Physiological characteristics, activity patterns and physiological responses of elite women field hockey players during competition.

By

Richard John Walsh

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Supervisors:

Dr Michael McKenna
Department of Physical Education and Recreation
Victoria University of Technology

Professor John Carlson
Centre for Rehabilitation, Exercise and Sports Science
Victoria University of Technology
Melbourne, Australia.

DECLARATIONS

1. This thesis is less than 20,000 words in length, exclusive of tables, references and appendices.

2. The experimental and analytical work presented in this thesis were performed by the author. The exceptions being assistance with filming from Jeremy Darval, Simon McIness and David Buttifant, intravenous blood sampling by Dr Jill Grogan and a small amount of blood analysis by Steve Fraser.

3. No material from this thesis has been previously submitted to any other University or Institution for the award of any degree or diploma.

Abstract

Despite the popularity of field hockey very little research has investigated the physical requirements of, and the responses to, a game of field hockey. This study investigated the physiological characteristics of six elite women hockey players, their movement patterns during a game and the accompanying acute physiological responses. Players were chosen from the Victorian State Women's Field Hockey team on the basis of playing positions characterised by a high work-rate.

All players completed a series of laboratory tests comprising a maximal 10 second cycle ergometer sprint, five 6 second maximal cycle ergometer sprints and a maximal incremental treadmill test. During a competition game subjects were videotaped and analysed for physical movement activities using a computerised video analysis system. The frequency and duration of movement patterns were continuously recorded on computer whilst viewing the video in real time. Selected physiological responses of the subjects were analysed before, during and following the same game. Blood samples were taken before, at half time and after the game to determine plasma acid-base status, fluid shifts, metabolite and electrolyte concentrations. Fingertip capillary blood lactate was determined at these times and at the midpoint of each half. Heart rate was monitored throughout the game. The match-induced decline in body mass corrected for water intake was measured as an indicator of total fluid loss.

Laboratory sprint tests showed a peak power output of 912.3 ± 171 W (mean ± SD) for the 10 second sprint with a decline of 11.4 % in peak power by the fifth bout in the intermittent sprint test ($p<0.05$). Peak $\dot{V}O_2$ during treadmill testing was 51.8 ± 3.9 ml.kg-1.min-1 and the peak heart rate was 186 ± 5 bts.min-1.

Although the hockey matches were played under cool (11.6 ± 2.8 °C), humid (64.8 ± 14%) conditions, the calculated sweat loss was 1.0 ± 0.2 $l.hr^{-1}$. Time motion analysis revealed that 84% of game time was spent in low intensity activity comprising walking (45 ± 8%), jogging (29 ± 5%), stationary (8 ± 2%) and sideways motion (2 ± 2%). High intensity activity totalled 16 % of game time and consisted of sprinting / striding (12 ± 2%) and shuffling (4 ± 2%). The total

number of events was 1184 ± 111, with an average duration of 2.9 ± 0.3 s, indicating a change in events every 3.6 ± 0.4 s. The mean heart rate during game time was 157 ± 15 bts.min^{-1} representing 85 ± 8% of the peak heart rate recorded during the maximal incremental test.

Fingertip capillary blood [Lac^-] (mmol.l^{-1}) was increased ($p < 0.05$) above rest (1.9 ± 0.3) at mid-first half (6.0 ± 1.5), half time (4.6 ± 2.5), mid-second half (6.0 ± 2.3) and full time (4.7 ± 0.4). Similarly, venous plasma [Lac^-] (mmol.l^{-1}) was elevated ($p < 0.05$) from rest (1.5 ± 0.5), at half time (4.8 ± 3.6) and at the end of the match (4.5 ± 1.8). Venous plasma [glucose] was elevated ($p < 0.05$) at half-time and at the end of the match compared to rest, whilst plasma [K^+] was reduced from rest at half time ($p < 0.05$). Other biochemical changes in venous blood including pH were minor.

Laboratory tests confirmed that the subjects tested were in an elite class when compared to published data on international hockey players. The activity patterns of the players during competition indicates hockey is a sport characterised by a rapid turnover of activity with a high percentage of the total time involving low intensity recovery from very brief high intensity efforts. The physiological responses were high with sustained high heart rates and increased circulating

[Lac^-] which indicates that glycolysis is an important energy source during a game of hockey. Time motion analysis reveals that elite women hockey players in positions of the highest work rate perform a relatively short period in high intensity activities and yet the physiological responses and therefore the physiological cost remains high throughout.

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CHAPTER 1

INTRODUCTION

Within Australia there are approximately seventy eight thousand male and thirty thousand female registered field hockey players, with possibly another two hundred thousand unregistered players. However, very little research has investigated the acute physiological responses and movement patterns during a game of field hockey.

This study explores the physiological characteristics, activity patterns and physiological responses of elite women hockey players in positions of the highest work rate during competition. This will extend prior research into women's field hockey by investigating the relationship between activity patterns and the corresponding physiological responses that occur in elite female hockey players during a game. The information from this investigation may be used to provide a benchmark for the future prescription of exercise and physiological testing protocols for field hockey coaches and sports scientists to assist women hockey players to efficiently reach peak performance.

1.1 Definitions and abbreviations

Term	*Definition*
Intermittent exercise	Activity requiring alternating low and high intensity activities.
Intermittent team sports (ITS)	Team sports requiring intermittent exercise
Intermittent field team sports (FITS)	Intermittent team sports played on a field, eg hockey, soccer, rugby and Australian rules football.
Intermittent court team sports (CITS)	Intermittent team sports played on a court of fixed dimension eg basketball, netball and volleyball.
Game Time (GT)	Time during which the competition game clock was running.
Low intensity activity (LIA)	The categories of movement considered to be at a low workrate, ie stationary, walk, jog and sideways motion.
High intensity activity (HIA)	The categories of movement considered to be at a high work rate, ie Sprint/stride and shuffle
Stationary	No movement.
Walk	Minimal intensity activity
Sideways	Side on movement with the legs extended.
Jog	Forward and backward running activity requiring less intensity than striding but greater than walking.
Stride/Sprint	Forward running movement at a greater intensity than jogging, indicated by longer strides and

	intense effort at or close to maximum.
Shuffle	A shuffling action of the feet in a forward, sideways or backward action
$\dot{V}O_2$ peak	The highest volume of oxygen consumed during a continuous incremental treadmill test in the laboratory. It is expressed in absolute ($l.min^{-1}$) or relative terms ($ml.kg^{-1}.min^{-1}$).
% $\dot{V}O_2$ peak	A percentage of a $\dot{V}O_2$ peak.
Heart rate (HR)	The frequency of ventricular contractions per minute.
Peak Heart rate (HRPeak)	The highest heart rate value recorded for each subject whilst completing the $\dot{V}O_2$ peak testing the laboratory.

Abbreviations

Muscle metabolism

ADP	Adenosine diphosphate	
AMP	Adenosine monophosphate	
ATP	Adenosine 5'triphosphate	
CP	Creatine phosphate	

Cardiorespiratory

RER	Respiratory exchange ratio	
$\dot{V}_E$	Expired ventilation per minute	($l.min^{-1}$)
$\dot{V}O_2$	Volume of oxygen consumption per minute	($l.min^{-1}$)

Haematology, derived fluid shifts and blood gas

[Hb]	Haemoglobin concentration	($g.dl^{-1}$)
Hct	Haematocrit	(%)
ΔBV	Change in blood volume from rest	(%)
ΔPV	Change in plasma volume from rest	(%)
PCO_2	Tension of carbon dioxide in plasma	(mmHg)
PO_2	Tension of oxygen in plasma	(mmHg)
SO_2	Oxygen saturation of haemoglobin	(%)

Electrolytes

$[H^+]$	Hydrogen ion concentration	$(nmol.l^{-1})$
$[HCO_3^-]$	Bicarbonate concentration	$(mmol.l^{-1})$
$[Na^+]$	Sodium concentration	$(mmol.l^{-1})$
$[K^+]$	Potassium concentration	$(mmol.l^{-1})$
$[Cl^-]$	Chloride concentration	$(mmol.l^{-1})$
$[Lac^-]_p$	Plasma lactate concentration	$(mmol.l^{-1})$
$[Lac^-]_{cap}$	Capillary blood lactate concentration	$(mmol.l^{-1})$
[SID]	Strong ion difference	$(mmol.l^{-1})$

CHAPTER 2

REVIEW OF LITERATURE

2.1.1 Introduction

This review is a critique of the physiological characteristics of elite women field hockey players, their activity patterns and physiological responses during elite women's field hockey competition. Where there is insufficient information on elite women field hockey players during competition this review will examine men's field hockey or other elite field intermittent sports (FITS) which include soccer, Australian Rules football, lacrosse, rugby league, rugby union and touch rugby. The different types of FITS are played on fields of varying sizes and require a wide variety of high impact, irregular, low and high intensity activities. A review of court intermittent sports (CITS) such as netball and basketball is not included due to reasons explained below. Other intermittent sports including squash and tennis are not included because arguably they are not considered to be team sports, they are played on a substantially smaller playing area and therefore do not have similar movement patterns to FITS. Ice hockey is not included because of the very different mode of movement, therfore whenever the term "hockey" is used in this thesis it refers to field hockey.

Previous reviews on intermittent team sports have not separately analysed CITS and FITS (McInness 1993), however data exist to suggest that these types of sports are not congruous (Table 2.1). Firstly the sizes of the playing areas and the durations of the games are considerably different which may restrict positional movement. Secondly the shorter duration and higher work to rest ratios in CITS suggest that the intensity of the game is higher than in FITS. The intensity of play during certain stages may be higher in CITS due to regular player interchange. This may allow players to work harder knowing they will have more regular rest intervals than FITS. Therefore as the playing area and duration of an

ITS decrease it appears players cover a shorter distance, the work to rest ratio is higher and the movement patterns occur more frequently. Following this it could also be argued that the activity patterns during Australian rules football should not be compared to soccer and hockey because of the large difference in the size of the field and the significantly lower work to rest ratio (Table 2.1). Finally sufficient studies exist for either FITS or CITS to focus on making a literature review more specific to the size of the playing area which in turn affects the nature of the activity patterns.

Although the above evidence for dividing the two types of sports for interpretation is strong, it could also be argued that the differences between the two types of sports are decreasing. A major objective for a coach is to facilitate players to produce greater work at a higher intensity, which in turn will increase the work to rest ratio. This objective is evident in Australian rules football where in recent times changes to the interchange of player rules and resulting changes to coaches tactics may allow the players in positions of the highest workrate to be interchanged more regularly. This suggests that players are able to rest more often so they may produce more work at a higher intensity while playing and following this it may illicit higher work to rest ratios. Basketball and netball coaches have used the interchange rule for many years to increase workrate while the players are on the court. Changes in the playing surface for hockey in the 1970s allowed a faster, more intense game (Cibich 1991). The characteristics of FITS may become more similar to present work to rest ratios in CITS due to previous and future changes to the playing surfaces, the rules and the resulting tactics by coaches.

Table 2.1: Size of playing area, duration of games, number of activities, calculated mean time of change in activity patterns, work to rest ratios in male (M) and female (F) court intermittent sports and field intermittent team sports.

Sport	Reference	Sex	Size of playing area	Duration of games	Number of activities	Mean time of change in activity	Work to rest ratio
		M/F	(m^2)	(min)		(s)	
Court Intermittent Team Sports							
Netball	1	F	465	4 x 15	-	-	1:3
Basketball	2	M	420	2 x 20	1007	2.2	1:4
Field Intermittent Team Sports							
Field Hockey	3	F	3600	2 x 35	1000	4.0	1:5.7
Rugby	4	M	6,800	2 x 40	-	6.1	1:6.7
Soccer	5	M	2,800 - 3,600	2 x 40 + extra	895	6.4	1:6.7
	6	M	2,800 - 3,600	2 x 40 + extra	Approx 1100	6.1	1:7
	7	M	2,800 - 3,600	2 x 40 + extra	1179	6.0	1:9
Australian Rules Football	8	M	15,000 - 17,000	4 x 25 + extra	880	7.3	1:14.2

Reference 1. Otago (1983) 2. McInnes et al.(1994), 3. Lothian and Farrally (1992), 4. Docherty et al. (1988) 5. Reilly and Thomas (1976) 6. Mayhew and Wenger (1985), 7. Bangsbo (1991), 8. McKenna et al. (1988)

2.2 Physiological characteristics of elite women field hockey players.

2.2.1 Introduction

A vast amount of literature exists on physical characteristics of elite intermittent sports performers however, a review of differences in physiological characteristics between FITS is probably of little relevance to the women field hockey players in this experiment. Studies investigating the physical characteristics of female ITS have found significant differences in individual test results (Withers 1982). Therefore a comprehensive review of all elite intermittent sports performers is not presented here, rather information on the physical characteristics of women field hockey players has been reviewed. The majority of literature on women's field hockey is descriptive information of their physical characteristics. Various fitness profiles have been provided on state and international teams, providing a profile on anthropometry, anaerobic power and maximal oxygen consumption of female field hockey players. However, a number of restrictions exist when integrating the literature, including measurement of physical characteristics at different times of the season reflecting different phases of training, different testing protocols used, a variety of regression equations used to convert skinfold measurements into a percentage. A more valid summary could be obtained if all measurements were taken prior to major competition with similar standards of teams using standardised exercise testing and analysis procedures. Information in this review will include a range of physiological test results on state and national women field hockey players according to the above restrictions.

2.2.2 Anthropometry

i) Height and Body mass

Height does not appear to be a prerequisite for elite field hockey players as mean values were in a relatively small range of 162 - 165 cm. The mean height was 164.6 for the South Australian squad in 1981, whilst the average body mass was 62.9 ± 9.2 kg (Withers and Roberts 1981). The Victorian field hockey squad had a mean body mass of 62.6 kg with a range of 48.7 - 74.6 kg throughout seasons 1991 - 1993 (Walsh 1996, unpublished research). The Australian National squad had a similar mean body mass of 61.4 kg and a range of 50.7 - 72.1 kg (Lawrence 1996, unpublished research).

ii) Body fat composition

Table 2.2 indicates a large range of % body fat and sum of skinfold measurements for women field hockey players which may be due to players becoming leaner since 1968, different regression equations used to convert a sum of millimetres to a percentage and or the measurement of different skinfold sites. There are two published reports of a calculated percentage of body fat on South Australian representative players using the Durnin and Womersley (1974) formula (Withers and Roberts 1981, Withers et al 1987) (Table 2.4). Errors introduced when multiple regressions are used to convert a sum of millimetres to a percentage have been shown to vary over twofold on occassions (Lohmann 1981 cited by Norton and Olds 1996). A more popular approach is to use a sum of at least six sites from the average of a minimum of two measurements within 0.2 mm at each site. According to correspondence from the International Society for the Advancement of Kinanthropometry (ISAK) these sites should comprise the bicep, tricep, supraspinale, subscapula, abdominal, front thigh and medial calf skinfolds (Correspondence from the Laboratory standards Assistance scheme, 1996). Due to the margin for error when using regression equations (Norton and Olds 1996) the sum of these skinfolds provides the coach and the player with a

more reliable and tangible means of intertest comparison and eventually will provide a database of norms for comparison for specific populations. The individual sum of the seven sites for the Victorian female hockey squad over a three year period from 1991 - 1993 was 92.5 mm with a range of 68 - 132 mm (Walsh 1996, unpublished research). Twenty Australian women's hockey members preparing for the 1996 Olympics had a sum of nine skinfolds of (mean $\pm$ SD) 77.1 $\pm$ 14.6 mm with a range of 51.7 - 106.5 mm. (Lawrence 1996, unpublished research).

2.2.3 Anaerobic Power and Capacity

Anaerobic power tests provide a performance measure of the maximal rate of anaerobic energy delivery which is important during intermittent sports. State female hockey players registered a maximum power output of 813.4 W using the Margaria stair climb test which is higher than those reported for other FITS (Withers and Roberts 1981) (Table 2.4). The maximum power output for the Victorian Field Hockey squad over three seasons from 1991-1993 measured during a ten second sprint on a front access cycle ergometer was similar to but higher than the Withers and Roberts (1981) report (Walsh, unpublished research). Results on the Australian women hockey squad members preparing for the 1996 Olympics had the highest maximum power output from a ten second sprint on a front access cycle ergometer (Lawrence, unpublished research) (Table 2.4). The higher maximium power outputs by the National squad can be attributed to different standards of players and a different type of computer software used by Lawrence to convert amplified high level pulses from the ergometer to calculated powerpulses on the computer resulting in higher peak power levels than the software used in this experiment (Lawrence, unpublished research).

2.2.4 Maximal Oxygen Consumption.

Maximal oxygen consumption provides an index of a player's aerobic fitness which is important to the energy demands of field hockey. Table 2.2 indicates that the $\dot{V}O_2$ max of elite female field hockey players has changed very little over the past eighteen years. The $\dot{V}O_2$ max of the Canadian Women's National field hockey team leading up to the 1984 Olympics ranged from a mean of 52.7 $ml.kg^{-1}.min^{-1}$ at the beginning of their preparation to 59.0 $ml.kg^{-1}.min^{-1}$ just prior to the 1984 Olympic games (Ready and van der Merwe 1986). The mean $\dot{V}O_2$ max of Western Australian hockey players was 50.1 $ml.kg^{-1}.min^{-1}$ at the end of an intense training program (Rate and Pyke 1978). The mean $\dot{V}O_2$ max for the Victorian field hockey squad over three seasons from 1991-1993 was 51.6 $ml.kg^{-1}.min^{-1}$ with a range of 44.3 - 62.4 $ml.kg^{-1}.min^{-1}$ (Walsh, unpublished research). The Australian women's hockey team perform a maximal multi stage shuttle run test to predict $\dot{V}O_2$ Max. The test, which reportedly has good reliability (Intra class correlation .97) when subjects have good motivation (Australian Institute of Sport, unpublished data), calculates $\dot{V}O_2$ from a level and stage reached during a progressive series of twenty metre shuttle runs to volitional exhaustion. The Intra class correlation was 0.93 in a report comparing the shuttle run test with directly measured $\dot{V}O_2$ max tests with 19-36 year old women (Ramsbottom et al 1988). According to maximal shuttle run test results the twenty Australian women hockey squad members preparing for the 1996 Olympics had a predicted $\dot{V}O_2$ max of 53.0 $\pm$ 3.4 $ml.kg^{-1}.min^{-1}$ (Lawrence, unpublished research).

Table 2.2: Physiological characteristics of elite women field hockey players

Subjects	Reference	Body fat (%)	Formulae for conversion	Skinfolds (Σ 7 sites)	$\dot{V}O_2$ max Ergometer	$\dot{V}O_2$ max ($ml.kg^{-1}.min^{-1}$)	Peak anaerobic power Method	Peak anaerobic power (W)
Welsh National Squad	1	25.8	Not reported	-	-	-	-	-
West Australian State squad	2	15.2	Sloan (1962)	-	Treadmill	50.1	-	-
USA National team	3	-	-	-	Bicycle	51.7	-	-
South Australian State squad	4	25.3 20.2	Durnin and Womersley (1974)	-	Treadmill	50.2	Margaria stair climb	813.4
Canadian National team	5	15.7	Not Reported	-	Treadmill	52.7	-	-
Australian National squad	6	-	-	77.1	Multistage shuttle run test	53.0#	Front load cycle ergometer	1045
Victorian state squad	7	-	-	92.5	-	51.6	Front load cycle ergometer	886

References 1. Johnston and Watson (1968), 2. Rate and Pyke (1978), 3. Zeldis et al. (1978) (Cited by Withers 1981), 4. Withers and Roberts (1981), 5. Ready and van der Merwe (1986), 6. Lawrence (Unpublished 1996), 7. Walsh (Unpublished 1996)

$\dot{V}O_2$ results were predicted from the maximal multistage shuttle run test

2.3 Activity Analysis

2.3.1 Classification of Match Activities.

Intermittent sports are characterised by a variety of movement types and the first stage in movement analysis is the classification of these activities. The most commonly described movements during FITS are jogging, walking and standing and the classification of these terms have a high reliability (Withers et al 1982). Other movements occurring less frequently during a game include backwards and sideways walking and/or jogging (Withers et al. 1982, Bangsbo 1991, Lothian and Farrally 1992). Mayhew and Wenger (1985) combined backwards running, shuffling and jumping under the heading of utility movements. Different terms used to describe striding movements include cruise (Reilly and Thomas 1976, Lothian and Farrally 1992), running (Mayhew and Wenger 1985) and moderate to high intensity running (Bangsbo 1991). Due to the difficulty of distinguishing between striding and sprinting several authors combined them into terms such as running (Jacques and Pavia 1974), sprinting (Hahn et al. 1979) and high intensity runs (McKenna et al. 1987). Reliability was increased when striding and sprinting were classified into a single category (Withers et al. 1982). In field hockey Lothian and Farrally (1992) included the high intensity activity (HIA) category of hockey skills which involved periods the player spent with the ball. The justification for this category was that when moving with the ball the stooping posture required an additional energy cost compared to moving with an upright posture (Reilly and Seaton 1990).

