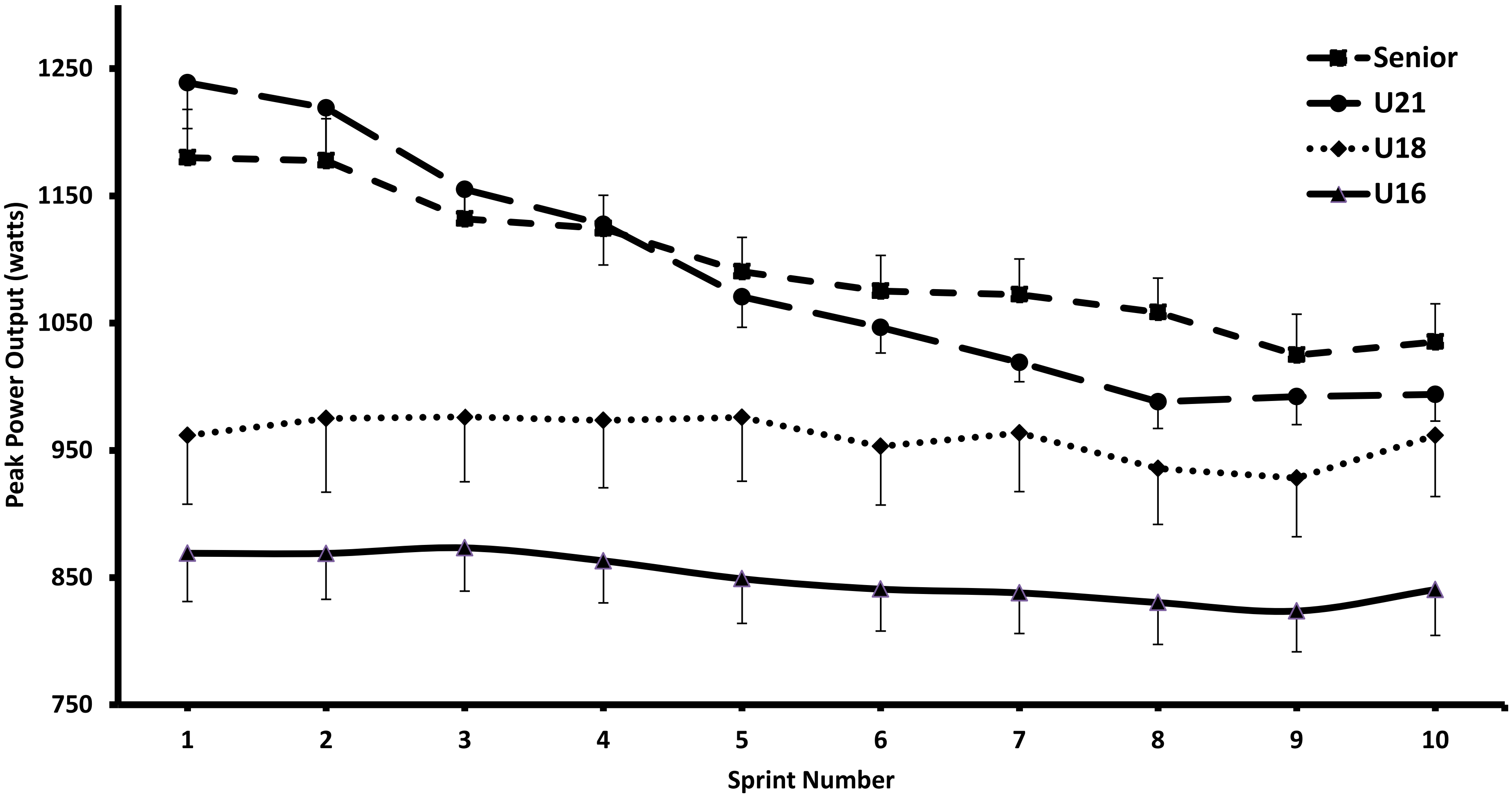

Figure 4.2: Peak power output (PPO) assessed during 10 x 6 s repeated sprints on a cycle ergometer (mean±*S.E.*).

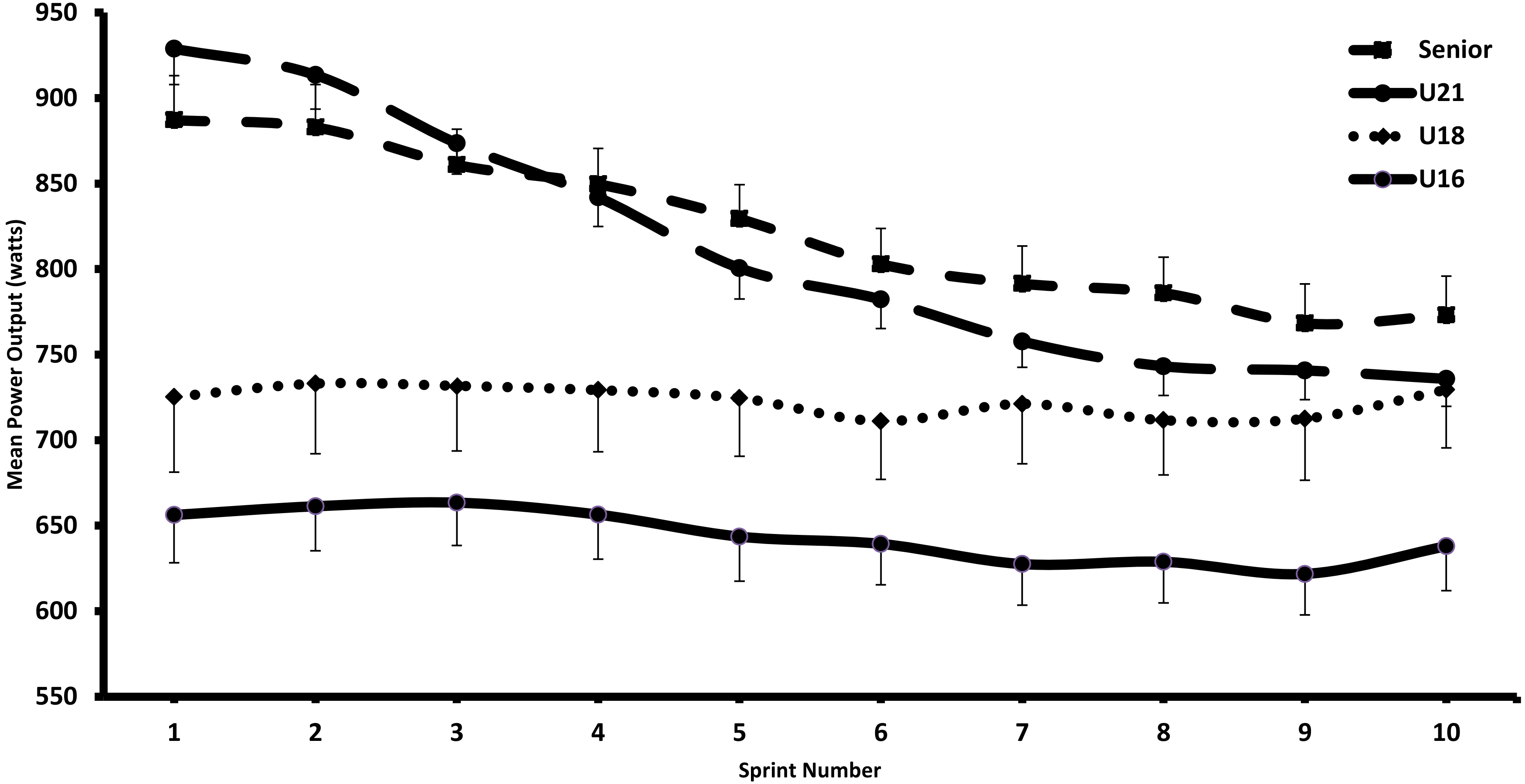

Figure 4.3: Mean power output (MPO) assessed during 10 x 6 s repeated sprints on a cycle ergometer (mean±*S.E.*).

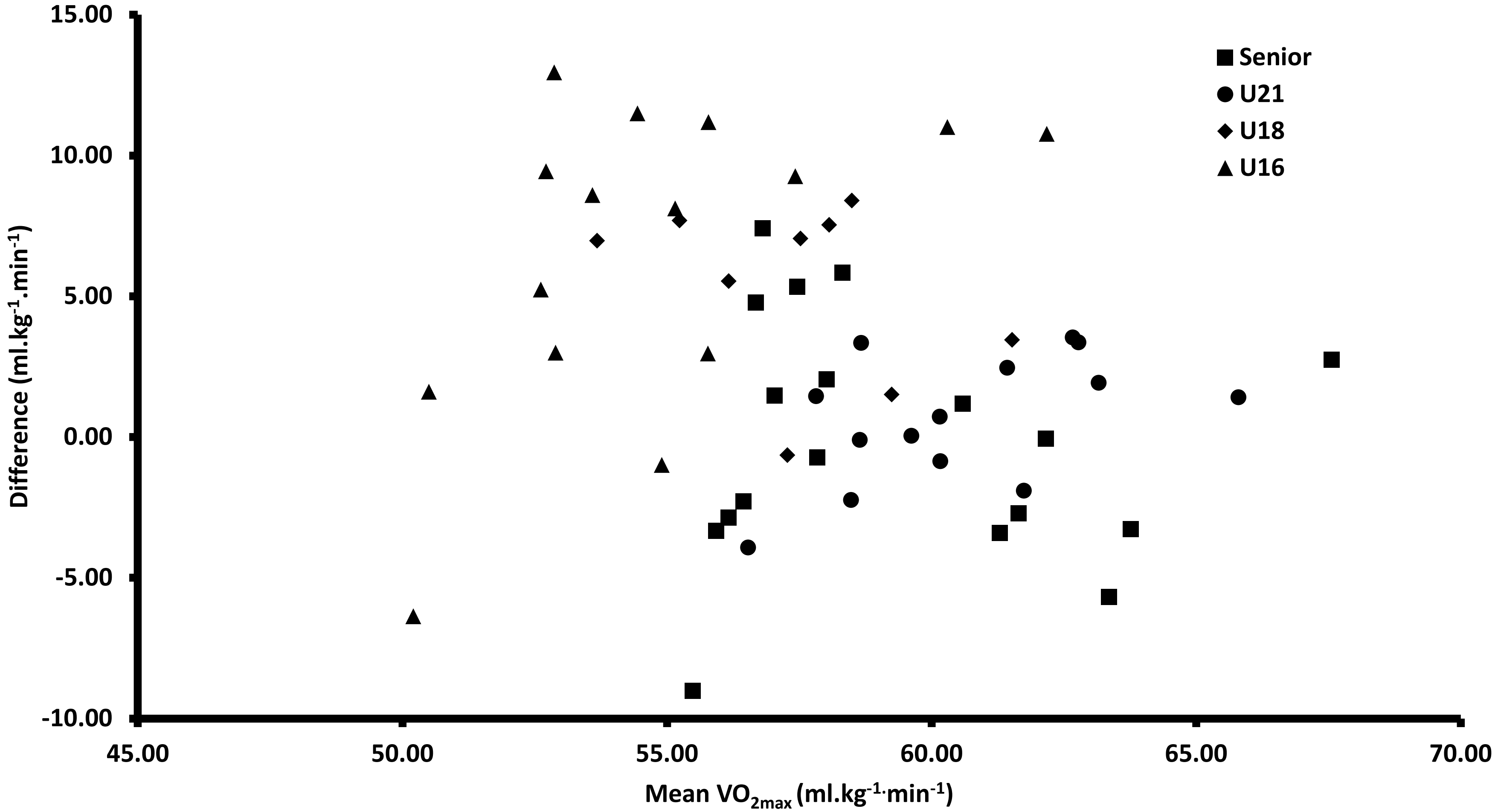

Figure 4.4: Bland-Altman plot for laboratory and MSFT assessed VO_{2peak}. Mean difference ± *LOA* for each of the age groups: U16 (6.5±*10.8* ml.kg^{-1}.min^{-1}), U18 (5.3±*6.3* ml.kg^{-1}.min^{-1}), U21 (0.7±*4.5* ml.kg^{-1}.min^{-1}) and senior (0.2±*8.6* ml.kg^{-1}.min^{-1}).

Table 4.3: Fifteen metre sprint times and MSFT predicted VO_{2peak} of successful and unsuccessful junior international field hockey players (n) (mean±*S.E.*)

	U16		U18		U21	
MSFT Predicted VO_{2peak} ($ml.kg^{-1}.min^{-1}$)						
Successful	52.1±*1.3*	(5)	56.0±*0.9*	(7)	59.7±*0.6*	(21)
Unsuccessful	50.0±*0.6*	(31)	56.0±*0.7*	(33)	58.6±*0.7*	(23)
15m Sprint time (s)						
Successful	2.63±*0.06*	(7)	2.39±*0.02*	(8)	2.35±*0.03**	(21)
Unsuccessful	2.61±*0.02*	(40)	2.42±*0.02*	(34)	2.43±*0.02*	(22)

*P=0.014

4.4. Discussion

The primary findings from this study suggest that a high peak aerobic power (approximately 60 $ml.kg^{-1}.min^{-1}$) is required to compete at elite level hockey from at least 15 years of age. While this is an essential characteristic necessary to compete even at junior level, it is sprint speed which appears to be a crucial performance component determining potential progression to elite senior level.

While development of the physiological characteristics of elite hockey players has not previously been examined, development of performance-related variables in other populations have received attention in the literature. Peak aerobic power from childhood through to adolescence and adulthood has been examined in numerous cross-sectional and longitudinal studies. Maximal aerobic power ($L.min^{-1}$) has consistently been shown to increase with age (Astrand, 1952; Davies *et al.,* 1972; Kobayashi *et al.,* 1978, Mirwald and Bailey, 1986; Kemper, 1995). Such increases in VO_{2peak} with age are largely attributed to increases in body mass during growth and development (Krahenbuhl *et al.,* 1985). Development of peak aerobic power ($L.min^{-1}$) in elite junior hockey players follows a similar pattern, increasing as players get older and heavier.

Equivocal findings have been reported with respect to the development of VO_{2peak} relative to body mass in males ($ml.kg^{-1}.min^{-1}$). Several studies have reported a decrease with age (Weber *et al.,* 1976; Rutenfranz *et al.,* 1982; Mirwald and Bailey, 1986; Kemper, 1995), others have found VO_{2peak} to increase with age (Kobayshi *et al.,* 1978), while some report

VO_{2peak} to remain relatively unchanged from adolescence though to adulthood (Astrand, 1952, Andersen *et al.,* 1974; Daniels *et al.,* 1978). Krahenbuhl *et al.,* (1985) reviewed data from almost 6000 boys and concluded that VO_{2peak} (ml.kg^{-1}.min^{-1}) in males remains stable throughout childhood and adolescence. Findings from the current study are in agreement with this suggestion, with mean squad values ranging from 59.0 ml.kg^{-1}.min^{-1} (U16) to 60.9 ml.kg^{-1}.min^{-1} (U21) (table 2). This supports the observation that elite male players require a peak oxygen consumption of ~60 ml.kg^{-1}.min^{-1} and suggests that junior elite players may require a similar VO_{2peak} from at least U16 level onwards. More recent (2006) physiological assessment of 17 Great Britain international players (mean±*S.E*. age, 25.9±*0.9* years) reported similar mean VO_{2peak} values of 62.3±*1.4* ml.kg^{-1}.min^{-1}, (Sunderland, unpublished data) supporting findings of the present study.

Estimation of VO_{2peak} from MSFT performance provided fairly accurate assessment of the U21 and senior squads' aerobic power when compared with the directly measured values. However, MSFT VO_{2peak} of U16 and U18 players was significantly underestimated compared with the laboratory measurement. The mean difference ± LOA suggest that the MSFT may be useful in estimating VO_{2peak} of U21 and senior players (0.7±*4.5* and 0.2±*8.6* ml.kg^{-1}.min^{-1}, respectively). The MSFT does not appear to provide accurate estimation of VO_{2peak} compared with laboratory assessment in U16 and U18 players (mean difference *± LOA;* 6.5±*10.8* and 5.3±*6.3*, ml.kg^{-1}.min^{-1} respectively) and results should therefore be interpreted with caution. Age-associated variations in running economy (figure 4.1) are likely to account, at least in part, for these underestimations. The MSFT requires participants to run to exhaustion at increasingly faster speeds. Under-sixteen and -eighteen players utilise significantly more oxygen at the same speed as U21 and senior players (figure 4.1), thus at almost any given running speed, younger players were working at a higher proportion of VO_{2peak} and therefore reached their peak at a lower level/shuttle of the field test. Nevertheless, the MSFT probably provides an accurate reflection of the endurance running performance of the different age groups and in young footballers has been shown to relate to the distance covered during a match (Goto, unpublished, 2010).

In agreement with the present study, the oxygen cost of submaximal running (running economy) is well documented to improve with age (Daniels and Oldridge, 1971; Krahenbuhl and Pangrazi, 1983; Krahenbuhl and Williams, 1992; Ariëns *et al.,* 1997). Explanations for this change in running economy have been attributed to differences in leg length, stride length, basal metabolic rate, body surface area to mass ratio, reduced glycolytic capacity, training, ventilation and cardiac output (MacDougall *et al.*, 1983; Daniels and Oldridge, 1971; Daniels *et al.,* 1978; Krahenbuhl *et al.,* 1989; Rowland and Green, 1988 and Ariëns *et al*., 1997). Increases in body mass with age are often cited as contributing to age-related variation in running economy (Bergh *et al.,* 1991; Bourdin *et al.,* 1993; Welsman and Armstrong, 2000). Such variation may be minimised by relating VO_2 to $BM^{-0.75}$ rather than BM^{-1} (Sjodin and Svedenhag, 1992).

The results from the submaximal treadmill running test showed that U16 players reached 4 $mmol.L^{-1}$ at a lower speed than the U21 or senior players. However, this may be associated with variations in running economy as the % VO_{2peak} at 4 $mmol.L^{-1}$ was not different between U16, U18 and U21 players. These findings are in contrast to earlier studies which suggest 'lactate threshold' occurs at higher % VO_{2peak} in younger participants (Tolfrey and Armstrong, 1995). It is often cited that children and adolescents have lower blood lactate concentrations due to lower phosphofructokinase activity when compared with adults (Eriksson *et al.,* 1973). However, increased activity of the oxidative enzymes succinate dehydrogenase and isocitric dehydrogenase and an increased reliance on fat metabolism during exercise may also explain the lower lactate concentrations in children and adolescents (Eriksson *et al.,* 1973; Fournier *et al.,* 1982). Several of the players from the U16, U18 and U21 squads did not obtain a blood lactate concentration ≥4 $mmol.L^{-1}$. The U16 players (n=2) were exercising at 79-80% VO_{2peak} during the last stage of the protocol, whilst the exercise intensity of the U18 (n=3) and U21 (n=2) players was 78-94 % and 80-85 % respectively. It is possible to explain why an exercise intensity of ~80 % did not elicit a blood lactate response of ≥ 4$mmol.L^{-1}$ in U16 players (i.e. higher reliance on oxidative pathways; increased fat metabolism) however, whether these explanations are valid for the U18 and U21 players remains unclear.

The aerobic energy system clearly plays a substantial role in elite hockey. However, brief bouts of high intensity activity are frequent and require players to possess the capacity to accelerate and decelerate rapidly (Reilly and Borrie, 1992). From the only match analysis of elite male field hockey to date, it is clear that only a small proportion (1.5%) of total match time is spent in sprint activity (Spencer *et al.,* 2004). However, as noted in soccer, these high intensity bouts can be crucial to the outcome of a match as they can often involve movements to win the ball or to pass defending players (Di Salvo *et al.,* 2009). The importance of speed in hockey is highlighted by comparison between successful and unsuccessful players. Fifteen metre sprint times were found to discriminate between successful and unsuccessful players in U18 and U21 squads, reaching significance in U21 players. Therefore while a high VO_{2peak} may be required to play elite hockey from an early age, speed appears to be crucial in determining a players' progression to senior international level.

As well as the capacity to produce single rapid bursts of speed, the ability to perform repeated sprints with minimal recovery between bouts is as an important characteristic for intermittent team sports such as hockey (Spencer *et al.,* 2005). During the repeated cycle sprint test senior and U21 players obtained higher PPO than U18 and U16 players, but were unable to maintain these high values for all ten sprints. Age-related differences in PPO are well documented (van Praagh, 2000). Higher absolute values in adults are largely attributed to the development of muscle mass (Duché *et al.,* 1992). However, increased muscle mass alone cannot account for the observed differences. Neuromuscular activation, changes in enzyme activity and improved motor coordination may also contribute to the ability to generate higher PPO in adulthood (Mercier *et al.,* 1992).

The mean changes in PPO between the first and final sprints for senior, U21, U18 and U16 players were -11, -19, +1 and -2 % respectively. In adult populations the exact mechanisms underlying the failure to maintain multiple sprint performance are not fully understood. The limiting factors are likely to be associated with anaerobic metabolism, namely PCr availability and intracellular inorganic phosphate accumulation (Glaister, 2005). Conversely, U18 and U16 players were able to maintain PPO throughout the sprints, possibly due to higher reliance on energy derived aerobically (Hebestreit *et al.,* 1993;), faster resynthesis of PCr stores during recovery periods (Kuno *et al.,* 1995; Taylor *et al.,* 1997) and greater ability to exchange and remove lactate and H^+ within muscle during recovery (Ratel *et al.,* 2003). Differences could also be attributed to younger players having a lower initial power output than that recorded for U21 and senior players. How these age-related differences in repeated sprint performance translate into 'real world' match situations requires further investigation.

4.5. Conclusions

The findings from this study suggest that a high peak aerobic power of approximately 60 $ml.kg^{-1}.min^{-1}$ is a prerequisite for elite level hockey from at least 15 years of age. From cross-sectional analysis of the players in this study, it would appear that individuals not possessing this characteristic are unlikely to succeed as elite hockey players, even at junior level. Age-related variation in running economy may mean that use of the MSFT in U16 and U18 hockey players will provide an underestimation of aerobic power when compared with directly determined values. In order to obtain reliable field test estimations of VO_{2peak} in these younger players, differences in submaximal VO_2 must be considered. Sprint speed appears to be crucial determinant of elite hockey success. Future senior international players were faster in U18 and U21 squads, reaching significance at U21 level. The PPO of U16 and U18 players was maintained during repeated cycle sprints while senior and U21 players demonstrated a decline in PPO during the protocol. Match analysis of players' performance during competition may determine whether this fatigue resistance of the younger players translates into improved repeated sprint ability during match-play.

Chapter 5. Match Performance Characteristics of Elite Male Junior and Senior Field Hockey Players

5.1 Introduction

The previous chapter of this thesis examined the development of physiological characteristics of elite male hockey players. Two of the principle findings of the chapter suggest that while VO_{2max} remains largely unchanged from U16 to senior level, U16 and U18 players were more fatigue resistant during repeated sprint exercise. Whilst profiling such characteristics can provide useful information for training and selection of players, analysis of players' performance during competitive matches provides crucial insight into the demands placed on players and their ability to maintain a given intensity throughout a match.

Previous time-motion analyses of modern elite hockey have concluded that the game is predominantly low intensity in nature with >90 % of match play spent in low intensity activities such as standing, walking and jogging (Boddington *et al.,* 2002; Johnston *et al.,* 2004; Spencer *et al.,* 2004; MacLeod *et al.,* 2007). However, existing studies have been restricted to senior elite level play, with the development of performance characteristics from junior to senior level receiving little attention. In addition, existing match analysis literature is largely based on video time-motion analysis where match activities rely largely on manual subjective rankings of movement categories. The development and recent validation (MacLeod *et al.,* 2009) of sport-specific non-differential Global Positioning Systems (GPS) offer an alternative to traditional video-based time-motion analysis.

In the previous chapter peak power output and 15 m sprint times were shown to improve with age, with such variation largely attributed to age-associated increases in muscle mass. When examining a cross-sectional sample of players it is therefore important to consider that older players may have the potential to generate higher maximal speeds than younger players during competitive match play. Data should therefore be analysed in relative terms (e.g. relative to maximal speed) as well as in absolute terms (i.e. $km.h^{-1}$).

Using GPS match analysis, this study sought to profile the performance characteristics of elite U16, U18 and senior hockey players during international tournaments. Data were analysed to determine if there were any differences in the absolute and relative activity profiles of U16, U18 and senior players. Comparison of activity profiles from the first and second halves will demonstrate whether the age of players affects the ability to maintain high intensity activities during competitive hockey.

5.2 Methods

5.2.1. Participants

Players from England U16 (16.0±*0.3* years; n=8), U18 (17.8±*0.1* years; n=14) and senior (25.7±*0.6* years; n=16) male international hockey squads took part in GPS match analysis during the U16 Home Nations Tournament (Cardiff, 2007), U18 Home Nations Tournament (Cardiff, 2008) and Men's Champion Challenge (Antwerp, 2007) respectively. Institutional ethics and England Hockey approval were gained prior to data collection.

5.2.2. GPS Data Collection

Each player wore a non-differential GPS device (SPI Elite, GPSports, Canberra, Australia) for at least one game. The device was small (91 x 45 x 21 mm), light (75 g) and was worn in a backpack harness between the scaplulae to permit normal movement during match play. The GPS unit measured at 1 Hz and the integrated accelerometer at 100 Hz. Data were subsequently downloaded to a personal computer for analysis.

5.2.3. GPS Data Analysis

Data were downloaded and analysed using appropriate software (Team AMS, version 1.2.1.12, GPSports, Canberra, Australia). Continuous substitutions are permitted in field hockey, therefore only the data collected during spells on the pitch were included in the analysis (i.e. periods of substitution were excluded). Duration, distance covered, mean speed and maximum speed were obtained for the total match and the 1st and 2nd halves.

5.2.4. Absolute Analysis

Data were analysed using the following absolute speed categories: standing (0-3 km.h^{-1}), walking (3-6 km.h^{-1}), jogging (6-10 km.h^{-1}), running (10-14.5 km.h^{-1}), fast running (14.5-19 km.h^{-1}) and sprinting (>19 km.h^{-1}). These zones were later divided into 3 broader categories: low (0-6 km.h^{-1}), moderate (10-14.5 km.h^{-1}) and high (>14.5 km.h^{-1}) intensity activities. Any period of activity >19 km.h^{-1} was considered an individual sprint. Each spell of play was analysed individually to determine the time interval between sprints. Sprint intervals could only be calculated for spells where >1 sprint was completed.

5.2.5. Relative Analysis

In order to compare the relative intensities of match play between age groups, the highest speed recorded for each player was considered maximum speed. The following categories were then used to analyse data relative to maximum speed: zone 1 (0-15%), zone 2 (15-30%), zone 3 (30-50%), zone 4 (50-60%), zone 5 (60-75%) and zone 6 (>75%). Each player was analysed individually relative to their own maximum speed. The mean speed zones used for relative analysis are shown in table 5.1. These relative zones were divided into 3 broader categories: 0-30 %, 30-60 % and >60 % maximum speed. Any individual period of activity >75% maximal speed was considered a relative sprint. As with the absolute sprint analysis, sprint intervals were calculated for spells where >1 relative sprint was completed.

Table 5.1: Mean (±*S.E.*) relative speed (km.h^{-1}) categories for the male U16, U18 and senior squads

Squad	15 %	30 %	50 %	60 %	75 %
U16	4.1±*0.1*	8.1±*0.2*	13.6±*0.4*	16.2±*0.4*	20.3±*0.6*
U18	4.0±*0.1*	7.9±*0.1*	13.2±*0.2*	15.8±*0.2*	19.8±*0.3*
Senior	4.3±*0.1*	8.7±*0.1*	14.5±*0.2*	17.4±*0.2*	21.8±*0.2*

5.2.6. Statistical Analyses

Mean match data were calculated for each player who completed more than one game. For cross-sectional analysis of match performance between squads, means for each squad were compared using a one-way ANOVA with *post hoc* Tukey test. Differences between the 1st and 2nd halves were analysed using a paired sample *t*-test. All data are presented as the mean and standard error of the mean (mean±*S.E.*) and significance was accepted at P<0.05.

5.3 Results

5.3.1. Total Match

Data were collected from 2.0±*0.3*, 1.9±*0.8* and 4.4±*1.0* matches during the U16, U18 and senior tournaments respectively. Total match data are presented in table 5.2. There were no differences between the squads' match duration, distance covered during match, maximum speed or mean speed (P>0.05).