2.3.2 Distance Covered

Most early studies estimated the distance covered during intermittent team sports. Several authors simply observed the game and used special ground markings or cues to estimate the distance covered (Pyke and Smith 1975, Reilly and Thomas 1976). Use of ground markings minimised the potential errors involved in measuring by observation and then estimating the distance however, this would still provide a large margin for error due to parallax error and an inability to replay the event (Pyke and Smith 1975).

To reduce the errors inherent in this method, more recent investigations have videotaped the game and counted the number of steps taken in each activity, using a predetermined stride length to estimate the distance covered (Craig et al. 1981, Withers et al 1982). However, limitations with this technique include the problems of changing step frequency and length, as well as the exorbitant amount of time needed to conduct this analysis (Craig et al 1981, Douge 1982, Jacques and Pavia 1974). Further, it is possible that gait characteristics may change during the game due to fatigue. Thus, considerable potential errors remain in distance based activity analyses.

Male soccer players travelled between 8.7 km and 13.2 km per game, with an average of approximately 11 km during a match (Bangsbo et al 1991; Van Gool et al 1987; Ekblom, 1986; Withers et al 1982; Reilly and Thomas 1976). Differences in playing patterns existed between the different positions on the field. Mid-fielders cover an overall greater distance during the game than defenders and attackers and also do more work at a lower intensity (Reilly and Thomas 1976; Van Gool et al 1987). However a comparison between the distance covered at various speeds indicated that there was no statistically significant difference between the fullbacks, central defenders, midfield players and forwards in a game of soccer (Withers et al. 1982). No published data exists on the distance travelled by women ITS athletes. Unpublished data by Ekblom states that female soccer players travelled just

under 8.5 km during a game (Cited in Brewer 1994). Time motion analyses using video editing equipment linked to a cassette tape recorder found that during a practice game in positions of the highest workrate two elite women field hockey players travelled similar distances to Ekblom's reports (6-7 km) whilst two males travelled 8-10 km (Walsh1992, unpublished data).

2.3.3 Time Spent in various movement activities.

A more precise method involves determination of time spent in different activities rather than the estimation of distance (Green et al. 1976; McKenna et al.1987; Mayhew and Wenger 1985; Lothian and Farrally 1992). This information can then be used to obtain the mean and range of durations spent in different activities as well as to calculate work to rest ratios, which provide a more detailed indication of the intensity of the game (Mayhew and Wenger 1985; McKenna 1987; Withers 1982). Mayhew and Wenger (1985) reported the work to rest ratio averaged over the whole game whilst, Withers et al (1982) presented the frequency that ratios exceeded certain values at any time during the game. Lothian and Farrally (1992) used the time spent and an estimate of energy cost to calculate energy expenditure for each movement category. Bangsbo (1991) used the product of mean velocity and total time spent for each activity pattern to calculate the match distance by the sum of the distances covered during each type of activity.

Time motion analysis of field hockey shows that 78.0 % of the game is spent in low intensity activity (LIA) including; standing, walking and jogging whilst 22 % is spent in HIA including; cruising (or striding), sprinting and hockey skills (Lothian and Farrally 1992). Unfortunately Lothian and Farrally (1992) did not provide a complete breakdown in percentages of the individual high intensity and low intensity activities. Some 31% of the total playing time in soccer was spent in LIA such as standing and walking, 47% was spent

in medium intensity activity such as jogging and 19% was spent in the HIA movement patterns of striding or sprinting (Withers et al 1982). Similar values were found by Reilly and Thomas (1976) and Van Gool et al (1987) for soccer players, although high intensity exercise only accounted for 8% and 11% respectively. Additionally, data collected by Reilly and Thomas (1976) found that soccer players sprint for approximately 15 meters every 90 seconds. Mayhew and Wenger (1985) claim the ratio of high intensity to low/medium intensity work in soccer is 1:7 and therefore for every 4 sec of hard/sprint running approximately 28 s is spent in activities more aerobic in nature. They also combined distance and time measures. This provided a clearer picture of the range and distance of intensities, the frequency and distance of the higher intensities and hence, the maximal workrate achieved by the players during the game. A common characteristic of high intensity sprint periods for all FITS was the short duration indicated by the range of 1.9 - 4.0 seconds (Table 2.4). The periods of high intensity activities only account for a small percentage of the total game time however, these movements occur during decisive phases of the match which were directly connected to the scoring potential of the team and often were the deciding factor in the game (Yamanaka et al. 1988).

With the use of video recordings and computer analysis McKenna et al. (1987) described the activity patterns of Australian Rules football rovers (on ball running players). Activity patterns were classified into high intensity (HI) and low intensity (LI). HI activity included high intensity running comprising sprinting and striding and game related activities such as tackling, jumping, diving and physical clashes. LI activity included standing, walking and jogging. The study revealed that the rovers spent 94% of the game time in LI activities. There was a high intensity run every 73 sec, with an average duration of 2.7 sec (max 10.4 sec). It was also reported that 65% of all HI activity lasted less than 4.5 sec, with 80% lasting less than 6.0 sec. On average there was a change of event every 7.3 sec.

Table 2.3: The time spent in movement activities expressed as a percentage of the total game time in field intermittent team sports.

Sport	Reference	Stationary	Walk	Jog	Stride/Sprint	Other *
Hockey	1	-	-	78.2♦	21.8β	-
Australian Rules Football	2	12.5	63.8	19.6	4.5	-
	3	8.8	44.5	40.9	4.1ϖ	-
Rugby Union	4	37.7	31.0	16.4	5.8	9.1
Soccer	5	2.3	46.4	38.0	11.3	2.0
	6	4 -10	-	83-88#	7-10	-
	7	7	56	30	7	-
	8	17.1	40.4	35.1	8.1	-

Reference. Lothian and Farrally (1992), 2. Jacques and Pavia (1974), 3. McKenna et al (1988), 4. Docherty et al (1988) 5. Mayhew and Wenger (1985), 6. Yamanaka et al (1988), 7. Ali and Farrally (1991), 8. Bangsbo et al (1991).

♦ indicates a combination of stationary, walking and jogging; # indicates a combination of walking and jogging.; * "Other" includes backwards, jumping, running, sideways, shuffling and tackling; β Includes field hockey activities; ϖ Includes game related activities

Table 2.4: Average duration of the high intensity (sprint) periods in elite field intermittent team sports.

Sport	Reference	Average Duration (sec)	Comments
Australian Rules Football	1	Not reported	80 % < 6.0 sec 65 % < 4.0 sec
	2	2.7	Max = 10.4 sec % < various time
Rugby	3	Not reported	Range 3.0 - 4.0 sec
	4	2.1	-
Soccer	5	4.4	-
	6	2.9	-
	7	1.9	-
	8	2.0	-

N.B. % refers to the proportion of the total number of sprints

References 1. Hahn et al. (1979), 2. McKenna et al. (1988), 3. Allen (1989), 4. Docherty et al. (1988) 5. Mayhew and Wenger (1985), 6. Withers et al. (1982), 7. Brodowicz et al. (1990), 8. Bangsbo et al. (1991)

2.3.4 Conclusions

The most objective analysis of intermittent sport activity patterns should include a classification of a range of reliable movement types, the determination of time spent in each movement activity and calculated work to rest ratios during the game. Analysis of an intermittent sport should focus on either CITS or FITS as sufficient studies exist for analysis of either type of sport to focus on making a literature review more specific to the sport. Comparing CITS and FITS could confuse activity pattern conclusions due to the differences in the playing area, duration and the work to rest ratios. If sufficient research exists on a FITS for a particular sex this should be the major focus of the investigation. Very little published data has investigated field hockey, including only one incomplete analysis of the activity patterns in women's field hockey.

2.4 Physiological responses to Elite field Intermittent sports.

2.4.1 Estimation of exercise intensity.

i) Heart rate

Heart rate (HR) responses during intermittent sports can be easily measured with the use of a micro-computer which is strapped to the wrist or around the waist and will continuously record and display the average of the previous five seconds. Very little literature exists on heart rates measured during competition field hockey (Table 2.5). HR monitoring of female hockey players during a match has shown average HR values of 171 bts.min^{-1} (Lothian and Farrally 1992) while published data on males reports average HR values of 159 bts.min^{-1}. (Boyle et al 1992). Heart rates were measured in male state hockey players at the Australian Men's senior championships in 1988 and during a men's domestic division 1 competition four state players were monitored in the 1988 and 1989 seasons (Cibich 1991). The right inner, striker and back liners spent approximately 28 % of their time with HR exceeding 92 % of their maximum HR, 80 % of their total time was spent above 75 % of their maximum HR. The mean percentage time for the four positions measured (back, centre half, inner and striker) was 60.5 % of time with HR exceeding 85% of maximum HR (Cibich 1991). These figures are similar to heart rates reported during soccer matches in which 2/3 of the game were spent above 85 % of maximum HR (Smodlaka 1978). Soccer players during a game have shown average HR values of 165-169 (Van Gool et al. 1987) and 160-180 bts.min^{-1}, with occasional peak values over 190 bts.min^{-1} (Ekblom 1986). While Pyke and Smith (1975) showed Australian rules footballers' game average heart rates appear to increase according to their position with rovers at 178 bts.min^{-1} and half back flankers at 160 bts.min^{-1}. Thus despite the vast majority of time spent in low intensity activities HR remains very high throughout in all of these FITS. This suggests that an average HR is not always a true indicator of the intensity of the game.

Table 2.5 Mean heart rate and percentage of maximum heart rate values during field intermittent team sports.

Sport	Reference	Competition level	Position	Average HR (bts.min^{-1})	HR (% max #)
Hockey	1	English International	-	159	65 % of game > 85
	2	South Australian state league	-	-	60 % of game > 85
	3	National league	-	171	-
Australian Football	4	-	Rover (n=1)	178	-
		-	Half back flank	160	-
	5	-	Rovers	164	-
				159	
Rugby	6	Rugby Union League	Backs	161	-
Soccer	7	1st division	-	165	-
	8	1st division		165	
	9	Swedish national	-	175	-
	10	Australian National	-	165	86
	11	State	Centre back	155	-
			Forward	171	-
			Full back	155	-
			Mid fielder	170	-
	12	Belgian University	-	1st half 169	78
				2nd Half 165	74

% of max heart rate is the percentage of the laboratory derived maximum heart rate.

Authors 1. Boyle et al (1992), 2. Cibich (1991), 3. Lothian and Farrally (1992) 4. Pyke and Smith (1975), 5. Hahn et al (1979), 6. Morton (1978), 7. Seliger (1968a), 8. Seliger (1968a), 9. Astrand and Rodahl (1977), 10. Cochrane and Pyke (1976), 11. Van Gool et al (1987), 12. Van Gool et al (1988)

ii) Oxygen consumption

Oxygen consumption during continuous sports has been estimated from heart rate based on the linear relationship between HR and $\dot{V}O_2$ during submaximal exercise (Malhotra, Gupta and Rai 1963, Morgan and Bennett 1976). However the linearity between HR and $\dot{V}O_2$ is not seen at maximal workloads (Åstrand and Rodahl 1977 p.460). Also HR may be markedly affected by previous exercise, emotion, heat, environmental conditions and the mode of exercise (Washburn and Montoye 1986; Montgomery 1988). The influence of emotional factors on HR can be clearly seen in a study on basketballers (Ramsay et al 1970). During basketball free throws (approximately 40 sec rest) and time outs (1 minute rest) the HR dropped by approximately 12 bts.min^{-1} and 22 bts.min^{-1} respectively, the players' HR did not decrease when actually taking the free-throw, indicating that the emotional and physical involvement of taking a free-throw is such that the HR rate does not decrease significantly (Ramsay et al 1970) and therefore is unrelated to $\dot{V}O_2$ changes. Despite these limitations several authors have reported estimated $\dot{V}O_2$ based on an assumed relationship between $\dot{V}O_2$ and HR in field hockey (Skubic and Hodgkins 1967; Boyle et al. 1992; Lothian and Farrally 1992) and soccer (Van Gool et al. 1988; Ali and Farrally 1990). Lothian and Farrally (1992) also attempted to estimate energy expenditure from activity patterns by calculating the work performed from data obtained at different speeds on a treadmill for the LIA and using various formulae to predict and estimate the HIA energy expenditure. It was decided not to calculate $\dot{V}O_2$ during this investigation due to i) the inherent errors in using regression equations involved in calculating $\dot{V}O_2$ (Tumilty 1993) and energy expenditure during intermittent games (Van Gool et al. 1988; Ali and Farrally 1990; Lothian and Farrally 1992), ii) the arbritary choice of speeds for the movement categories during intermittent sports (Lothian and Farrally 1992) and iii) unfounded assumptions made regarding the use of regression equations calculated during submaximal

workloads and then used for maximal efforts during a game (Lothian and Farrally 1992). In summary it was decided too many errors and invalid assumptions exist to estimate $\dot{V}O_2$ during ITS.

2.4.2 Metabolic responses

i) The sources of energy during intermittent team sports

It is important that the activity patterns during FITS are considered to enable an understanding of the sources of energy during FITS. Common characteristics of FITS were that the average HIA period lasts for approximately three to four seconds and that on average they occur every fifteen to thirty seconds. In between the HIA the player recovers during a LIA period until the nature of the game requires another HIA period. This pattern will occur sporadically throughout the game in varying HIA to LIA ratios. The intermittent test protocol used during this study is more intense than an average passage of play during hockey however, the tests does provide an indication of metabolic responses and intermittent fitness for FITS.

The test protocols in the literature used to investigate metabolic sources of energy during intermittent exercise manipulate the time and intensity of the exercise bout and the intervening recovery period. Due to the nature of FITS outlined earlier this review will concentrate on exercise bouts less than six seconds in duration and with recovery periods of less than thirty seconds, since these are more specific to field hockey.

A recent study used muscle biopsies to investigate the sources of energy during 10 sprints of 6 seconds duration, interspersed with 30 seconds of recovery (Gaitanos et al 1993). The contribution of creatine phosphate (CP) increased throughout the sprint bouts whilst the contribution of anaerobic glycolysis decreased. Gaitanos et al. (1993) speculated that this may be due to an inhibition of glycolysis and glycogenolysis with increasing intramuscular acidosis resulting in an increased contribution of CP and aerobic metabolism to the energy demands. It is interesting that power output declined by 26.6 % from the first to the last bout which suggests that CP levels were not fully restored during the thirty seconds rest. This is consistent with the long time (~ 6 min) required for near full recovery of CP

(Bogdanis et al. 1995). Following this a FITS player involved in several relatively long HIA periods in succesion may fatigue due to an inadequate period required to restore CP levels. Blood lactate concentrations may indicate the contribution of glycolysis during intermittent exercise but it does not provide information on all of the sources of anaerobic energy. As the time period of the intermittent exercise increases a decrease in blood lactate concentration may suggest a decrease in the contribution of the anaerobic system when in fact CP contribution is increasing (Boobis 1987). According to Boobis (1987) during supramaximal exercise of less than six seconds the majority of energy is supplied by the simultaneous breakdown of CP and muscle glycogen.

Inactive periods during intermittent exercise may provide time for the resynthesis of CP and ATP, the decrease in inorganic phosphate (Harris et al. 1976), ADP and AMP (Essen et al. 1977) and the restoration of resting intramuscular pH levels (Holymard et al.1988; Balsom et al. 1992a). The energy used to resynthesise CP during these periods is believed to be supplied predominantly by aerobic pathways (Sahlin et al. 1979). Therefore lengthening the recovery periods during intermittent exercise may reduce the contribution of glycolysis and prevent an excessive increase in blood lactate and hydrogen ion concentrations (Saltin et al. 1976; Essen and Kaijser 1978). The accumulation of hydrogen ions in the muscle is believed to be a major cause of fatigue during high intensity exercise (Metzger and Fitts 1987; Tesch and Wright 1983). However more recent studies are not as definite about the effect of hydrogen ions on fatigue.

Shortening the recovery period during intermittent exercise decreases sprint performance (Balsom et al. 1992a), increases HR (Keul 1973; Balsom et al. 1992a), blood lactate concentration (Keul 1973; Margaria 1969) and VO_2 (Margaria et al. 1969) during intermittent exercise. This suggests that the shorter recovery periods do not allow sufficient

time for the restoration of CP resulting in an increased reliance on glycolysis during subsequent exercise bouts (Holymard et al. 1988; Saltin et al. 1976; Essen 1978).

It appears that the major sources of energy during the high intensity activity during FITS will be derived from the intramuscular CP stores and glycolysis whilst, the energy during the lower intensity activity exercise is likely to be predominantly provided by the aerobic pathway. During intense periods of play with small rest periods glycolysis may be inhibited by a fall in intramuscular pH of the muscle during which the CP stores are likely to provide the majority of energy along with an increasing contribution from the aerobic pathways.

ii) *Blood glucose*

Muscle glycogen is the major source of carbohydrate during exercise at intensities exceeding 65 - 70 %, whilst with increasing duration of exercise the contribution of muscle glycogen declines and that of blood glucose increases (Romijn et al. 1993). Blood glucose concentration is maintained by liver glycogenolysis and gluconeogenesis as well as absorbed glucose from the dietary intake (Costill and Hargreaves 1992). Glucose is an essential fuel for the central nervous system and becomes an increasingly important substrate for prolonged exercise with carbohydrate supplementation (Coyle et al. 1986). Fatigue during strenuous exercise is associated with the depletion of glycogen, additionally an increase in blood glucose occurs when muscle glycogen levels decrease (Costill and Hargreaves 1992). Hypoglycaemia (low blood glucose concentrations) can have serious effects on performance and health. Low blood glucose concentrations between 2.8 to 3.9 $mmol.l^{-1}$ can cause nervousness and trembling, whilst levels below 2.8 $mmol.l^{-1}$ can cause a person to lose consciousness (Guyton 1981). It has been proposed that low blood glucose concentrations may have a deleterious effect on tactical thought as well as cooperative action between players (Shephard 1982).

In a study of Canadian National soccer players Leatt (1986) reported a pre game blood glucose concentration of 4.96 $mmol.l^{-1}$, which was increased by half time to 5.67 $mmol.l^{-1}$ and decreased to less than rest at 4.74 $mmol.l^{-1}$ at the end of the game. In contrast to an increase in blood glucose levels, a study by Ekblom (1986) found that the average glucose concentration at the end of a soccer game had fallen to 3.8 $mmol.l^{-1}$ with three players having readings of only 3.0 - 3.2 $mmol.l^{-1}$. With no pre game glucose concentrations reported by Ekblom (1986) it is difficult to assess the condition of the players before the game however, the lower than rest blood glucose concentrations at the end of the game may be explained by low pre game liver glycogen levels.

Provided the pre exercise liver glycogen reserves are adequate and the glucose precursors are available, the intense nature of soccer will normally result in blood glucose levels close to or slightly above resting levels during a match (Reynolds and Ekblom 1985a; Shepherd and Leatt 1987; Leatt and Jacobs 1989). Due to the restrictions of fluid replacement during soccer and field hockey it is difficult to supplement with glucose polymer drinks during the match. The only occasions available appear to be immediately before the game during injury time or at half time. There have been no published reports of blood glucose concentrations for a game of field hockey.

iii) *Lactate*

Muscle lactate increases when the rate of glycolysis exceeds the rate of pyruvate entering the tri Krebs citric acid cycle (Powers and Howley 1990). Several authors have taken muscle biopsies before, following and during soccer matches (Agnevik 1970; Jacobs et al 1982; Ekblom 1986); however, no study has reported more than pre and post muscle biopsies. Obtaining multiple muscle biopsies during field testing in ITS is largely impractical due to the availability and access of elite players as well as the potential adverse effects. Body contact also raises the risk of excessive bleeding and spread of infection compared to

laboratory studies. Therefore blood sampling and measurement of blood lactate concentration is the preferred method for measuring the glycolytic contribution to FITS. Mean venous blood lactate concentrations from studies reporting only pre and post game samples ranged between 4.9 and 9.5 $mmol.l^{-1}$ at half time to 2.8 - 7.2 $mmol.l^{-1}$ at the end of the match with most investigations reporting a lower blood lactate concentration at the end of the game (Table 2.6). Between four (Table 2.6) and ten capillary blood samples (Ekblom 1986) have been taken during a match to obtain a clearer picture of blood lactate concentrations during soccer and rugby games (Ekblom 1986, Bangsbo 1991, Bangsbo 1994, McClean 1991).

Despite the increasing use of blood lactate concentration measurements to estimate the anaerobic contribution to the energy demands of intermittent sports, there are a number of problems with their use. These blood samples have usually been taken after a half or quarter has been completed. Blood lactate concentration represents a balance between lactate production and subsequent entry into the bloodstream and it's clearance and each of these are dependent on the exercise intensity and work to rest ratio of the activity (Brooks 1986 Anderson and Rhodes 1989). However blood lactate concentration was related to the percentage of high intensity running during the five minutes prior to blood sampling (Bangsbo 1991). Therefore it could be suggested that blood lactate concentrations give a crude indication of the anaerobic contribution to the energy demands of play during this five minute period. (Bangsbo 1991). It should be emphasised that post game or average game lactate concentrations give no indication of the range of individual player concentrations produced during the game (Table 2.6) or of the degree of lactate production and clearance from the blood during heavy and light work loads. The effects of FITS on blood lactate concentrations are shown in table 2.6.

Table 2.6: Blood lactate concentration ($mmol.l^{-1}$) during and at the end of each half in elite field intermittent team sports.

Sport	Reference	Game level	1st half		2nd half		Site	Mean	Range#
			During	End	During	End			
Australian Football	Dawson et al (1991)	League	-	-	-		Capillary	-	3.0- 9.0
Rugby	Docherty et al (1988)	Club & National	-	-	-	2.8 ± 1.6*	Venous	-	-
	Allen (1989)	National	-	-	-	3.8 ± 1.2*	Venous	-	-
	McClean (1991)	National	6.3	5.6	5.6	6.3	Capillary	6.0	3.6-9.8
Soccer	Agnevik (1970)	1st div	-	-	-	10.0	Venous	-	max 15.5
	Smaros (1980)	2nd div	-	4.9 ± 1.9*	-	4.1 ± 1.3*	Venous	4.5	-
	Ekblom (1986)	1st div	-	9.5	-	7.2	Venous	8.4	6.9-10.8
		2nd div	-	8.0	-	6.6	Venous	7.3	5.1-11.0
	Bangsbo (1991)	Div. 1&2	4.9	-	3.7	4.4	Capillary	4.3	1.8-10.3
	Bangsbo (1994)	League	4.1	2.6	2.4	2.7	Capillary	3.0	1.6 - 6.0
		League	6.6	3.9	4.0	3.9	Capillary	4.6	2.3 - 9.3

* Data expressed as mean ± SD.
# Range of individual blood lactate concentrations.

iv) Potassium

Muscle K^+ plays an important role in muscle function with disturbances in the intracellular-to-extracellular muscle K^+ concentration gradient regulation linked with reduced membrane potential and excitability (Sjøgaard 1991; McKenna 1992; McKenna et al 1996). A decrease of this gradient has been reported during both intense and prolonged exercise (Sjøgaard 1991). During intense exercise plasma K^+ concentration increases rapidly due to release from contracting muscle. However in recovery, unlike lactate concentration, plasma K^+ falls rapidly to below resting levels by approximately three minutes post exercise, due to rapid re-uptake by the muscle (Medbø and Sejersted 1990). This probably accounts for the 10 % decrease in plasma K^+ concentration of 23 Australian rules footballers at the end of the game (Pohl et al 1981). There are no other reports on muscle or plasma K^+ concentrations during other FITS.

v) Fluid regulation

During exercise heat is produced due to inefficient energy transduction processes which may elevate core temperature. Regulations governing hockey, soccer, and ice hockey do not allow trainers onto the ground during play to supply the team with fluids, the only opportunities for hydration are at half time or when an injury break occurs. The rise in core temperature during these FITS is dependent on the intensity and duration of the exercise bouts, recovery periods, environmental factors such as temperature, relative humidity and player clothing, sweat loss and fluid intake (Maughan and Leiper 1994). It has been reported that intermittent sports raise the core body temperature higher than continuous sports at the same oxygen consumption (Ekblom et al 1981). The extent of this increase is not only affected by the prevailing environmental conditions but also by the standard of the game. Most studies examining fluid regulation on FITS have examined soccer players (Mustafa and Mahoumad 1979, Ekblom et al 1981, Shepherd and Leatt 1987, Kirkendall

1993). At the completion of the game first division soccer teams had a higher rectal temperature (39.5° C) when compared with teams from three lower divisions (39.0-39.2 ° C) (Ekblom et al. 1981).

Very high increases in core temperature occur in the warmer weather (Mustafa and Mahoumad 1979). A major criticism of these papers investigating the effects of intermittent sport on core temperature is the lack of information on environmental conditions at the time. Despite this a study involving African soccer players in "warm conditions" found losses of 4-5 kg representing 3% of the subject's body mass (Mustafa and Mahoumad 1979). A decrease of more than 2% in body mass can impair both the performance of an athlete and increase core temperature during exercise (Costill et al.1970). Mustafa and Mahoumad (1979) report that a major reason for the decrease in body mass was inadequate fluid replacement during the half time break. Shepherd and Leatt (1987) found that dehydration adversely affected the player when between one and two kilograms were lost. Given a player can absorb a litre or more of fluid during a game dehydration is only a concern during warmer conditions ie above 21° C (Shepherd and Leatt 1987). However a study by Pohl et al (1981) investigating fluid loss and rectal temperature in Australian rules footballers with the temperature at 12-15° C and humidity of 55 - 88% suggests that temperatures below 21° C can also cause significant hypohydration. During this match players drank freely from a 2.5 % solution of glucose in distilled water. By the end of the game the mean fluid deficit was 2 % of the players' body mass while rectal temperatures had increased to 39.5 °C. An increase of more than 2°C in core temperature can cause significant impairment of mental and physical function (Guyton 1981; Gopinathan et al. 1988). Therefore air temperature, humidity and the hydration of the athlete all affect both the core temperature and body mass loss of athletes. As a result of these responses performance can be adversely effected and in extreme cases, compromise the health of the

athlete. No published data exists on fluid loss during FITS involving women or during a game of field hockey.

2.4.3 Conclusions

It appears that the major sources of energy during the HIA periods in FITS will be derived from the intramuscular CP stores and anaerobic glycolysis whilst the energy during the LIA periods is likely to be predominantly provided by the aerobic pathway. During intense periods of play with shorter rest periods (between 30 - 60 secs) anaerobic glycolysis may be inhibited by a fall in pH of the muscle during which the CP stores are likely to provide the majority of energy. It is reported that during these very intense periods of play in FITS the aerobic contribution increases.

Heartrate (HR) is the only continuous variable that can be easily measured during FITS without impeding the players' normal game. The continuous monitoring of HR shows that despite the vast majority of time spent in LIA heart rate remains very high throughout in all FITS, therefore HR is not always a true indicator of the intensity of the game. It appears that the calculation of VO_2 from HR or activity patterns is more unreliable than heart rate as a measure of exercise intensity during FITS. Unlike HR and discrete biochemical concentrations measured directly from blood samples, $\dot{V}O_2$ is calculated indirectly using unreliable regression equations from HR or the activity patterns. Therfore it may be suggested that a physiological response ($\dot{V}O_2$) calculated using unreliable regression equations from another physiological response (HR) which is already not always a true indicator of the intensity of the game contains too many errors and invalid assumptions for a calculated VO_2 to be reported as a reliable measure of intensity during FITS. Lactate, glucose and potassium concentrations exhibited during competition and the suggested implications for training have been made on the basis of discrete or average values. Individual lactate concentrations vary a great deal in FITS, this could be due to the sporadic nature of the activity patterns and of different playing positions. Therefore, conclusions regarding average values obtained from a number of different sample times cannot be very

accurate or specific to exactly what is occurring during the game. As a consequence, for example, single or average concentrations cannot be seen as representative of blood lactate production throughout an entire game. Blood lactate concentrations taken during matches may reflect, but appear to underestimate, lactate production in a short period prior to the blood sampling. Despite the limitations regarding the use of discrete measures such as blood lactate, glucose and potassium measurements during competition, values obtained may still be of some value. If the patterns of play prior to the blood sample being taken are analysed for work and rest ratios and also the intensity and duration of the activity, then the values obtained may provide a reference point for further investigation. It may be beneficial to take a number of capillary blood samples during rather than following the game in order to get a better indication of blood lactate concentrations throughout FITS. HR is the only physiological response documented on field hockey players and very little data has been documented on the physiological responses of women during FITS.

2.5 Aims of the study:

The aims of the study were to investigate

1. The physiological characteristics of elite female field hockey players through extensive laboratory testing.
2. The physical activity patterns of elite female field hockey players during a game using a computerised video analysis technique.
3. The acute physiological responses (cardiovascular, metabolic and biochemical responses) that occur during a game of women's field hockey.
4. Investigate the relationships between activity patterns and the corresponding physiological responses in elite female field hockey players that occur during a game of women's feld hockey.

CHAPTER 3

METHODOLOGY

3.1 *Subjects*

Six healthy women (age 23.4 ± 2.1 yr, height 166 ± 7.8 cm, body mass 60.0 ± 7.8 kg, Mean ± SD) were chosen from the Victorian Women's Field Hockey team on the basis of their playing position; all were inners or centre halves, positions characterised by a high work-rate. The players gave informed consent (Appendix 1) and were familiarised with all experimental procedures prior to participation in the study which was approved by the Victoria University of Technology Human Research Ethics Committee.

3.2 *Laboratory tests*

Laboratory tests, in order, comprised anthropometric measures, tests of maximal sprint and multiple sprint performance and maximal aerobic power. All subjects completed the tests within two weeks of the field measurements. Subjects reported to the laboratory in a rested and at least 3 hour post-prandial state and completed a 24 hr inventory form detailing their general condition, diet, sleep and physical activity. Testing was conducted during a routine testing session for the state hockey squad, which restricted the rest intervals between the tests.

3.2.1 *Anthropometric Measures*

Height and body mass were recorded. Subcutaneous body fat was determined using Harpenden skinfold calipers, with three measurements taken on the right side of the body at each of seven sites: bicep, tricep, Iliac crest, subscapula, abdomen, quadricep and calf. An average of two readings within 0.2 mm of each other were used to obtain the measurement for each site. These were then used to calculate the sum of seven skinfolds.

3.2.2 *Maximal Sprint Performance Measures*

One "all-out" 10 second sprint was performed to determine the subject's peak power and cumulative work output during a single maximal effort. An intermittent test comprising five 6 second all-out sprints with a 24 second recovery between each sprint was completed six minutes after the maximal anaerobic sprint test. This test was performed to determine the subjects peak power, cumulative work output and fatigue ability during exercise simulating an intense passage of match play. A running sprint test would have been more specific for field hockey however the bike test enabled a more reliable measure and compared to standards provided by previous testing on field hockey players. The sprints were performed on an Exertech front access, air-braked, cycle ergometer (Repco Cycle and Health Systems, Melbourne, Australia). The bike was not dynamically calibrated therefore it is possible that there is an error with the power outputs. Each subject completed a warm up of five minutes cycling at a workrate of 50 W. After a short rest each sprint was conducted with the subject in a standing position with feet secured to the pedals by toe clips and a heel strap. The subjects were verbally encouraged to produce a maximal effort for each bout. Power output and work done were calculated via an Exertech work monitor unit (Repco Cycle and Health Systems, Melbourne, Australia). A 60 tooth cog attached to the wheel of the bike provided pulses for each revolution, which were collected by a Hall effect device. Amplified high level pulses then passed through a Schmitt trigger and converted the pulses to square waves which made the frequency proportional to the revolution rate of the bike. This frequency was then converted to analog voltage in a tachometer circuit which via a cubic function converted revolutions to power. The analog signal from the work monitor unit was converted to digital figures by an analog to digital converter by an IBM 486 computer.

3.2.3 *Maximal Aerobic Power*

The maximal aerobic power test was conducted 20 minutes after the completion of the maximal intermittent sprint test. The subject began running at 8 km. hr^{-1} on a treadmill and progressed to 14 $km.hr^{-1}$ with 2 $km.hr^{-1}$ increments every two minutes, after which the grade was increased by 2.5 % every minute until the subject reached volitional fatigue. The test was conducted using an on-line open-circuit spirometry system. Expired air was collected while the subject breathed through a Hans Rudolph two-way valve; expiratory flow was determined with a turbine ventilometer (KL engineering, Sunnyvale, California, U.S.A), with expired gas analysed for oxygen and carbon dioxide fractions (Applied Electrochemistry Analysers, Ametek, Pittsburgh, U.S.A.) which were calibrated immediately before each test using room air and a beta standard gas checked against an alpha standard gas. Oxygen consumption ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$) and ventilation ($\dot{V}_E$) were calculated by an IBM PC computer every thirty seconds. The average of the two highest consecutive VO_2 values was used to give the $\dot{V}O_2$ peak. Heart rate was monitored throughout the test and averaged over five seconds using a Polar PE 4000 sports tester (Polar electro oy, Kempele, Finland). The peak heart rate was the highest heart rate recorded during the exercise test.

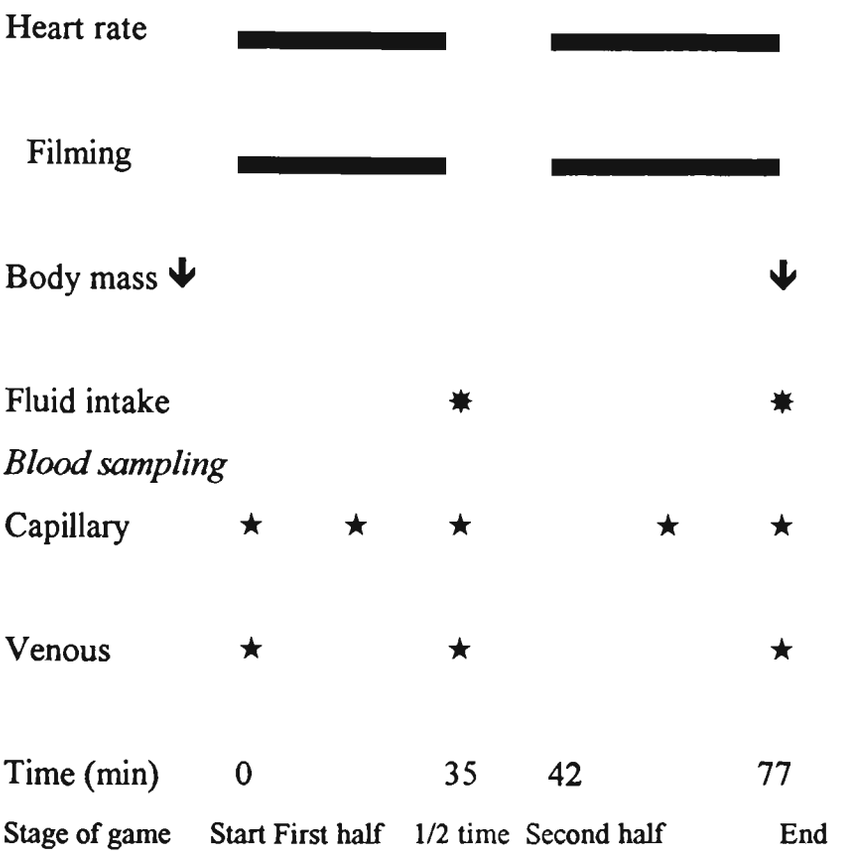
3.2.4 *Capillary blood sampling.*

Capillary blood samples were taken using the method described below, at one, three and five minutes following the maximal ten second, the multiple sprint tests and the maximal aerobic power test, to determine the peak capillary blood lactate concentration ($[Lac^-]_{cap}$).

3.3 Field tests

Subjects were monitored for physical movement activities and selected physiological responses before, during and following five different competition games in preparation for the National Hockey Championships (Figure 1). The hockey matches were played under cool (11.6 ± 2.8 °C), humid (64.8 ± 14 %) conditions.

Figure 1. Field measurements during field testing



3.3.1 *Computer-Video Movement Pattern Analysis*

A video camera (National M-7) was mounted on a tripod stand in an elevated position, 15 metres from the playing surface, to obtain the best viewing position available. Filming began just prior to the start of the game when the sports tester stop watch was activated to record heart rates. The camera operator followed the same subject for the game and continued filming during the half time interval. Recording stopped when the game finished.

Player activities during the hockey match were categorised into activity related events:- stationary, walking, jogging, sideways motion, striding or sprinting and shuffling. These categories were then divided into low intensity activity (LIA) which included stationary, walking, jogging, sideways motion and high intensity activity (HIA) which included striding or sprinting and shuffling. Video-recordings were analysed using a JVC VCR (AG 5700-B, Mitsubishi electric company Inc, Japan) interfaced to a IBM compatible 486 computer. The software was developed by Mr Peter Horan and Assoc. Professor Jon Patrick Department of Computing and Mathematics, Deakin University, Geelong, Victoria. Movement patterns were identified by keystrokes on computer while viewing the video of the game in real time. A pause facility enabled the operator to stop the tape to note errors or review a particular section for verification of movement activities. During the video analysis classification a file containing the individual events, their durations and the cumulative total time was obtained. This information was transferred into a file to develop a series of statistics for analysis of individual players. These included the number of occurrences, total accumulated time; as well as the mean, standard deviation, minimum, maximum and percentage of time spent in each activity. The total time spent in the low intensity activity (LIA) and high intensity activity (HIA) categories was then summed and used to calculate a mean work : rest ratio. A print out of selected statistics for each player was then obtained for each activity classification, for the entire game of each quarter and for each five minute segment prior to the capillary blood sampling.

3.3.2 *Variability of the movement analysis*

The variability of the computer video analysis technique was assessed during two separate sessions by one video analyst. Firstly an inexperienced analyst assessed the activity patterns of one player, for one quarter of a game, twice in the same analysis session, separated by a ten minute interval. The previously inexperienced analyst then gained extensive experience with the computer video analysis technique before repeating the analysis of the same quarter and game of the same player. The variability of the video analysis technique was calculated by the percentage difference between trials for the inexperienced compared with the experienced user, for the number of occurrences and mean durations for all movement categories. This data provided intra-trial variability in an inexperienced and experienced analyst and a comparison of the changes in results after extensive experience was gained.