First and second half comparisons are given in table 5.4. Senior players covered less distance during the second half (P<0.05). Under-18 and senior players had a lower mean speed during the second half compared to the first (P<0.001 in both cases). There were no differences in mean maximum speed obtained when halves were compared (P>0.05).

5.3.2. Absolute Analysis

The proportion time spent in each activity category for the squads are presented in table 5.3. Seniors spent a higher % time standing than U16 (P<0.05) and U18 (P<0.001) players. Seniors spent less time in moderate intensity activities than U16 and U18 players (P<0.05 in both cases). There were no differences between squads for the % time spent walking, jogging, running, fast running, sprinting or % time spent engaged in high intensity activity. Mean (*±S.E.*) total sprint number for U16, U18 and senior players were 25*±4*, 40*±4* and 36*±2* respectively. Under-18 players completed more sprints than U16 players (P<0.05). Mean sprint duration was 2.6±*0.2*; 2.5±*0.1* and 2.7±*0.1* s (P>0.3) with a mean interval of 99±*13*; 85±*17* and 88±*11* s between sprints for U16, U18 and senior players respectively (P>0.7). There were no differences in the distance covered during individual absolute sprints when squads were compared (15.2±*1.0* *vs*. 14.6±*0.4* *vs*. 15.2±*0.5* m; U16 *vs*. U18 *vs*. senior; P>0.2). Senior players obtained higher maximal speeds during individual sprints than U18 players

(21.8±*0.1* *vs*. 21.3±*0.1* km.h^{-1}; *P*<0.05) and a tendency to reach higher speeds than U16 players (21.8±*0.1* *vs*. 21.3±*0.2* km.h^{-1}; *P*=0.074).

5.3.3. Absolute Comparison of First and Second Halves

Figures 5.1-5.4 show the activity profiles of players during the first and second halves. All squads spent a higher % time standing during the second half (figures 5.1-5.3). Under-18 and senior players were involved in more walking during the second half (*P*<0.01 and *P*<0.05 respectively). Under-18 and senior players spent a lower proportion of time engaged in jogging, running and fast running during the second half (figures 5.2 and 5.3). Senior players spent a lower % time sprinting in the second half (*P*<0.001, figure 5.3). There were no differences in the % time spent in low, moderate or high intensity activities when the U16 first and second halves were compared (*P*>0.05, figure 5.1). Under-18 and senior players spent a higher % time in low intensity and a lower % time in moderate and high intensity activities during the second half (figure 5.4).

For U16 players there were no differences in the mean (*±S.E.*) number of sprints (>19 km.h^{-1}) completed in the first and second halves (12*±2* *vs.* 14*±2*), sprint duration (2.5±*0.1* *vs*. 2.7±*0.25* s; *P*>0.2), sprint interval (98±*11* *vs*. 106±*17* s; *P*>0.5) or sprint distance (14.9±*0.9* *vs*. 16.0±*1.1* m; *P*>0.2). Under-16 players reached higher maximal speeds during sprints in the second half compared to the first (21.2±*0.2* *vs*. 21.5±*0.2* km.h^{-1}; *P*<0.01). When U18 absolute sprints were compared from the first and second halves, there were no differences in the number (20±*2* *vs*. 20±2), duration (2.5±*0.1* *vs*. 2.6±*0.1* s; *P*>0.9), interval (79±*13* *vs*. 91±*20* s;

P>0.1), distance covered (14.8±*0.7 vs*. 15.0±*0.7* m; *P*>0.8) or maximal speed obtained (21.3±*0.1 vs*. 21.4±*0.1* km.h^{-1}; *P*>0.8). Similarly, seniors showed no difference in the number (19±*1 vs*. 17±*1*), duration (2.7±*0.1 vs*. 2.7±*0.1* s; *P*>0.9), interval (85±*11 vs*. 94±*11* s; *P*>0.05) maximal speed (21.8±*0.1 vs*. 21.8±*0.1* km.h^{-1}; *P*>0.9) or distance (15.7±*0.4 vs*. 15.8±*0.6* m; *P*>0.9) of sprints in the first and second halves.

5.3.4 Relative Analysis

The mean (*±S.E.*) maximum speeds used for calculation of relative speeds for male U16, U18 and senior players were 27.0±*0.7*, 26.4±*0.4* and 29.0±*0.3* km.h^{-1} respectively. Senior players had a higher recorded maximum speed than U16 and U18 players (*P*<0.05 and *P*<0.001 respectively). There were no differences in maximum speed between U16 and U18 players (*P*>0.6).

The % time spent in each relative speed category by U16, U18 and senior players are presented in table 5.5. Seniors spent more time at 0-15 % maximum speed than U16 (*P*<0.01) and U18 (*P*<0.001) players. Senior players spent less time at 50-60 % and 60-75 % maximum speed than U16s and U18s (table 5.5). Under-18 players spent a higher proportion of match time >75 % maximum speed than senior players (*P*<0.01). Senior players were involved in more activity at 0-30 % maximum speed and less activities at >60% maximum speed than U18 players (*P*<0.01 in both cases). Mean (±*S.E.)* relative total sprint number for U16, U18 and senior players were 17±*3*, 31±*3* and 15±*1* respectively. Under-18 players completed more individual sprints than U16s and seniors (*P*<0.01 and *P*<0.001

respectively). The mean(*±S.E*) duration of individual sprints was 2.5±*0.08*; 2.4±*0.05* and 2.3±*0.04* s (*P*>0.2) with a mean interval between sprints of 160±*31*; 110±*22* and 172±*19* s (*P*>0.1) for U16, U18 and senior players respectively. Senior players covered more distance during individual relative sprints than U18 players (15.4±0.3 vs. 14.1±0.3 m; *P*<0.05). Under-16 relative sprint distance (15.2±0.6) was not different from U18 or senior distances (*P*>0.1).

5.3.5. Relative Comparison of First and Second Halves

Figures 5.5-5.8 show the activity profiles of players during the first and second halves relative to maximum speed. Under-16, U18 and senior players spent a higher % time in zone 1 during the second half (*P*<0.05; *P*<0.001; *P*<0.001 respectively). Under-18 players spent a lower proportion of time engaged in zone 3 and 4 activities in the second half (both *P*<0.001). Senior players were involved in less zone 2, 3, 4 and 5 activities during the second half compared with the first (figure 5.7). During the second half, U18 and senior players completed more work at 0-30% maximum speed and a lower proportion at 30-60 % maximum speed (*P*<0.001 in all instances). Senior players spent a lower % time at >60% maximum speed in the second half (*P*<0.01).

Comparison of first and second half relative sprints (>75% maximum speed) for U16, U18 and senior players (respectively) revealed no differences in sprint number (8±*2 vs*. 10±*1*; 16±*2 vs*. 15±*2*; 8±*1 vs*. 7±*1*; *P*>0.05), duration (2.6±*0.2 vs*. 2.5±*0.1*; 2.4±*0.1 vs*. 2.4±*0.1*; 2.4±*0.1 vs*. 2.3±*0.1* s; *P*>0.7), interval (224±*58 vs*. 142±*24*; 97±*15 vs*. 132±*33;* 192±*29 vs*. 172±*20*; s *P*>0.05), maximal speed (22.7±*0.9 vs*. 22.3±*0.6*; 21.9±*0.3 vs*. 21.9±*0.3*; 24.0±*0.3 vs*.

23.8±*0.2* $km.h^{-1}$) or distance (16.6±*2.0* *vs*. 15.2±*0.7*; 14.2±*0.5* *vs*. 14.2±*0.6*; 15.7±*0.3* *vs*. 15.4±*0.5* m; P>0.5).

Table 5.2: Total match GPS data for male U16, U18 and senior international players (mean±*S.E.*)

	U16 (n=8)	**U18 (n=14)**	**Senior (n=16)**
Total Duration (hh:mm:ss)	00:40:11±*00:02:24*	00:50:12±*00:03:28*	00:50:20±*00:03:06*
Total Distance (m)	5385.0±*315.7*	6608.4±*317.9*	6260.4±*296.2*
Total Spells	4.0±*0.3*	3.9±*0.4*	3.8±*0.3*
Max. Speed ($km.h^{-1}$)	26.3±*0.9*	25.7±*0.3*	27.0±*0.3*
Mean Speed ($km.h^{-1}$)	8.0±*0.2*	8.1±*0.3*	7.6±*0.1*

Table 5.3: Absolute % time spent in activity categories for male U16, U18 and senior international field hockey players (mean±*S.E.*).

% Time	U16 (n=8)	U18 (n=14)	Senior (n=16)	Analysis
Standing (0-3 km.h^{-1})	19.4±*0.7*	17.6±*0.8*	22.0±*0.5*	Senior vs. U18 *P*<0.001 Senior vs. U16 *P*<0.05
Walking (3-6 km.h^{-1})	26.7±*1.2*	28.1±*1.6*	28.8±*0.9*	NS.
Jogging (6-10 km.h^{-1})	19.5±*0.8*	20.0±*0.6*	18.4±*0.4*	NS.
Running (10-14.5 km.h^{-1})	22.0±*1.3*	21.0±*1.0*	18.6±*0.7*	NS.
Fast Running (14.5 -19 km.h^{-1})	9.5±0.7	9.7±0.9	8.7±0.5	NS.
Sprinting (>19 km.h^{-1})	2.8±0.6	3.6±0.4	3.5±0.3	NS.
Low Intensity (0-6 km.h^{-1})	46.1±*1.3*	45.7±*2.2*	50.8±*1.1*	NS.
Moderate Intensity (6-14.5 km.h^{-1})	41.5±*1.2*	41.0±*1.2*	37.0±*0.7*	Senior vs. U18 *P*<0.05 Senior vs. U16 *P*<0.05
High Intensity (>14.5 km.h^{-1})	12.4±*1.2*	13.3±1.3	12.1±*0.8*	NS.

Table 5.4: First and second half comparisons for male U16 (n=8), U18 (n=14) and senior (n=16) international hockey players (mean±*S.E.*)

	Duration (hh:mm:ss)	Distance (m)	Mean Speed (km.h^{-1})	Max. Speed (km.h^{-1})
U16 First Half	00:19:30±*00:01:18*	2648.8±*186.8*	8.1±*0.2*	25.4±*1.0*
U16 Second Half	00:20:41±*00:01:29*	2736.2±*180.3*	8.0±*0.2*	25.1±*0.5*
U18 First Half	00:24:21±*00:01:54*	3371.1±*219.2*	8.5±*0.3*	25.1±*0.3*
U18 Second Half	00:25:50±*00:02:11*	3241.9±*207.0*	7.7±*0.3***	25.2±*0.4*
Senior First Half	00:24:51±*00:01:28*	3197.3±*139.7*	7.8±*0.2*	26.8±*0.3*
Senior Second Half	00:25:28±*00:01:39*	3063.1±*161.4**	7.3±*0.1***	26.5±*0.3*

* = P<0.05   ** = P<0.001

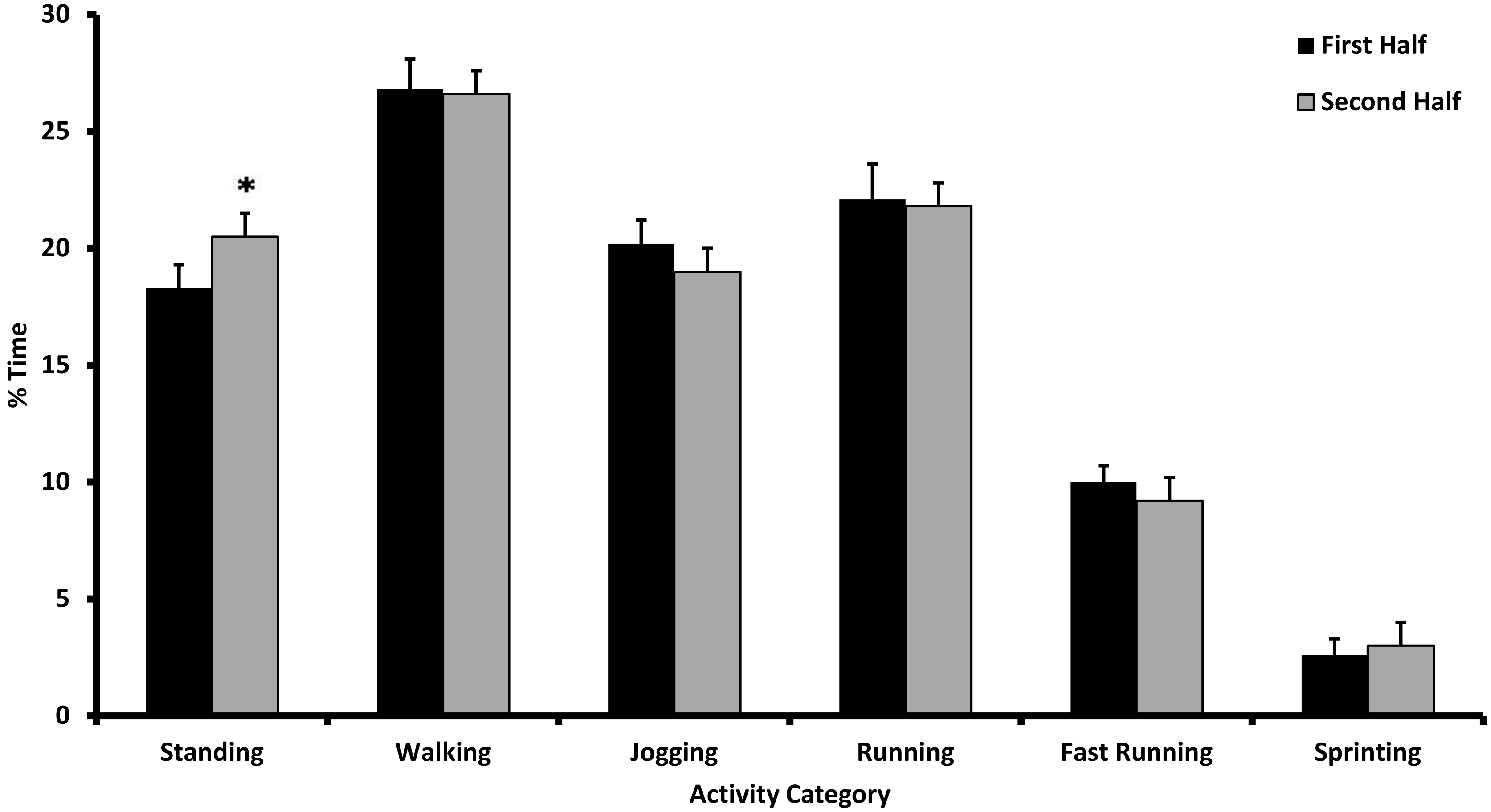

Figure 5.1: Comparison of male U16 players' activity profile during the first and second halves (mean±*S.E.*) (* P<0.05).

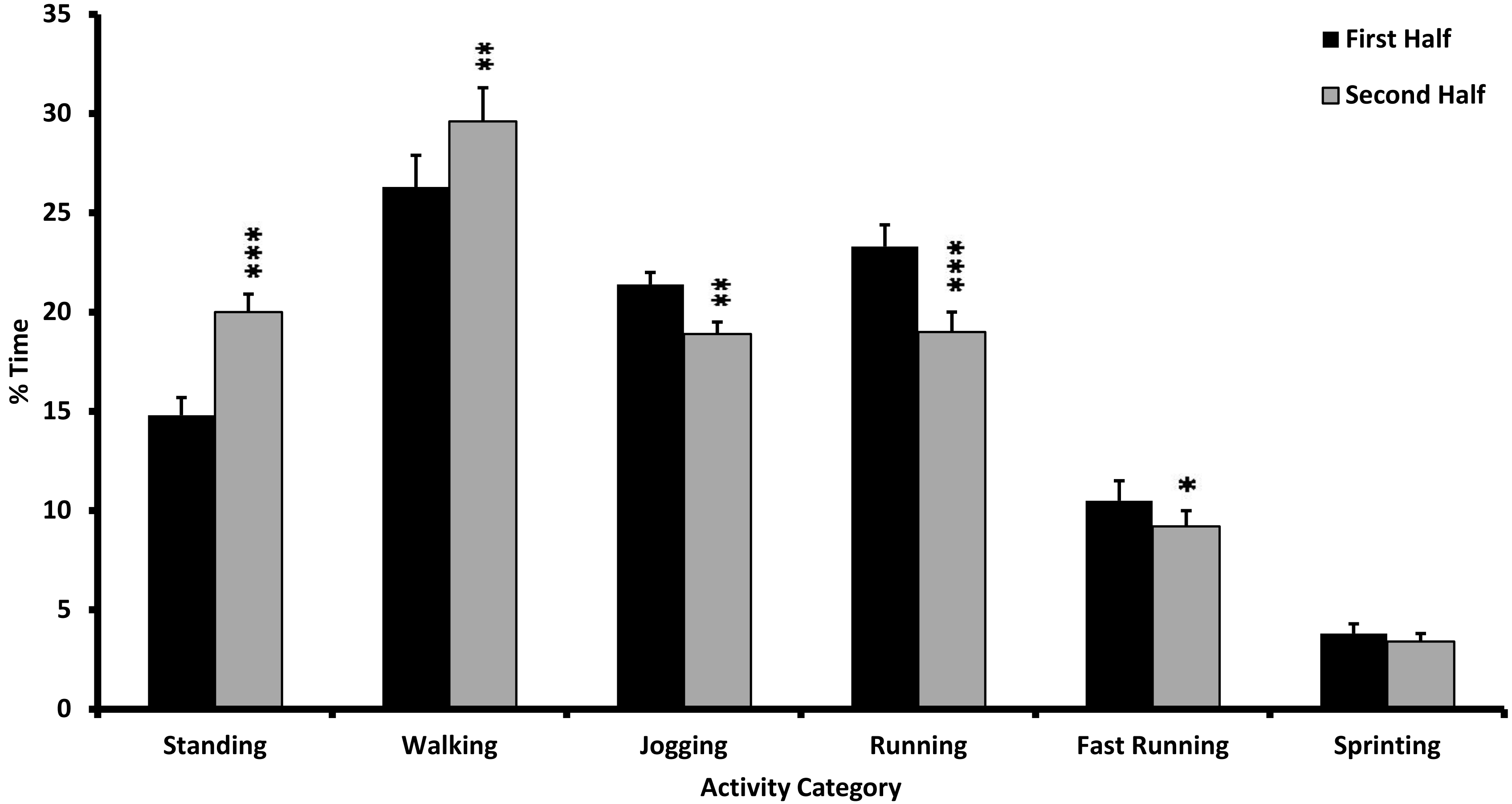

Figure 5.2: Comparison of male U18 players' activity profile during the first and second halves (mean±*S.E.*) (*P<0.05 **P<0.01 ***P<0.001).

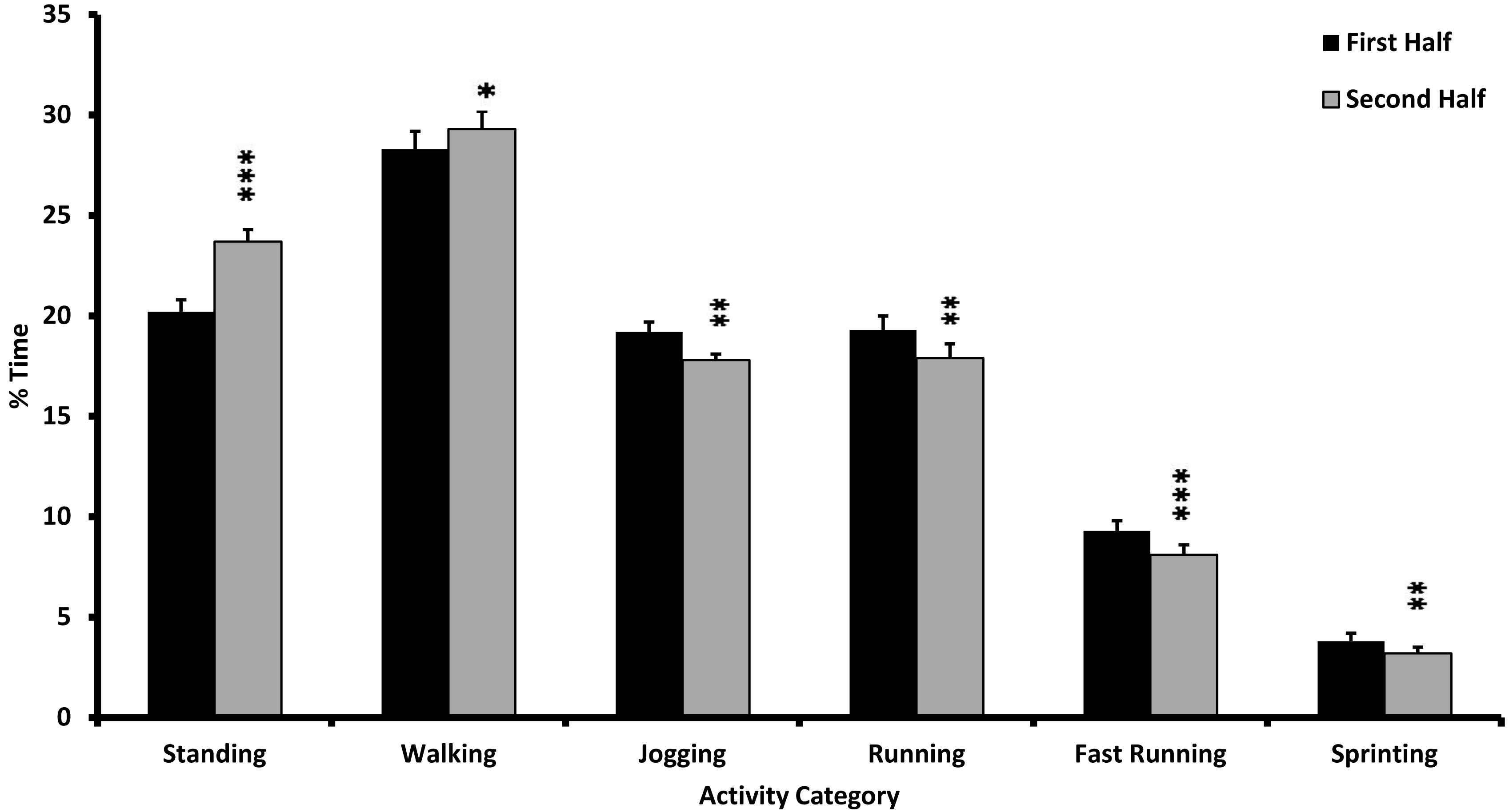

Figure 5.3: Comparison of male senior players' activity profile during the first and second halves (mean±*S.E.*) (**P*<0.05 ***P*<0.01 ****P*<0.001).

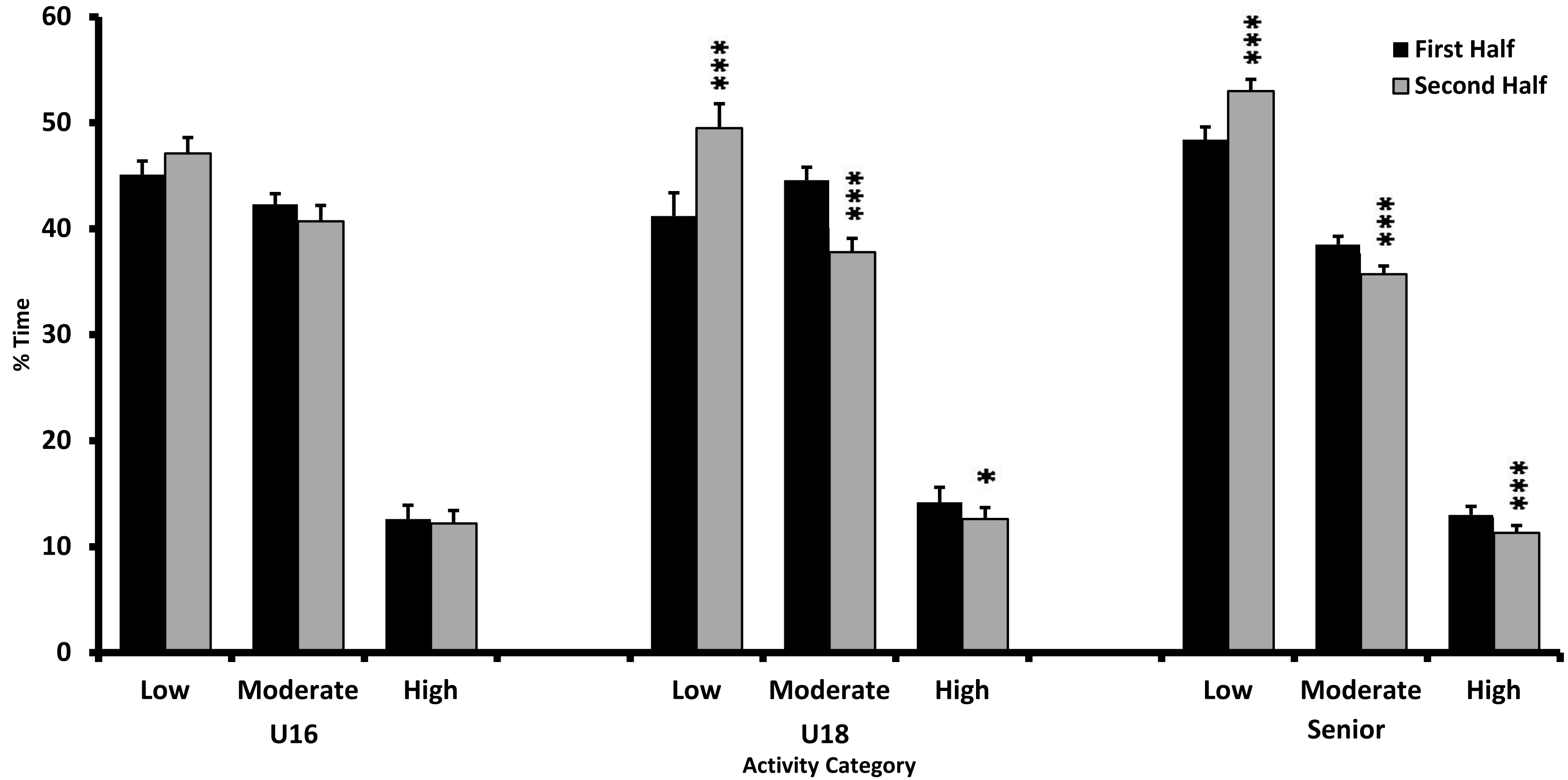

Figure 5.4: Male U16, U18 and senior players' % time spent in low, moderate and high intensity activities during the first and second halves (mean±S.E.) (*$P<0.05$; ***$P<0.001$).