3.3.3 *Physiological Measurements*

i)Heart Rate

Heart rate was monitored throughout the game and averaged over five second intervals using a Polar PE 4000 sports tester. The transmitter was strapped to the chest of the subject and ECG signals transmitted to a microcomputer attached to the wrist of the subject. A sweat band was placed over the wrist watch to prevent damage or activation of buttons on the watch. Heart rate monitoring was synchronised with filming to enable heart rate responses to be matched with the subjects game activities. This was achieved by recording on film the commencement of heart rate monitoring. From this point filming and heart rate monitoring continued throughout the entire game, including all intervals. Heart rate data from the sports tester was subsequently down loaded onto an IBM PC computer. Heart rate values recorded before the game, during the half time interval and at the end of the game were removed for analysis of the "game time" data. This was achieved by matching the time the data was recorded on the watch with the video recording of the subject. Game time is defined as any time that the game clock was running.

ii) Fluid Balance

The subject's body mass in underwear was measured one hour prior to and ten minutes following the game. The scales used (UC - 300, AND Precision health scales) were calibrated and accurate to within $\pm$50 g. Subjects drank from an individual water bottle with fluid intake during the match monitored by measuring the volume of water ingested between the measurement of body mass before and at the end of the game. Urine output was measured after the first body mass measurement to correct body weight losses, but this was required with only one subject during the experiment.

iii) Blood sampling and analyses

Subjects reported to the stadium in a rested state at least 3 hours post-prandial. Blood samples were taken from an antecubital vein with the subject supine, at two hours before the game, at half time and at one minute after the game to determine plasma acid-base status, fluid shifts, metabolite and electrolyte concentrations. Identical postural controls were used for all venous sampling: a 20 G needle was inserted into an antecubital vein directly after the subject attained the supine position, with all venipuncture performed in the player change rooms. A longer postural stabilisation period was not possible during and following the match due to the importance of obtaining metabolite determinations as soon as possible after exercise. Two blood samples were drawn, the first into a 2.5 ml preheparinised syringe for blood gas analysis, and the second immediately following into a 5 ml syringe for plasma ion and metabolite determinations. Air bubbles were expelled from the syringes and the blood was well mixed. The 2.5 ml syringe was capped, placed in ice and transported to the laboratory located five minutes from the stadium, for duplicate analyses of haemoglobin concentration ([Hb], OSM2 Hemoximeter, Copenhagen, Denmark) plasma CO_2 and O_2 tensions (PCO_2, PO_2) and plasma pH (Radiometer ABL 30 Acid Base analyser, Copenhagen, Denmark). One ml of blood from the 5 ml syringe was placed into an Eppendorf tube for haematocrit and plasma lactate determinations. Haematocrit (Hct) was determined in triplicate after centrifugation for ten minutes at 3000 rpm (Hettich haematocrit centrifuge). Five hundred µl of blood was transferred into an Eppendorf tube containing 250 µl of cold perchloric acid (7%), vortexed and the supernatant placed on ice for later analysis of lactate concentration ($[Lac]_V$) using an enzymatic spectrophotometric technique (Lowry and Passonneau, 1972). The remainder of the 5 ml syringe was emptied into a tube containing lithium heparin, mixed and then portioned into Eppendorf tubes. The tubes were then

centrifuged for five minutes at 4000 rpm (Eppendorf centrifuge, Brand 5414 S), and plasma separated for duplicate determinations of glucose concentration (YSI 23 AM glucose analyser, Sunnyvale, USA), sodium ($[Na^+]$), potassium ($[K^+]$) (Radiometer KNA2, Copenhagen, Denmark), chloride $[Cl^-]$ and $[protein^-]$ (Beckman TX-5). All analytical instruments were calibrated immediately before and during the analysis with precision standards.

Capillary blood samples were taken one hour prior to the game, halfway through the first and second halves and two minutes after the game. Samples taken during the two halves were collected less than 30 seconds after the subject stopped playing, whilst samples at half time and at the end of the game were taken no more than two minutes immediately following the end of play. This delay was due to the prioritisation of the intravenous samples necessitating the subject to jog to the change rooms. The subject was seated at the side of the playing area, a finger swabbed with alcohol and pricked with an Auto-clix lancet. The first drop of blood was discarded and the finger dried. Approximately 30 µl of blood was collected in a capillary tube which contained lysing agent (F/NO2/Hep/lysing agents, Analox Instruments, Melbourne, Australia). The blood was mixed for two minutes, capped and stored on ice. Most capillary blood samples were analysed within two hours after the game. However due to technical problems samples from subjects one and five remained on ice and were analysed after twelve hours post game. Capillary blood lactate concentrations ($[Lac^-]_{cap}$) were determined in 7 µl blood samples (PLM 4 Analog lactate analyser). The analyser was calibrated every ten samples. An average of two readings within 0.2 $mmol.l^{-1}$ of each other were used to obtain $[Lac^-]_{cap}$.

iv) ***Calculations***

Changes in plasma (%Δ PV) and blood volume (%Δ BV) from resting levels (1) were calculated from changes in [Hb] and Hct (Equations 1 and 2, Harrison 1985).

Equation 1 $\%\Delta BV = \{([Hb_1]) - 1) \times 100\} / [Hb_2]$

Equation 2 $\%\Delta PV = [Hb_1] \times (1 - Hct_2) / [Hb_2] \times (1 - Hct_1) - 1] \times 100$

Calculation of plasma strong ion difference [SID] were derived from plasma strong ion concentrations (Equation 3, McKenna 1992)

Equation 3 $[SID] = [Na^+] + [K^+] - [Cl^-] - [Lac^-]$

3.4 ***Statistical analysis***

Standard deviation and means were calculated where appropriate. A one way ANOVA ($P<0.05$) with repeated measures was used to determine significant differences between the blood variables measured at rest, mid - half, half time and at the end of the game. The Newman- Keuls procedure was used as the post-hoc test.

CHAPTER 4

RESULTS

4.1 Laboratory Tests

Exercise performance and accompanying physiological data for all laboratory tests, specifically 10 second sprint, intermittent sprint exercise and maximal incremental exercise, are presented in Tables 4.1- 4.3. The ten second sprint test produced a peak power of 912.3 $\pm$ 171.4 W (Table 4.1), while the intermittent sprint test after sprint one showed percentage decrements in peak power of 5.2 $\pm$ 1.2, 9.3 $\pm$ 2.5 ($p<0.05$), 10.3 $\pm$ 2.7 ($p<0.05$) and 11.4 $\pm$ 3.0 ($p<0.05$) % respectively.

Table 4.1; Performance data during a ten second sprint test. All data mean $\pm$ SD; n = 6.

Variable		Values
Work	(kJ)	7.3 $\pm$ 1.2
	($J.kg^{-1}$)	123.0$\pm$ 9.8
Peak Power	(W)	912.3$\pm$ 171.4
	($W.kg^{-1}$)	15.2 $\pm$ 1.0

Table 4.2; Intermittent sprint test performance data. All data mean ± SD, n = 6.

* significantly different to bout 1 ($p<0.05$).

Variable		Bout 1	Bout 2	Bout 3	Bout 4	Bout 5
Work	(kJ)	4.2 ±1.0	3.9 ±0.9	3.8 ± 0.9	3.7 ± 0.8	3.5±0.8
	($J.kg^{-1}$)	71.6± 5.4	66.6 ± 4.8	63.8 ± 3.6	62.6 ± 4.7	60.0 ± 3.9
Peak Power	(W)	826 ± 176	783 ± 175	749 ± 158*	741 ± 152*	732 ± 149*
	($W.kg^{-1}$)	14.0 ± 1.0	13.2 ± 1.0	12.7 ± 0.8*	12.5± 0.8*	12.4 ± 0.9*

Table 4.3; Peak workrate, respiratory and cardiovascular data during maximal incremental exercise. All data mean ± SD, n = 6.

Variable		Peak Values
HR	($b.min^{-1}$)	186 ± 5
RER		1.14 ± 0.07
$\dot{V}_E$	($l.min^{-1}$)	112.1 ± 16.3
$\dot{V}O_2$	($l.min^{-1}$)	3.09 ± 0.45
	($ml.kg^{-1}.min^{-1}$)	51.8 ± 3.9

All capillary lactate concentrations were significantly higher ($p<0.05$) than rest but did not differ from each other during recovery in the same test (Table 4.4).

Table 4.4; Capillary lactate concentrations ($mmol.l^{-1}$) at rest one, three and five minutes after the 10 second sprint test, the intermittent sprint test and the maximal incremental exercise test. * Significantly > rest ($P<0.05$).

Test	Rest	1'post	3'post	5'post
10 s sprint	1.1 ± 0.2	8.8 ± 0.9*	9.2 ± 0.4*	8.2 ± 0.8*
Intermittent sprint	-	13.1 ± 0.6*	13.1 ± 0.2*	13.3 ± 0.4*
$\dot{V}O_2$ max	-	11.9 ± 1.2*	11.8 ± 0.9*	11.4 ± 1.1*

4.2 Variability data for analysis of the activity patterns for field hockey.

Intra session variability data for the inexperienced and experienced analyst are given in tables 4.5 and 4.6, respectively. Variability for the mean duration of each category ranged between 1.5 and 20 % when performed by an inexperienced analyst. This was particularly pronounced for the categories with only a small number of occurrences (eg. stationary, sideways and shuffle). The percentage difference in the number of occurrences between trials for an experienced analyst was less than 10%, apart from the sideways and shuffling categories.

Table 4.5; Intra-session video analysis variability by an inexperienced analyst.

	Stationary	Walk	Jog	Sideways	Stride	Shuffle	Mean difference
Number							
Trial#1	27	87	89	4	32	10	
Trial#2	19	95	96	2	32	16	
%difference	29.6	8.4	7.3	50.0	0.0	37.5	22.1
Mean							
Trial#1	3.0 ± 3.1	6.5 ± 6.6	3.3 ± 3.7	1.4 ± 0.6	3.0 ± 2.3	1.5 ± 1.0	
Trial#2	2.7 ± 2.0	6.6 ± 6.6	2.8 ± 2.3	1.2 ± 0.4	2.9 ± 2.1	1.2 ± 0.4	
%difference	10.0	1.5	15.1	14.3	3.0	20.0	10.7
Range							
Trial#1	0.8-14.4	0.8-43.7	0.8-24.7	0.8-1.7	0.8-8.8	0.9-4.2	
Trial#2	0.8-7.2	0.8-43.4	0.8-11.0	1.0-1.5	0.9-7.4	0.8-2.4	

Table 4.6; Intra session video analysis variability by an experienced analyst.

	Stationary	Walk	Jog	Sideways	Stride	Shuffle	Mean difference
Number							
Trial#1	21	105	88	13	41	24	
Trial#2	18	106	80	15	43	18	
%difference	7.0	0.9	9.0	13.3	4.7	25.0	10.0
Mean							
Trial#1	2.3 ± 1.7	6.0 ± 5.8	2.6 ± 2.2	1.2 ± 0.4	2.4 ± 1.9	1.2 ± 0.4	
Trial#2	2.5 ±1.6	6.1 ± 6.1	2.8 ± 2.2	1.2 ± 0.4	2.2 ± 1.8	1.1 ± 0.3	
%difference	8.0	1.6	7.1	0.0	8.3	8.3	5.6
Range							
Trial#1	0.7-6.8	0.8-43.5	0.8-10.5	0.8-2.2	0.8-7.6	0.8-2.5	
Trial#2	0.9-7.2	0.8-43.7	0.8-10.2	0.8-2.2	0.8-8.0	0.8-2.2	

4.3. Activity patterns analysis for field hockey matches.

High intensity activity (HIA) totalled 16 % of game time with a mean duration of 2.1 ± 1.1 seconds, while the mean duration of the sprint/stride category was 2.9 ± 0.4 seconds. The total number of events was 1185 ± 111, with an average duration of 2.9 ± 0.3 seconds, indicating a change in events every 3.6 ± 0.4 seconds (Table 4.7). The average HIA to LIA work to rest ratio was 1:5.6 ± 0.4. The HIA to LIA work to rest ratio in the last quarter was significantly different ($p<0.05$) from the third quarter (Table 4.8).

Table 4.7; Activity analysis of female field hockey players during competition. All data mean ± SD; n = 6.

Activity	Percent time	Number	Duration (seconds)	
			Mean	Maximum
Low intensity activity				
Stationary	8 ± 2	100 ± 27	3.4 ± 0.6	20.1 ± 13.6
Walk	45 ± 8	340 ± 31	5.5 ± 0.7	36.3 ± 9.3
Jog	29 ± 5	386 ± 49	3.2 ± 0.2	16.7 ± 5.1
Sideways	2 ± 2	63 ± 41	1.4 ± 0.2	4.5 ± 2.7
High intensity activity				
Stride/Sprint	12 ± 2	176 ± 30	2.9 ± 0.4	12.7 ± 3.2
Shuffle	4 ± 2	120 ± 47	1.3 ± 0.1	4.9 ± 2.3
Total		1185		

Table 4.8; Calculated work to rest ratios for each quarter and the whole game during field hockey. All data mean ± SD; n = 6, * quarter 4 is significantly different to quarter 3, ($p<0.05$).

Quarter	Value
1	1:5.4 ± 1.9
2	1:5.5 ± 2.2
3	1:5.2 ± 1.2
4	1:6.5 ± 1.8*
Game	1:5.6 ± 0.4

4.4 Heart rate responses to field hockey

The mean heart rate (HR) during game time was 157 ± 15 bts.min^{-1}, representing 85 ± 8 % of the heart rate peak recorded during the maximal incremental test (Table 4.9). A typical heart rate response during a game of field hockey is shown in Figure 2. Some 60 ± 5.2 % of the mean game heart rates were above 85% of the subjects' heart rate peak (Table 4.10). Mean heart rates (Table 4.10) and percentage of peak heart rates (Table 4.11) averaged over the five minute intervals preceding the following blood sampling times did not differ from the mean and percentage of peak game heart rates.

Table 4.9;. Mean heart rate and heart rate expressed as a % of peakHR data during a game of field hockey. All data mean ± SD; n = 6.

Subject	Mean HR (bts.min^{-1})	Mean HR (% HRpeak)
1	165 ± 11	90 ± 6
2	168 ± 12	89 ± 6
3	162 ± 14	85 ± 7
4	144 ± 20	81 ± 11
5	157 ± 16	85 ± 8
6	145 ± 16	78 ± 8
Mean ± SD	157 ± 15	85 ± 8

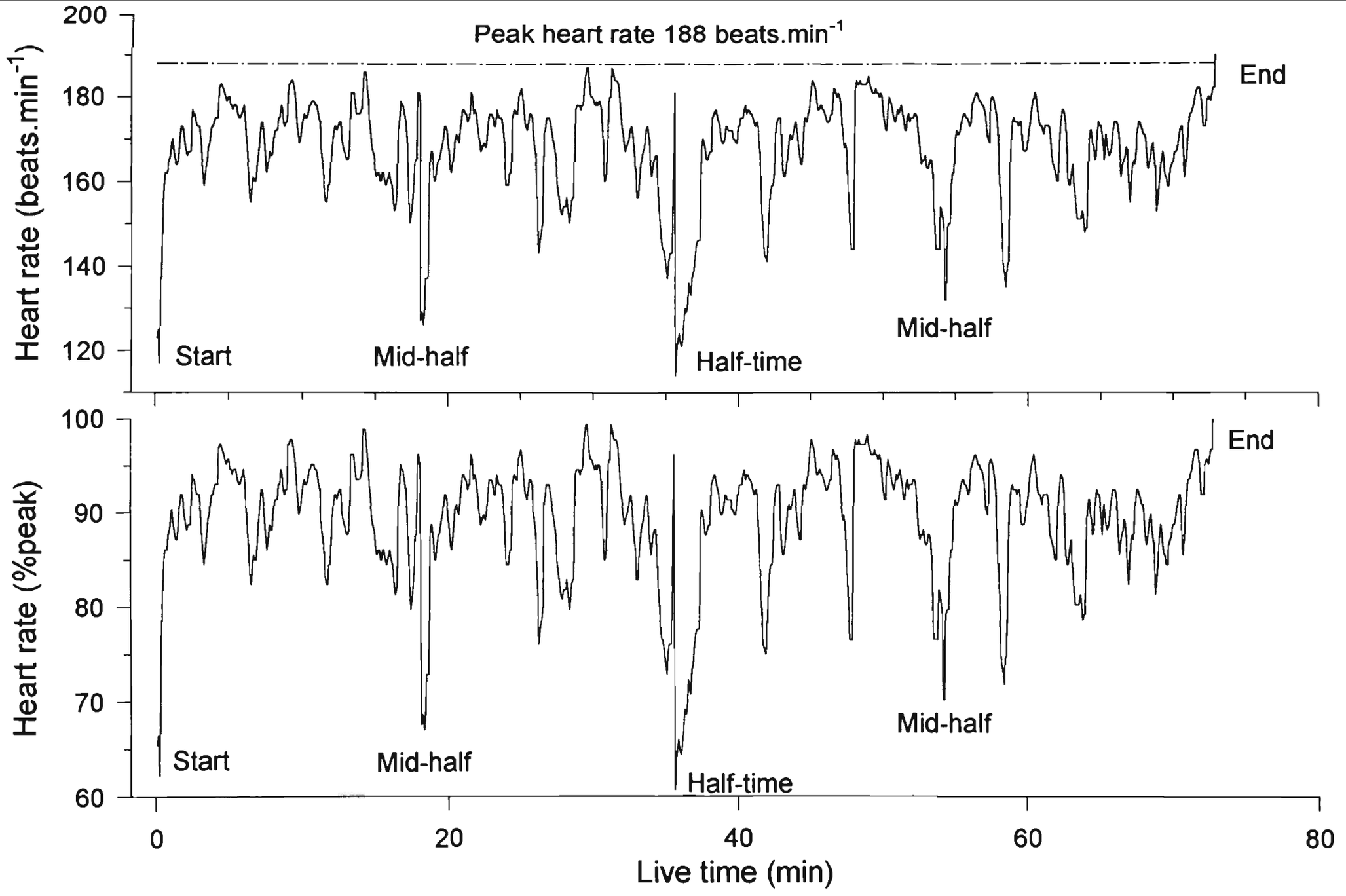

Peak heart rate 188 beats.min-1
Heart rate (beats.min-1)
200
180
160
140
120
Start
Mid-half
Half-time
Mid-half
End
Heart rate (%peak)
100
90
80
70
60
Start
Mid-half
Half-time
Mid-half
End
0
20
40
60
80
Live time (min)

Table 4.10;. Percentage of time spent in different categories during a game of field hockey. All data mean ± SD; n = 6.

	Range (%HRpeak)					
Subject	0-74%	75-79%	80-84%	85-89%	90-94%	95-100%
1	3.2	2.5	5.3	18.6	44.8	25.5
2	4.3	4.9	8.1	27.8	41.0	13.9
3	7.5	13.6	23.8	23.7	23.5	7.8
4	21.5	11.0	23.7	29.4	14.2	0.0
5	11.2	6.8	13.0	26.2	24.7	18.1
6	37.4	17.3	24.6	16.5	3.9	0.2
Mean ± SD	14.2 ± 13.1	9.3 ± 5.6	16.4 ± 8.7	23.7 ± 5.2	25.4 ± 15.5	10.9 ± 10.2

Table 4.11; Heart rate data averaged over the following five minute intervals each preceding a blood sampling time during a game of field hockey. All data Mean ± SD; n = 6.

Game time range (mins)				
Subject	12-17	30-35	47-52	65-70
1	168 ± 9	166 ± 9	168 ± 7	169 ± 5
2	169 ± 10	165 ± 13	170 ± 11	170 ± 8
3	165 ± 13	176 ± 5	168 ± 12	161 ± 7
4	141 ± 13	156 ± 11	151 ± 9	136 ± 12
5	168 ± 9	151 ± 14	162 ± 13	162 ± 10
6	149 ± 11	145 ± 13	148 ± 11	145 ± 13

Table 4.12; Heart rate data expressed as a percentage of maximum heart rate averaged over the following five minute intervals each preceding a blood sampling time during a game of field hockey. All data Mean ± SD; n = 6

Game time range (mins)				
Subject	12-17	30-35	47-52	65-70
1	92 ± 5	91 ± 5	92 ± 4	92 ± 3
2	90 ± 5	88 ± 7	90 ± 6	91 ± 4
3	87 ± 7	92 ± 3	88 ± 6	85 ± 4
4	79 ± 7	88 ± 6	85 ± 5	76 ± 7
5	92 ± 5	82 ± 8	88 ± 7	88 ± 5
6	80 ± 6	77 ± 7	79 ± 6	78 ± 7

4.5 Body mass changes and fluid intake

Body mass was unchanged by the match (pre 59.7 ± 9.8 vs post 59.9 ± 9.9 kg). Since players ingested an average 1.2 ± 0.5 litres of water, the calculated sweat loss was 1.0 ± 0.2 $l.hr^{-1}$ (Table 4.13).

Table 4.13. Body mass changes, fluid intake, sweat loss and environmental conditions during field hockey. All data n = 6.

Subject	Pre game mass (kg)	Post game mass (kg)	Fluid intake (ml)	Sweat loss ($l.hr^{-1}$)	Dry bulb air temp (^{o}C)	Humidity (%)
1	57.3	57.2	1010	0.95	8.0	74
2	50.7	50.2	420	0.79	13.1	54
3	69.6	70.4	1930	0.97	13.1	54
4	59.1	59.0	1140	0.98	12.6	84
5	73.0	72.9	1225	1.14	14.5	49
6	48.7	49.5	1310	1.29	8.0	74
Mean ± SD	59.7 ± 9.8	59.9 ± 9.9	1172.5 ± 488	1.0 ± 0.17	11.6 ± 2.8	64.8 ± 14

4.6 Fluid shifts and Blood Gas Status

Venous haematocrit and [Hb] and consequently ΔPV and ΔBV were not significantly different from rest at any time. ΔPV and ΔBV showed large inter-subject variability. (Table 4.14). Venous oxygen saturation and plasma PO_2 were elevated at half time and at the end of the match compared to rest and also at half time compared to the end of the match ($p< 0.05$, Table 4.14). Plasma PCO_2 was lower at half time compared to rest ($p< 0.05$, Table 4.14).

Table 4.14; Haematological data, derived fluid shifts and blood gas status in venous blood sampled before (PRE) at half time (HALF) and at the end of the field hockey match (POST). All data mean ± SD, n = 5; * significantly different to PRE , $p<0.05$.

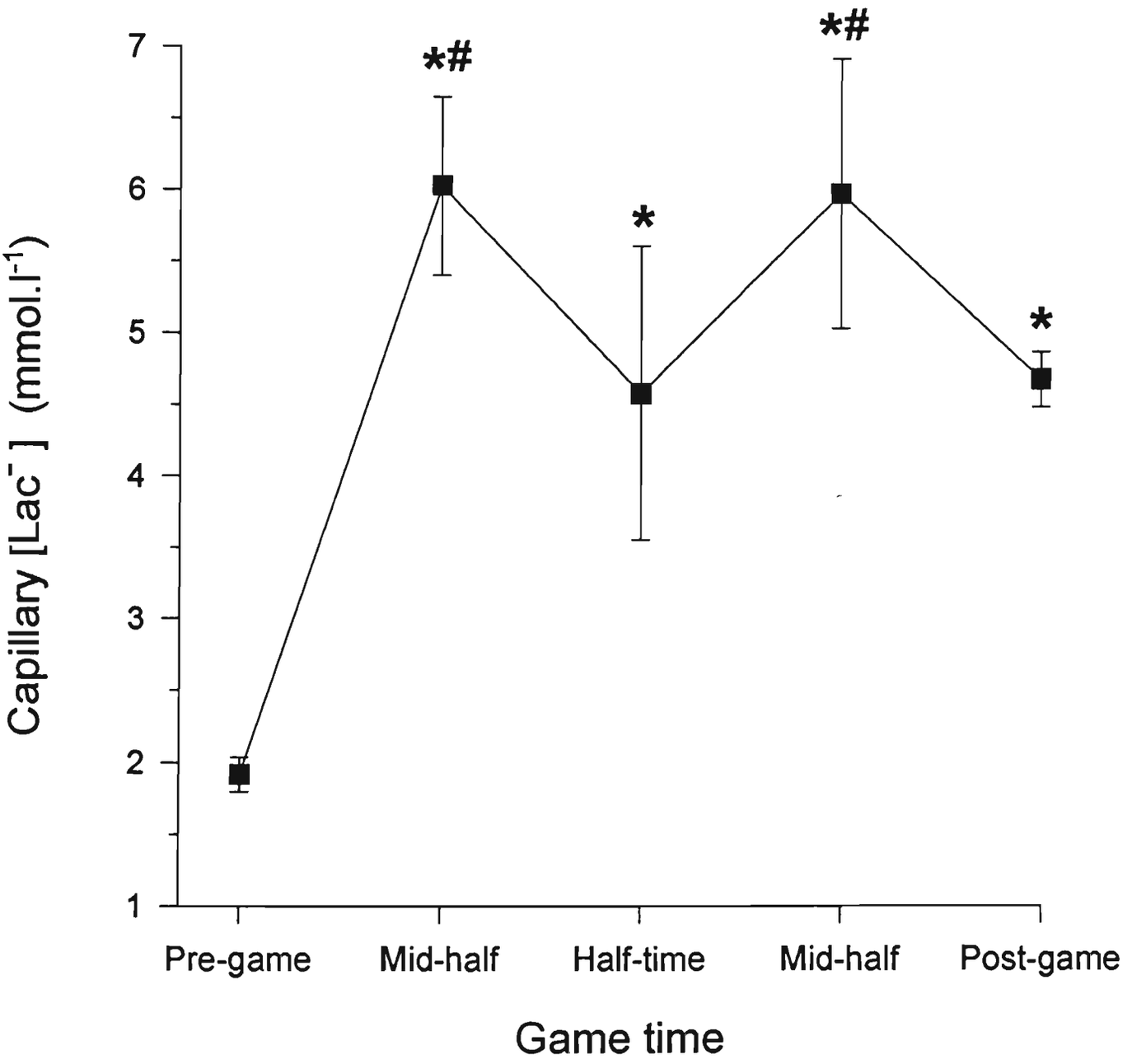
Variable		PRE	HALF	POST
[Hb]	($g.dl^{-1}$)	14.2 ± 0.6	14.0 ± 0.9	14.1 ± 1.1
Hct	(%)	41.8 ±1.7	41.9 ± 1.8	41.5 ± 2.2
ΔBV	(%)	_	1.3 ± 4.0	-0.3 ± 3.4
ΔPV	(%)	_	1.3 ± 7.4	0.5 ± 5.0
PCO_2	(mmHg)	56.7±7.5	42.0 ± 7.0*	46.6 ± 9.8
PO_2	(mmHg)	18.3 ± 3.6	52.7 ± 15.3*	35.6 ± 7.5*
SO_2	(%)	29.0 ± 7.9	81.3 ±13.7*	64.7 ± 12.5*

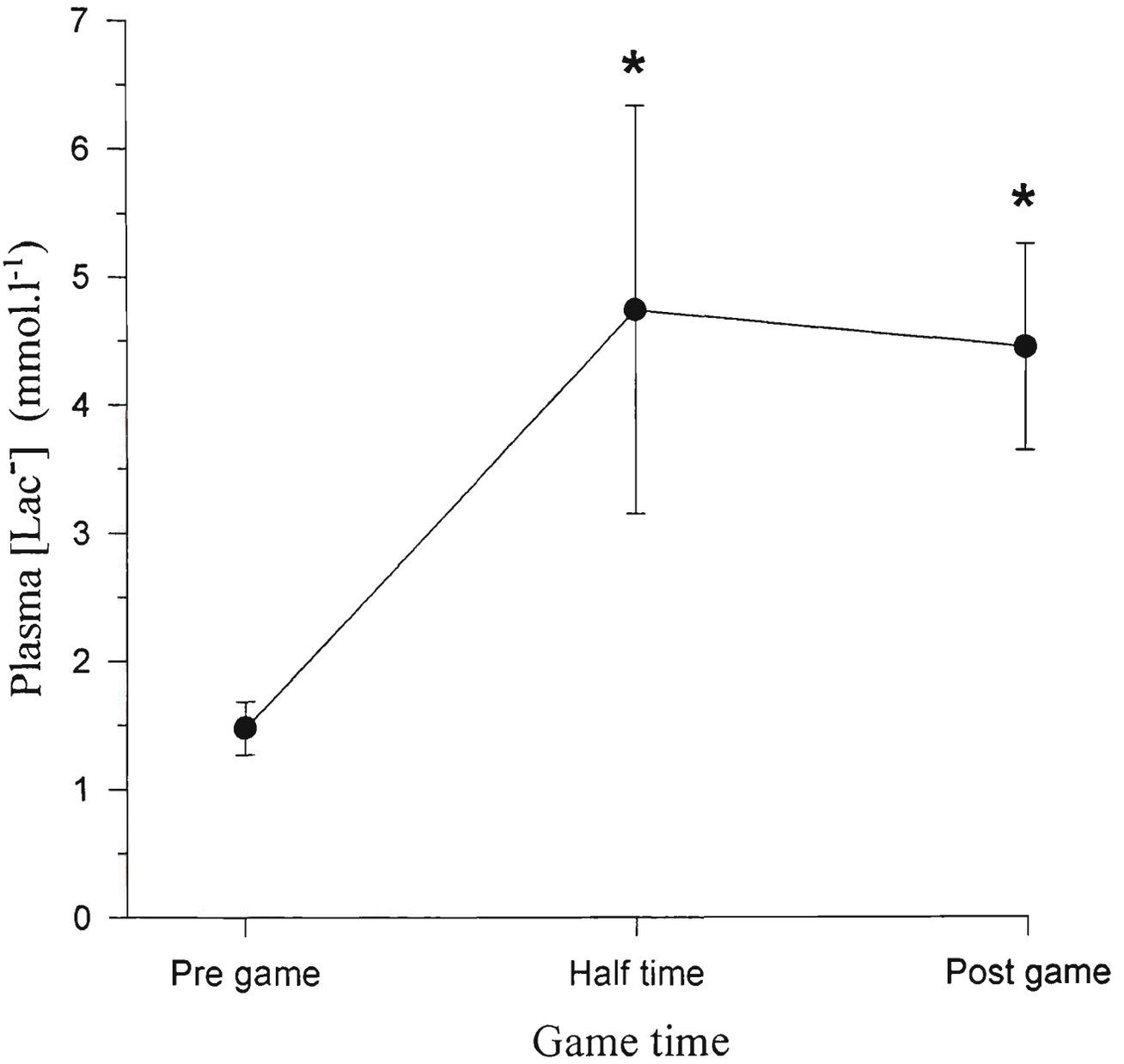
4.7 Metabolite and electrolyte concentrations.

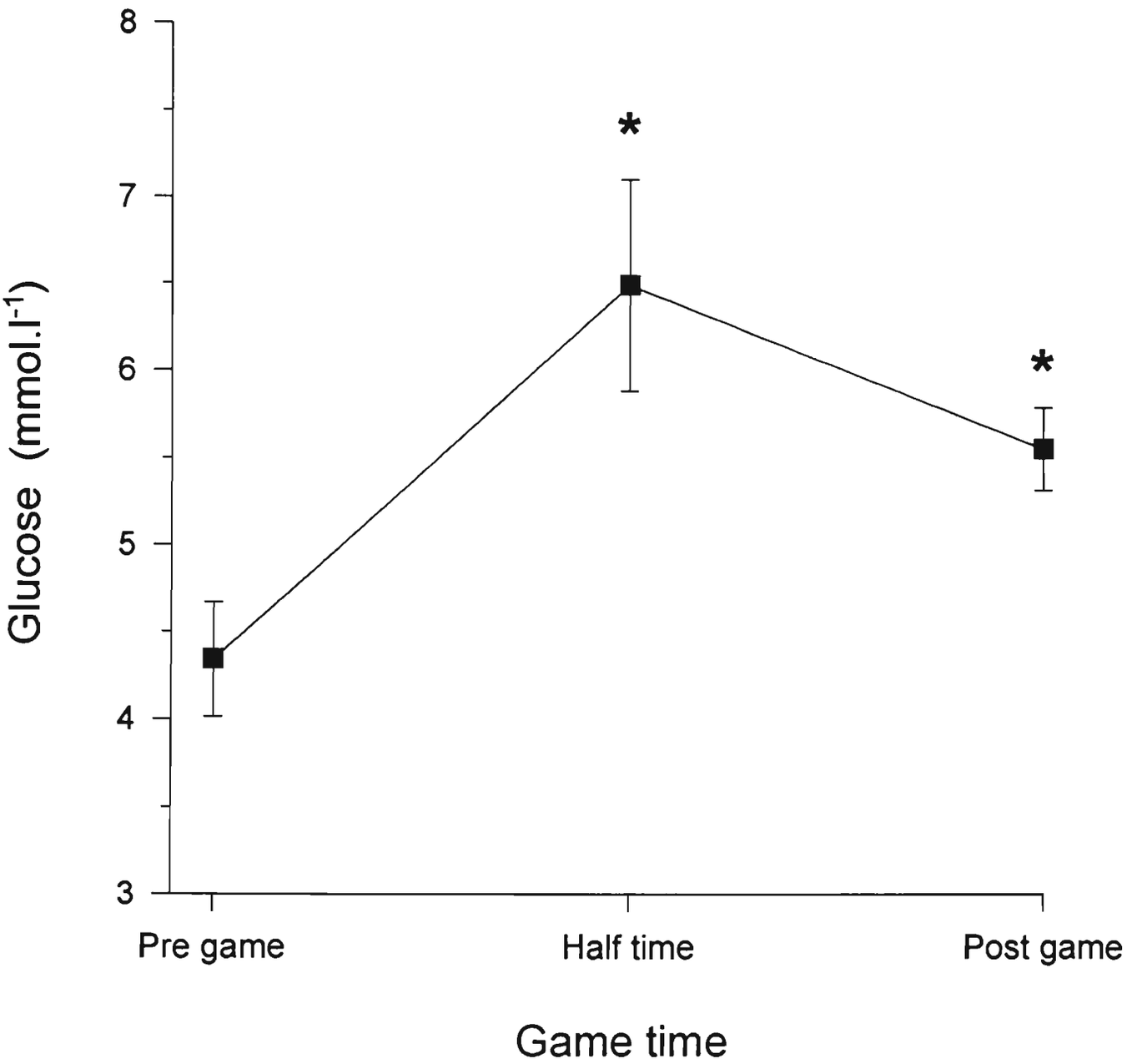
Blood $[Lac^-]_{cap}$ was increased above rest at all times ($P< 0.05$) decreasing ($P< 0.05$) at half time and at the end of the match, at all times remaining higher than resting values (Table 4.15, Figure 3). Venous plasma $[Lac^-]$ was elevated 3 fold at half time and at the end of the match compared to rest ($P< 0.05$, Table 4.16, Figure 4). Despite this, plasma $[H^+]$ was unchanged from rest (Table 4.16). Plasma $[Na^+]$, $[Cl^-]$, $[protein^-]$ and [SID] were all also unchanged from rest. ($p< 0.05$, Table 4.16). Plasma $[K^+]$ was reduced from rest at half time ($p< 0.05$), but this was not significant at the end of the match due to a slightly greater variability. (Table 4.16, Figure 5). Plasma [glucose] was elevated at half-time and at the end of the match compared to PRE($P< 0.05$, Table 4.16, Figure 6).

Table 4.15; Capillary Blood $[Lac^-]$ ($[Lac^-]_{cap}$) before, during (17, 35, 52 min) and following (70 min) a game of field hockey. All data mean ± SD, n=6; * $p<0.05$ significantly greater than PRE, # significant difference between mid-half and the end of each half.

	PRE	HALF			POST
Time (mins)	0	17	35	52	70
$[Lac^-]_{cap}$ ($mmol.l^{-1}$)	1.9 ± 0.3	6.0 ± 1.5#*	4.6 ± 2.5*	6.0 ±2.3#*	4.7 ± 0.4*


Capillary [Lac⁻] (mmol.l⁻¹)
7
6
5
4
3
2
1
*#
*
*#
*
Pre-game
Mid-half
Half-time
Mid-half
Post-game
Game time


7
6
5
4
3
2
1
0
Plasma [Lac⁻] (mmol.l⁻¹)
*
*
Pre game
Half time
Post game
Game time


8
7
6
5
4
3
Glucose (mmol.l-1)
*
*
Pre game
Half time
Post game
Game time

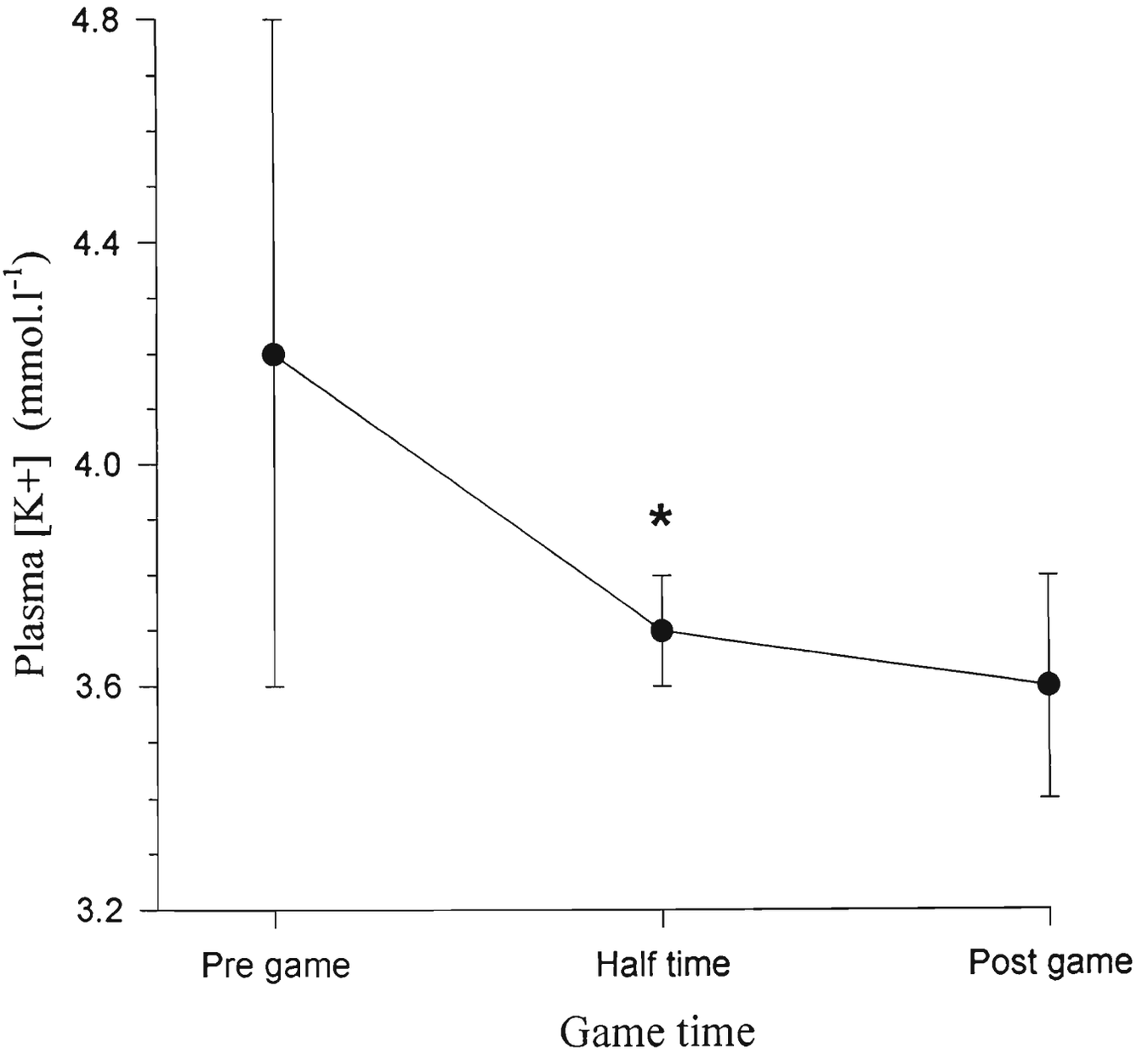

4.8
4.4
4.0
3.6
3.2
Plasma [K+] (mmol.l-1)
*
Pre game
Half time
Post game
Game time

Table 4.16; Plasma electrolyte, glucose and protein concentrations in venous blood sampled before (PRE), at half time (HALF) and at the end of the field hockey match (POST). All data mean ± SD; n=5; * significantly different from PRE, $p<0.05$.