Table 5.5: Percentage time spent in relative activity categories for male U16, U18 & senior international field hockey players (mean±*S.E.*)

% Maximum Speed	U16 (n=8)	U18 (n=14)	Senior (n=16)	Analysis
Zone 1 (0-15 %)	27.5±*1.5*	25.3±*1.3*	33.0±*0.6*	Senior vs. U18 *P*<0.001 Senior vs. U16 *P*<0.01
Zone 2 (15-30 %)	29.1±*1.5*	30.6±*1.4*	31.0±*0.9*	NS.
Zone 3 (30-50 %)	26.3±*1.1*	25.7±*1.1*	23.8±*0.8*	NS.
Zone 4 (50-60 %)	8.8±*0.8*	8.8±*0.6*	6.7±*0.3*	Senior vs. U18 *P*<0.05 Senior vs. U16 *P*<0.05
Zone 5 (60-75 %)	6.4±*1.0*	6.8±*0.6*	4.3±*0.3*	Senior vs. U18 *P*<0.01 Senior vs. U16 *P*<0.05
Zone 6 (>75 %)	1.9±*0.4*	2.6±*0.3*	1.2±*0.1*	Senior vs. U18 *P*<0.01
Low Intensity (0-30 %)	56.6±*2.6*	56.0±*2.3*	64.0±*1.2*	Senior vs. U18 *P*<0.01
Moderate Intensity (30-60 %)	35.1±*1.7*	34.6±*1.6*	30.5±*1.0*	NS.
High Intensity (>60 %)	8.3±*1.3*	9.5±*0.9*	5.5±*0.4*	Senior vs. U18 *P*<0.01

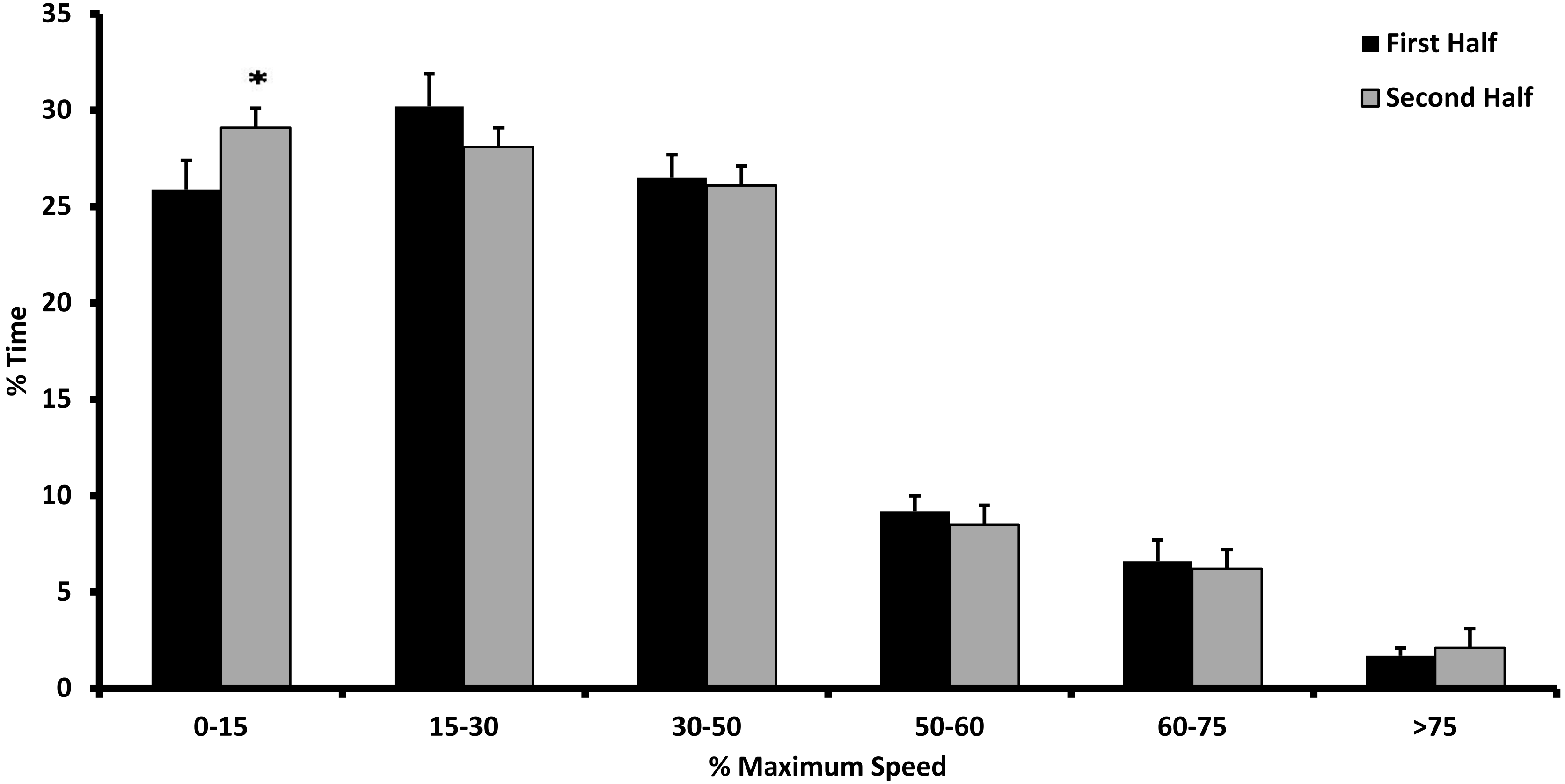

Figure 5.5: Comparison of male U16 players' activity profile (relative to maximum speed) during the first and second halves (mean±S.E.)

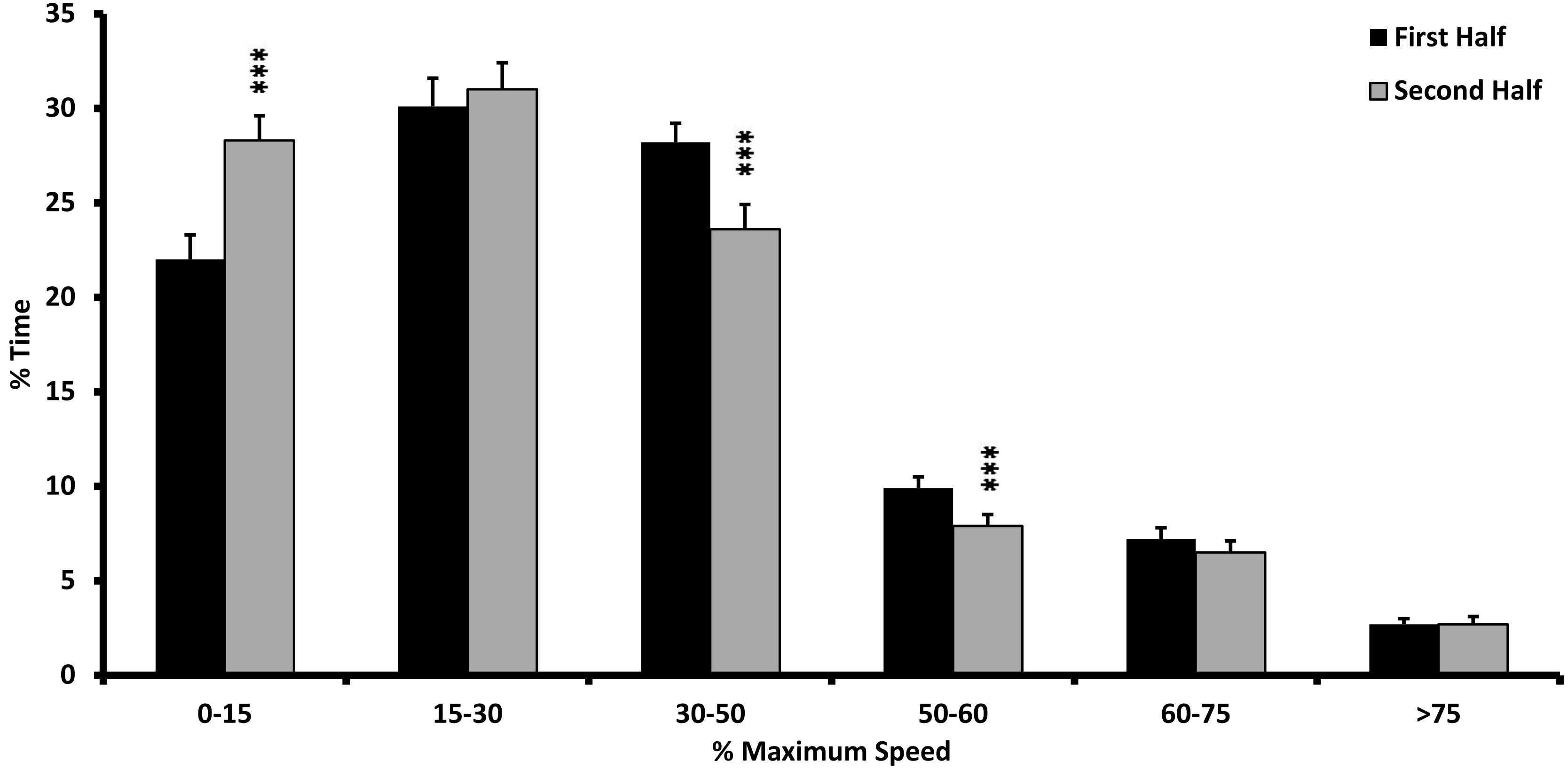

Figure 5.6: Comparison of male U18 players' activity profile (relative to maximum speed) during the first and second halves (mean±*S.E.*) (****P*<0.001).

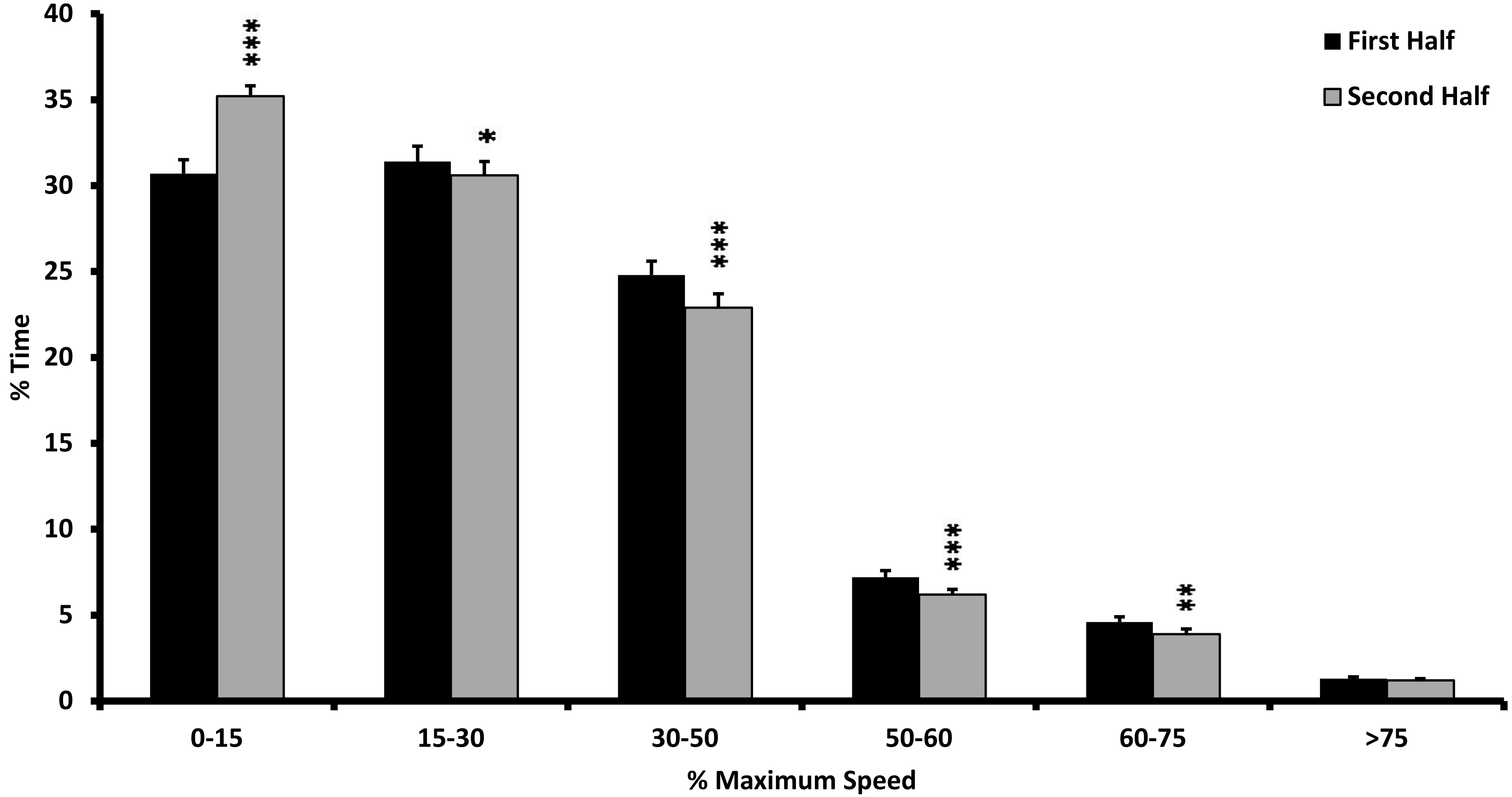

Figure 5.7: Comparison of male senior players' activity profile (relative to maximum speed) during the first and second halves (mean±*S.E.*) (**P*<0.05, ***P*<0.01, ****P*<0.001).

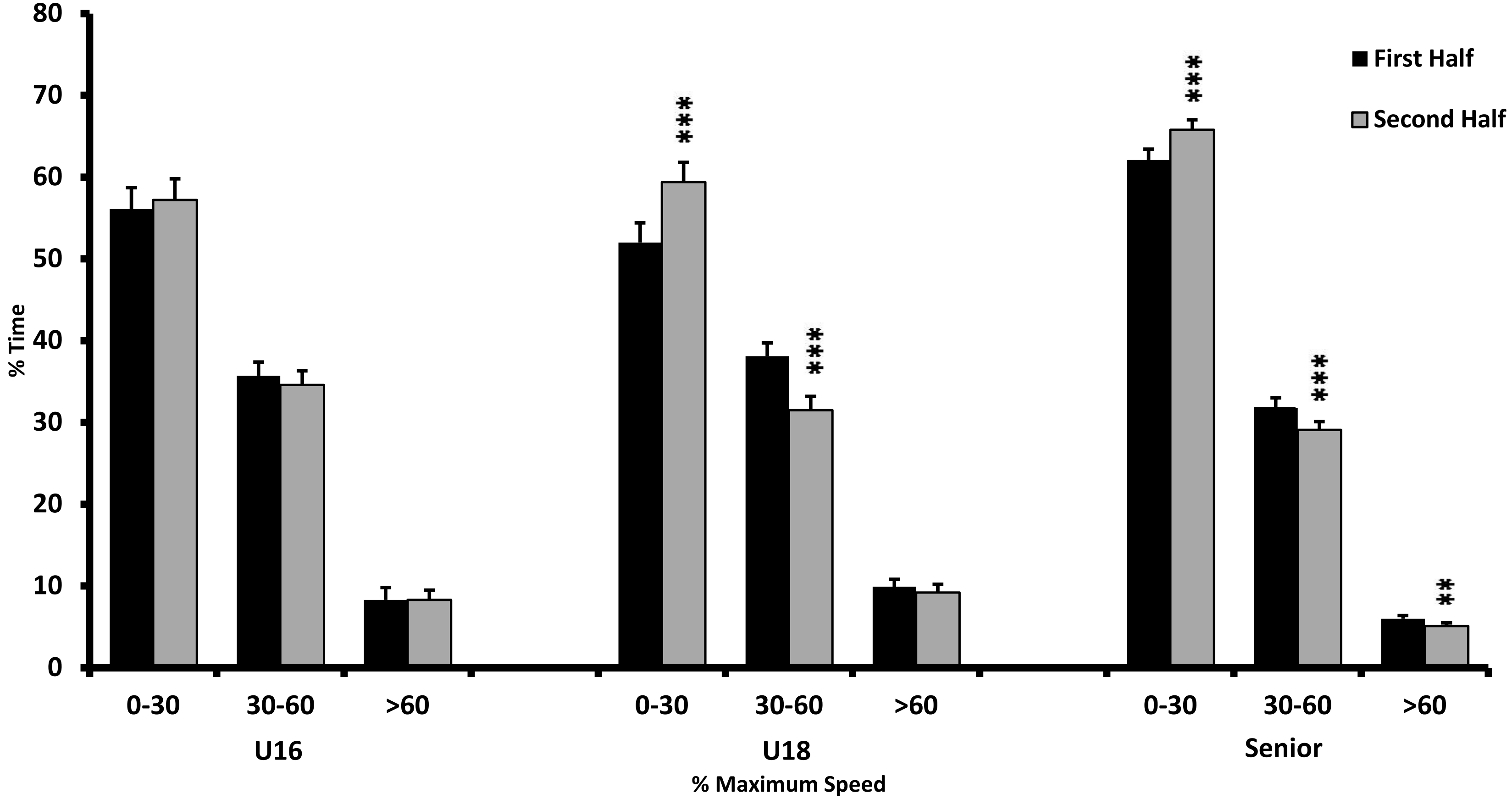

Figure 5.8: Male U16, U18 and senior players' % time spent at 0-30, 30-60 and >60 % maximum speed during the first and second halves (mean±S.E.) (**P*<0.05; ****P*<0.001).

5.4. Discussion

The main findings from this study suggest that elite level field hockey players are predominantly engaged in low to moderate intensity activities during competitive games. In the three age-groups examined, 90 % of total match-play was spent in low-moderate intensity activities (<14.5 km.h^{-1}). When analysed relative to maximum speed, 90-95 % of the total match was spent engaged in activities <60 % maximum speed. Whilst U16, U18 and senior male players all spent the majority of time in such activities, the senior game appears to be of a lower overall intensity, with senior players spending more time standing and at 0-15 % maximum speed than either of the younger squads. In addition, whilst all three squads demonstrated some degree of fatigue in the second half, it was senior players who experienced the largest decrement in high intensity activities.

When analysed in both absolute and relative terms, it appears that elite male hockey players spend the majority of match time engaged in low to moderate intensity activities. Previous time-motion analyses of field hockey have reported similar findings with over 90 % of activities being classed as low intensity (Boddington *et al.,* 2002; Johnston *et al.,* 2004; Spencer *et al.,* 2004; MacLeod *et al.,* 2007). The only existing study examining male international hockey was based on data collected from a single match played by the Australian Men's squad, with the authors reporting players to spend an average of 94.4 % of the game standing, walking and jogging (Spencer *et al.,* 2004). This is considerably higher than the 65.6, 65.7 and 69.2 % of time spent by U16, U18 and senior players respectively in similar activity categories in the present study. Whilst it appears that the majority of elite hockey match play is spent in low intensity activities, high intensity actions are often crucial to the outcome of a game. Previous analysis of international men's hockey reported players to spend 1.5 % of match play sprinting (Spencer *et al*., 2004) which is considerably lower than the 2.8, 3.6 and 3.5 % for U16, U18 and senior players (respectively) in the present study. The principle difference in the sprint profile of players from these two studies is the duration of individual sprints. In the present study, the mean absolute sprint duration was between 2.5 s (U18) and 2.7 s (senior) compared to 1.8 s reported for the Australian mens team (Spencer *et al*., 2004). Discrepancies in movement classification may account for the variation in the proportion of time involved in activity categories reported in the current study compared with existing time motion analyses of hockey. To the author's best knowledge, this is the first field hockey study to have analysed match data using motion categories based on players' speed of movement. The subjective motion categories used in previous analyses of field hockey (Lothian and Farrally, 1994; Spencer *et al*., 2004) make direct comparison of activity profiles difficult. The advent of sport-specific GPS devices may permit more direct comparison between future studies due to the objective classification of match activities.

Surprisingly little research has examined the development of match performance characteristics in intermittent team sports, with no studies to date investigating match activity of junior field hockey players. Of the limited published work analysing match play of junior soccer players (e.g. Capranica *et al*., 2001; Castagna *et al*., 2003; Strøyer *et al*., 2004), inconsistencies in measurement technique, match duration, pitch dimensions and movement classification make comparison with adult data difficult. Despite this, Strøyer and colleagues (2004) concluded that the activity profile of elite young soccer players was comparable with that of elite adult players. Likewise, cross-sectional analysis of data from the present study suggests many similarities exist between the activity profiles of junior and senior elite field hockey players. Whilst absolute analysis of U16, U18 and senior match play showed seniors to spend more time standing and less time in moderate intensity activities, there were no differences in the distance covered, mean speed or the proportion time spent walking, jogging, running, fast running, sprinting or in low or high intensity activities. Cross-sectional analysis of the physiological characteristics of U16, U18, U21 and senior players in Chapter 4 suggested that a VO_{2peak} of around 60 $ml.kg^{-1}.min^{-1}$ or more is a prerequisite for male elite level hockey players from 16 years of age. In soccer, a moderate correlation between VO_{2max} and the distance covered in a match has been observed ($r=0.52$, $P<0.05$) (Krustrup *et al*., 2003). This suggests that measurable match performance variables may be influenced by players' maximal aerobic power. Similarities in the absolute match demands placed on U16, U18 and senior players may partially explain why elite players require such a high VO_{2peak} from at least U16 level onwards.

However, when activity was analysed relative to maximum speed, senior players spent a higher proportion of game time at 0-15% maximum speed and less time at 50-60% and 60-75% maximum speed than either U16 or U18 players. Relatively, senior players also spent more time at 0-30% and less time at >60 and >75% maximum speed than U18 players. This suggests that whilst the absolute demands placed on players are not age-related, senior match-play is of an overall lower intensity. This may reflect the higher absolute speeds generated by the senior players and an inability to recover rapidly from high intensity exercise. As described in the literature (e.g. Ratel *et al.*, 2006) and in the previous chapter, the ability to recover from one or several repeated bouts of high intensity work is age-dependent. Differences in oxidative capacity, PCr resynthesis rates and accumulation of metabolic by-products are thought to explain young peoples' ability to better resist fatigue during such activities. As a result, senior players may need to spend longer periods recovering from high intensity bouts while engaged in lower intensity activities (e.g. standing/0-15% maximum speed) and may not be able to sustain moderate-high intensity bouts during this time. Alternatively, the senior games used in this analysis may have incurred more set pieces and time stoppages (e.g. short corners and injuries) where players were required to wait for normal play to resume. Perhaps a limitation of GPS used as a distinct tool is that these factors cannot be as easily incorporated into analysis of data as during video-based time-motion analysis methods.

Analysis of the first and second halves suggests that players from all three age groups experienced some degree of fatigue as indicated by an increase in the % time spent standing and at 0-15% maximum speed in the second half. During the second half U18 and senior players also showed a decrease in mean speed, an increase in proportion of time spent walking with concurrent decreases in % time jogging, running, fast running and % time at 15-30 %, 30-50 %, 50-60 % and 60-75 % maximal speed. In addition, senior players covered less distance and spent a lower % time sprinting during the second half. This would suggest that the ability to maintain a given intensity during elite hockey is age dependent, with senior players experiencing the largest decrement in performance and U16 the least over the course of a match. Decrements in physical performance as a consequence of fatigue during match play have been widely reported in hockey and soccer literature. Such declines in match performance are typically manifested as reductions in the distance covered (Drust *et al*., 1998; Boddington *et al*., 2002; Mohr *et al*., 2003) and decreased high intensity activity (Lothian and Farrally, 1994; Mohr *et al*., 2003; MacLeod *et al*., 2007; Rampini *et al*., 2007) during the second half of a match. However, the underlying mechanism(s) of such reductions in match performance towards the end of a match remain unclear with numerous factors including interstitial potassium accumulation (Fitts, 1994), hyperthermia (Ekblom, 1986), dehydration (Mustafa and Mahmoud, 1979) glycogen depletion (Saltin, 1973) and accumulation of H^+ and lactate in muscle (Sahlin, 1992) being implicated with the onset of fatigue during match play.

One factor which has received considerable attention as a contributor to fatigue during a match is muscle glycogen. Saltin and Karlsson (1973) found that soccer players who began a game with low levels of muscle glycogen (7 $g.kg^{-1}$ wet weight) covered less distance sprinting, spent more time walking and covered less distance during the second half than players who started the game with higher muscle glycogen concentrations (15 $g.kg^{-1}$ wet weight). More recently, Krustrup and colleagues (2006) found around 50 % of muscle fibres to be empty or nearly empty of glycogen at the end of a soccer game and concluded that glycogen depletion in individual fibres may contribute to the development of fatigue during match play. If glycogen depletion does indeed play a significant role in the development of fatigue in the second half of a match, age-associated variation in glycogen depletion rates may explain why senior players demonstrated a higher degree of fatigue than U16 or U18 players. However, due to the invasive techniques involved, data regarding glycogen depletion rates in young people are sparse and contradictory (e.g. Eriksson *et al*., 1973; Eriksson, 1980) meaning no firm conclusions can be drawn. Non-invasive techniques such as respiratory exchange ratio (RER) and ^{13}C isotope methodologies have been used to assess substrate utilisation during exercise in children, adolescents and adults to provide an indication of the relative contributions of carbohydrate and lipid as metabolic substrates. From such work it appears that children and adolescents utilise considerably more lipid and less carbohydrate than adults at the same relative exercise intensity (Morse *et al*., 1949; Montoye 1982; Timmons *et al*., 2003; Stephens *et al*., 2006). As puberty proceeds it is thought that the rate of lipid oxidation is attenuated and an adult-like metabolic profile is developed between mid to late puberty (Stephens *et al*., 2006). Heavier reliance on lipid metabolism in younger players could result in a carbohydrate sparing effect and offset the depletion of glycogen often associated with decrements in match performance and could explain the age-related decline in activity toward the end of a game.

5.5 Conclusions

In agreement with existent literature, the present study suggests that the activities engaged in during elite male field hockey match play are predominantly low intensity in nature. Periods of low to moderate intensity activity may be required in order to facilitate recovery from high intensity bouts. Cross-sectional analysis of U16, U18 and senior players' match performance characteristics demonstrated that the demands placed on players from all age groups were markedly similar and may be reflected by the similarities in the physiological characteristics required to compete at the elite level (Chapter 4). Analyses of the first and second halves revealed the three age groups all experienced fatigue during the second half of a game as demonstrated by an increase in the proportion time spent in lower intensity activity categories. However, it was senior players who exhibited the largest decrement in performance and inability to maintain sprint activities toward the end of a game. Age-related changes in substrate utilisation and muscle metabolism most likely account for these differences. Dietary manipulation of muscle glycogen content and tactical use of continuous substitutions should be considered to minimise the effects of fatigue. Future investigations should examine elite junior and senior female hockey to investigate whether similar activity profiles and performance decrements are exhibited by female players.

Chapter 6. Match Performance Characteristics of Elite Female Junior and Senior Field Hockey Players

6.1 Introduction

Chapter 5 provided a cross-sectional analysis of the match performance characteristics of elite junior and senior male field hockey players. Results from match analyses suggest that while there are many similarities in the absolute demands placed on junior and senior players, senior international hockey players spend more time at lower relative intensities during matches. The chapter also highlighted that whilst all age groups exhibited decrements in performance during the second half, it was senior males who experienced the greatest fatigue toward the end of a match. Whilst age has an impact on the physiological mechanisms underpinning match performance, sex may influence factors which may have considerable impact on match performance such as power output, energy metabolism and fatigue resistance.

Sex differences in power output, substrate utilisation and fatigue resistance have been reported (e.g. Mayhew and Salm, 1990; Tarnopolsky *et al*., 1990; Hicks *et al*., 2001) and could have a considerable impact on field hockey performance. Additionally, females typically enter and finish puberty 2 years before males (Marcell, 2007) which could have implications for the activity and metabolic profiles of junior female players.

The primary aims of this study were therefore to profile the match performance characteristics of elite female U16, U18 and senior hockey players using GPS match analysis techniques. Data were analysed in both absolute and relative terms to determine any differences in activity profile between age groups. Decrements in performance over the course of a match were analysed by comparing activity patterns from the first and second halves.

6.2 Methods

6.2.1. Participants

Players from female England U16 (16.2±*0.1* years; n=7), U18 (17.6±*0.2* years; n=5) and senior (24.5±*0.8* years; n=15) international squads took part in GPS match analysis during the U16 Home Nations Tournament (Cardiff, 2007), U18 Home Nations Tournament (Cardiff, 2008) and Women's Champion Challenge (Baku, 2007) respectively. Institutional ethics and England Hockey approval were gained prior to data collection.

6.2.2. GPS Data Collection

Each player wore a non-differential GPS device (SPI Elite, GPSports, Canberra, Australia) for at least one game. The device was small (91 x 45 x 21 mm), light (75 g) and to permit normal movement during match play, was worn in a backpack harness between the scaplulae. The GPS unit measured at 1 Hz and the integrated accelerometer at 100 Hz. Data were subsequently downloaded to a personal computer for analysis.

6.2.3. GPS Data Analysis

Data were downloaded and analysed using appropriate software (Team AMS, version 1.2.1.12, GPSports, Canberra, Australia). Continuous substitutions are permitted in field hockey, therefore only the data collected during spells on the pitch were included in the analysis (i.e. periods of substitution were excluded). Duration, distance covered, mean speed and maximum speed were obtained for the total match and the 1st and 2nd halves.

6.2.4. Absolute Analysis

Data were analysed using the following absolute speed categories: standing (0-3 km.h^{-1}), walking (3-6 km.h^{-1}), jogging (6-10 km.h^{-1}), running (10-14.5 km.h^{-1}), fast running (14.5-19 km.h^{-1}) and sprinting (>19 km.h^{-1}). Any period of activity >19 km.h^{-1} was considered an individual sprint. These zones were later divided into 3 broader categories: low (0-6 km.h^{-1}), moderate (10-14.5 km.h^{-1}) and high (>14.5 km.h^{-1}) intensity activities.

6.2.5. Relative Analysis

In order to compare the relative intensities of squads, for each player the highest speed recorded during all matches was considered maximum speed. The following categories were then used to analyse data relative to maximum speed: zone 1 (0-15%), zone 2 (15-30%), zone 3 (30-50%), zone 4 (50-60%), zone 5 (60-75%) and zone 6 (>75%). Any period of activity >75% maximal speed was considered a relative sprint. Each player was analysed relative to their own maximum speed. The mean speed zones used for relative analysis are shown in table 6.1.

Table 6.1: Mean (±*S.E.*) relative speed ($km.h^{-1}$) categories for the female U16, U18 and senior squads

Squad	15 %	30 %	50 %	60 %	75 %
U16	3.7±*0.1*	7.3±*0.2*	12.1±*0.2*	14.6±*0.8*	18.2±*0.4*
U18	3.7±*0.2*	7.4±*0.3*	12.4±*0.5*	14.8±*0.6*	18.5±*0.8*
Senior	3.9±*0.1*	7.7±*0.1*	12.9±*0.2*	15.5±*0.2*	19.3±*0.2*

6.2.6. Statistical Analyses

Mean match data were calculated for each player who completed more than one game. For cross-sectional analysis of match performance between squads, means for each squad were compared using a one-way ANOVA with *post hoc* Tukey test. Differences between the 1st and 2nd halves were analysed using a paired sample *t*-test. All data are presented as the mean and standard error of the mean (mean±*S.E.*) and significance was accepted at $P<0.05$.

6.3. Results

6.3.1. Total Match

Data were collected from 3±*0*, 2±*0.4* and 5±*0.3* matches during the U16, U18 and senior tournaments respectively. Total match data are presented in table 6.2. There were no differences between the squads' match duration, distance covered, maximum or mean match speed ($P>0.05$).

First and second half comparisons are given in table 6.4. None of the squads showed any differences when the duration, distance covered and maximum speed of the first and second halves were compared ($P>0.05$). Senior players had a lower mean speed during the second half ($P<0.001$).

6.3.2 Absolute Analysis

The proportion of time spent in each of the absolute activity categories are presented in table 6.3. There were no differences between squads for the % time spent standing, walking, jogging, running, fast running or sprinting ($P>0.05$). There were no differences in the proportion time spent in low and moderate intensity activities ($P>0.05$). Seniors spent a higher % time engaged in high intensity activities than U16 players (*P*<0.05). There were no differences between U16, U18 and senior players for the total absolute sprint number (11±*3*, 14±*3* and 17±*1* respectively, *P*>0.05).

6.3.3. Absolute Comparison of First and Second Halves

Absolute comparisons of the first and second halves for U16, U18 and senior players are shown in figures 6.1-6.4. Under-16 players spent a higher % time standing (*P*<0.05) and a lower % time jogging (*P*<0.001) during the second half (figure 6.1). When the first and second half % time spent in low moderate and high intensity activities were compared, there were no differences for U16 players (*P*>0.05; figure 6.4). There were no differences in the % time U18 players spent in any of the absolute activity categories when the first and second halves were compared (*P*<0.05; figures 6.2 and 6.4). Senior players spent more time standing (*P*<0.001) and less time jogging (*P*<0.001), running (*P*<0.05) and sprinting (*P*<0.05) during the second half (figure 6.3). Senior players spent a higher proportion of the second half in low intensity activities (*P*<0.001) and a lower proportion in moderate (*P*<0.001) and high (*P*<0.05) intensity activities than the first half (figure 6.4). There were no differences in the number of absolute (>19 $km.h^{-1}$) sprints performed in the first vs. second halves for U16 and U18 players (5±*1 vs*. 6±*1* and 7±*1 vs*.7±*2* respectively; mean±*S.E.*; *P*>0.05). Senior players completed more sprints in the first *vs*. second half (9±*1 vs*. 8±*1*; mean±*S.E.*; *P*<0.05).

6.3.4. Relative Analysis

The mean±*S.E.* maximum speeds used for calculation of relative speeds for female U16, U18 and senior players were 24.3±*0.5*, 24.7±*1.0* and 25.8±*0.3* $km.h^{-1}$ respectively. There were no differences in maximum speed between age groups. Mean squad comparisons of total relative match activities are presented in table 6.5. There were no differences between squads based on match activities when analysed relative to maximum speed (*P*>0.05 in all cases; table 6.5). The number of relative sprints (>75 % relative speed) were not different between U16, U18 and senior players (16*±3*, 22*±6* and 15*±1*; mean*±S.E.*; *P*>0.05).

6.3.5. Relative Analysis of First and Second Halves

Relative comparisons of the first vs. second halves for female U16, U18 and senior players are shown in figures 6.5-6.8. Based on the relative activity categories used, there were no differences between the first and second halves for U16 or U18 players (*P*>0.05; figures 6.5, 6.6 and 6.8). Senior players spent a higher % time in zone 1 (*P*<0.001) and a lower % time in zones 2 (*P*<0.05) and 3 (*P*<0.001) during the second half (figure 6.7). During the second half senior players spent a higher proportion of time at 0-30% maximum speed and less time at 30-60% (*P*<0.001) and >60% (*P*<0.05) maximum speed (figure 6.8).

Table 6.2: Total match GPS data for female U16, U18 and senior international players (mean±*S.E.*)

	U16 (n=7)	U18 (n=5)	Senior (n=15)
Total Duration (hh:mm:ss)	00:46:43±*00:01:49*	00:46:26±*00:02:37*	00:49:25±*00:02:59*
Total Distance (m)	4962.3±*295.1*	5202.5±*155.5*	5581.1±*208.8*
Max. Speed (km.h^{-1})	23.3±*0.6*	23.5±*0.7*	24.3±*0.3*
Mean Speed (km.h^{-1})	6.4±*0.3*	6.8±*0.3*	6.9±*0.2*

Table 6.3: Absolute % time spent in activity categories for female U16, U18 and senior international field hockey players (mean±*S.E.*).

% Time	U16 (n=7)	U18 (n=5)	Senior (n=15)	Analysis
Standing (0-3 km.h^{-1})	23.7±1.6	21.0±1.8	21.4±1.2	NS.
Walking (3-6 km.h^{-1})	35.1±*1.4*	35.2±*1.7*	32.6±*1.0*	NS.
Jogging (6-10 km.h^{-1})	21.4±*0.8*	21.7±*1.1*	21.2±*0.7*	NS.
Running (10-14.5 km.h^{-1})	14.9±*1.1*	16.1±*1.4*	17.3±*1.0*	NS.
Fast Running (14.5 -19 km.h^{-1})	4.1±*0.7*	4.7±*0.5*	6.0±*0.5*	NS.
Sprinting (>19 km.h^{-1})	0.9±*0.2*	1.2±*0.3*	1.5±*0.1*	NS.
Low Intensity (0-6 km.h^{-1})	58.7±*2.5*	56.2±*2.6*	54.0±*1.8*	NS.
Moderate Intensity (6-14.5 km.h^{-1})	36.2±*1.7*	37.9±*2.2*	38.5±*1.4*	NS.
High Intensity (>14.5 km.h^{-1})	5.0±*0.8*	5.9±*0.6*	7.5±*0.6*	Senior vs. U16 $P<0.05$

Table 6.4: First and second half comparisons for female U16 (n=7), U18 (n=5) and senior (n=15) international hockey players (mean±*S.E.*)

	Duration (hh:mm:ss)	Distance (m)	Mean Speed (km.h^{-1})	Max. Speed (km.h^{-1})
U16 First Half	00:23:46±*00:01:24*	2542.6±*97.2*	6.5±*0.3*	22.6±*0.6*
U16 Second Half	00:26:58±*00:01:35*	2787.1±*156.9*	6.3±*0.3*	22.5±*0.4*
U18 First Half	00:23:48±*00:03:15*	2707.4±*232.7*	7.0±*0.4*	22.7±*0.9*
U18 Second Half	00:22:38±*00:02:12*	2495.2±*248.4*	6.6±*0.2*	22.9±*0.8*
Senior First Half	00:24:34±*00:01:17*	2851.7±*104.9*	7.1±*0.2*	23.6±*0.2*
Senior Second Half	00:24:51±*00:01:55*	2729.3±*141.1*	6.8±*0.2**	23.3±*0.3*

* = $P<0.001$

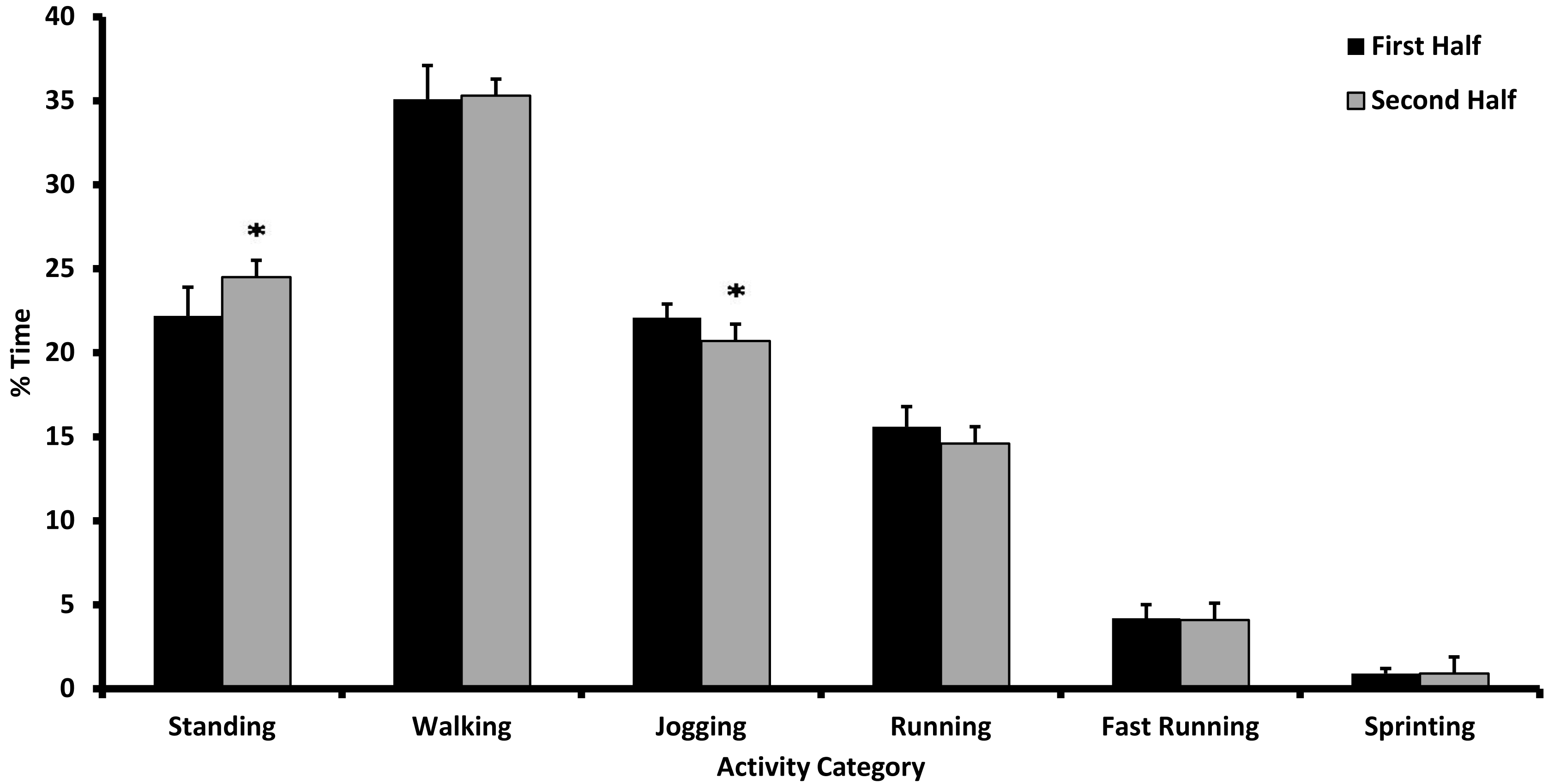

Figure 6.1: Comparison of female U16 players' activity profile during the first and second halves (mean±*S.E.*) (* *P*<0.05).

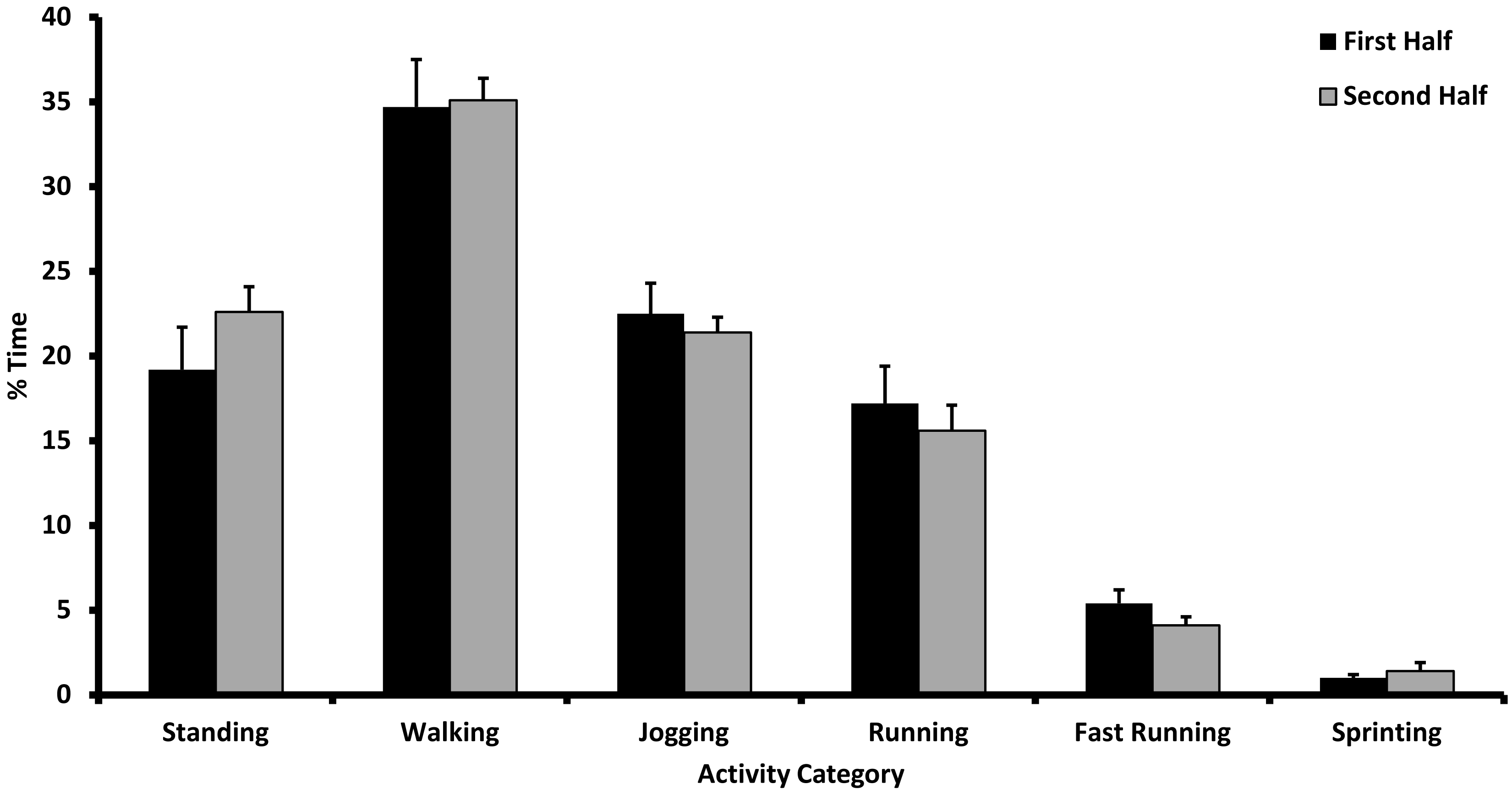

Figure 6.2: Comparison of female U18 players' activity profile during the first and second halves (mean±*S.E.*) (all $P>0.05$)).

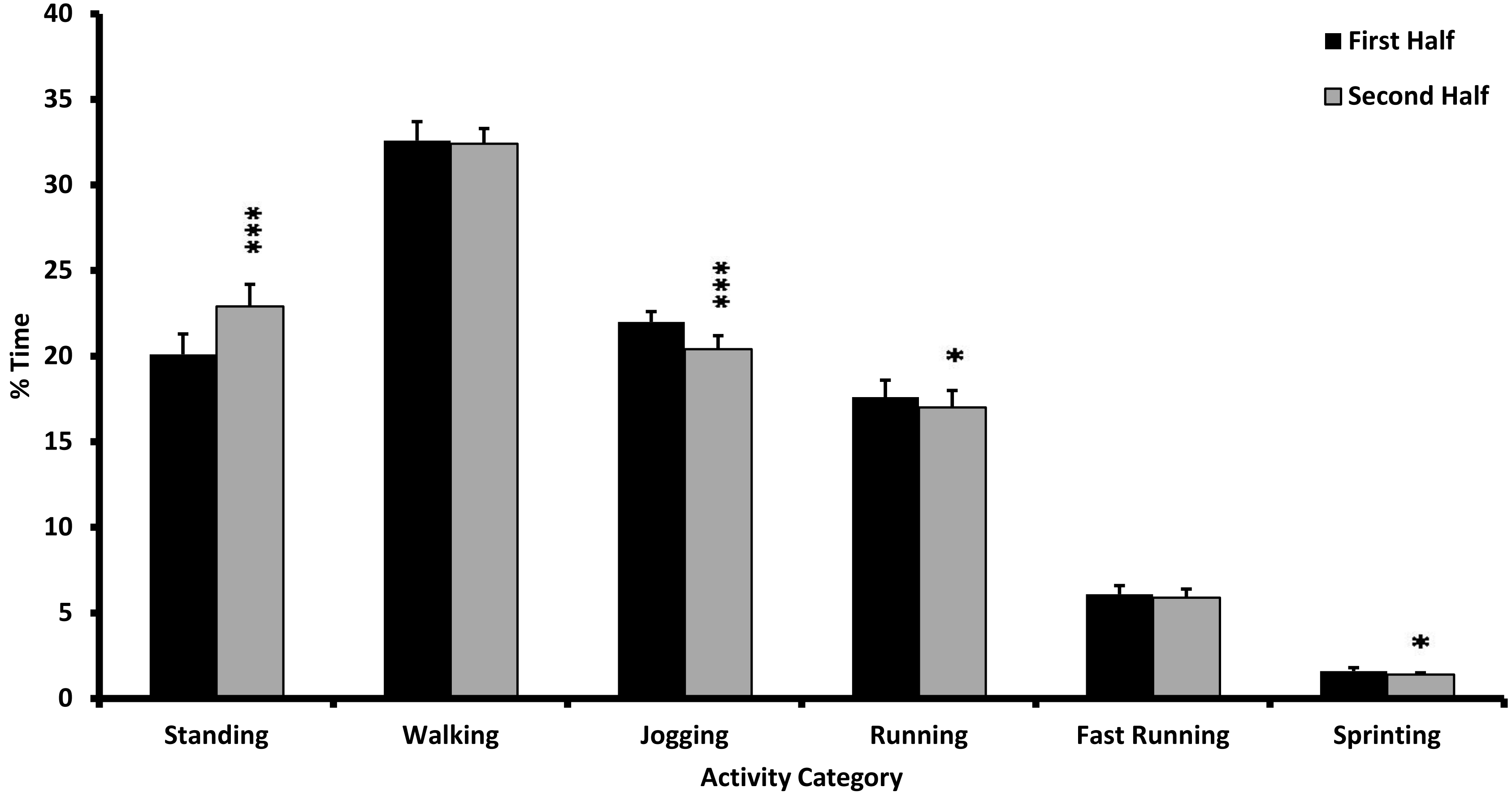

Figure 6.3: Comparison of female senior players' activity profile during the first and second halves (mean±*S.E.*) (**P*<0.05 ***P*<0.01).

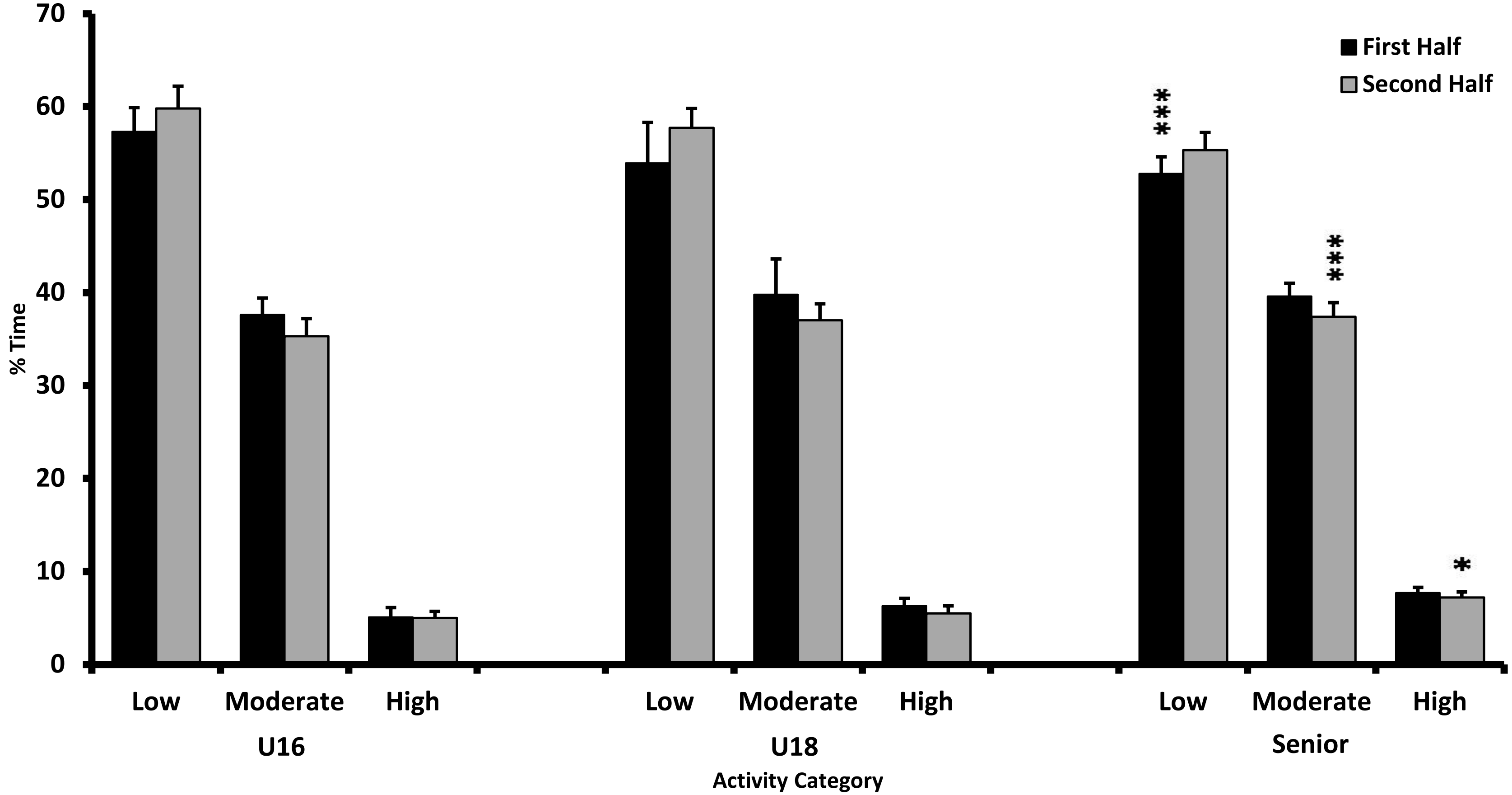

Figure 6.4: Female U16, U18 and senior players' % time spent in low, moderate and high intensity activities during the first and second halves (mean±S.E.) (**P*<0.05; ****P*<0.001).

Table 6.5: Percentage time spent in relative activity categories for female U16, U18 & senior international field hockey players (mean±*S.E.*)

% Maximum Speed	U16 (n=7)	U18 (n=5)	Senior (n=15)	Analysis
Zone 1 (0-15 %)	30.6±*2.0*	28.8±*3.5*	29.2±*1.6*	NS.
Zone 2 (15-30 %)	36.2±*1.4*	35.9±*1.2*	34.7±*0.9*	NS.
Zone 3 (30-50 %)	22.2±*0.9*	23.2±*1.6*	23.9±*1.0*	NS.
Zone 4 (50-60 %)	5.8±*0.8*	5.9±*1.0*	6.4±*0.5*	NS.
Zone 5 (60-75 %)	3.9±*0.7*	4.5±*1.0*	4.6±*0.5*	NS.
Zone 6 (>75 %)	1.4±*0.3*	1.8±*0.5*	1.3±*0.2*	NS.
Low Intensity (0-30 %)	66.7±*2.6*	64.7±*3.9*	63.9±*2.1*	NS.
Moderate Intensity (30-60 %)	28.0±*1.7*	29.1±*2.6*	30.3±*1.5*	NS
High Intensity (>60 %)	5.2±*1.0*	6.2±*1.5*	5.9±*0.6*	NS.