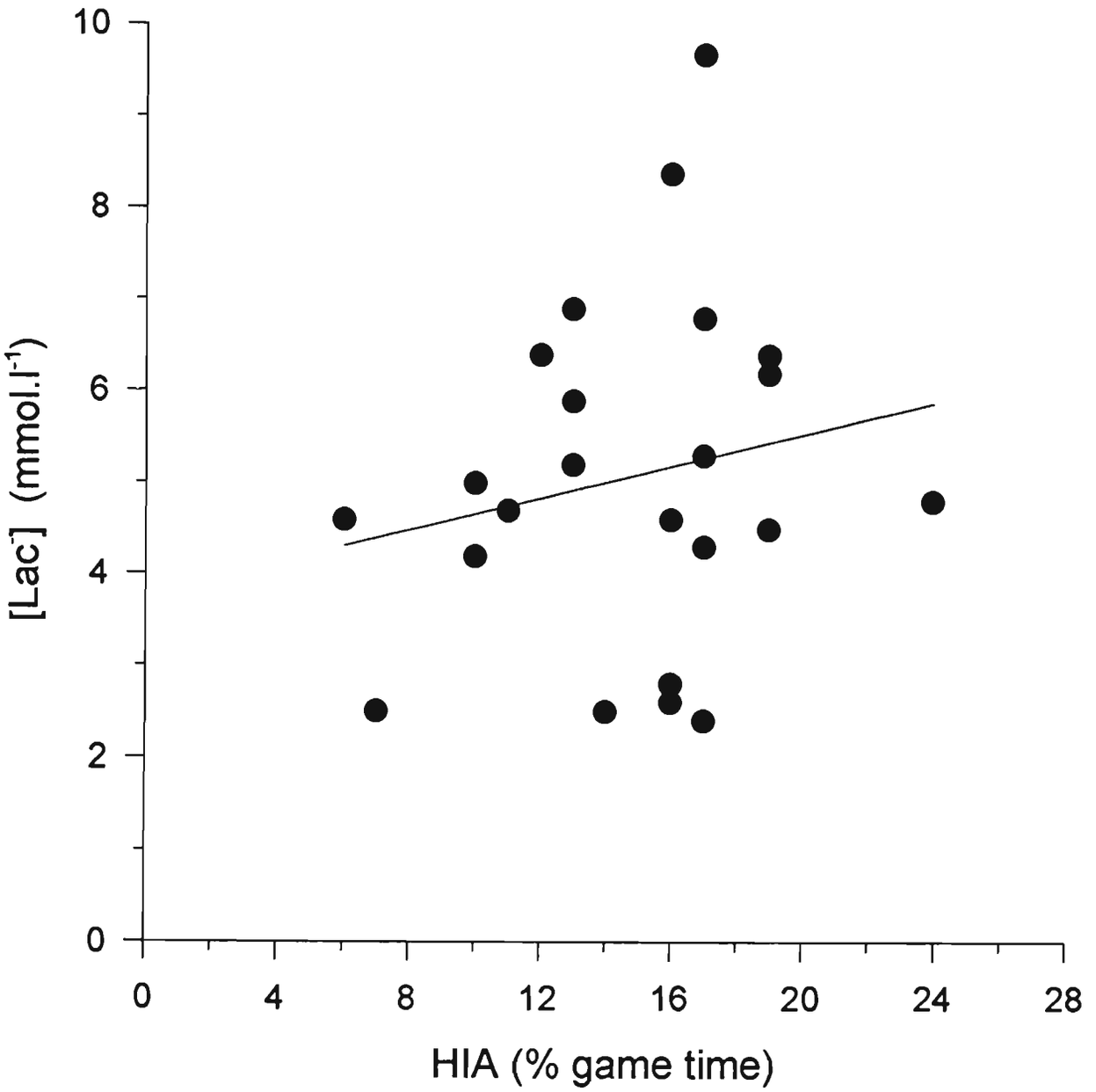
Variable		PRE	HALF	POST
$[H^+]$	$(nmol.l^{-1})$	46.7 ± 4.9	47.5 ± 7.9	48.9 ± 7.3
$[HCO_3^-]$	$(mmol.l^{-1})$	27.9 ± 2.7	21.1 ± 4.2	23.0 ± 1.7
$[Na^+]$	$(mmol.l^{-1})$	139 ± 1 0	138 ± 5	139 ± 1
$[K^+]$	$(mmol.l^{-1})$	4.2 ± 0.6	3.7 ± 0.1*	3.6 ± 0.2
$[Cl^-]$	$(mmol.l^{-1})$	106 ± 2	103 ± 4	106 ± 2
$[Lac^-]_p$	$(mmol.l^{-1})$	1.5 ± 0.5	4.8 ± 3.6*	4.5 ± 1.8*
[SID]	$(mmol.l^{-1})$	36.3 ±2.4	33.1 ±7.2	32.5± 1.4
$[Protein^-]$	$(g.l^{-1})$	71.6 ± 2.3	74.5 ± 3.7	73.8 ± 1.9
[Glucose]	$(mmol.l^{-1})$	4.3 ± 0.7	6.5 ± 1.4*	5.6 ± 0.5*

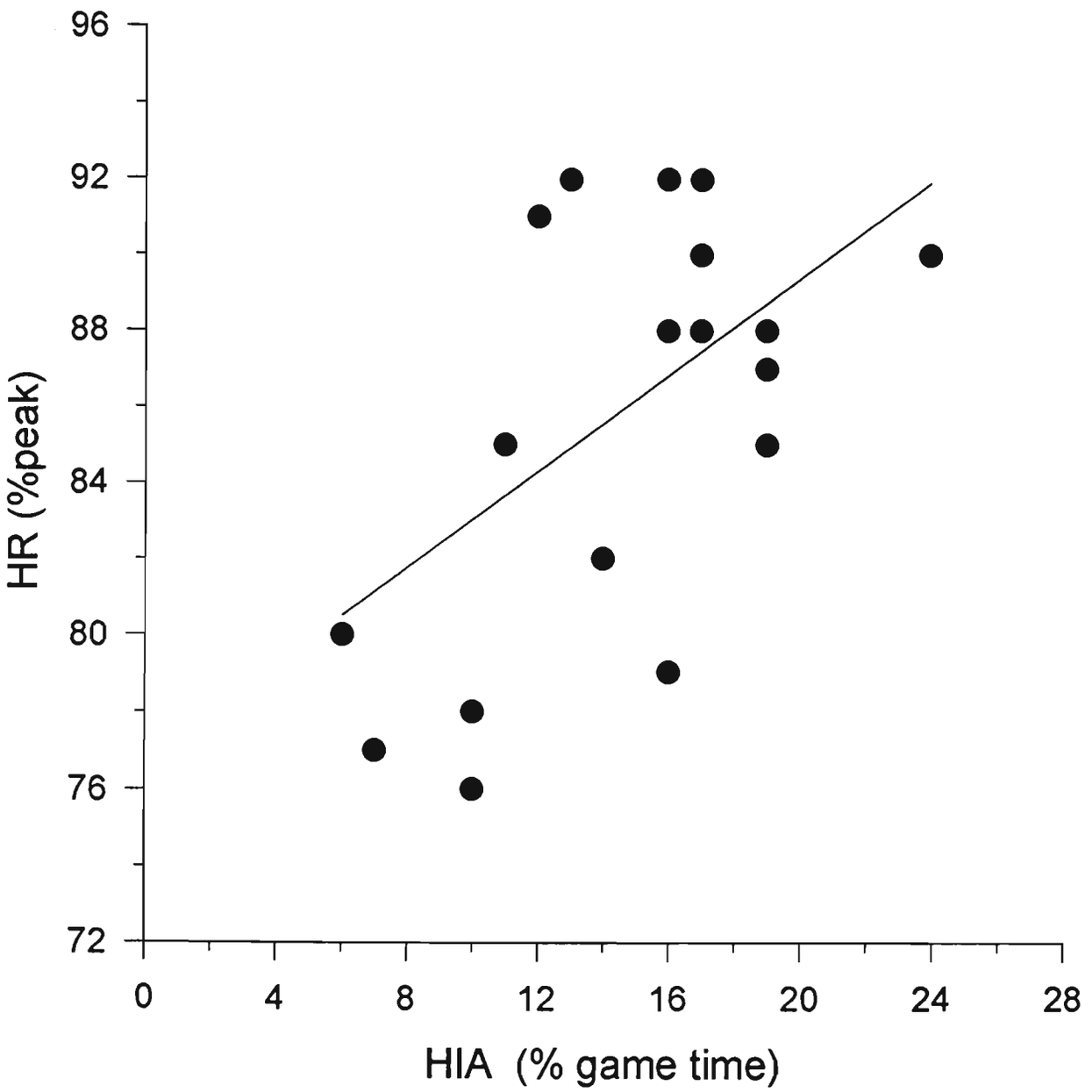
4.8 Integration of activity patterns and physiological responses

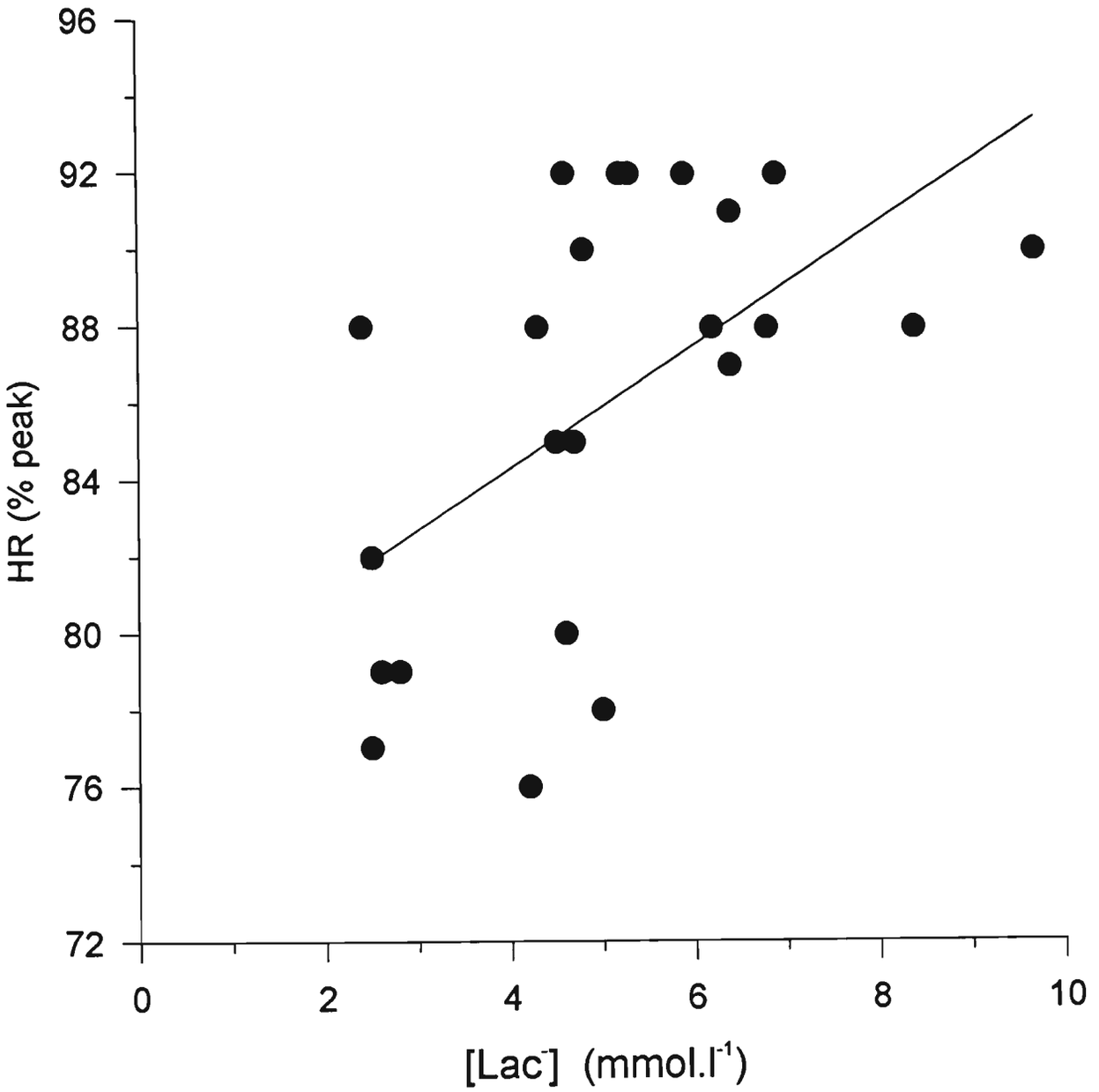
Data for mean percentage of high intensity activity (HIA), work to rest ratios, blood $[Lac^-]_{cap}$ and percentage peak heart rate are given in Table 4.17. There was no significant relationship between the capillary blood lactate and the percentage time spent in HIA five minutes prior to sampling {[Lac-] = 0.1(%HIA) + 3.7 (r=0.22)}(Figure 7). However there was a significant relationship between the percentage of maximum HR and the percentage time spent in HIA five minutes prior to sampling {[HR] = 0.63 (%HIA) + 77 (r=0.49)}(Figure 8) as well as the capillary blood lactate and the percentage of maximum HR five minutes prior to sampling {[Lac-] = 1.6(% of max HR) + 77.9 (r=0.56)}(Figure 9).

Table 4.17; Mean percentage of high intensity activity (HIA), work to rest ratio, blood $[Lac^-]_{cap}$ and percentage peak heart rate data for the five minute interval before the capillary blood samples during field hockey competition. All data mean ± SD; n = 6.

Subject	Mean % HIA	Work / Rest ratio	Lactate	Mean % peak hr
1	12.8 ± 0.5	1:7.0 ± 0.5	6.1 ± 0.7	92 ± 1
2	19.3 ± 3.8	1:4.4 ± 0.8	5.6 ± 3.7	90 ± 1
3	16.5 ± 3.8	1:5.3 ± 2.0	5.7 ± 0.8	88 ± 3
4	15.3 ± 3.8	1:5.8 ± 2.1	4.9 ± 2.5	82 ± 5
5	14.7 ± 1.9	1:5.6 ± 0.8	5.2 ± 1.8	86 ± 2
6	9.8 ± 4.5	1:8.5 ± 1.3	3.7± 1.3	79 ± 1
Mean ± SD	14.7 ± 1.5	1:5.6 ± 0.8	5.2 ± 1.8	86 ± 2


10
8
6
4
2
0
[Lac-] (mmol.l-1)
0
4
8
12
16
20
24
28
HIA (% game time)


96
92
88
84
80
76
72
HR (%peak)
0
4
8
12
16
20
24
28
HIA (% game time)


96
92
88
84
80
76
72
HR (% peak)
0
2
4
6
8
10
[Lac-] (mmol.l-1)

CHAPTER 5

DISCUSSION

This experiment investigated the physiological characteristics of elite women field hockey players, as well as their activity patterns and physiological responses during competition. Comprehensive laboratory testing showed that the subjects tested were in the elite class when compared to published data on international women field hockey players. Integrated analyses of the physiological responses and activity patterns during field hockey revealed a paradox of a low percentage time spent in HIA but a high physiological cost as indicated by high heart rates and blood lactate concentrations.

5.1 The physiological characteristics of elite women field hockey players

Laboratory tests showed that the subjects tested were in the elite class when compared to published data on international women field hockey players. Subjects in this study showed a higher peak power than an earlier report for state hockey players (Withers and Roberts 1981). This may be due to improved testing methodology, together with the increased training requirements of state female hockey players since 1981. The results were somewhat lower than the peak power found for the 1996 Australian National Hockey Squad using the same ergometer (Lawrence, unpublished data). However, this difference can most likely be attributed to different computer software used in the two laboratories.

The peak $\dot{V}O_2$ during treadmill testing was ~25% higher than Australian female white collar workers in the same age range (Green et al. 1995) and similar to Canadian and Australian National female squad members (Lothian and Farrally 1992; Lawrence, unpublished data) and Australian State female hockey players (Withers and Roberts 1981; Walsh, unpublished data). It is very interesting to note that the $\dot{V}O_2$ max for elite women hockey players has not changed appreciably over the past twenty years. The $\dot{V}O_2$ max reported for the above National squads were only 1-3 $ml.kg^{-1}.min^{-1}$ higher than the present results, which can probably be accounted for by fluctuations caused by different testing procedures, individual performance variability or small technical errors. It might be expected that players in the positions of the highest workrate would have the highest peak $\dot{V}O_2$. However, the peak $\dot{V}O_2$ for the six players in this study did not differ from the means for all National and State squad players (Withers and Roberts 1981; Lothian and Farrally 1992; Walsh unpublished data; Lawrence unpublished data). This is consistent with the findings of Withers (1981) who found no significant relationship between $\dot{V}O_2$ max and the position of elite female field hockey players.

The body composition of field hockey players was assessed by measurement of skinfold thickness at seven different sites. Although more precise methods exist for the determination of body composition, such as DEXA scanning (Withers et al. 1992), skinfolds measurements were chosen for this study as they are practical for repeated testing of athletes, inexpensive and reasonably reproducible when performed by an experienced tester (Norton 1996). Reporting of the sum of skinfolds also removes imprecision incurred by estimation of percentage body fat from regression equations, which are population specific (Costill et al. 1970; Wilmore and Behnke 1969). No regression equation has been developed specifically for elite female hockey players.

The sum of 7 skinfold measurements in this study was similar to results from the 1996 Australian women's hockey squad, when comparing the same skinfold sites (Lawrence, unpublished data). There are no published studies that report a sum of skinfolds for female hockey players. Therefore in order to compare the current findings with those of others, a sex-specific regression equation (Sloan, 1962) was used to convert the sum of skinfolds into an estimated body fat percentage. The estimated body fat percentage was 14.4 $\pm$ 5.2 %, similar to results obtained using the same equation for State hockey players (Rate and Pyke 1978), but lower than previous reports for State female field hockey players (Withers and Roberts 1981). This difference may be explained by the selection in this study of players in positions of a high workrate who are presumably advantaged by a lower percentage of body fat. Additionally the discrepancies could be due to the different regression equation (Durnin and Womersley, 1974) used by Withers and Roberts (1986). The Durnin and Womersley (1974) equation has been shown to overestimate percentage body fat, whilst the Sloan (1962) regression equation underestimates body fat percentage in females (Norton, 1996). These data show elite women field hockey players have low levels of body fat when compared to females in the general population (McArdle et al. 1991).