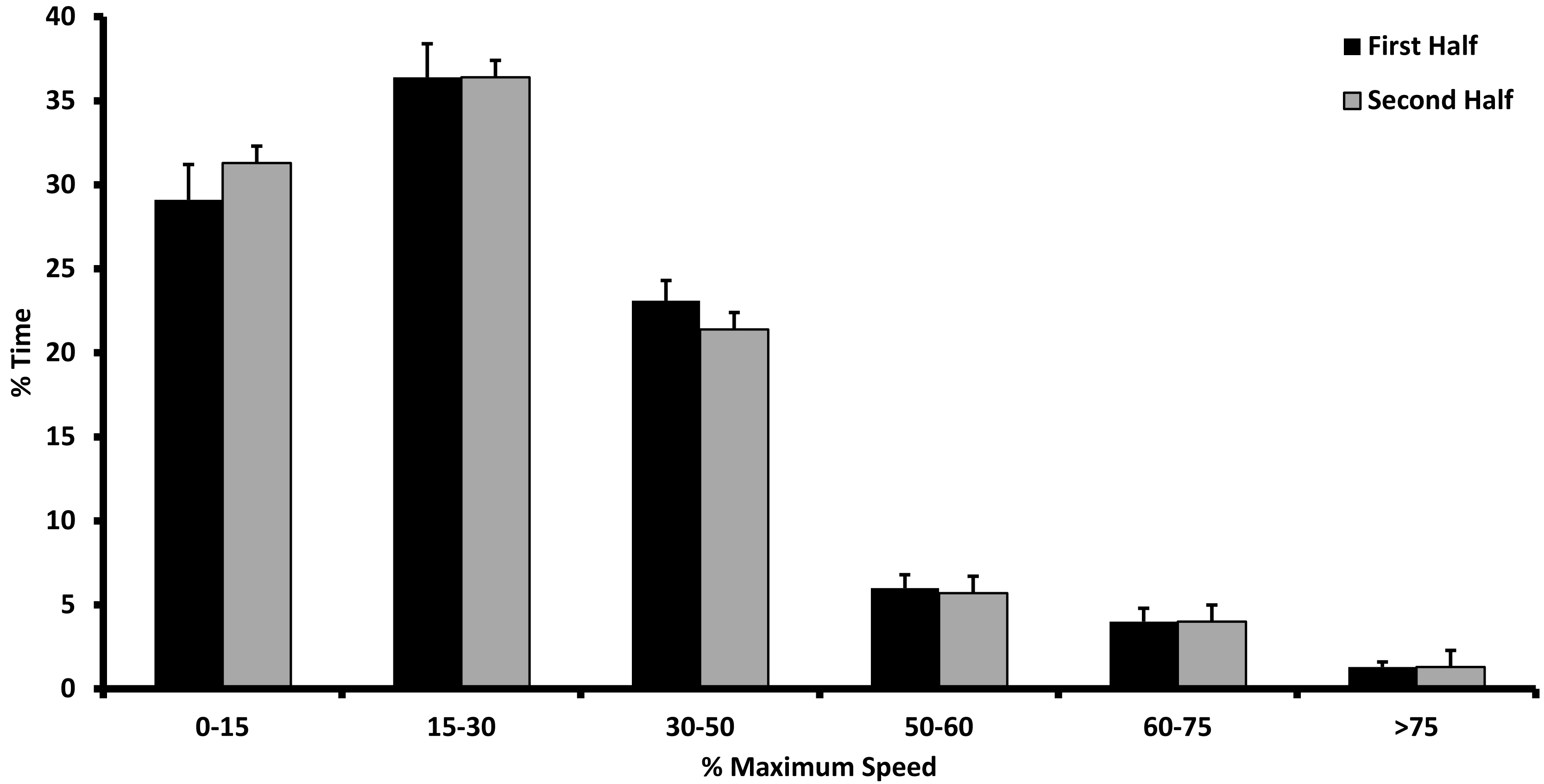

Figure 6.5: Comparison of female U16 players' activity profile (relative to maximum speed) during the first and second halves (mean±*S.E.*)

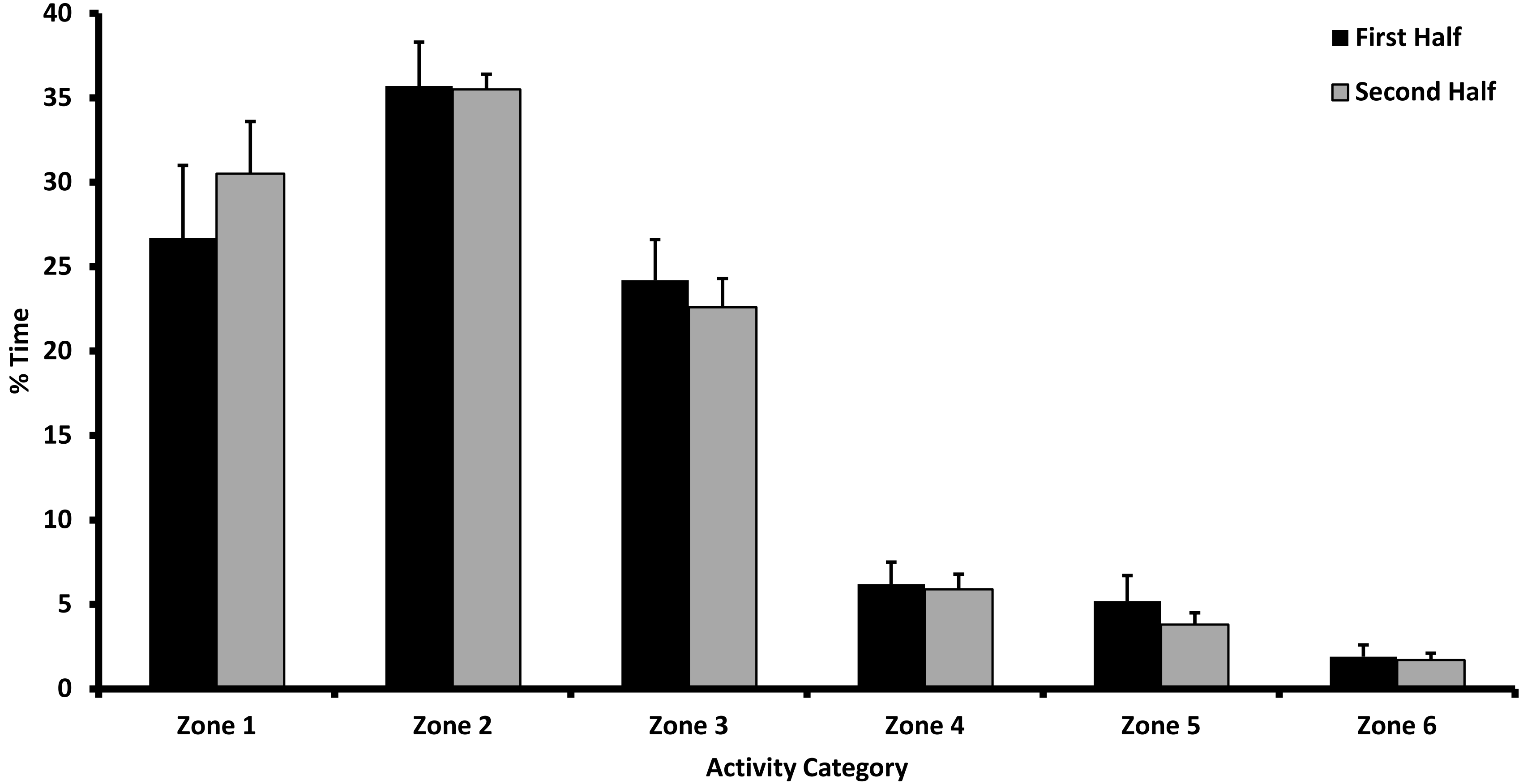

Figure 6.6: Comparison of female U18 players' activity profile (relative to maximum speed) during the first and second halves (mean±*S.E.*)

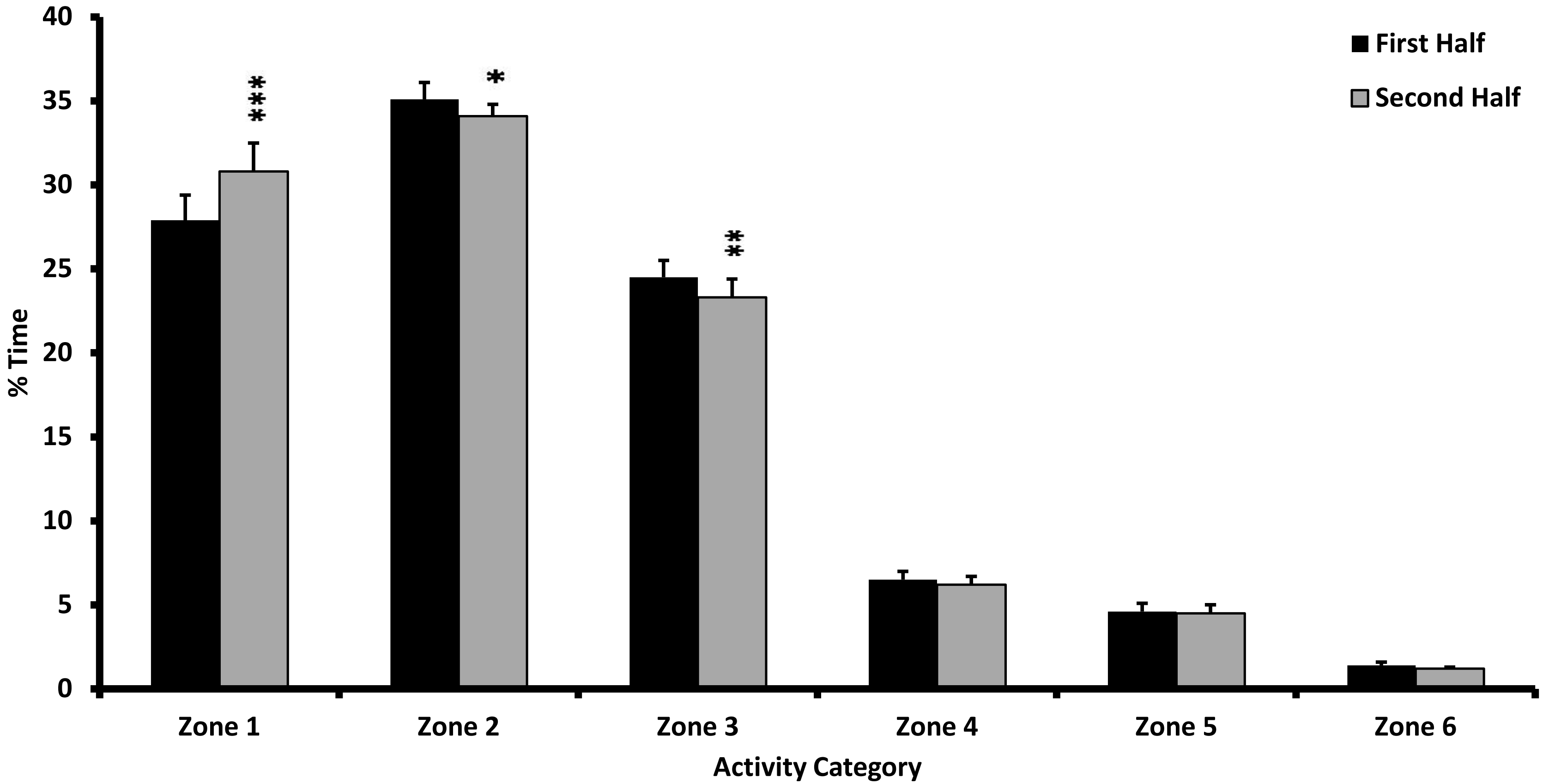

Figure 6.7: Comparison of female senior players' activity profile (relative to maximum speed) during the first and second halves (mean±*S.E.*) (**P*<0.05, ***P*<0.01, ****P*<0.001).

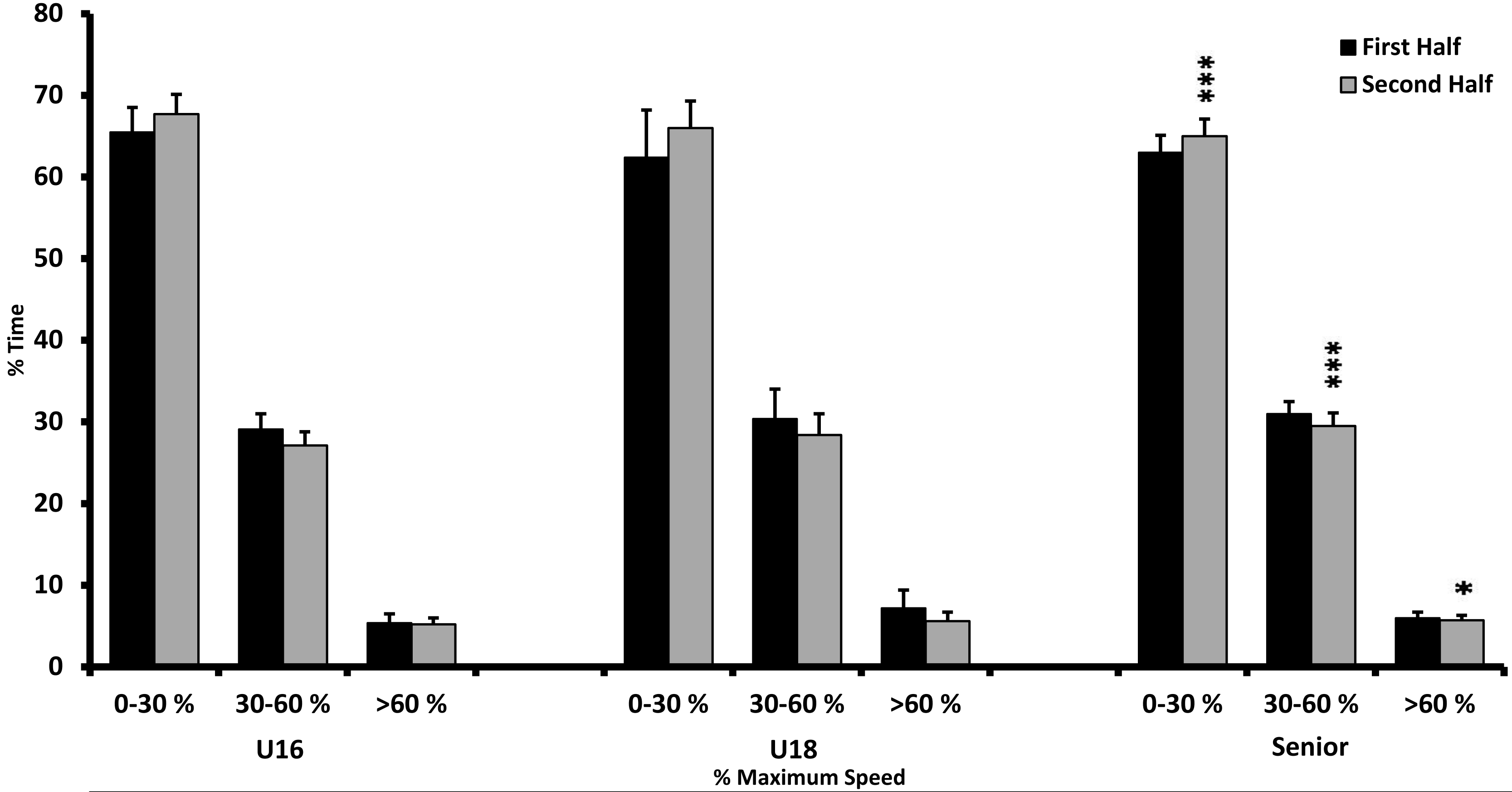

Figure 6.8: Female U16, U18 and senior players' % time spent at 0-30, 30-60 and >60 % maximum speed during the first and second halves (mean±S.E.) (**P*<0.05; ****P*<0.001).

6.4. Discussion

Results from this study suggest that the majority of female U16, U18 and senior elite field hockey is spent engaged in low-moderate intensity activities with almost 95 % of total match time spent at 0-14.5 km.h^{-1} or at less than 60 % maximal speed. Senior female players spent a higher proportion of time engaged in high intensity activities (>14.5 km.h^{-1}) than U16 players, however there were no other differences between age groups when activity profiles were analysed in either absolute or relative terms. Both U16 and senior players showed decrements in absolute match performance during the second half. However, the extent of the decline was more pronounced in senior players. The small number of U18 players involved in this study may have resulted in insufficient statistical power to detect differences between U16 and senior players or between activity patterns in the first and second halves.

In line with findings from the previous chapter for elite male players, elite female U16, U18 and senior hockey players were predominantly involved in activities of a low to moderate intensity. This is also consistent with video time-motion analyses of women's hockey which report between approximately 80-95 % of match play to be spent in low intensity activities (Lothian and Farrally, 1992; Lothian and Farrally 1994; Boddington *et al.,* 2002; MacLeod *et al.,* 2007). Due to differences in match analyses methodologies and classification of activities, direct comparison with previous studies proves difficult. One relatively recent analysis of women's field hockey (Boddington *et al*., 2002) used video analysis to profile players' match characteristics. The method determined match activity using manual plotting of player position every 15 seconds on a scale diagram of the pitch to determine horizontal displacement. An obvious limitation of this method is that the amount of time spent in discrete movements (e.g. walking, running, sprinting) cannot be deduced because activity categories are based on the displacement of players every 15 s. Analysis of player movement in field hockey suggests players demonstrate a change in motion, on average, every 3 seconds (MacLeod *et al*., 2007). Therefore averaging the displacement of a player every 15 s to determine intensity of movement, is unlikely to provide a true indication of match activities. Nevertheless, the authors reported players to spend 97.4 % of match play in low intensity activities (<11.9 km.h^{-1}) and 2.6 % in high intensity activities (>11.9 km.h^{-1}). The definition of "high intensity" activity adopted by Boddington and colleagues (2002) is also questionable, and in relation to the present study, would be considered within the moderate intensity classification. A more recent examination of activity profiles in female field hockey reported similar overall activity profiles to those of junior and senior international players in the present study. MacLeod *et al*., (2007) used video-based time-motion analysis to investigate the match performance characteristics of English National League players (nine of whom had international experience). Subjective classification of motion categories revealed players to spend 92.1 % of match time in low intensity activities (standing, walking and jogging) and 7.9 % of play engaged in high intensity activities (cruising, sprinting and lunging).

Whilst differences in methods of match analysis do not permit direct comparison between MacLeod *et al*., (2007) and data from the present study, overall match profiles of players are very similar. As discussed previously, the development of match analysis systems such as

GPS which are valid, reliable and objective will hopefully provide more insight into match performance characteristics of field hockey and permit between-study comparisons of data.

As indicated in Chapter 5, there is a paucity of information regarding the development of match characteristics amongst intermittent sports players. To the author's best knowledge, the data presented in the previous chapter is amongst the first to examine elite field hockey performance in relation to age. Analysis of junior and senior male players suggested similar absolute demands were placed on players from U16, U18 and senior age groups, with varying levels of fatigue developing during the second half. In relative terms, senior competitive matches were of a lower overall intensity than U18 or U18 matches. In the present chapter, absolute analysis of female international U16, U18 and senior players revealed senior players to complete more high intensity activity than U16 players, with no other differences existing between age-groups. Similarly, there were no differences between squads when match activity was analysed relative to maximal speed. The greater degree of fatigue demonstrated by senior players in the second half may be as a result of completing more high intensity activity over the course of the match than younger players. The similarities in the match performance profiles of elite junior and senior females may be associated with similarities in physiological profiles (as discussed in chapter 5). Further investigation of the relationship between physiological and match performance characteristics is warranted.

6.5. Conclusions

In agreement with existing literature and with the data presented in chapter 5, the match activity profile of elite female hockey suggests that the majority of game play is spent engaged in activities which could be classified as low to moderate intensity. Such activities may be required to permit recovery from high intensity activities such as sprinting. The demands placed on U16, U18 and senior female players were markedly similar and may be related to similarities in physiological attributes. Further investigation is required to determine the age-associated variations in physiological characteristics and how these relate to performance during a competitive game.

Chapter 7. The Relationship Between Physiological and Match Performance Characteristics of Female Field Hockey Players

7.1 Introduction

The previous chapters have sought to profile the physiological and performance characteristics of male and female players field hockey players from a variety of ages. However, the relationship between physiological characteristics and performance during match-play has not yet been addressed.

Field and/or laboratory based physiological testing has become commonplace among competitive field hockey players. However, how performance in such tests relates to performance during game play remains undetermined. Work with male soccer players has identified relationships between VO_{2max} and the total distance covered by players in a match (r=0.52, *P*<0.05) and between Yo-Yo Intermittent Recovery Test performance and the amount of high intensity running (>15 $km.h^{-1}$) completed during a game (r=0.71, *P*<0.05)

(Krustrup *et al*., 2003). Whether such relationships exist between other physiological parameters and match performance and how such relationships translate to field hockey is yet to be elucidated. Therefore, the primary purpose of the present study was to examine the relationships between performance in field and laboratory based physiological tests and performance during competitive field hockey matches. In addition, a secondary purpose was to evaluate the relationship between performance in laboratory assessments and performance in field-based physiological tests.

7.2 Methods

7.2.1 Participants

Twenty-six female field hockey players (mean±*S.E.* age 20.8*±0.5* years, body mass 65.1±*2.0* kg, height 166.7±*1.3* cm) from Loughborough University Ladies Hockey Club were assessed during the 2006-2007 competitive season. University Ethical Committee approval was gained prior to testing. Informed consent was obtained from all players before data collection began.

7.2.2. Match Analysis

Players wore a Global Positioning System (GPS) device (SPI Elite, GPSports, Canberra, Australia) during at least one full match (i.e. were not substituted at any point). Data were downloaded to a personal computer and analysed (Team AMS version 1.2.1.12., GPSports, Canberra, Australia) for maximum and mean speeds, total distance covered, distance covered in each activity category and the % time spent in each activity category. The speed zones used to categorise activity were: standing (0-3 $km.h^{-1}$), walking (3-6 $km.h^{-1}$) jogging (6-10 $km.h^{-1}$) running (10-14.5 $km.h^{-1}$), fast running (14.5-19 $km.h^{-1}$) and sprinting (>19 $km.h^{-1}$). These zones were later combined to form three broader categories of low (0-6 $km.h^{-1}$), moderate (10-14.5 $km.h^{-1}$) and high (>14.5 $km.h^{-1}$) intensity activity.

7.2.3. Laboratory Physiological Assessment

Speed at 4 $mmol.L^{-1}$ whole blood lactate concentration was determined during 4 minute stages of treadmill running at 4-6 submaximal intensities. A finger-prick blood sample was obtained at the end of each 4 minute stage and immediately analysed for whole blood lactate concentration (YSI 2300 Stat Plus, Yellow Springs, Ohio, USA). Maximal oxygen uptake (VO_{2max}) was determined directly using a continuous uphill treadmill protocol (adapted from Taylor *et al*., 1955).

7.2.4. Field Physiological Assessment

For field-based physiological assessment, players completed the Multi-Stage Fitness Test (MSFT) (Ramsbottom et al., 1988), Interval Shuttle Run Test (ISRT) (Lemmick et al., 2000) and the Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1) (Bangsbo, 1994).

7.2.5. Statistical Analyses

To identify any relationship between physiological and match performance variables, Pearson's correlation coefficient was used. Group data are presented as mean and standard error of the mean (mean ±S.E.). Significance was accepted at $P<0.05$.

7.3. Results

7.3.1. Physiological and Match Performance Characteristics

Results from laboratory- and field- based physiological assessments are presented in table 7.1. Mean±*S.E*. maximal heart rate values recorded during laboratory VO_{2max}, YYIRT, ISRT and MSFT were 192±*2*, 192±*2*, 192±*2* and 195±*2* beats.min^{-1} respectively. Match performance data were collected during 3.4±*0.4* full matches (mean±*S.E.*) over the course of the competitive season. Match activity data are given in tables 7.2 and 7.3.

7.3.2. Relationship Between Laboratory Test Performance and Match Performance

Pearson correlation coefficients for laboratory test performance and match performance are presented in table 7.4. There were moderate correlations between VO_{2max} and the total distance covered during a match (r=0.58, P<0.01), mean speed (r=0.58, P<0.01), % time running (r=0.53, P<0.05), % time fast running (r=0.62, P<0.01), % time sprinting (r=0.44, P<0.05) and % time spent in high intensity activity (r=0.60, P<0.01). Maximal oxygen uptake was negatively correlated with the % time walking (r=-0.52, P<0.05) and % time in low intensity activity (r=-0.53, P<0.05).

Speed at 4 mmol.L^{-1} blood lactate was found to correlate moderately with total match distance (r=0.67, P<0.01), mean speed (r=0.71, P<0.001), % time jogging (r=0.56, P≤0.01), % time running (r=0.64, P<0.01), fast running (r=0.49, P<0.05), the % time spent in moderate intensity activity (r=0.68, P<0.01) and the % time spent in high intensity activity (r=0.45, P<0.05). Speed at 4 mmol.L^{-1} was shown to negatively correlate with % time standing (r=-

0.46, $P<0.05$), % time walking (r=-0.60, $P<0.01$) and % time engaged in low intensity activity (r=-0.70, $P<0.001$).

7.3.3. Relationship Between Field Test Performance and Match Performance

Pearson correlation coefficients for field test performance and match performance are presented in table 7.4. Performance in the YYIRT showed moderate correlations with the distance covered during a match (r=0.67, $P<0.01$), mean speed (r=0.61, $P<0.01$), % time running ((r=0.54, $P<0.01$), % time fast running (r=0.58, $P<0.01$), % time sprinting (r=0.53, $P<0.01$), % time in moderate activities (r=0.44, $P<0.05$) and % time in high intensity activities (r=0.60, $P<0.01$). Yo-Yo Intermittent Recovery Test performance was negatively correlated with the % time engaged in low intensity activity (r=-0.54, $P<0.01$).

Interval Shuttle Run Test performance significantly correlated with total distance covered (r=0.61, $P<0.01$), mean speed (r=0.62, $P<0.01$), % time jogging (r=0.45, $P<0.05$), % time running (r=0.68, $P<0.001$), % time fast running (r=0.58, $P<0.01$), % time in moderate intensity activities (r=0.62, $P<0.01$) and % time in high intensity activities (r=0.54, $P<0.01$). Performance in the ISRT was negatively correlated with the % time spent walking (r=-0.72, $P<0.01$) and % time in low intensity activity (r=-0.69, $P<0.001$).

The MSFT correlated with total distance covered (r=0.58, $P<0.05$), mean speed (r=0.54, $P<0.05$), % time running (r=0.61, $P<0.01$) and % time spent in moderate intensity activity (r=0.52, $P<0.05$). There were negative correlations between MSFT performance and % time spent walking (r=-0.62, $P<0.01$) and % time in low intensity activities (r=-0.55, $P<0.05$).

7.3.4. Relationship Between Performance in Field & Laboratory Physiological Assessments

Performance in the YYIRT and ISRT correlated highly with VO_{2max} ($r=0.71$, $P<0.01$ and $r=0.69$, $P<0.01$ respectively) and speed at 4 $mmol.L^{-1}$ ($r=0.82, P<0.001$ in both cases). Distance covered during the MSFT correlated moderately with VO_{2max} ($r=0.51$, $P<0.05$) and speed at 4 $mmol.L^{-1}$ ($r=0.61$, $P<0.05$).

Maximal heart rate (HR_{max}) obtained during treadmill assessment of VO_{2max} correlated highly with HR_{max} recorded during the YYIRT ($r=0.90$, $P<0.001$), ISRT ($r=0.88$, $P<0.001$) and MSFT ($r=0.86$, $P<0.001$).

Table 7.1: Physiological characteristics of players assessed during laboratory and field based tests (mean±*S.E.)*

Measure	Mean±*S.E.*
VO_{2max} ($L.min^{-1}$)	3.1±*0.1*
VO_{2max} ($ml.kg^{-1}.min^{-1}$)	48.6±*1.0*
Speed at 4mmol.L^{-1} lactate ($km.h^{-1}$)	11.3±*0.2*
YYIRT Distance (m)	875±*59*
ISRT (number of 20 m runs)	70±*2*
MSFT Distance (m)	1608±*52*

Table 7.2: Results from GPS match analysis (mean±*S.E.*)

Variable	Mean±*S.E.*
Match Duration (hh:mm:ss)	01:09:30±*00:00:26*
Total Distance (m)	7230±*147.4*
Mean Speed (km.h^{-1})	5.9±*0.1*
Maximum Speed (km.h^{-1})	23.0±*0.3*
Total Sprints	12±*2*

Table 7.3: Percentage time spent in activity categories for female field hockey players (mean±*S.E.)*

Activity Category	% Time
Standing (0-3 km.h^{-1})	27.6±0.8
Walking (3-6 km.h^{-1})	38.6±1.0
Jogging (6-10 km.h^{-1})	17.5±0.6
Running (10-14.5 km.h^{-1})	12.2±0.6
Fast Running (14.5 -19 km.h^{-1})	3.5±0.2
Sprinting (>19 km.h^{-1})	0.6±0.1
Low Intensity (0-6 km.h^{-1})	66.2±1.3
Moderate Intensity (6-14.5 km.h^{-1})	29.7±1.1
High Intensity (>14.5 km.h^{-1})	4.1±0.3

Table 7.4: Pearson's correlation coefficients for physiological and match performance characteristics of female field hockey players

Match Variable	VO_{2max}	Speed at 4 $mmol.L^{-1}$	YYIRT	ISRT	MSFT
Total Distance	0.58**	0.67**	0.67**	0.61**	0.58*
Mean Speed	0.58**	0.71***	0.61**	0.62**	0.54*
Max. Speed	0.24	-0.10	0.25	-0.12	-0.02
% Standing	-0.26	-0.46*	-0.19	-0.15	-0.1
% Walking	-0.52*	-0.60**	-0.53*	-0.72***	-0.62**
% Jogging	0.23	0.56*	0.24	0.45*	0.33
% Running	0.53*	0.64**	0.54**	0.68***	0.61**
% Fast Running	0.62**	0.50*	0.58**	0.58**	0.44
% Sprinting	0.44*	0.22	0.53**	0.30	0.22
% Low Intensity	-0.53*	-0.71***	-0.54**	-0.69***	-0.55*
% Moderate Intensity	0.43	0.68**	0.44*	0.62**	0.52*
% High Intensity	0.60**	0.45*	0.60**	0.54**	0.41

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

7.4. Discussion

The principle finding of the present study is that the match performance characteristics of university-level female field hockey players are related to the physiological characteristics of players. Players' performance in both laboratory and field-based physiological assessments were associated with performance during match play. The degree of association with match performance was not different for laboratory and field measures. Evaluation of the relationship between field test performance and laboratory measures demonstrated YYIRT and ISRT to better correlate with VO_{2max} and speed at 4 $mmol.L^{-1}$ than MSFT performance.

The physiological profiles of female field hockey players in the present study are comparable with those reported previously for female players. Maximal aerobic power (48.6 $ml.kg^{-1}.min^{-1}$) was similar to values reported for players of comparable competitive levels (Withers and Roberts, 1981; Lothian and Farrally, 1992) but lower than those of international players (Ready and van der Merwe, 1986; Bishop *et al*., 2003). Yo-Yo Intermittent Recovery Test scores were similar to those observed in state-level hockey players (Thomas *et al*., 2006) but were markedly lower than the scores of elite (Krustrup *et al*., 2005) and university level (Kirkendall *et al*., 2005) female soccer players. Performance in the MSFT was comparable with those reported for Australian state level players (Thomas *et al*., 2006) but considerably higher than South African regional and club level players (Keogh *et al*., 2003). However, MSFT scores were distinctly lower than the values obtained by Australian international players (Spencer *et al*., 2004). Fewer comparative ISRT data are available, however, profiling of female players considered to be the second highest skill level in the Netherlands produced similar scores to the players in the present study. Between-study comparison of physiological characteristics is considerably simpler than that of match performance characteristics. Direct comparison of match activity profiles with other field hockey match analyses is difficult due to different methodologies and classification of movement categories. In line with the general observation of field hockey match performance data, players in the present study were predominantly engaged in low to moderate intensity activities, with only a small proportion of match play spent in high intensity activity. Compared with South African club standard players (Boddington *et al*., 2002), the players in the current study covered almost double the distance (3904 m vs. 7230 m) and completed almost 60% more high intensity activity. Differences in high intensity profiles are even more marked when it is considered that the classification of 'high intensity' activity was defined as >11.9 $km.h^{-1}$. This example highlights the potential pitfalls associated with cross-study comparisons of match performance characteristics.

While a number of existing studies provide information regarding the physiological profile of hockey players, physical performance during intermittent sports can be difficult to quantify and therefore problematic to establish interactions between physiological and performance profiles. Amongst the first published research to examine the relationship between physiological characteristics and match activity reported a correlation of 0.78 between VO_{2max} and the amount of high intensity match activity during female national league competition (Lothian and Farrally, 1994). Further research in soccer players and referees have provided mixed results. The VO_{2max} of top-class soccer referees and elite female players was also found to correlate with the amount of high intensity running (r=0.54 $P<0.05$, Krustrup *et al*., 2001; r=0.81, $P<0.05$, Krustrup *et al*., 2005) whilst VO_{2max} was not correlated with high intensity activity in elite male players (r=0.38, *P*>0.05, Krustrup *et al*., 2003). Maximal oxygen uptake was also shown to be related to the distance covered during a match in elite males (r=0.52, *P*<0.05, Krustrup *et al*., 2003) and top-class referees (r=0.50, *P*<0.05, Krustrup *et al*., 2001) but not in elite female players (r=0.20, *P*>0.05, Krustrup *et al*., 2005). In the present study, maximal aerobic power was found to correlate with the distance covered and the amount of high intensity activity (table 7.4). A number of additional relationships between VO_{2max} and mean speed, % time running and % time fast running were also established.

Similarly, the speed eliciting a blood lactate response of 4 $mmol.L^{-1}$ demonstrated associations with the total distance, mean speed, % time jogging, % time running, % time fast running and the % time in moderate intensity activity (table 7.4). However, speed at 4 $mmol.L^{-1}$ blood lactate demonstrated a weaker relationship with the amount of high intensity activity (r=0.45, *P*<0.05) than VO_{2max}. Krustrup and colleagues (2005) reported a similar correlation between speed at 2 $mmol.L^{-1}$ blood lactate and distance covered (r=0.64, *P*<0.05) and a stronger correlation with speed at 2 $mmol.L^{-1}$ and the amount of high intensity running (r=0.83, *P*<0.001). Results from the present study demonstrate that female field hockey match performance is related to laboratory assessed VO_{2max} and submaximal blood lactate response. Of the two laboratory measures, VO_{2max} was most strongly correlated with high intensity activity, thought to be a potential factor differentiating between good and poor match performance (Krustrup *et al*., 2005).

Field-based physiological assessments were also associated with match performance characteristics. Moderate correlations were found to exist between the total distance covered, mean speed, % time walking, % time running and % time spent in low and moderate intensity activities (table 7.4). The YYIRT and ISRT also correlated with the % time fast running and % time in high intensity activities. In addition, the YYIRT correlated with the amount of sprinting (table 7.4). The relationships between YYIRT and match performance are in accordance with existing observations. The YYIRT has been shown to correlate with total match distance and the amount of high intensity running during a match in top-class soccer referees (Krustrup *et al*., 2001), elite male (Krustrup *et al*., 2003) and elite female (Krustrup *et al*., 2005) soccer players.

Whilst several existing investigations have examined the relationship between YYIRT performance and activity during competitive play, to the author's best knowledge the present study is amongst the first to examine the associations between match activity characteristics of intermittent games players and performance in the MSFT and ISRT. Indeed, the developers of the ISRT have highlighted the lack of information regarding the test's relationship to physical performance measures during match play and recommend establishing such relationships to provide further insight into the validity of the ISRT. Based on the correlation coefficients in the present study, it appears that the three field-based physiological assessments provided a good indication of match activity characteristics of field hockey players. All three tests were associated with the total distance covered and mean match speed. Perhaps due to the intermittent nature of the tests, the YYIRT and ISRT demonstrated the strongest relationship with the amount of fast running and proportion time spent in high intensity activity. Whilst evidence from the current and existing investigations suggest physiological characteristics may determine match performance to an extent, external factors such as quality of opponent, motivation, tactical decisions and the importance of the match undoubtedly play a role in determining match performance (Boddington *et al*., 2002; Rampinini *et al*., 2007).

From the results of this study, there appears to be an association between field test performance and performance during match play. However, results from field-based assessments were also shown to be associated with laboratory measures. Establishing the relationship between field and laboratory test performance is important not only for establishing the validity of field test, but can also provide a time- and cost-effective alternative to laboratory assessments.

Both the YYIRT and ISRT were shown to be related to VO_{2max} and speed at 4 $mmol.L^{-1}$. Amongst male soccer players, similar relationships between VO_{2max} vs. YYIRT (r=0.71, $P<0.05$, Krustrup *et al*., 2003) and VO_{2max} vs. ISRT (r=0.77, $P<0.05$, Lemmink and Visscher, 2003) have been reported. Similarly, Krustrup and colleagues (2005) have demonstrated moderate correlations between YYIRT performance and speed at 2 $mmol.L^{-1}$ in elite female soccer players. Conversely, contradictory to the literature, the correlation coefficients for the relationship between MSFT performance and VO_{2max} were considerably lower than those previously reported. Several existing studies have cited coefficients of >0.80 between MSFT score and VO_{2max} (Léger *et al*., 1980; Ramsbottom *et al*., 1988). In the present study, MSFT performance was found to correlate only moderately with VO_{2max} (r=0.51, $P<0.05$), however, there was a stronger correlation between the distance covered in the MSFT and speed at 4 mmol.L^{-1}. Based on results from players within the present study, the YYIRT and ISRT could offer a viable alternative to laboratory testing of intermittent games players as a means of providing an indication of maximal and submaximal exercise performance.

7.5. Conclusions

In conclusion, VO_{2max}, speed at 4 mmol.L^{-1}, YYIRT, ISRT and MSFT performance were all associated with match performance characteristics. High intensity activity, which may be an indicator of the quality of match performance was most closely associated with VO_{2max}, YYIRT and ISRT performance. Examining whether training-induced improvements in physiological performance results in concurrent improvements in match performance will provide further insight to the extent to which a player's physiology determines competitive performance. Where laboratory assessment of field hockey players is impractical, the YYIRT and ISRT appear viable alternatives for establishing maximal and submaximal exercise performance.

Chapter 8. Physiological, Skill and Match Performance Characteristics of Female Hockey Players from Different Competitive Levels

8.1. Introduction

Intermittent team sports such as field hockey place demands on both a player's aerobic and anaerobic energy systems, with players required to work at submaximal intensities over long periods punctuated by short bouts of high intensity work (Boyle *et al*., 1994). This means that intermittent games players must possess a relatively high level of aerobic fitness but must also have the capacity to produce short, rapid bursts of power for activities such as sprinting (Reilly and Borrie, 1992). Along with these physiological characteristics, hockey players must possess a certain degree of hockey-specific technical and tactical abilities (Elferink-Gemser *et al*., 2004). Whilst such factors may be essential for competitive hockey, little existing research has focussed on how these characteristics and the demands placed on players during competitive matches differ between players from varying standards of competition. Understanding the ways in which high level players differ from players of a lower standard is important for identifying and selecting talented players.

Research from intermittent team sports has identified that performance in field tests and the amount of high intensity activity during competitive matches can discriminate between players of different playing standards. Mohr and colleagues (2003) found top-class soccer players to cover more distance in the Yo-Yo intermittent Recovery Test than moderate level players. Similarly, the Interval Shuttle Run Test has been shown to discriminate between soccer players from different levels of competition, with professional players scoring higher in the test than both high and low level amateurs (Lemmink *et al*., 2004). Match analysis of soccer has also discriminated between playing standards with top-class players involved in more high intensity activity (>15 $km.h^{-1}$) than moderate level players (Mohr *et al.,* 2003). The aim of the current study was to examine whether a battery of field and laboratory tests and/or GPS match analysis has the potential to discriminate between field hockey players of different competitive levels.

Whilst the majority of existing literature on field hockey and other intermittent adopted field and/or match analysis based assessments, the aim of this study was to identify any differences between field hockey players from different levels of competition based on field assessments of fitness, speed and dribbling skill, laboratory assessment of fitness and analysis of the demands placed on players during competition.

8.2. Methods

8.2.1 Participants

Thirty-nine players were recruited from Loughborough University first (n=13), second (n=10) and third (n=16) ladies hockey squads and were assessed during the 2006-2007 competitive season. University Ethical Committee approval was gained prior to testing. Informed consent was obtained from all players before data collection began.

8.2.2. Anthropometric Measurement

Height was determined to the nearest 0.1 cm using a stadiometer (Holtain Ltd., Crmych, UK). Body mass was measured to the nearest 0.1 kg using a calibrated balance beam (Model 3306ABV, Avery Industrial Ltd., Leicester, UK).

8.2.3. Field Tests

For physiological assessment, players completed the Multi-Stage Fitness Test (MSFT) (Ramsbottom *et al*., 1988), Interval Shuttle Run Test (ISRT) (Lemmick *et al*., 2000) and the Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1) (Bangsbo, 1994). Participants completed 5, 10, 20 and 30 m sprints for the assessment of speed and the Slalom Sprint and Dribble Test (Slalom SDT) (Lemmick *et al.,* 2004) for measurement of dribbling ability. Sprint and Slalom SDT times were measured to the nearest 0.01 second using a wireless infra-red timing system (Speedtrap 2, Brower Timing Systems, Utah, USA).

8.2.4. Laboratory Physiological Assessment

Submaximal running economy and whole blood lactate concentrations were determined during 4 min stages of incremental treadmill running at 4-7 intensities. Treadmill speed began at 8 km.h^{-1} and was increased by 1 km.h^{-1} every minute until a whole blood lactate concentration of >4.0 mmol.L^{-1} was reached. During the last minute of each 4 minute stage, heart rate was monitored and expired air was collected to determine VO_2 (running economy). A finger prick blood sample was obtained at the end of each 4 min stage and immediately analysed for whole blood lactate concentration (YSI 2300 Stat Plus, Yellow Springs, Ohio, USA). Maximal oxygen uptake (VO_{2max}) was determined directly using a continuous uphill treadmill protocol (adapted from Taylor *et al*., 1955). Using results from the submaximal test, a speed eliciting a heart rate of approximately 170-180 beats.min^{-1} was selected for the duration of the test. Participants began the test at the pre-determined speed and a 3% grade. Subjects ran for 3 min with heart rate and expired air collected during the final minute of the stage. The treadmill gradient was increased by 2% every 3 min until the participant reached volitional exhaustion. Expired air samples were analysed and the highest recorded VO_2 was considered VO_{2max}.

8.2.5. Match Analysis

Players wore a GPS device (SPI Elite, GPSports, Canberra, Australia) during at least one match during the 2006-2007 season. Data were then downloaded onto a computer for analysis using appropriate software (Team AMS, GPSports, Canberra, Australia). Data were analysed using categories based on the absolute speed of movement: standing (0-3 km.h^{-1}), walking (3-6 km.h^{-1}) jogging (6-10 km.h^{-1}) running (10-14.5 km.h^{-1}), fast running (14.5-19 km.h^{-1}) and sprinting (>19 km.h^{-1}). These zones were later combined to form three broader categories of low (0-6 km.h^{-1}), moderate (10-14.5 km.h^{-1}) and high (>14.5 km.h^{-1}) intensity activity. Any period of activity >19 km.h^{-1} was considered an individual sprint. For purposes of comparison, only players who completed a minimum of one full match (i.e. had not been substituted) were included in the analysis. For players who completed more than one full match, mean data from those matches were calculated.

8.2.6. Statistical Analyses

For cross-sectional analyses of results from match analysis, field and laboratory tests, means from each squad were compared (first *vs.* second *vs.* third) using a one-way ANOVA with *post hoc* Tukey test. Where comparisons were limited to 2 variables (e.g. comparison of first and second half match analysis data) paired t-tests were used. All data are presented as the mean and standard error of the mean (±*S.E.*). Significance was accepted at $P<0.05$.

8.3. Results

8.3.1. Anthropometric Measurement

The physical characteristics of players are given in table 8.1. There were no differences in age, height or body mass between squads ($P>0.05$).

Table 8.1: Physical characteristics of players (mean±*S.E.*)

	First Team	Second Team	Third Team
Age (years)	21.4±*1.0*	20.1±*0.4*	20.4±*0.2*
Height (cm)	168.1±*2.3*	166.0±*1.4*	164.9±*1.6*
Body Mass (kg)	62.4±*2.4*	67.0±*1.8*	64.5±*2.9*

8.3.2. Field Tests

Results from the MSFT, ISRT, YYIRT, sprints and Slalom SDT are given in table 8.2. There were no differences between the squads in any of the maximal running tests (P>0.1), sprints (P>0.6) or in the slalom sprint portion of the Slalom SDT (P>0.07). First team players were faster in the dribble portion of the Slalom SDT (P<0.01) resulting in a faster Δ slalom (skill) time than either second or third team players (P<0.01). There were no differences between 2^{nd} and 3^{rd} team players in either slalom dribble time (P>0.9) or Δ slalom time (P>0.3).

Table 8.2: Mean±S.E. field test results for 1st, 2nd and 3rd team players (n)

	1st Team	2nd Team	3rd Team
MSFT (m)	1778±*86* (8)	1633±*112* (8)	1609±*71* (14)
ISRT (number of 20 m runs)	71±*4* (9)	74±*3* (8)	69±*3* (16)
YYIRT (m)	1027±*92* (12)	916±*74* (9)	813±*69* (15)
5 m sprint (s)	1.11±*0.02* (13)	1.12±*0.01* (9)	1.11±*0.01* (15)
10 m sprint (s)	1.90±*0.02* (13)	1.92±*0.01* (9)	1.92±*0.02* (15)
20 m sprint (s)	3.34±*0.04* (13)	3.39±*0.03* (9)	3.38±*0.04* (15)
30 m sprint (s)	4.76±*0.06* (13)	4.76±*0.04* (9)	4.75±*0.06* (15)
Slalom Sprint (s)	15.24±*0.25* (13)	14.73±*0.14* (9)	15.40±*0.17* (15)
Slalom Dribble (s)	17.82±*0.27** (13)	19.15±*0.26* (9)	19.31±*0.24* (15)
Δ Slalom Time	2.58±*0.22** (13)	4.43±*0.28* (9)	3.90±*0.27* (15)

***P<0.01**

8.3.3. Laboratory Physiological Assessment

The running speed eliciting a blood lactate concentration of 4 $mmol.L^{-1}$ for the 1st, 2nd and 3rd team players were 11.7±0.3, 10.8±0.3 and 11.1±0.3 $km.h^{-1}$ respectively (mean±S.E.; $P>0.1$). There were no differences between squads in whole blood lactate concentrations at rest or during submaximal running ($P>0.2$) (figure 8.1). It should be noted that one 2nd team player and four 3rd team players completed only 4 stages of submaximal running so are therefore not included in figure 8.1. Maximal oxygen uptake was not different between squads when expressed in absolute ($P>0.2$) or relative ($P>0.1$) terms (figure 8.2). When running economy of squads were compared, 1st team players were more economical than 3rd team players at 8 $km.h^{-1}$ ($P<0.05$; figure 8.3). There were no differences in running economy between squads at 9-12 $km.h^{-1}$ ($P>0.1$; figure 8.3). As mentioned previously, one 2nd team player and three 3rd team players completed only 4 stages of submaximal running, so were excluded from running economy analyses.

8.3.4. Match Analysis

Data were collected during 4*±1*, 4*±1* and 2*±1* matches during the 1st (n=9), 2nd (n=8) and 3rd (n=11) teams' 2006-2007 competitive season respectively. Total match data are presented in table 8.3. There were no differences between the squads in match duration, distance covered during match, maximum or mean speed ($P>0.3$).

There were no differences between squads based on the proportion of match time spent in each activity category (table 8.4, $P>0.6$). Mean*±S.E*. total sprint number for 1st, 2nd and 3rd team players were 13±*3*, 12±*3* and 11±*2* respectively ($P>0.8$).

When first and second halves of match play were compared, none of the teams showed any differences in the distance covered (*P*>0.05, table 8.5). The 1st and 2nd teams showed no differences in mean or maximum speed between the two halves (*P*>0.05, table 8.5). Third team players showed a decrease in the mean speed (*P*<0.05) and an increase in maximum speed obtained during sprinting (*P*>0.05) during the second half (table 8.5).

During the second half 1st and 3rd team players showed increases in the % time spent standing and decreases in the % time spent jogging, running and fast running (figures 8.4 and 8.6 respectively). Second team players demonstrated a decrease in the % time spent sprinting during the second half compared with the first (figure 8.5). Players from the 1st and 3rd teams showed increased low intensity activity and decreased moderate intensity activity during the second half (figure 8.7). First team players also showed a reduction in the % time involved in high intensity activities (figure 8.7). Comparison of 2nd team players' activity profiles showed no differences in low, moderate or high intensity activity between the first and second halves (figure 8.7).

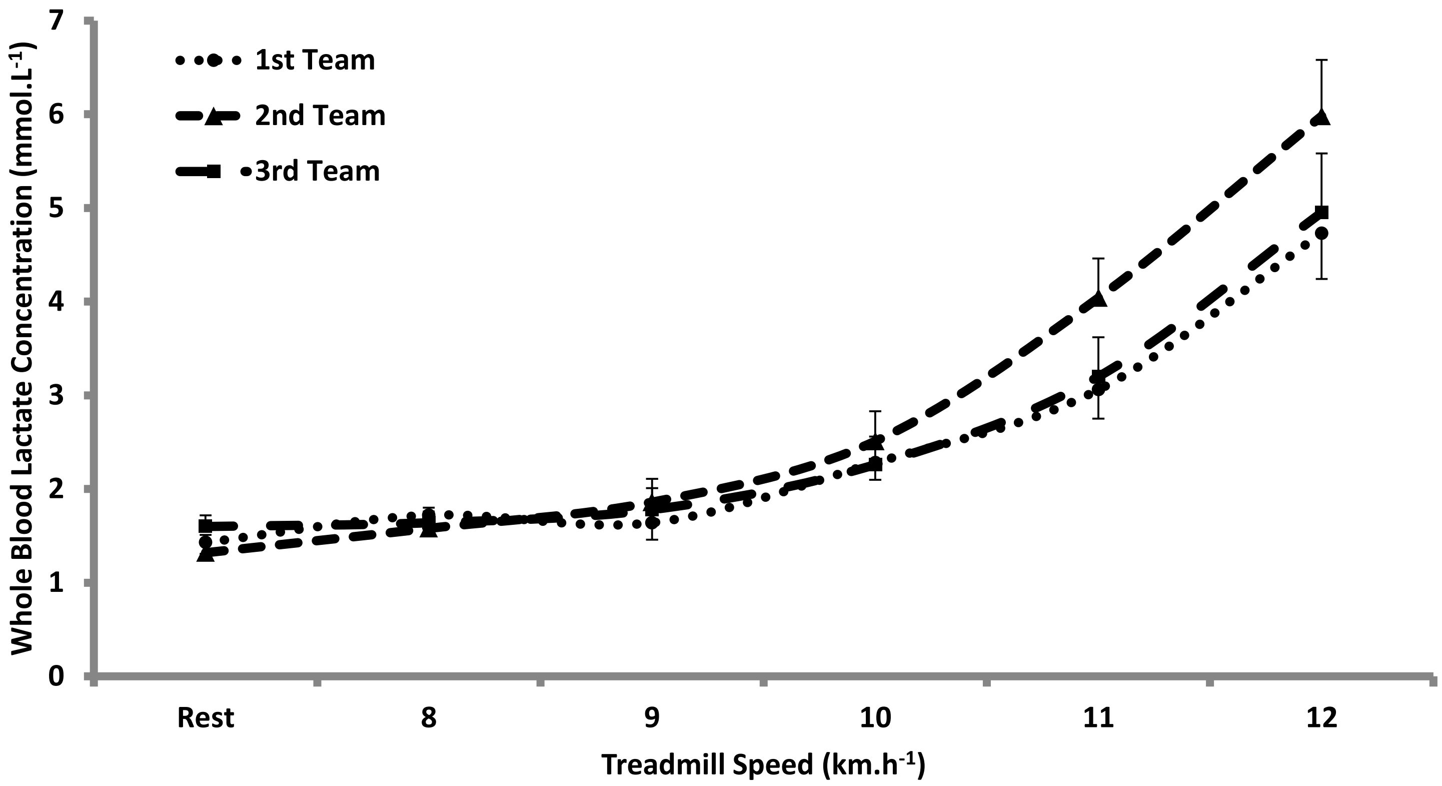

Figure 8.1: Whole blood lactate concentrations at rest and during submaximal treadmill running in 1st, 2nd and 3rd team players (mean±*S.E.*). There were no differences between squads (*P*>0.2).

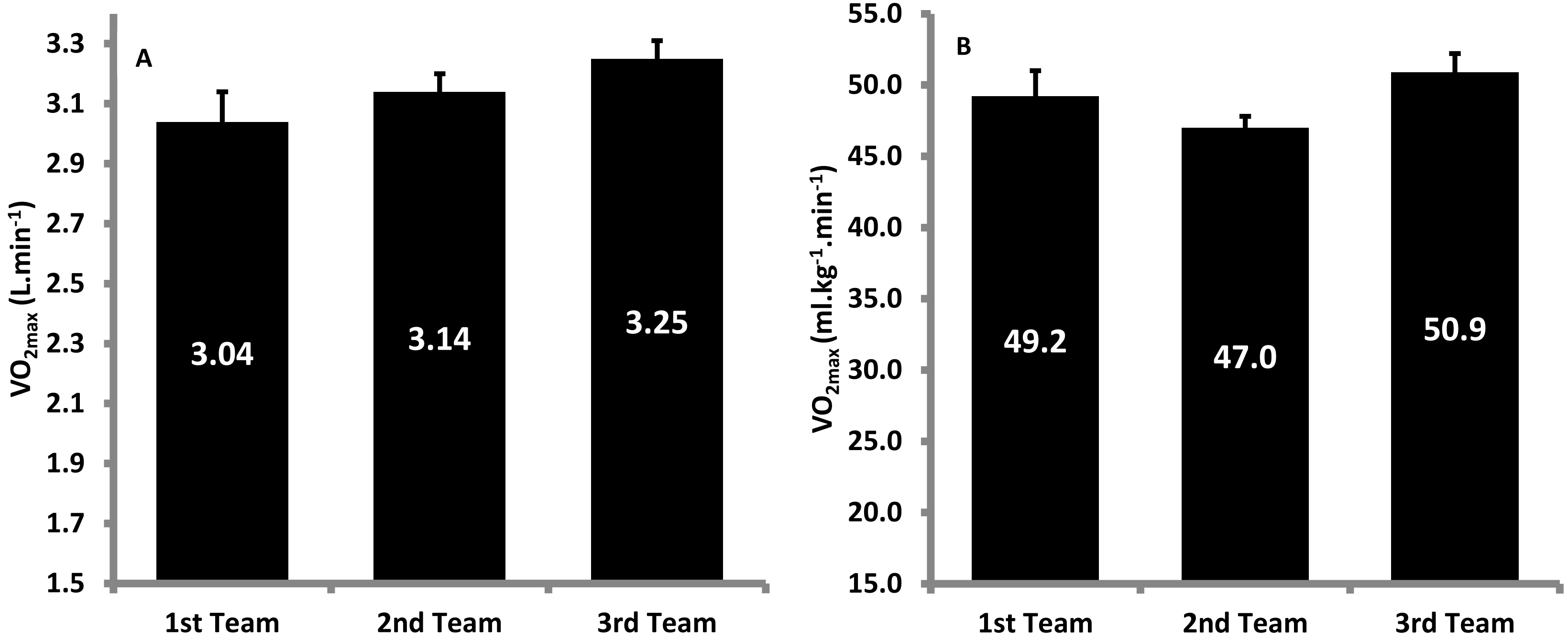

Figure 8.2: Absolute (A) and relative (B) maximal oxygen uptake of 1st, 2nd and 3rd team players. There were no differences between players in absolute (*P*>0.2) or relative (*P*>0.1) terms.

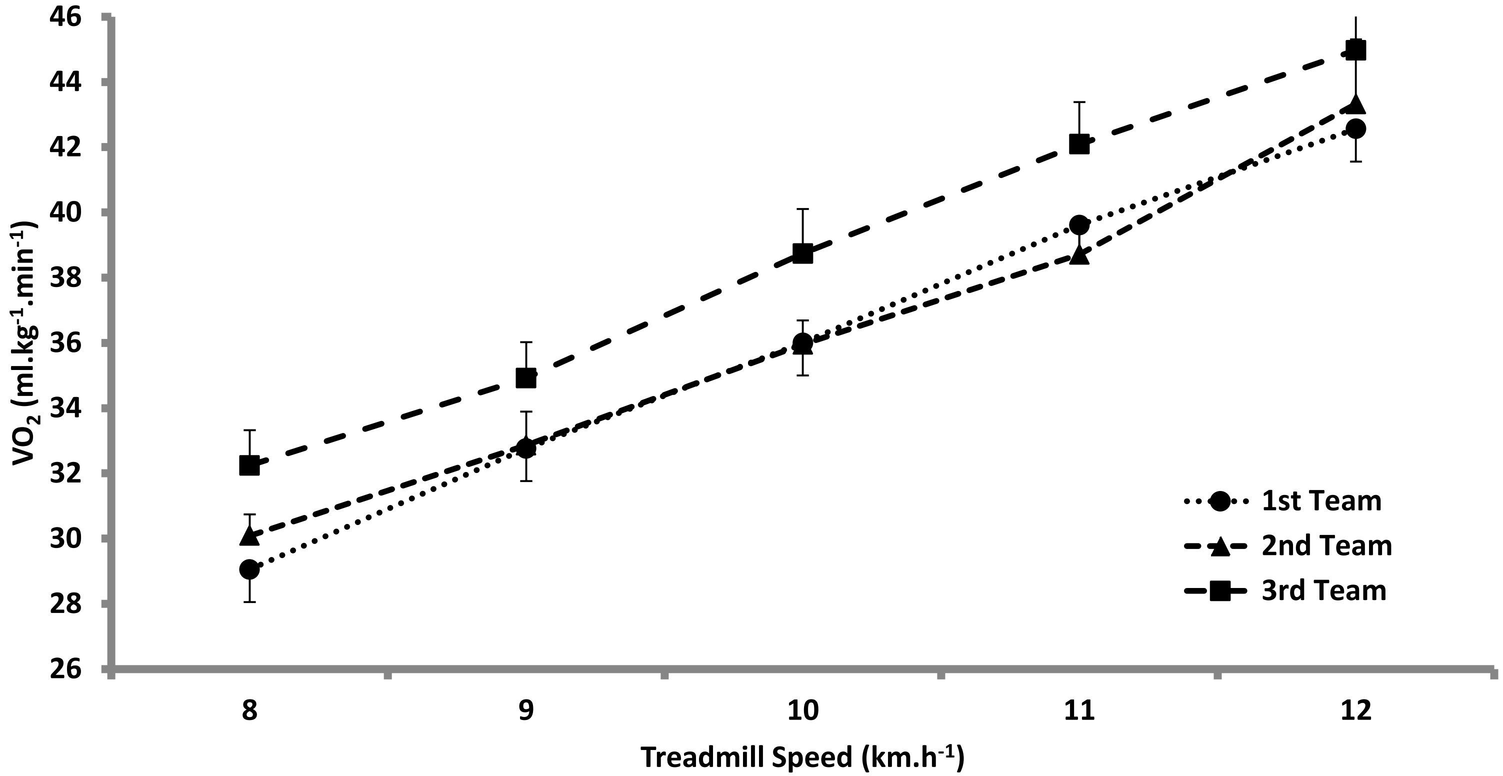

Figure 8.3: Running economy during submaximal treadmill running of 1st, 2nd and 3rd team players. First team players were more economical than third team players at 8 km.h^{-1} (P<0.05). There were no differences in running economy between squads at 9-12 km.h^{-1} (P>0.1).