A feature of the testing employed in this study was the intermittent sprint recovery test, involving five 6 second sprints with an intervening recovery period of 24 seconds. This test was designed to simulate high intensity game activity patterns for female hockey players. The players clearly fatigued during the intermittent test, with a significant decrease in peak power output by the third 6 second sprint. The work to rest ratio for the intermittent test (1:4) was higher than that revealed by activity analyses for field hockey (1:5.6±0.4), indicating that the test could only simulate demands during extreme periods of competition during a game. Consistent with this, were the higher blood $[Lac^-]_{cap}$ after the intermittent test, compared to during or after competition. The higher $[Lac^-]_{cap}$ is explained by the greater duration of the intermittent test sprints which were double the average time of HIA during competition. Therefore the sprint recovery test most likely placed a greater emphasis on glycolysis than the game. Measurement of $[Lac^-]_{cap}$ following the three laboratory tests enabled a further indication of the intensity during competition. Capillary blood concentrations during recovery from each of the three laboratory tests indicate that all tests were at a higher level of intensity than most periods of play during hockey, with $[Lac^-]_{cap}$ being 2 - 4 times higher than during the match. The highest recorded $[Lac^-]_{cap}$ for any individual during all of the matches did not reach the level of the average $[Lac^-]_{cap}$ for any of the laboratory tests. The competition $[Lac^-]_{cap}$ were probably also lower due to enhanced lactate clearance from blood during low intensity activity in the recovery periods (Brooks 1986).

5.2 Movement activities during field hockey and other FITS

5.2.1 Critique of methods used.

The computerised time based video analysis method used for the assessment of the activity patterns was similar to that used by McKenna et al. (1987). This method was chosen to minimise errors associated with distance based analyses and was preceded by two sets of pilot testing on elite male and female field hockey players during competition (Walsh, unpublished data). Thus variability was assessed by determining the percentage difference between trials for each category. More common methods to assess variability include the use of a Pearson product moment correlation coefficient, intraclass correlation coefficient and method error (McInnes et al. 1995), but these could not be applied to the present data due to differences in the number of occurrences of the different movement categories. Variability for the number of occurrences and mean duration of each category was high when performed by an inexperienced analyst. This was particularly pronounced for the categories with only a small number of occurrences (eg. stationary, sideways and shuffle). However, this variability was substantially reduced when performed by an experienced analyst. The percentage difference in the number of occurrences between trials for an experienced analyst was less than 10%, apart from the categories of sideways and shuffling. Together these two categories represented approximately 12% of the total number of movement activities in the quarter of play analysed. However the mean duration of these categories was very short ($\leq$1.2 seconds), such that they represented <1% of the total movement. The variability of the mean duration in an experienced analyst was low, being $\leq$8.3% for all movement categories. The results indicate an acceptable level of variability in the movement analysis. The computerised video analysis technique in real time was more variable than frame-by-frame analyses of video recordings (McInnes et al. 1995), but was found to be much more practical and time efficient. Although the method used in this

experiment may make subtle differences to the final analysis results, it does not change the final conclusions regarding the movement activities. It should be emphasised that all analyses during this experiment were performed by an experienced analyst.

5.2.2 Movement activity patterns

Movement analyses indicate that women's hockey is characterised by a rapid turnover of activity (every 3.6 seconds). The duration of stride/sprint efforts (2.9 seconds) was brief, only a small portion of a game spent performing HIA (16%). The game work to rest ratio was 1:5.6. The lack of research prevented a comprehensive specific comparison with published data. It may be argued that a game played by women is different to men, due to women hockey players having a higher percentage of body fat and lower $\dot{V}O_2$ max and peak power values (Lawrence, unpublished research). However it was decided to make comparisons of the activity patterns with other forms of FITS involving male subjects due to the lack of published data on the activity patterns of women FITS players.

i) Frequency of change in events

The frequency of the change of events was very similar to that reported for elite women hockey players (Lothian and Farrally 1992). Due to the differences in the total playing time period for each FITS game a comparison of the number of events for each game is irrelevant. However, calculation of the frequency of the change of events provides relevant information on the intermittent nature of each game. The frequency of change in event for hockey was more than two seconds lower than in rugby (Docherty et al. 1988), soccer (Reilly and Thomas 1976; Mayhew and Wenger 1985; Bangsbo 1991), and Australian rules football (McKenna et al. 1987). Comparison with court intermittent sports such as netball (Otago 1983) and basketball (McInnes et al. 1995) which have a much smaller playing area and a more frequent change of events, further evidence of the conclusion that a more frequent change of events may be a feature of the smaller playing arena size.

The total number of movement activities (1185 ± 111) was similar to that reported for another analysis on women's hockey (Lothian and Farrally, 1992), whilst some soccer analyses (Mayhew and Wenger 1985, Yamanaka et al. 1988) reported a lower total number of movement activities. Similar or lower numbers of movement activities in hockey when compared to other FITS is surprising considering the playing time of other FITS is more than ten minutes longer in duration.

ii) Time spent in the movement categories

Low intensity activity totalled 84 % of game time with the mean duration of the categories stationary, walk and jog being only 3.4, 5.5 and 3.2 seconds, respectively, while the mean duration of the sprint/stride category was 2.9 seconds. The only other published information on women's hockey reported a similar LIA percentage (78%) for the same combination of categories in this investigation however, they did not include time spent in individual categories (Lothian and Farrally 1992). The percentage of time spent in specific movement categories for the remaining published literature on FITS gives varying results within the same sports (see Table 2.3). This may be due to differences between the methods used for analysing the movement activities, as well as differences in the style of the games from one year to the next.

The current published LIA data suggests that hockey players spend proportionately less time at a low intensity than other FITS. The percentage of the stationary category was less than that reported for soccer (Mayhew and Wenger 1985; Bangsbo et al. 1991), Australian rules football (McKenna et al. 1987) and rugby (Moreton 1978) but similar to one soccer study (Ali and Farrally 1991). While the percentage of walking is similar to some soccer reports (Mayhew and Wenger 1985; Bangsbo et al. 1991) and Australian rules football (McKenna et al. 1987). However this similarity is inconsistent because other studies on soccer (Ali and Farrally 1991) and Australian rules football (Jacques and Pavia 1974). have

considerably lower percentages of time in the walking category. Jogging showed a similar percentage of time spent to soccer investigations (Bangsbo et al. 1991; Ali and Farrally 1991) but considerably less than Australian rules football (McKenna et al. 1987) and one study on soccer (Mayhew and Wenger 1985).

Activity analyses in this investigation shows that based on the higher percentage of time spent in the category of striding and sprinting (HIA) illustrates that hockey players appear to play at a higher intensity than Australian rules footballers (Jacques and Pavia 1974; McKenna et al. 1987) and soccer players (Mayhew and Wenger 1985; Yamanaka 1988; Ali and Farrally 1991; Bangsbo et al. 1991). The short average duration of the sprint/stride category in hockey is equivalent to other FITS analyses (Moreton 1978; Withers et al. 1982; Docherty et al 1988; McKenna et al. 1987; Bangsbo et al. 1991). This suggests that players very rarely reach peak velocity, which may suggest a decrease in the need for peak velocity training. Field hockey has a higher percentage of time spent in HIA than other FITS and finally there are many inconsistencies between published data when comparing activity patterns within the same sports and between other FITS.

iii) Work to rest ratios

The game work to rest ratio in this experiment of 1:5.7, which was remarkably similar to the only other published work to rest ratio for women's hockey (Lothian and Farrally 1992). Activity patterns during competition indicates field hockey is a sport characterised by a more rapid turnover of activity and a high but lower percentage than other FITS of the total time involving low intensity recovery from very short high intensity efforts. Soccer generally has a lower work to rest ratio (Reilly and Thomas 1976; Mayhew and Wenger 1985). Surprisingly a more recent study on soccer shows that the work to rest ratio decreased (Bangsbo 1991) from previous studies (Reilly and Thomas 1976; Mayhew and Wenger 1985). Australian rules football (McKenna et al. 1987) has considerably lower

work to rest ratios which could be due to the larger arena providing more area to rest from the more active periods of play.

An interesting finding in the present study was that the work to rest ratio declined significantly in the last quarter. This may be explained by fatigue, as well as the possibility that players activity levels decline because the result of the game is obvious (Ekblom 1986; Bangsbo 1991).

5.3 Physiological responses

5.3.1 Fluid loss

Hockey players have very limited opportunities for fluid intake during a game. Under hot humid conditions maintaining fluid during a hockey game may be difficult as players have very limited opportunities for fluid intake. Field hockey rules do not allow trainers to run onto the ground during the game. Players can only rehydrate during intervals or injury breaks when players move to the sideline for fluid replacement. This investigation indicates that although the humidity was reasonably high all players were able to replace most of their fluid loss which suggests the ambient temperature was not high enough to cause hypohydration. It has been reported that dehydration affects performance when the temperature is over 21 degrees Celsius (Shepherd and Leatt 1987) and more than 2 % of body mass is lost during the game (Costill 1970). Neither of these conditions occurred in this experiment however during warmer conditions heat stress would be a possibility due to the hydration restrictions during field hockey.

5.3.2 Heart rate

Sustained high heart rates were found in this study averaging 157 bts.min^{-1} throughout the game, or 85 % of HR peak. All subjects reached 99.1 % HR peak at some times during the game with rapid declines during rest periods for blood sampling or in between halves. These results are consistent with previous reports for male hockey players (Boyle et al 1992) as well as for other FITS (Seliger 1968a; Cochrane and Pyke 1976; Moreton 1978; Hahn et al. 1979; Patterson 1979; Van Gool et al. 1988; Cochrane and Pyke 1976; Van Gool et al. 1988). Interestingly the only study not to show similar mean heart rates was the only published study on elite female hockey players which produced a higher mean HR and did not report a mean relative HR (Lothian and Farrally 1992). A more valid comparison

between studies is for percentage HR peak and unfortunately these authors did not report a mean relative HR (Lothian and Farrally 1992).

The results of this investigation revealed that subjects spent a mean of 60% of the game time with a heart rate value greater than 85% of HR peak. This is similar to the results reported for women's field hockey (Unpublished data Ekblom as cited by Brewer 1994), men's field hockey (Reilly and Borrie 1992, Cibich 1991) and soccer (Smodlaka 1978). The remaining time was equally divided between percentage of time spent with the HR less than 75% and between 75% and 85% of HR peak. The HR responses to field hockey indicate that the intensity of exercise during competition was high and were similar to those recorded for other FITS.

It was decided not to estimate oxygen consumption in this study based on HR/$\dot{V}O_2$ relationship as strong evidence suggests that too many inherent errors would confuse the assessment of the metabolic requirements of field hockey. The use of HR values to estimate oxygen consumption has been reported for field hockey (Lothian and Farrally 1992) and other FITS (Van Gool et al. 1988; Boyle et al. 1992). Paterson (1979) and MaClaren (1990) suggest that it can provide an estimation of the energy requirements; however, there has been very little research which can validate this method of estimating energy cost during non steady state exercise (McArdle et al. 1981; Tumilty 1993). Balsom (1992a) suggests that HR cannot be used to predict oxygen uptake during intermittent exercise. Costill (1970) claims an increase in body temperature will increase HR during prolonged exercise which potentially could alter the HR/$\dot{V}O_2$ relationship.

5.3.3 Blood analyses

This is the first study to sample capillary and venous blood during a game of field hockey. The capillary samples were used for determination of [Lac^-] during the game, whilst the venous samples allowed more detailed investigations into the fluid shifts, blood gas status, metabolite and electrolyte concentrations. The ease of taking capillary blood samples allows several blood samples during the game providing a more substantial indication of capillary blood lactate concentration. This study also reports for the first time concentrations of venous plasma K^+ and glucose concentrations during a game of field hockey.

i) Lactate

Capillary blood [Lac^-] was substantially increased during and following field hockey, with the highest individual $[Lac^-]_{cap}$ being 9.7 $mmol^{-1}$, the average peak value for all players being 7.2 $mmol^{-1}$ and the average $[Lac^-]_{cap}$ in this investigation being 5.3 $mmol.l^{-1}$.

Of considerable interest was the finding that $[Lac^-]_{cap}$ showed a significant decline between the mid-half sample and the end of half samples. One criticism of the capillary blood sampling methodology is that the mid-half capillary samples were taken with the subject seated at the side of the field, whilst capillary samples taken at half time and the end of the match were taken with the subject lying down. This was due to the prioritisation of supine postural controls for the venous sampling. Higher $[Lac^-]_{cap}$ would be expected for seated than for supine blood sampling, but this haemoconcentration effect would be expected to be substantially less (Harrison 1985) than the 22-23% higher $[Lac^-]_{cap}$ obtained with the subject seated at half- and full-time. Thus, the decline in $[Lac^-]_{cap}$ at the end of the half cannot be explained by altered fluid shifts resulting from postural differences. The decrease in $[Lac^-]_{cap}$ at the end of the halves compared to the mid-halves could have been partly due to the extra minute taken to move into the change rooms for blood sampling. If the subject

had just completed a period of predominantly low intensity activities, $[Lac^-]_{cap}$ would have decreased due to greater lactate clearance time. Alternately, if the subject had completed an intense period of exercise immediately prior to coming off the field, the blood $[Lac^-]_{cap}$ may have continued to rise during the interval before the blood sample. The decrease in high intensity activity as shown by the decrement in work to rest ratio at half time (not significant) and the end of the match may also help to explain the lower capillary lactate concentration at these times. Perhaps the most plausible explanation for the lower concentrations at the end of the halves compared to mid-half samples may be explained by the additional time taken for blood sampling, as well as the decline in work to rest ratios, with the latter being more important in the second half. Soccer studies indicate a similar response in blood lactate and explain this decrease as being due to lower work to rest ratios before the end of the half which may result from the predictable state of the game result and / or low levels of muscle glycogen (Ekblom 1986; Bangsbo1994). It has been reported that a decrease in blood $[Lac^-]$ is related with lower muscle glycogen which may be associated with the periods of play at the end of the game (Ekblom 1986).

The average $[Lac^-]_{cap}$ in this investigation (5.3 $mmol.l^{-1}$) was similar to values reported in Australian rules football (Dawson et al. 1991), Rugby (McClean 1991) and Soccer (Gerisch 1988, Rohde and Esperson 1988). Other published data for the same sports reported slightly lower mean $[Lac^-]_{cap}$ for soccer (Bangsbo 1991) or appreciably lower for rugby (Docherty 1988, Allen 1988). Higher maximum blood $[Lac^-]$ of 10 - 13 $mmol.l^{-1}$ have been reported for soccer (Ekblom 1986; Gerisch et al. 1988; Bangsbo et al 1991; Smith et al 1993). The large range in the concentration of blood $[Lac^-]$ levels reported in the FITS literature (2-13 $mmol.l^{-1}$) and in this investigation (2.5-9.7 $mmol.l^{-1}$) may be explained by the unpredictable nature of FITS which produce sporadic involvement of players in very different work to rest ratios throughout the game and particularly during the period

immediately prior to blood sampling. Higher maximal [Lac$^-$] during male soccer games may indicate that although the involvement of the glycolytic system is high during some periods of play in women's field hockey, the engagement or maximal capacity of the glycolytic system may not be as high as for male soccer players.

Lactate is the one of the end products of glycolysis. Therefore blood lactate can be used to illustrate that glycolysis has been stimulated (Balsom et al. 1992a) and provides some indication of the glycolytic energy supply (Gollnick and Hermansen 1973, Cheetham et al. 1986, McInnes et al 1995). Therefore blood lactate is limited to showing an indication of the nature of metabolic sources of energy during field hockey. The accumulation of lactate in the blood has been used as an indicator of the anaerobic glycolytic turnover during FITS (Bangsbo et al. 1991). The concentration of lactate in the blood is the balance of the entry into the blood from muscle and the removal from the blood by other tissues including the liver and inactive tissues (Brooks 1985, Gollnick and Hermansen 1973). Therefore an increase in blood lactate concentration may be due to either entry into and / or decreased removal from the blood. In addition a large percent of the lactate produced during glycolysis is metabolised within the muscle itself. Despite these limitations the use of blood lactate to reflect the glycolytic contribution to the metabolic demands of FITS is defended because under some conditions an increase in blood lactate can be used to indicate an increase in the use and intensity of exercising muscle.

ii) Glucose

Plasma glucose concentration was elevated at half-time and at the end of the match compared to rest. This response is similar to some studies information on soccer players (Shepherd and Leatt 1987; Leatt and Jacobs 1989). This investigation did not see evidence of low blood glucose concentrations, which may suggest that the ability of the players to make tactical decisions was not decreased (Guyton 1981; Shephard 1982).

It is difficult to make statements about muscle glycogen content from blood glucose concentration. However because the rate of glucose uptake increases as muscle glycogen decreases (Coyle et al. 1986) and this corresponds to decreasing blood glucose concentrations it can be suggested that it is likely there was not major muscle glycogen depletion during the games in these experiment. Reilly and Borrie (1992) suggest that the activity demands of hockey would not lead to depleted muscle glycogen stores by the end of the match however, they do suggest that significant glycogen depletion may occur during a hockey tournament. This is in contrast to soccer matches during which it is reported that players with lower muscle glycogen levels covered less distance in the second half with all players having depleted muscle glycogen levels at the end of their matches (Ekblom 1986). Kirkendall et al (1987) found soccer players covered significantly longer distances with the ingestion of a glucose polymer drink in the second half. This would suggest that, during a hockey tournament or a game in which the player has depleted glycogen stores, a glucose polymer drink may increase distance covered and performance in the second half of the game.

iii) Potassium

The decrease in plasma [K^+] in this study at half time and the end of the match from rest is consistent with exercise induced activation of the Na^+ K^+ pump which after exercise may lower [K^+] to sub resting values. (Medbø and Sejersted 1990). This suggests that plasma [K^+] most likely oscillates during a game increasing during exercise and decreasing during recovery but more measures need to be taken for this to be substantiated.Elevations in plasma [K^+] may contribute to fatigue but this cannot be substantiated by this study.

iv) Other biochemical changes

Despite the 2-3 fold elevation in plasma lactate concentration plasma [H^+] was unchanged at the end of each half. This may be explained by the lack of change in any of [SID], PCO_2 and plasma protein concentration, which collectively determine the plasma [H^+] (Kowalchuk et al. 1988). The other biochemical changes in blood during the games were minimal.

5.3.4 Summary

The physiological responses during competition imply that performance was not affected by the environmental conditions as body mass was unchanged by the match indicating that fluid intake was sufficient to match calculated sweat loss. The mean % HR peak during competition was high and comparable with other studies on elite FITS, blood lactate was 2-3 fold higher than rest and plasma glucose concentrations during matches showed similar responses to intermittent exercise performed in other studies. Unlike previous research on soccer, there was no significant relationship between the blood lactate responses and the % of HIA just prior to blood sampling. However, the relationship between heart rate and the % of HIA, as well as between heart rate and blood lactate during the same periods were significant. This could be explained by the increased work required during field hockey which unlike continuous sports have the additional energy requirements of repeated and

dramatic changes of direction and speed and also the stooping action when playing the ball or defending. This study reveals that the intensity during hockey is high and places considerable demands on the cardiovascular system. Reflected by sustained high heart rates. The 2-3 fold increase in venous plasma [Lac^-] and $[Lac^-]_{cap}$ during the game compared to rest suggests that glycolysis is an important energy source during a game of field hockey.

5.4 Integration of the movement activities and physiological responses in women's field hockey

In this study the continuous variables of HR and time motion analysis and the discrete biochemical measures from capillary and venous blood samples were used to firstly identify the sources of muscular energy during field hockey.