Table 8.3: Total match GPS data for 1st, 2nd and 3rd team female hockey players (mean±*S.E.*)

	1st Team (n=9)	**2nd Team (n=8)**	**3rd Team (n=11)**
Total Duration (hh:mm:ss)	01:14:10±*00:00:49*	01:13:23±*00:00:43*	01:13:53±*00:00:40*
Total Distance (m)	7345.5±*242.3*	7123.9±*236.3*	7171.4±*247.3*
Max. Speed (km.h^{-1})	22.7±*0.6*	22.5±*0.2*	23.4±*0.5*
Mean Speed (km.h^{-1})	5.9±*0.1*	5.8±*0.2*	5.8±*0.2*

Table 8.4: Percentage time spent in activity categories for female 1st, 2nd and 3rd team field hockey players (mean±*S.E.*).

% Time	1st Team (n=9)	2nd Team (n=9)	3rd Team (n=11)
Standing (0-3 km.h^{-1})	27.3±*0.7*	27.6±*1.1*	28.0±*1.6*
Walking (3-6 km.h^{-1})	38.6±*1.4*	38.8±*1.3*	38.2±*2.0*
Jogging (6-10 km.h^{-1})	18.3±*0.6*	17.2±*0.6*	17.3±*1.4*
Running (10-14.5 km.h^{-1})	11.9±*0.8*	12.4±*1.2*	12.3±*1.0*
Fast Running (14.5 -19 km.h^{-1})	3.2±*0.5*	3.5±*0.5*	3.7±*0.3*
Sprinting (>19 km.h^{-1})	0.6±*0.2*	0.6±*0.1*	0.6±*0.1*
Low Intensity (0-6 km.h^{-1})	66.0±*1.2*	66.4±*2.0*	66.3±*2.5*
Moderate Intensity (6-14.5 km.h^{-1})	30.2±*0.9*	29.5±*1.5*	29.5±*2.4*
High Intensity (>14.5 km.h^{-1})	3.8±*0.6*	4.1±*0.6*	4.2±*0.4*

Table 8.5: First and second half comparisons for1st, 2nd and 3rd team female field hockey players (mean±*S.E.*)

	Duration (hh:mm:ss)	**Distance (m)**	**Mean Speed (km.h^{-1})**	**Max. Speed (km.h^{-1})**
1st Team First Half	00:35:57±*00:00:15*	3743.7±*99.4*	5.6±*0.7*	22.3±*0.5*
1st Team Second Half	00:38:04±*00:00:49**	3590.3±*156.3*	5.6±*0.1*	22.4±*0.6*
2nd Team First Half	00:36:55±*00:00:29*	3582.7±*94.1*	5.3±*0.1*	22.1±*0.3*
2nd Team Second Half	00:36:27±*00:00:21*	3541.3±*146.0*	5.8±*0.2*	22.1±*0.3*
3rd Team First Half	00:36:43±*00:00:17*	3651.1±*106.5*	6.0±*0.2*	22.0±*0.5*
3rd Team Second Half	00:37:10±*00:00:28*	3520.3±*152.8*	5.7±*0.7**	23.3±*0.6**

*$P<0.05$

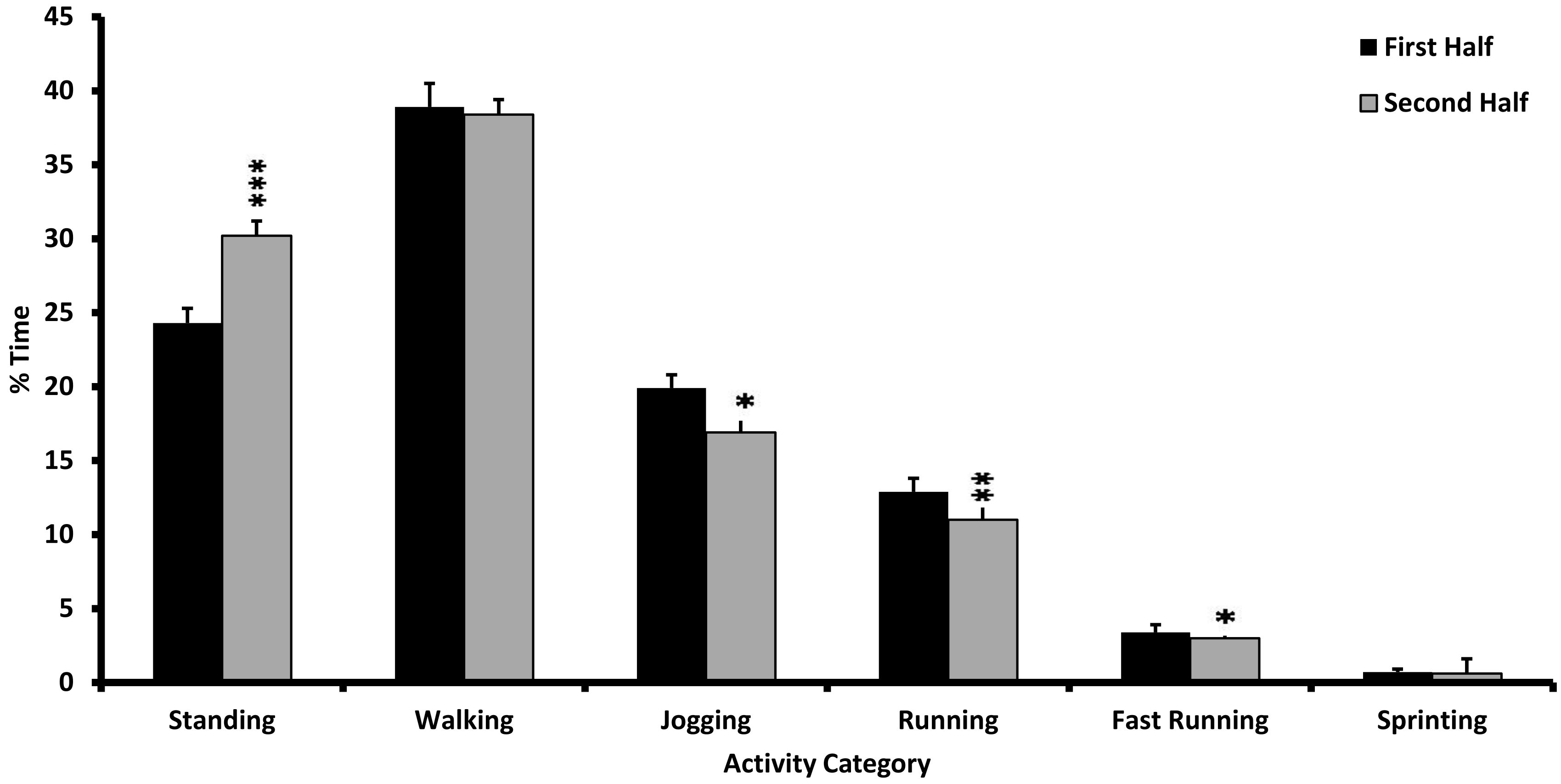

Figure 8.4: Comparison of 1st team players' activity profile during the first and second halves (mean±*S.E.*) (**P*<0.05 ***P*<0.01 ****P*<0.001).

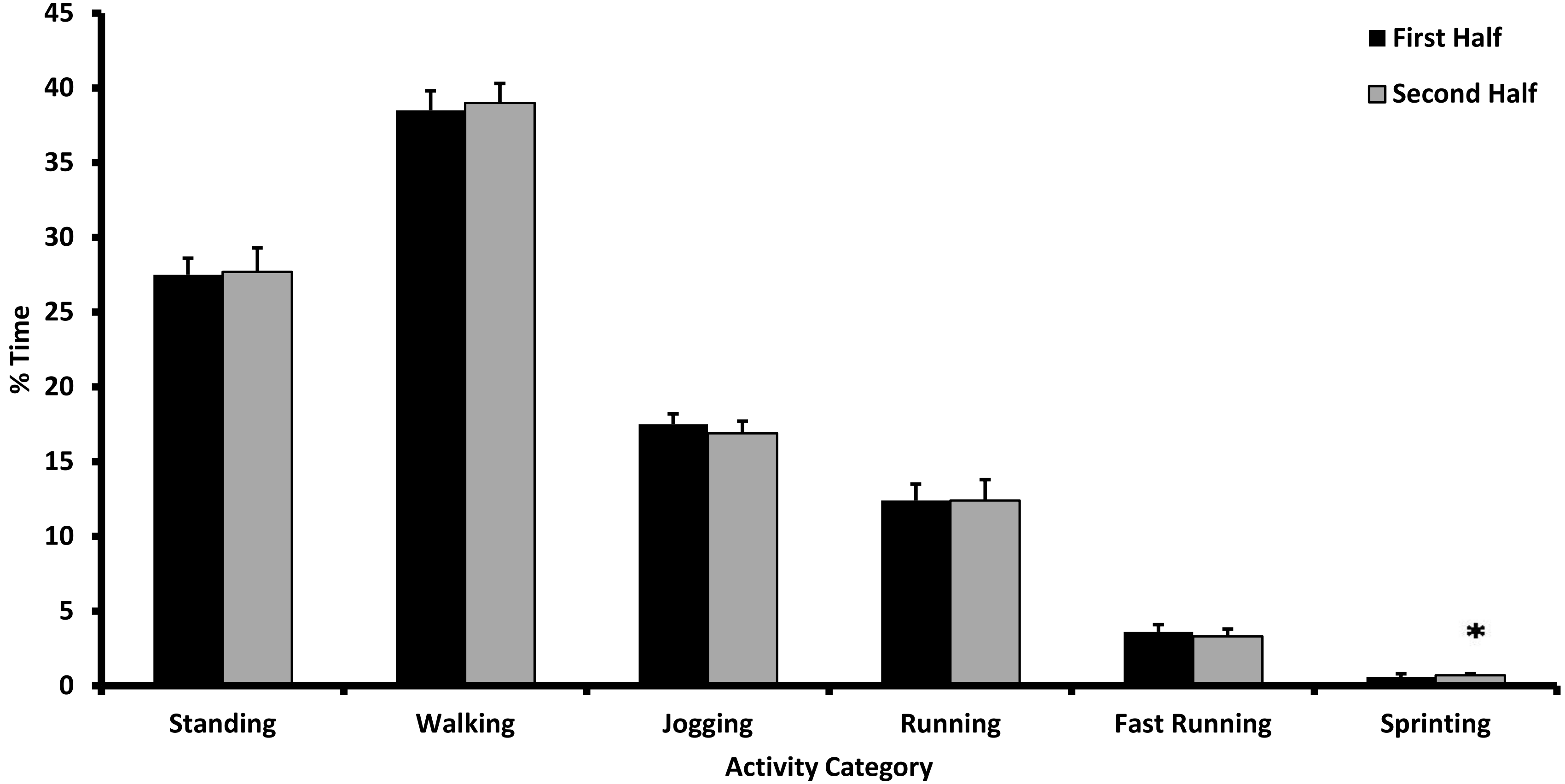

Figure 8.5: Comparison of 2nd team players' activity profile during the first and second halves (mean±*S.E.*) (**P*<0.05).

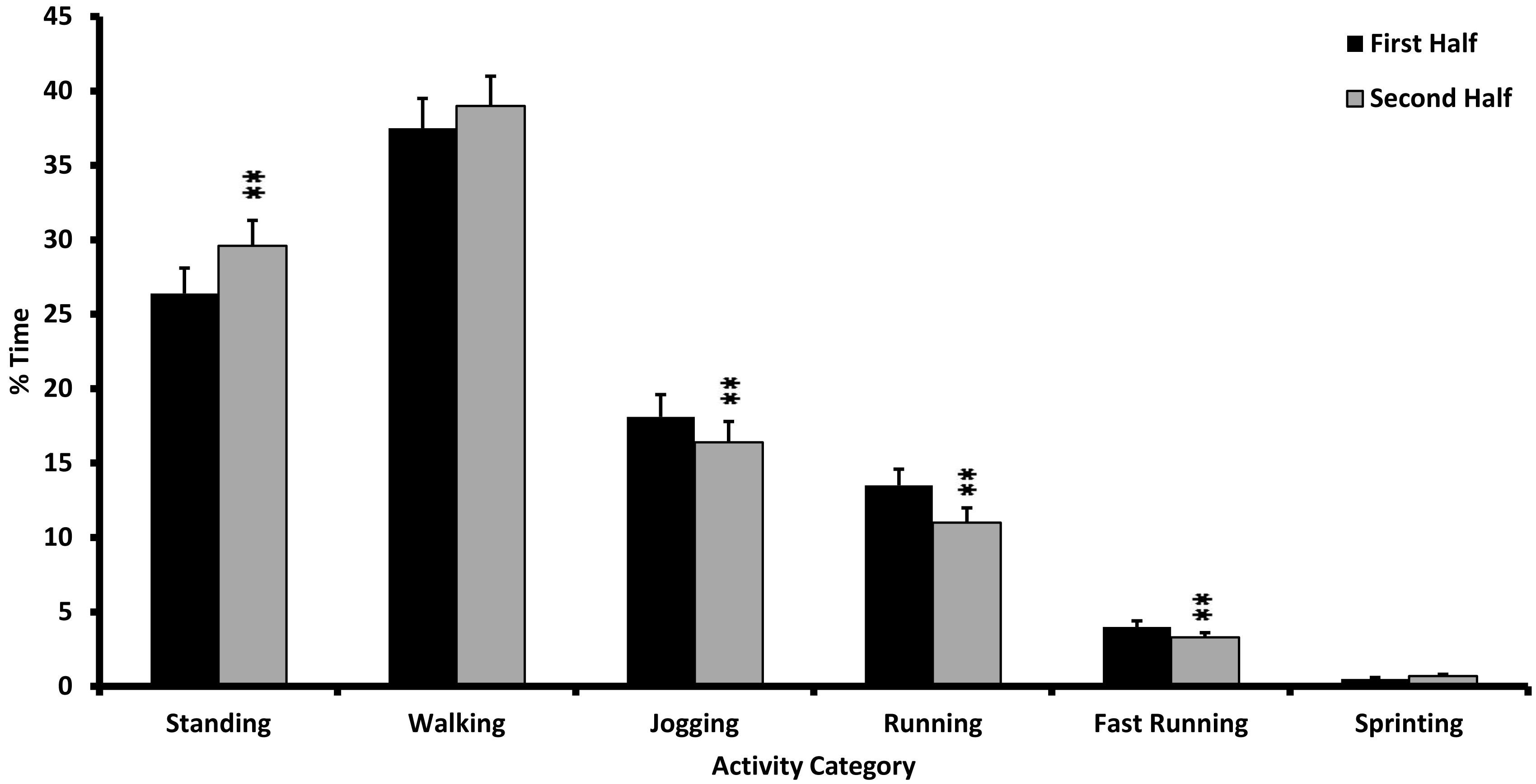

Figure 8.6: Comparison of 3rd team players' activity profile during the first and second halves (mean±*S.E.*) (**P*<0.05 ***P*<0.01).

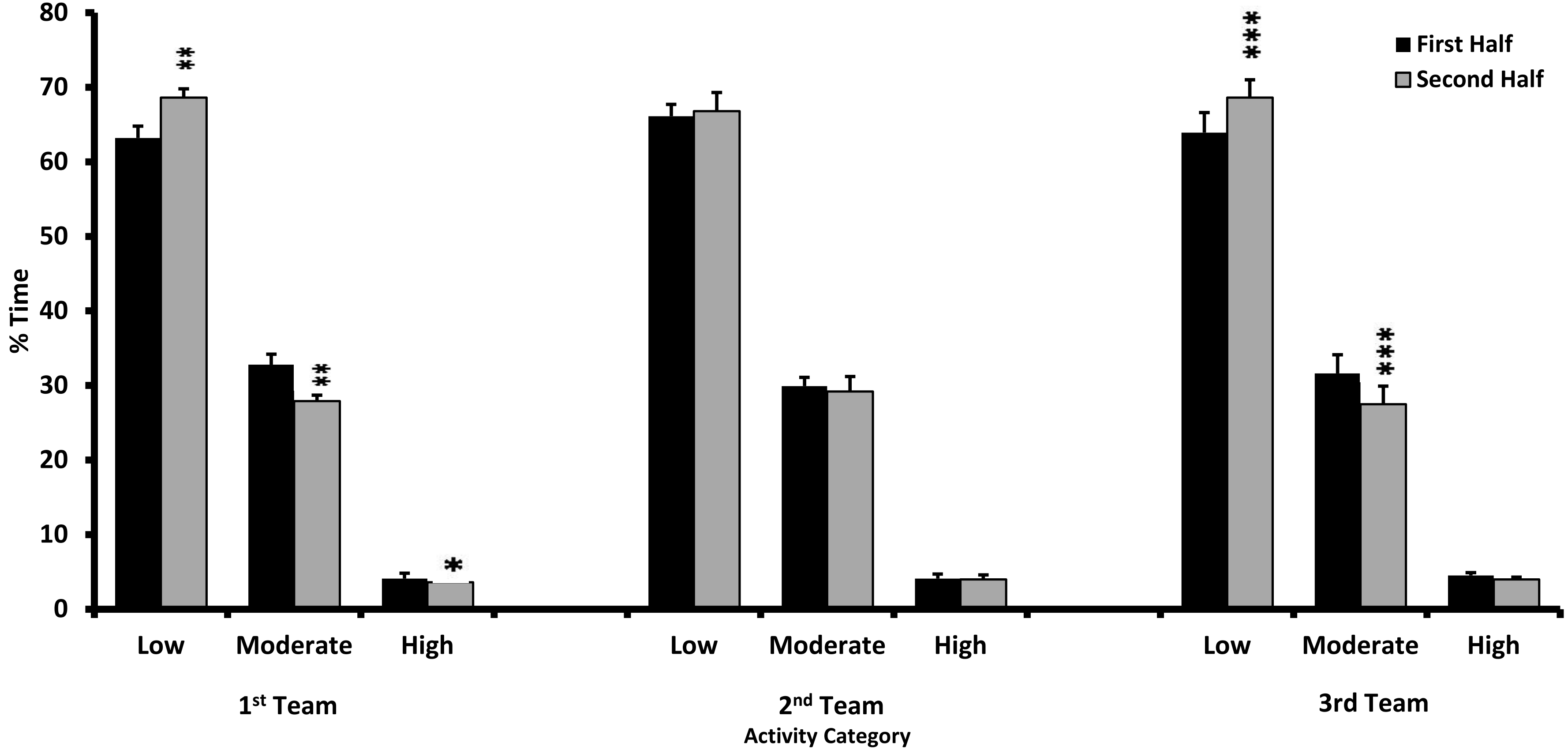

Figure 8.7: 1st, 2nd and 3rd team players' % time spent in low, moderate and high intensity activities during the first and second halves (mean±*S.E.*) (**P*<0.05 ***P*<0.01 ****P*<0.001).

8.4. Discussion

Results from this study suggest that at university level, there are few differences between field hockey players of different competitive standards when physiological and match performance characteristics are compared. Both laboratory and field-based assessment of physiological characteristics and speed failed to discriminate between players from different levels. Likewise, match activity profiles were not different between the three groups of players tested. Of the tests utilised in this investigation, the field based assessment of hockey-specific dribbling skill was the single discriminatory factor differentiating 1st from 2nd and 3rd team players.

A number of previous investigations have identified differences between intermittent sports players based on physiological tests and measures of speed. In Chapter 4 of this thesis, sprint speed was found to be crucial to success in elite competitive hockey. Several studies have provided additional evidence to support the importance of sprint speed to field hockey. Sprint performance has been shown to discriminate between elite and county standard female players (Reilly and Bretherton, 1986), regional and club standard players (Keogh *et al.*, 2003) and also between successful and less successful youth players (Nieuwenhuis *et al.*, 2002). However, contrary to this evidence, there were no differences between the three groups of players assessed in the present study based on 5, 10, 20 or 30 m sprint times (P>0.6, table 8.2).

Performance in laboratory and field based physiological assessments also failed to discriminate between the different standards of players assessed in this chapter. Few studies have compared the maximal aerobic power of hockey players of different standards. Cheetham and Williams (1987) reported considerably different VO_{2max} values for county and club level female players (50.1 vs. 43.9 $ml.kg^{-1}.min^{-1}$ respectively), however the purpose of the study was not comparing the two standards, so statistical significance was not provided. From various profiles of field hockey players, it appears that VO_{2max} may increase with competitive standard. Higher VO_{2max} values have been reported for Australian international (55.7 $ml.kg^{-1}.min^{-1}$, Bishop *et al*., 2003) and Canadian international (59.3 $ml.kg^{-1}.min^{-1}$, Ready and van der Merwe, 1986) than British club-level (49.8 $ml.kg^{-1}.min^{-1}$, Lothian and Farrally, 1992) and Australian regional (50.2 $ml.kg^{-1}.min^{-1}$, Withers and Roberts, 1981) players. However, due to differences in experimental procedure and design between studies, it is difficult to draw firm conclusions on the differences in VO_{2max} between hockey players of varying levels.

Equally, field-based physiological assessments (MSFT, ISRT and YYIRT) did not differentiate between the groups of players in the present study. In contrast to several existing studies, MSFT performance was not significantly different between the three standards of players assessed (P>0.2, table 8.2). In female field hockey regional players have been shown to out-perform local club level players in the MSFT (Keogh *et al*., 2003) and successful female youth players have scored higher in the test than less successful counterparts (Nieuwenhuis *et al*., 2002). Additionally, MSFT predicted VO_{2max} has been shown to be 20-42 % higher in professional compared with amateur rugby league players (Gabbet, 2000). Whilst such evidence suggests that the MSFT may be a useful tool to differentiate between players of different standards, this was not the case in the current investigation. Such findings have also been reported among soccer players with no differences detected between professional, high-level amateur and low-level amateur players' MSFT performance (Lemmink *et al*., 2004) or between test performances of recreationally active soccer players and those contracted to a the academy of a professional club (Edwards *et al*., 2003). The lack of evidence to support the use of the MSFT as a tool to differentiate between intermittent games players of different standards may be due to the continuous nature of the test. The MSFT does not replicate or reflect the intermittent nature of the activity patterns associated with sports such as hockey.

Similar to the MSFT, ISRT scores from participants in the present study were not different between the three standards of player assessed (71±*4* *vs*. 74±*3* *vs*. 69±*3*; 1st *vs*. 2nd *vs*. 3rd team, P>0.5) which is contradictory to the existent literature. Comparison of professional, high-level amateur and low-level amateur soccer players has revealed professional players to score significantly higher on the ISRT than either groups of amateurs (Lemmink *et al*., 2004). Similarly, amongst talented young soccer players, elite players outscored less skilled players in the ISRT (Visscher *et al*., 2006).Finally, using multi-level modelling, elite male and female youth hockey players demonstrated more promising ISRT performance than sub-elite youth players (Elferink-Gemser *et al*., 2006). Therefore whilst there is evidence to suggest that the ISRT may be a useful test to potentially discriminate between hockey and soccer players of varying competitive levels, the ISRT did not discriminate between the different standards of 1st, 2nd and 3rd team female field hockey players in the present study.

Much of the previous research adopting the YYIRT to examine physiological differences between players of various standards has found the test to successfully discriminate between groups of players. Performance in the YYIRT was found to be significantly higher in top-class professional soccer players (2260±*80* m) than in moderate-level professional players (2040±*60* m) (Mohr *et al*., 2003). In a recent review of female soccer players' YYIRT performance, it was reported that similar differences may exist amongst players of different levels, with top-elite players (1600m) appearing to cover more distance in the test than moderate-elite (1360 m) and sub-elite (1160 m) players (Bangsbo *et al*., 2008). In addition, when experienced Italian soccer referees officiating at different levels (top-level, medium-level and low-level league matches) completed the YYIRT, top level referees scored higher than medium- and low-level referees (Castagna *et al*., 2005). Conversely, no differences in YYIRT were found between the three groups of players tested in the present study (P>0.1, table 8.2). As discussed previously, no significant physiological differences were identified between the teams based on any of the parameters assessed (submaximal lactate response, VO_{2max}, MSFT, ISRT or YYIRT performances). The absence of any detectable differences in the physiological profiles of players may be due to the players recruited for the study being of too similar a competitive standard. Additionally, the similar physiological profiles of players may be attributed to the similar demands placed on players during competitive play (as discussed shortly). It may be the case that, at the standards of play examined, certain physiological characteristics are required for competitive play, however technical and/or tactical characteristics may have an important role in determining the level of competition at which an individual competes.

In the present study there were no differences in the match performance characteristics of players from three competitive levels based on match activity profiles (tables 8.3 and 8.4). From work with other intermittent sports, it has been suggested that the quality of game-play is associated with the amount of high intensity activity during a match (Bangsbo *et al.*, 1991). When top-class and moderate level professional soccer players were monitored during competitive play, top-class players were found to perform 28 % more high intensity running and 58 % more sprinting than moderate professionals (Mohr *et al.*, 2003). Similar results have been reported between elite and semi-elite rugby league players, with elite players performing more high intensity running and very high intensity running than their semi-elite counterparts (Sirotic *et al.*, 2009). Whilst there were no differences between the high intensity profiles of 1st, 2nd and 3rd team players in the present study, players spent considerably shorter proportion of match time engaged in high intensity activity (mean range 3.8-4.2 %) than that reported for elite female international players in Chapter 6 (7.5 %). Although the University level players covered 27-33 % more distance during a match than international players, the mean and maximum speeds of 1st, 2nd and 3rd team players were lower than those recorded for elite players. Additionally, players in the present study spent more time in low intensity activities (standing/walking) and less time in moderate intensity activities (jogging/running) than the elite players studied in Chapter 6. This suggests that while there were no detectable differences in match performance characteristics of the different playing standards in the present study, high intensity activity during match play may be higher during elite competitive hockey compared with sub-elite competition. However, direct comparison of match characteristics of players the present study with those in chapter 6 must be treated with caution due to variation in the mean match duration (~74 vs. 49 minutes respectively). A higher frequency of substitutions during international competition may be adopted to maintain players' ability to perform high intensity bouts and may account for differences in high intensity activity profiles between elite and sub-elite players. Further investigations of high intensity activity of elite vs. sub-elite players and the influence of player substitutions on match performance are warranted.

Whilst there were no differences in the physiological or match performance profiles of the three standards of players assessed in this study, performance in a hockey-specific dribbling test differentiated 1st team players from 2nd and 3rd team players. Scores from the slalom sprint portion of the test (i.e. without the ball) were not different between teams, however, 1st team players completed the course significantly faster than the other two teams while dribbling a ball, thus demonstrating superior dribbling skill. Several previous studies have shown hockey-specific technical ability to distinguish between players of varying levels of competition. Reilly and Bretherton (1986) reported greater dribbling ability in female elite *vs.* county players. Such differences have also been demonstrated between regional and club level players, with regional players outperforming club players in a dribbling test (Keogh *et al.*, 2003). Even amongst young players (14-15 year-old girls) detectable differences in hockey-specific skills have been demonstrated with successful young players performing better in tests of technical ability (Nieuwenhuis *et al*., 2002). Control of the ball during match play is crucial for accurate passing, ball possession and ensuring that the ball remains in play (Nieuwenhuis *et al*., 2002). Therefore, whilst certain physiological characteristics may be required to meet the demands of competitive field hockey, well-developed hockey-specific technical skill appears to be crucial to determining success in female field hockey.

8.5. Conclusions

Results from the comparison of the physiological, skill and match performance characteristics of three different standards of female university field hockey players show It was possible to discriminate 1st team players from 2nd and 3rd team players based on their superior dribbling skill. There were no other differences between the three teams when match performance and laboratory and field based physiological measures were compared. Similarities in the requirements of competitive play may account for the similar physiological profiles of players from differing standards of competition. Further investigation of the interplay between the physiological and performance characteristics of female field hockey players is required to determine the importance of physiological parameters to competitive play.

Chapter 9. General Discussion

9.1. Introduction and key findings

Despite field hockey's popularity throughout the world, few research studies have investigated the physiological and performance characteristics of its adult participants, and almost no data exists for young players. The purpose of the research presented in this thesis was to address this gap in the existent literature by examining the physiological and performance characteristics of players in relation to age, sex and playing standard. By examining how these characteristics develop from junior to senior level, it may be possible to identify factors crucial to elite level hockey performance and therefore assist in talent identification, detection and selection procedures.

The following provides a brief summary of the principle findings of the research presented in the preceding experimental chapters:

- A cross-sectional analysis of U16, U18, U21 and senior male international players suggests that a relatively high peak aerobic power (~60 $ml.kg^{-1}.min^{-1}$)

is a prerequisite for elite level hockey from at least 15 years onwards, although it is probably not a discriminating factor (chapter 4.).

- Sprint speed appears to be a crucial determinant of elite level success: a comparison of successful (those who progressed to senior international level) and unsuccessful (those who did not progress) U18 and U21 international male players showed that successful players were faster, with differences reaching statistical significance at U21 level (chapter 4).
- Younger elite players (U16 and U18 age groups) demonstrated greater fatigue resistance than senior and U21 players during 10 x 6 s repeated cycle sprints in the laboratory (chapter 4).
- Analysis of elite male and female match performance characteristics using GPS analysis, found players spent around 90-95 % of match play engaged in low-moderate intensity activities (<14.5 km.h^{-1}) (chapters 5 and 6).
- Absolute match activity profiles of U16, U18 and senior male and female players were similar when analysed in absolute terms (chapters 5 and 6). There were no differences between female age groups when data were analysed relative to maximal speed (chapter 6). However, relative analysis of male data showed that senior players spent more time in lower intensity activities than either of the younger squads (chapter 5).
- During the second half of match play, the three male age groups (U16, U18, senior) and senior females all demonstrated reductions in the amount of high

intensity activities (>14.5 km.h^{-1}) (chapters 5 and 6). Senior males exhibited the greatest decrement in performance and inability to maintain sprint activities toward the end of a game (chapter 5).

- It appears that a number of testing procedures (VO_{2max}, speed at 4 mmol.L^{-1}, YYIRT, ISRT and MSFT) relate to performance in a match. The amount of high intensity activity (>14.5 k.h^{-1}) completed during a match was most closely associated with VO_{2max}, and performance in the YYIRT and ISRT (chapter 7).
- Perhaps surprisingly, physiological and match performance characteristics did not discriminate between three standards of female University players. However, 1st team players demonstrated superior dribbling skill when compared to 2nd and 3rd team players (chapter 8).

The remainder of this chapter will discuss how the results from the experimental chapters of this thesis contribute and advance the current knowledge of physiological and performance characteristics of field hockey players.

9.2. Physiological and skill characteristics of hockey players

Undoubtedly, there are a number of physiological and skill characteristics which contribute to elite level hockey. Identifying such characteristics is important for ensuring specificity of training programmes, as well as providing an indication of favourable characteristics in promising young players. To date, few studies have sought to profile the physiological characteristics of field hockey players and as a result, there is little existing comparative data particularly with reference to younger players. Chapter 4 provides one of the first cross-sectional analyses of the physiological profile of elite junior and senior players.

The characteristics examined in chapter 4 included peak aerobic power, repeated sprint performance, running economy and MSFT performance. Individually, these aspects have been previously examined in relation to age in a general population, however, results from chapter 4 provide data on how a number of these factors develop in elite hockey players.

9.2.1. Maximal aerobic power

In the 1990s, Reilly and Borrie (1992) reviewed the physiological characteristics associated with hockey. Among the principle findings, the authors noted that VO_{2max} in elite male players was approximately 60 $ml.kg^{-1}.min^{-1}$. Data from elite senior elite players in chapter 4 was consistent with this observation, however, in addition data collected from the junior elite players suggests that such a peak aerobic power is necessary from at least U16 level. This highlights the importance of aerobic power to hockey and also provides coaches and players with an indication of the level required for elite performance. However, as most of the players examined possessed this level of aerobic power, in talent identification terms this characteristic would appear to be a prerequisite for elite performance but not a discriminatory factor.

Whilst maximal aerobic power has been identified as a key attribute of successful hockey players, how VO_{2max} relates to an individual's performance during a match has received little attention. In chapter 7, laboratory assessment of VO_{2max} was found to be associated with a number of match performance parameters, namely the total distance covered, mean speed and the amount of high intensity activity. Similar relationships have been demonstrated in field hockey (Lothian and Farrally, 1994) elite soccer players (Krustrup *et al*., 2005) and top-class soccer referees (Krustrup *et al*., 2001). Such associations between VO_{2max} and match performance may explain why a high aerobic power is advantageous in field hockey competition.

9.2.2. Speed

In chapter 4, comparison of 15 m sprint times between players who went to on to complete at senior international level (successful) and those who did not (unsuccessful) revealed successful U21 players to be significantly faster than their unsuccessful counterparts. This finding suggests that sprint speed over a short distance discriminates between elite and non-elite players. Similar results have been reported among female players, with sprint speed discriminating between elite and county standard players (Reilly and Bretherton, 1986) and regional and club levels (Keogh *et al*., 2003). In chapter 8 however, there were no differences between 1st, 2nd and 3rd team players based on 5, 10, 20 or 30 m sprint times. In this instance, the three levels of players may have been too homogenous a sample to detect differences based on speed. However, it is also possible that the players were drawn from an environment where emphasis was placed on physical preparation at all standards of play.

Based on results from chapter 4 and evidence from the literature, sprint speed appears to be a crucial characteristic of elite level hockey players. The ability to sprint over a short distance with and without the ball is essential (Nieuwenhuis *et al*., 2002) and should therefore be targeted in training. Establishing minimum standard criteria for sprint speed could assist coaches and players in reaching training targets, and provide benchmark values for assisting in the identification of talented young players.

9.2.3. Hockey-specific skill

The physiological profile of a player appears to influence performance during competitive matches and also play a role in determining the level of success obtained. However, as demonstrated in chapter 8, hockey-specific dribbling skill is a key determinant of playing standard.

Results from the comparison of three different competitive standards of female hockey players revealed no differences between teams based on any of the physiological or match activity parameters assessed. This finding was perhaps surprising given the discussion above, particularly with respect to short distance sprint speed, however the players investigated were from an environment where physical preparation was emphasised and valued at all levels of play. Nevertheless, in this study, the single discriminating factor between playing levels was dribbling skill, as assessed using a hockey-specific test (Lemmink *et al*., 2004). It appears that at the very least, a successful player must also demonstrate a high level of ball control.

Findings from chapter 8 are consistent with several other studies which have reported technical ability to differentiate between players of different competitive levels. Dribbling ability was greater in elite vs. county players (Reilly and Bretherton, 1986) and regional level players demonstrated superior skill compared with club level players (Keogh *et al*., 2003). Among young females, successful players have been shown to outperform less successful players in tests of technical ability (Nieuwenhuis *et al*., 2002). Taken together, these results indicate that whilst certain physiological characteristics may be prerequisite in order to meet the demands of competitive hockey, well-developed hockey specific technical abilities are a crucial determinant of success in field hockey. Player assessments, particularly in the talent identification setting, should include a measure(s) of hockey-specific skill.

9.3. Match performance characteristics of field hockey players

When compared with other intermittent team sports such as soccer, relatively little research has been undertaken to profile player activities during field hockey matches. Existing research studies (e.g. Lothian and Farrally, 1992; Lothian and Farrally, 1994; Spencer *et al*., 2004; MacLeod *et al*., 2007) have all adopted video-based time-motion analysis techniques. Such methodologies are time consuming and do not provide an objective measure of match activities. Whilst several studies have attempted to document the match performance characteristics of adult play, to date, there is no information available concerning young players' activity during competitive play and no investigations of how match performance may change with age. Advances in technology have permitted development of match analysis techniques to allow simultaneous assessment of multiple players during games. Global positioning systems provide a valid and objective method for assessing performance characteristics during match-play (MacLeod *et al*., 2009). Chapters 5 to 8 of this thesis employed GPS match analysis techniques to examine match performance characteristics in relation to physiological characteristics, age and playing standard.

9.3.1. Match performance characteristics in relation to age

To date, there have been no previous analyses of the match performance characteristics of young elite field hockey players. Chapters 5 and 6 sought to address this lack of information by providing cross-sectional analyses of the activity profiles of male and female elite U16, U18 and senior players.

Analysis of match activities of male and female elite junior and senior players demonstrated players to spend 90-95 % of match play involved in low-moderate intensity activities (<14.5 $km.h^{-1}$). High intensity activities (>14.5 $km.h^{-1}$) accounted for between 5% (U16 females) and 12.4 % (U16 males) of a game. Whilst the majority of match-play was spent in activities categorised as low-moderate, these classifications are based on speed of movement. Over the course of a game mean heart rate values of around 170 $beats.min^{-1}$ have been reported for females (MacLeod *et al.*, 2007) and male players have been shown to spend more than 60 % of match time at intensities eliciting a heart rate of >75 % HR_{max} (Johnston *et al.*, 2004). These HR data demonstrate that whilst the movements and activities associated with competitive play may appear to be of a low intensity nature, the physiological demand placed on players is considerably higher.

When cross-sectional data were analysed relative to absolute speeds, there were few differences between the match activity profiles of U16s, U18s and seniors in both male and female players. Similarities in the match performance characteristics of age groups may be associated with similarities in physiological profile. As described in chapter 4, there were no differences in the peak aerobic power ($ml.kg^{-1}.min^{-1}$) of elite male U16, U18, U21 and senior players. Physiological characteristics including aerobic power appear to be associated with an individual's performance during competitive play. Results from chapter 7 showed VO_{2max} to be related to the total distance covered during a match, mean speed and amount of high intensity activity. Similar physiological profiles (i.e. aerobic power) of junior and senior players may account for the similarities observed in performance during competition.

Whilst the absolute demands of elite field hockey were not different between age-groups, senior males and females players demonstrated a greater reduction in high intensity activity (>14.5 $km.h^{-1}$) than junior players during the second half of a match. The more pronounced declined in high intensity activity among older players may be accounted for by age-associated variation in fatigue resistance. Laboratory assessment of the repeated sprint performance of junior and senior players in chapter 4 showed U16 and U18 players maintained peak and mean power outputs during 10 x 6 sprints (with 30 s passive recovery). Conversely, U21 and senior were unable to maintain power output during the protocol. The age-associated variations in fatigue resistance may be explained in a number of ways: it has been suggested that young athletes have a higher reliance on energy derived aerobically (Hebestreit *et al*., 1993); have a faster resynthesis of PCr during recovery (Kuno *et al*., 1995; Taylor *et al*., 1997) and have a greater ability to exchange/remove lactate and H^+ within muscle during recovery (Ratel *et al*., 2003). Any one of these characteristics or some combination of them all could explain the variation in repeated sprint performance as elite players get older.

During the laboratory based repeated sprint test, the PPO of senior players was higher than that of U16 and U18 players. Similarly, in the game situation, maximum speeds produced by senior players were greater than those of U16 and U18 players in both male and female squads (although differences were not statistically significant between female age groups). As noted in chapter 4, the fatigue seen in older senior males and females may be a consequence of the higher power outputs/speeds they were able to generate during laboratory tests and match play and the metabolic consequences of this.

9.3.2. Relationship between physiological and match performance characteristics

In order to assess players' endurance running performance and responses to training, coaches frequently utilise various physiological testing procedures. However, the relationships between performance in many of these tests and performance during competition are poorly understood. In chapter 7 the association between a number of physiological characteristics derived from various testing procedures and their relationship with actual match performance was examined. Results showed that laboratory (VO_{2max} and speed at 4 mmol.L^{-1} lactate) and field (YYIRT, ISRT and MSFT) based physiological assessments were related to a number of match characteristics in female field hockey players. All the tests utilised in the investigation were found to be correlated to the total distance covered and mean speed during a match. The amount of high intensity activity, which is often thought by coaches to be associated with the quality of match performance, was most closely associated with VO_{2max} and YYIRT and ISRT performance. These results provide a rationale for using field and laboratory based testing as an indicator of a player's likely physical performance during match-play. Importantly, the degree of association with match performance was not different for laboratory and field measures. Therefore, field measures (particularly the YYIRT and ISRT) appear to provide viable alternatives to laboratory assessment of players.

9.3.3. Match performance characteristics in relation to playing standard

High intensity activity during intermittent team sports has been suggested to give an indication of the quality of game-play. Indeed, in soccer (Mohr *et al*., 2003) and rugby league (Sirotic *et al*., 2009) the amount of high intensity activity has been shown to discriminate between players of different standards. However, in chapter 8 comparison of three different competitive standards of female players failed to detect any differences based on match activity profiles. Whilst it is possible that match activities do not vary between competitive hockey standards, it is likely that the players recruited for the study described in chapter 8 were too homogenous in terms of their physiological characteristics. This is demonstrated by the similarity in their test performances. This similarity was unexpected, but as noted earlier, may be a function of the environment in which the players trained, which placed emphasis on physical preparation. Given the similarity in their physical characteristics and the link between the physiological attributes of a player and their match performance characteristics, similarities in the match performance of the three teams seems consistent and is therefore perhaps not unexpected. In addition to similar match performance profiles, there were no differences between the teams based on physiological parameters. As discussed in chapter 7 and in the previous section, the physiological attributes of a player are related to performance during game. On this basis, similar performance characteristics between the three teams may be expected.

However, comparison of the activity profiles of university level females (chapter 8) and elite level females (chapter 6) shows elite players to spend between 79 -97 % more of match time engaged in high intensity activities than university players. Direct statistical comparison between elite and university match analysis data is problematic due to differences in match duration (approximately 49 vs. 74 minutes respectively). These differences are due to the frequent substitution of elite players during game play. Of course the tactical use of substitutions in the elite game may permit improved recovery of players, thereby facilitating the potential to engage in high intensity activities throughout a game. However, although inconclusive, it is possible as these match analysis data suggest that differences may exist in the match performance characteristics of elite and sub-elite hockey players, particularly with reference to high intensity activity.

9.4. Summary

The primary aims of this thesis were to provide information regarding the physiological and match performance characteristics of field hockey players with respect to age, sex and playing standard and to identify factors which may be important for talent identification procedures . From the data obtained, it appears that in order to succeed at the elite level of field hockey players must be fast, possess a relatively high aerobic power and demonstrate a certain degree of hockey specific technical skill. Analysis of junior and senior elite male and female match play suggests that similar demands are placed on players from U16 to senior level and these similarities may, in part, explain why a relatively high peak aerobic power is required for elite male success from at least U16 level onwards. Also, elite players seem to spend a greater % of their playing time in high intensity activities than sub-elite players. Finally, there seems to be a strong link between the physical characteristics of a player and their capabilities during match play. The physiological characteristics of a player can be examined using both laboratory and field based tests such as VO_{2max} or performance in the YYIRT or ISRT to provide an indication of performance during competitive play.

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Appendices

Appendix 1: Participant Information

Appendix 2: GPS Participant Information

Appendix 3: Health History Questionnaire

Appendix 4: Informed Consent (laboratory)

Appendix 5: Informed Consent (GPS and field tests)

Appendix 6: Informed Consent (GPS)

Appendix 7: Informed Consent/Assent (Junior player GPS)

Loughborough University

Physiological and Performance Characteristics of Field Hockey Players

Participant Information:

Match Analysis, Laboratory Measurement and Field Test Protocols

ENGLAND HOCKEY

Aims and Objectives

The aim of this project is to improve our understanding of the physiological and match performance characteristics of hockey players. The project will look at how performance during hockey matches relates to performance in laboratory fitness tests and field-based fitness, skill and speed tests. The results from this research will help coaches with training and also in the development of young hockey players.

Summary of Tests

Match Analysis

- This will require you to wear a small GPS device during one or more hockey matches

Laboratory Measurements

- A number of physical measurements will be made upon your arrival at the laboratory including height and weight.
- A submaximal run on the treadmill lasting around 20 minutes.
- A maximal run on the treadmill lasting 8-14 minutes.

Field Tests

- A hockey test for sprinting and dribbling ability
- Timed sprints

GPS Match Analysis

This part of the project will require you to wear a small, lightweight global positioning system (GPS) device during a normal hockey match. The device should not interfere in any way with your normal movement during play as it will be attached to a strap worn across you back. The GPS device will monitor and store a number of different measurements such as the distance covered during the match and the speed at which you run. Information will then be downloaded from the GPS equipment onto a computer where it can be analysed.

Laboratory Tests

Physical Measurements

When you first arrive in the laboratory, your height and weight will be measured.

Submaximal Treadmill Test

This test will require you to run on the treadmill at increasing speeds. You will run at each speed for 4 minutes. During the final minute of each stage you will be asked to wear a nose-clip and insert a mouthpiece to allow collection of expired air. At the end of each 4 minute stage you will be asked to step from the treadmill to allow a small finger prick blood sample to be taken (a resting sample will also be obtained before the test begins). You will then resume running on the treadmill at a faster speed than the previous stage.

Treadmill Maximal Oxygen Uptake Test

You will be given some time to rest between the submaximal and maximal tests. During this test the speed of the treadmill will remain constant, however, the gradient of the treadmill will gradually increase every 3 minutes until you reach exhaustion. As with the submaximal test, expired air will be collected during the final minute of each stage, but no blood samples will be taken so you are not required to step off the treadmill between stages.

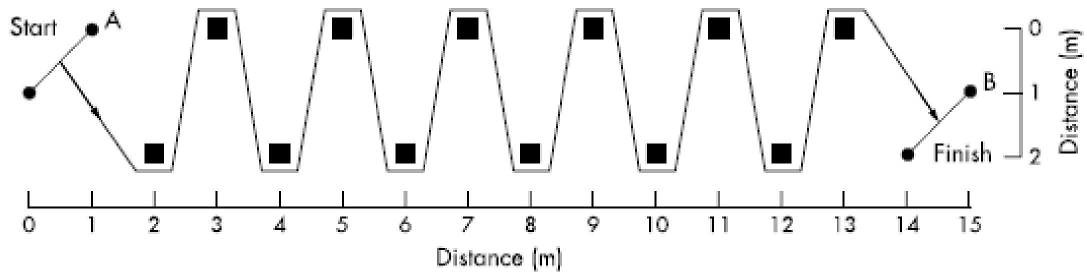
Field Tests

Multi-stage Fitness Test (MSFT), Interval Shuttle Run Test (ISRT) and Yo-Yo Intermittent Recovery Test

These three tests are all fairly similar and you will be asked to complete only one of them during a single session. All require repeated 20 m runs until exhaustion at an increasingly faster pace, with the speed controlled by bleeps from a pre-recoded CD. The MSFT (or bleep test) requires continuous 20 m runs to exhaustion, while runs on the ISRT and Yo Yo test also require bouts of walking (ISRT) and jogging (Yo Yo test) between some of the runs. Each test takes about 20 minutes to complete. Due to the maximal effort required from these tests, you will only complete one of these tests per field session.

Slalom Sprint and Dribble Test

This test is designed to assess sprint speed and dribbling speed. You will be asked to complete the course shown below twice.



The test is split into 2 parts:

1. *Sprinting*: you will be asked to complete the course as fast as possible while carrying a hockey stick.
2. *Dribbling*: you will be asked to complete the course as fast as possible while dribbling a hockey ball. If you lose control of the ball whilst dribbling (i.e. more than 2 metres away from the cone) you will be asked to repeat the test.

You will be given 5 minutes recovery during the sprint and dribble parts of the test.

Timed Sprints

You will be asked to perform maximal sprints over various distances (i.e. 5, 10, 20 and 30 metres). These sprints will be timed using electronic timing gates placed at the start and finish of the course.

How much time will it take?

Match analysis will take place during a ordinary matches – you will only need to fit the GPS device before the game and remove it afterwards.

Laboratory assessment will take around 3 hours to complete.

The field based session will take 2-3 hours to complete.

Associated Risks and Discomfort

High intensity exercise will cause breathlessness and temporary fatigue. Any vigorous exercise results in an increase in the risk of cardiovascular emergency above that at rest. To identify any potential risk, you will complete a health questionnaire and be asked to disclose any reasons why exercise, specifically maximal exercise, is a contraindication to your health. If there are any reasons why maximal exercise may pose a risk to your health, you are to decline from taking part in these procedures. You are free to withdraw from the tests at any time without penalty or prejudice.

Finger prick blood sampling may cause minor bruising.

Associated Benefits

Information obtained from these tests will provide valuable information for the physiological profiling of hockey players. Individual results from testing can be used to structure and monitor training programs.

Confidentiality

Although information will be stored on a computer, you will be entered by a number rather than by your name. All data will be stored in accordance with the Data protection Acts of 1984 and 1998. Results will be used for research purposes only, unless results are requested by individuals such as your coach. Under these circumstances, information will only be provided following your consent.

Informed Consent

You are free to withdraw from these procedures and tests at any time without incurring penalties or prejudice.
Before any testing begins, please make sure you have:

- Completed the health-screen questionnaire
- Had any questions or queries answered to your satisfaction
- Signed the consent form

Contact Details

If you have any questions or would like any additional information, please do not hesitate to contact the researchers involved in the study:

Miss Vikki Leslie V.Leslie@lboro.ac.uk tel. 01509 226 351
Dr. John Morris J.G.Morris@lboro.ac.uk tel. 01509 226 314

GPS Match Analysis: Information for Participants

Loughborough University

Aims and Objectives

The aim of this project is to improve our understanding match performance characteristics of hockey players. The project will look at how performance during hockey matches is related to factors such as age and playing standard. The results from this research will help coaches with training and also in the development of young hockey players.

What's involved?

To allow us to monitor your activity during a match, you will be required to wear a small, lightweight global positioning system (GPS) device during a normal hockey match(es). The device should not interfere in any way with your normal movement during play as it will be attached to a strap worn across you back. The GPS device will monitor and store a number of different measurements such as the distance covered during the match and the speed at which you run. Information will then be downloaded from the GPS equipment onto a computer where it can be analysed.

How much time will it take?

Match analysis will take place during a ordinary matches – you will only need to fit the GPS device before the game and remove it afterwards.

Confidentiality

Although information will be stored on a computer, you will be entered by a number rather than by your name. All data will be stored in accordance with the Data protection Acts of 1984 and 1998. Results will be used for research purposes only, unless results are requested by individuals such as your coach. Under these circumstances, information will only be provided following your consent.

Informed Consent

You are free to withdraw from these procedures and tests at any time without incurring penalties or prejudice. Before any testing begins, please make sure you have:

- Had any questions or queries answered to your satisfaction

- Signed the consent form (if under 18 years old, a parent/guardian must also provide consent).

Contact Details

If you have nay questions or would like any additional information, please do not hesitate to contact the researchers involved in the study:

Miss Vikki Leslie V.Leslie@lboro.ac.uk tel. 01509 226 351

Dr. John Morris J.G.Morris@lboro.ac.uk tel. 01509 226 314

ENGLAND HOCKEY

HEALTH SCREEN FOR VOLUNTEERS

Loughborough University

INSTITUTE OF YOUTH SPORT

ENGLAND HOCKEY

Name / Number ……………………………………………

Date of Birth ……./……/………

Date………………………………

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:

   (a) on medication, prescribed or otherwise .... Yes ☐ No ☐

   (b) attending your general practitioner .... Yes ☐ No ☐

   (c) on a hospital waiting list... Yes ☐ No ☐

2. **In the past two years,** have you had any illness which require you to:

   (a) consult your GP .... Yes ☐ No ☐

   (b) attend a hospital outpatient department.............................. Yes ☐ No ☐

   (c) be admitted to hospital .... Yes ☐ No ☐

3. **Have you ever** had any of the following:

   (a) Convulsions/epilepsy.. Yes ☐ No ☐

   (b) Asthma .... Yes ☐ No ☐

   (c) Eczema .... Yes ☐ No ☐

(d) Diabetes.. Yes ☐ No ☐

(e) A blood disorder .... Yes ☐ No ☐

(f) Head injury .... Yes ☐ No ☐

(g) Digestive problems .... Yes ☐ No ☐

(h) Heart problems .... Yes ☐ No ☐

(i) Problems with bones or joints .... Yes ☐ No ☐

(j) Disturbance of balance/coordination .... Yes ☐ No ☐

(k) Numbness in hands or feet .... Yes ☐ No ☐

(l) Disturbance of vision.. Yes ☐ No ☐

(m) Ear / hearing problems... Yes ☐ No ☐

(n) Thyroid problems .... Yes ☐ No ☐

(o) Kidney or liver problems .... Yes ☐ No ☐

(p) Allergy to nuts... Yes ☐ No ☐

4. **Has any,** otherwise healthy, member of your family under the age of 35 died suddenly during or soon after exercise? .... Yes ☐ No ☐

If YES to any question, please describe briefly if you wish (eg to confirm problem was/is short-lived, insignificant or well controlled.)

....

....

5. **What is your ethnic origin?**

(Ethnic origin questions are not about nationality, place of birth or citizenship. They are about colour and broad ethnic group – UK citizens can belong to any of the groups indicated).

White

British ☐

Irish ☐

Any other White background ☐

(please specify)…………………

Mixed ☐

White & Black Caribbean ☐

White & Black-African ☐

White & Asian ☐

Any other Mixed background

(please specify)………………………….

Asian or Asian British ☐

Indian ☐

Pakistani ☐

Bangladeshi

Any other Asian background

(please specify)………………….

Black or Black British ☐

Caribbean ☐

African ☐

Any other Black background

Chinese or other ethnic group

Chinese ☐

Any other ☐

(please specify)………………….

6. **Do you smoke**?………………………………………………….. Yes ☐ No ☐

No per day………………………….

7. **Do you drink alcohol**?………………………………………….. Yes ☐ No ☐

Amount per week…………………...

(one unit = ½ pint beer; 1 measure spirits, 1 glass wine)

Additional questions for <u>female</u> participants

(a) Have your periods started yet?.. Yes ☐ No ☐

If yes please answer (b) to (e)

(b) At what age did your periods start (as accurately as you can remember)?
Age………………….years and……………….months

(c) are your periods normal/regular? .... Yes ☐ No ☐

(d) are you on "the pill"?…………………………………… Yes ☐ No ☐

If yes what type?…………………………………………….

(e) could you be pregnant?………………………………… Yes ☐ No ☐

(f) What was the date of the first day of your most recent period?.... ….. ….. …. …. …

All responses will be treated in the strictest confidence

Thank you for your cooperation!

Loughborough University

Statement of Informed Consent

Loughborough University

Physiological and Performance Characteristics of Field Hockey Players

The purpose and details of this study have been explained to me.

I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence.

I agree to participate in this study.

Your name ____

Your signature ____

Witness ____

Date ____

ENGLAND HOCKEY

PHYSIOLOGICAL AND PERFORMANCE CHARACTERISTICS OF HOCKEY PLAYERS

What's involved: completing a series of field based tests to assess fitness, speed and skill and wearing a GPS device during a game(s)

Player Consent

- I understand that I am under no obligation to take part the field tests
- I understand that I have the right to withdraw from the field tests and/or GPS at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.
- I agree to participate in the field tests and GPS match analysis

Name: ____

Date of Birth: ……./ ……./ …………..

Preferred email address: ____

Mobile Number ____

Signature ____

Date ____________

ENGLAND HOCKEY

MATCH PERFORMANCE CHARACTERISTICS OF ELITE HOCKEY PLAYERS

What's involved: wearing a GPS device during a game(s)

Player Consent

- I understand that I am under no obligation to take part the field tests
- I understand that I have the right to withdraw from the field tests and/or GPS at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.
- I agree to participate in the GPS match analysis

Name: ____

Date of Birth: **……./……./…………..**

Preferred email address: ____

Mobile Number ____

Signature ______________________________

Date ______________

ENGLAND HOCKEY

PHYSIOLOGICAL AND PERFORMANCE CHARACTERISTICS OF JUNIOR FIELD HOCKEY PLAYERS

What's involved: wearing a GPS device during a game(s)

Parent / Guardian Consent

- I have been provided with information and fully understand what is involved
- I give permission for this player to be involved in the testing

Player Name: ____

Parent / guardian signature ____

Parent / Guardian name (please print) __________________________________

Player Consent

- I understand that I am under no obligation to take part the field tests
- I understand that I have the right to withdraw from the field tests and/or GPS at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.
- I agree to participate in the field tests and GPS match analysis

Name: ____

Date of Birth: **……. / ……. / ………….**

Preferred email address: ____

(***so we can email your results to you***)

Signature ____

Date ______________

If you have any questions, please contact

Miss Vikki Leslie email: v.leslie@lboro.ac.uk telephone: 01509 226 351 or

Dr. John Morris email: j.g.morris@lboro.ac.uk telephone: 01509 226 314