The HIA efforts were very brief, lasting on average less than 3 seconds, which would suggest that anaerobic energy sources and particularly ATP and CP were the principal sources of energy. However, the maximum duration of HIA ranged up to 12.7 seconds, during which time glycolysis would have been a major provider of energy. In addition the very short recovery intervals (on average <20 seconds) between HIA would indicate that resynthesis of CP would be incomplete and therefore require an additional contribution from glycolysis in subsequent HIA. This explanation would be consistent with the 2-3 fold increase in blood [Lac^-] which suggests that glycolysis was an important contributor to energy metabolism during field hockey. Thus, although only a small percentage of time was spent in HIA (16%) anaerobic energy sources were most likely very important in field hockey. The vast majority of time was spent in LIA, which suggests the predominance of aerobic metabolism during the match. Likely fuels for this include the oxidation of lactate, glucose and free fatty acids. There have been no detailed studies investigating the rates of appearance and disapearance of these substrates during intermittent sports. However it is likely that oxidation of each of these fuels would be increased during the LIA periods (Saltin et al. 1976).

In this investigation a paradox existed between the high physiological cost and predominantly low intensity activity patterns. This paradox may be partially explained by additional energy requirements unique to field hockey. The relative heart rate and blood [Lac^-] responses during soccer and field hockey are similar however, the work to rest ratios

and the frequency of the change in the movement activities are higher in field hockey. This suggests that the activity patterns in field hockey are at a higher intensity than soccer. Arm and shoulder movements when using the hockey stick (Reilly and Borrie 1992) and the additional energy cost of the stooping action when playing the ball (Reilly and Seaton 1990) both contribute to the extra total energy requirements of field hockey. The severity of the physiological cost during matches may also be influenced by the synthetic playing surface, other FITS (eg. soccer) are played on grass. According to Malhotra (1983) the more consistent surface and the increase in the speed of the ball due to less friction has caused changes to the style of play which may suggest an increase in the physiological requirements of the game. A portion of the extra energy expenditure in FITS appears to involve overcoming inertia and decelerating the body mass (Reilly and Borrie 1992) which is not as exaggerated in continuous sports. During ice hockey it is reported that the work done during acceleration and deceleration is not shown when studying the velocity analysis (Green et al 1976). Similar conclusions were reached by reports on football codes (Mayhew and Wenger 1985, McKenna et al.1988). Therefore the additional physical requirements due to unique skills and the playing surface of field hockey and the added physiological cost of changing speed and direction in FITS may explain the paradox between the physiological responses and activity patterns in field hockey. Following this the estimation of metabolic requirements from the activity patterns during field hockey is questionable without the physiological responses of heart rate and blood lactate concentrations. Unlike previous research on soccer (Bangsbo 1991), there was no significant relationship between blood [Lac^-] and the %HIA just prior to blood sampling. This suggests that blood [Lac^-] is a poor marker of the total amount of HIA and presumably, the number and duration of these events during a game of field hockey. It is possible for example that a single long HIA may markedly affect the resultant blood [Lac^-], but have minimal impact on the %HIA. The

relationships between relative heart rate and the %HIA, as well as relative heart rate and blood [Lac^-] during the same periods were significant, but these were not strong relationships. These indicate that each of the three variables were to some extent dependent on common factors. Each of the two physiological responses would fluctuate markedly during the game due to the sporadic nature of HIA and game activities and the resultant varying sources of muscular energy.

5.5 Conclusions

This experiment investigated the physiological characteristics of elite women field hockey players, as well as their activity patterns and physiological responses during competition. As Body mass was unchanged by the match in a cool environment this suggests performance is also unlikely to be adversely affected. Comprehensive laboratory testing showed that the subjects tested were in the elite class of women hockey players. Post laboratory test lactate concentrations were considerably higher than peak values recorded during a game of field hockey indicating that standard laboratory tests for hockey players were at a higher intensity than most periods of a game. Activity analyses revealed that work to rest ratios during hockey were higher than soccer however the physiological cost of both sports appears to be similar. This may be due to the unique synthetic playing surface and the physiological strain of specific hockey skills. Blood lactate concentrations were 2-3 fold higher than rest whilst, plasma glucose concentrations during matches showed similar responses to intermittent exercise in other studies. Integration of the physiological responses and the activity patterns during field hockey shows a paradox between a very low percentage of time spent in HIA, but a high physiological cost. This could be explained by the activity patterns during FITS which unlike continuous activities have the additional energy requirement of repeated and dramatic changes in acceleration, deceleration and direction and also the stooping action when playing the ball or defending.

5.6 Exercise Prescription for Elite female field hockey players

The dilemma of exercise prescription is finding the right formula for a particular individual. The level of competition, time available, employment demands, level of fitness, playing position, injury status and style of play all effect the prescription used. For example state field hockey players play a competition over five weekends with two games each weekend and train up to 8-9 times per week. An international tournament is eight games over a fortnight and preparatory training is up to 10-15 sessions per week. Therefore the International tournaments are more demanding however, the player has more time to prepare because of the financial support by government funding providing more time to train and recover and a greater commitment and desire to reach the top in their sport.

The following five month exercise prescription is tailored for a state hockey player with an average level of fitness (VO_2 Peak 51ml.kg.min^{-1}, Skinfolds of 72 mm for seven sites), playing in the position of the highest workrate, with no predisposition to injury and able to train seven times per week.

Phase 1 - Preparatory phase (2 months)

I) Endurance training

The majority of aerobic work during this period would be in the range of 75-85 % of the player's maximum heart rate for 30 - 90 minutes. The predominant mode during this period should be running with a range of 2-4 sessions per week. For the first month the player would complete 3-4 sessions per week and the second month 2-3 sessions.

ii) Sprint recovery/Speed training

One session per week of swimming or riding as part of the aerobic training with a work to rest ratio of 1:6.

iii) Resistance training

For the first month the player would complete 2-3 sessions per week and the second month 3-4 sessions. The range of repetitions would be 10-15 for the first month and 5-10 for the second. Including 200 abdominal exercises and 10-20 mins of stretching. One session of 10-ten 25 metre "all out" sprints per week throughout the entire program would help to nurture the speed.

iv) Skills training

Two sessions per week

Phase 2 - Specific Preparatory Phase

i) Endurance training

The majority of aerobic work during this period would be at a low intensity 75 - 85 % for 45 -120 minutes and a frequency of 2-4 sessions per week. The predominant modes during this period should be swimming and bike riding. For the first month the player would complete 3-4 sessions per week and the second month 2-3.

ii) Sprint recovery

Skills training would include two specific game play sessions with a work to rest ratio of 1:5 for the first month and 1:4 for the second month.

iii) Resistance training

For the first month the player would complete 2-3 sessions per week and the second month 3-4. The range of repetitions would be 3-5 for the first month and 5-10 for the second incorporating more specific powerful movements along with weight training lifts. 400 abdominal exercises and 10-20 mins of stretching during each session.

iv) Skills training

3-4 sessions per week.

v) Games

1-2 per week

Phase 3 - Competition phase

i) Endurance training

The majority of aerobic work during this period would be at a very low intensity 75% for 45 -60 minutes. One 30 min run and one swim or bike ride both at 75% of maximum heart rate.

ii) Sprint recovery

Skills training would include 2-3 specific game play sessions with a work to rest ratio of between 1:4 and 1:5.

iii) Resistance training

One weight training session per week with a range of repetitions at 3-5. 400 abdominal exercises and 20 mins of stretching during each session. One speed/sprint session of 10-25 metre "all out" sprints per week.

iv) Skills training

3-4 sessions per week

v) Games

2-3 per week

5.7 Directions for future research

It is recommended that the physiological characteristics of FITS players be obtained prior to major competition with similar standards of teams using standardised exercise testing and analysis procedures.

Sufficient studies exist for either FITS or CITS to focus on making a literature review for an intermittent sport more specific to the size of the playing area which in turn affects the nature of the activity patterns.

It is recommended that more research investigate the activity patterns of elite and sub-elite women field hockey players. Very little published data has investigated field hockey. The most objective analysis of intermittent sport activity patterns should include a classification of a range of reliable movement types, the determination of time spent in each movement activity and calculated work to rest ratios during the game.

Included in an investigation of FITS activity patterns should be the physiological characteristics of the subjects, the measurement of physiological responses, fluid regulation and the environmental conditions. Together all of these will provide a more valid and reliable assessment of the physiological cost of the game.

Appendix 1

Subject information and informed consent

" PHYSIOLOGICAL CHARACTERISTICS, ACTIVITY PATTERNS AND PHYSIOLOGICAL RESPONSES OF ELITE WOMEN FIELD HOCKEY PLAYERS DURING COMPETITION "

INVESTIGATORS:
DR MICHAEL McKENNA, DR JOHN CARLSON AND MR RICHARD WALSH.
DEPARTMENT OF PHYSICAL EDUCATION AND RECREATION, VICTORIA UNIVERSITY OF TECHNOLOGY .

Aims of the study :
This study will investigate the relationship between activity patterns and the corresponding heart rate and blood biochemical responses that occur during a game in elite women hockey players.

Analysis of this data will help to provide the first substantial physiological profile on elite female hockey players during a game. As a result of this study the Human Performance Unit at Victoria University of Technology hopes to enhance the prescription of exercise programs for women's hockey.

INFORMATION SESSION

Prior to the test the subject will receive a verbal and written explanation of the test procedures. They will also be asked to fill in an informed consent form.

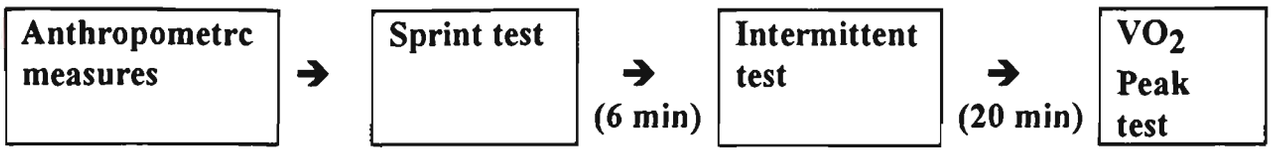
The tests to be conducted include;

1) **PHYSIOLOGICAL TESTS** (within two weeks of the field measurements)

This will involve a one and a half hour visit to Victoria University of Technology.

a) **Body Composition** will be measured using Harpenden skinfold calipers. (seven sites)
b) **Sprint test** - this will involve one sprint test on a bike for 10 seconds. From this test we will be measuring peak power and the work done. Three fingerprick blood samples will be taken one, three and five minutes post exercise.
c) **Intermittent test** - this will involve five six second sprints with twenty four seconds recovery after each sprint. Three fingerprick blood samples will be taken one, three and five minutes post exercise.
d) **Vo2 Peak test** - this involves measuring expired gases while the subject is running on a treadmill. The speed and gradient of the treadmill will be progressively increased until the subject reaches exhaustion. Three fingerprick blood samples blood samples will be taken one, three and five minutes post exercise.

Laboratory Measurements (Figure 2)



2) FIELD MEASUREMENTS

Before and after the game you will be filmed while walking and running at different speeds. This information will help us to analyse the activity patterns of players during a game. **This procedure will take approximately 10 minutes for each player.**

NON INVASIVE

1) CONTINUOUS

Heart rate will be monitored throughout the game using a Polar PE 4000 sports tester.Activity patterns will be measured by videotape while the subject is playing.

2) DISCRETE

Body mass will be measured before and after the game in a private room (wearing underwear). Perceived exertion, which is a subjective measure of the intensity of the previous period of exercise, will be measured during the game in both halves, at half time, and at the end of the game. Fluid intake will be determined by measuring the amount of water swallowed after the first measurement of body mass. Urine output will measured after the first body mass measurement, so that body weight losses will reflect fluid losses due to sweating.

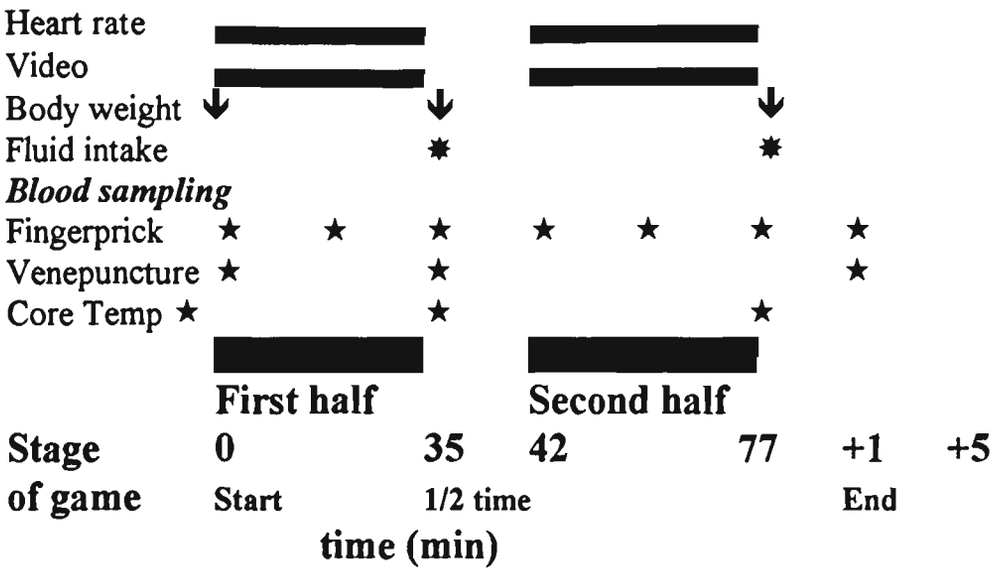
INVASIVE

Blood sampling

During the game **blood will be taken halfway through the first and second halves**. This will be done using a small lancet needle to take blood from the finger. This will tell us the level of lactic acid produced during a game.

Blood will also be taken two hours before the game, at half time and immediately after the game (one min post and five minutes post). At these times blood will be drawn from a needle inserted into the antecubital vein in the arm while the player is lying on a couch. These needles for drawing blood are used routinely for clinical purposes and exercise testing : however slight bruising may occur at the site of the needle insertion. On very rare occasions blood clots may form. To avoid any risk of infection, all needles, syringes and pads will be sterile and not previously used. These items will be immediately discarded after use. The drawing of the blood will be supervised by the team doctor -
Dr Jill Grogan. These samples will tell us blood glucose and pH levels obtained during a game of hockey.

Field measurements (Figure 1)



By signing the attached informed consent form you are indicating that the tests and procedures have been explained to, and understood by you. Also, it is accepted by the investigators and yourself that you are voluntarily participating in the study and that you are free to withdraw from the study at any time.

Thank you for your co-operation.

For further information contact

Richard Walsh 688 4160 (w) 8597016 (h) or
Dr Michael McKenna 6884499 (w)
Department of Physical Education and Recreation,
Victoria University of Technology.

VICTORIA UNIVERSITY OF TECHNOLOGY

STANDARD CONSENT FORM FOR SUBJECTS INVOLVED IN EXPERIMENTS

1 CERTIFICATION BY SUBJECT

I,
of
certify that I have the legal liability to give valid consent and that I am voluntarily giving my consent to participate in the experiment entitled

being conducted at the Victoria Hockey Centre by:

I certify that the objectives of the experiment, together with any risks associated with the procedures listed hereunder to be carried out in the experiment, have been fully explained to me by:

and that I freely consent to participation involving the use on me of these procedures.

Procedures - See Subject information sheet.

I certify that I have had the opportunity to have my questions answered and that I understand that I can withdraw from this experiment at any time and that this withdrawal will not jeopardise me in any way.

Signed

Witness other than the experimenter Date

2. CERTIFICATION BY THE COORDINATOR OF THE TESTS

I, have fully explained the objectives, risks and procedures of the above named experiment to the subject named herein.

Signed Date

NOTES

1. Those signing this form are reminded that while research workers have a duty to advance knowledge by research, the rights of the individual subject take precedence over the expected benefits to knowledge or to the community.

2. The experimenter is reminded of the need to observe confidentiality, when appropriate, to protect the interests of the subjects.

3. Subjects who are employees of the University should be advised that participation in the experiment does not effect in any way their entitlement or right to receive workers compensation.

Schedule for field testing

Week Before

Present ideas/plans/rationale to the group.

Organise 2 players to be tested - confirm with coach and players

- meet with the players.
- explain the perceived exertion scale.
- organise explanation of testing procedure, preparation for the game and informed consent form.
- ask players to arrive one and a half hours before the game.

Organise Doctor to take blood

Doctor to arrive one and a half hours before the start of the game.

Organise assistants to film players, provide them with written instructions before the test and an explanation of procedures. Ensure they bring wet weather gear.

Pre game

Ensure sports tester batteries are charged and that the time on each watch is synchronised with master watch.

Ensure all equipment is calibrated.

Blood analysis equipment is ready.

Equipment required

Hire cameras from EDD - tripod stands , spare batteries for each camera, cassette tapes, plastic covers in case it rains.

Sports testers - gel , ankle tape, sweat bands.

Electronic scales - ensure they are calibrated (extra battery).

Metre wheel, large bag and witches hats, stop watches from the sports centre.

Master clock.

One litre measuring flask..

Hct centrifuge

Eppendorf centrifuge

Vibrating device

All blood analyses consumables.

Heparin and perchloric acid.

Tourniquet, Needles (21 gauge), alcohol swabs, Sharps bucket, stop cocks, syringes and caps

Eppendorf tubes

Gauze, Tape, band aids, gloves, ice

Tubes and putty

Stickey labels, absorbent paper, pen and scissors.

Lab coat

Miscellaneous
Perceived exertion chart, informed consent forms and 24 hr inventory forms.
Esky, ice buckets, ice, blutac, power board, chocolate bars and fruit juice, clip boards and data sheet.

Testing Day
Arrive at the ground two and a half hours before the start of the game.
Set up cameras
Set up the room for taking blood etc.
Set up area for measuring stride length etc

Player preparation
Fill in 24 hr inventory forms.(with information on diet, exercise and amount of sleep.)
Ask subject to go to the toilet.
Obtain weight in underwear in separate room. Fill water bottle to the top, subject should only drink from this water bottle. If they need to go to the toilet the urine excreted must be measured
Player to get changed.
Place hand in warm water for five minutes
Obtain finger prick blood sample and resting venepuncture (supine) blood sample.
Put sports tester on right wrist of the player and sweat band over the top. Ask player not to touch buttons on sports tester until they are told.
Get player to warm up (3 laps and 5 mins of stretching) Video player over 20 metres at various types of locomotion. (walk, jog, sideways, stride and sprint)

Just prior to the start of the game.
Ensure the cameras are rolling on the player.
Start the stop watch on the sports tester and record the time on the data sheet.
Record the time at the start of the game.

Half way through the first half obtain fingerprick blood sample and perceived exertion.(record the time)

Half time
Record time at the end of the half..
Player should be advised before the game that they are to jog directly to the testing room.
Obtain perceived exertion level
Obtain blood sample by venipuncture and fingerprick blood sample within one minute if possible.(record the time on the master clock)
Obtain temperature measurement.
Ensure sports tester is still working.
Check fluid intake and fill bottle again before the start of the second half.

Half way through the second half obtain fingerprick blood sample and perceived exertion.

Full time

Obtain perceived exertion level
Push stop button on the sports tester and record the time.
Obtain venous and fingerprick blood sample within one minute.
Obtain weight in underwear and check fluid intake.
Player to change into dry clothes.
Video subjects at various types of locomotion. (walk, jog, sideways, stride and sprint)

Appendix 2

Physiological characteristics of elite women hockey players.

Anthropometric, exercise performance and accompanying physiological data for all laboratory tests, specifically body mass, height, sum of 7 skinfolds, 10 second sprint, intermittent sprint exercise and maximal incremental exercise, are presented in Tables A1 - A7. All data mean ± SD; n = 6. In the following appendices pilot testing is listed as test 1 whilst test data for this investigation is reported as test 2.

Table A 1

Anthropometric results

Test 1

Subject	Age	Body mass	Height	Skinfolds Sum of 7
	(yrs)	(kg)	(cm)	(mm)
1	23	59.0	164.0	90.1
2	26	50.7	153.5	70.3
3	22	67.9	172.0	105.1
4	25	60.4	163.5	73.6
n	4	4	4	4
mean	24.0	59.5	163.3	84.8
sd	1.8	7.0	7.6	16.1

Table A2

Anthropometric results

Test 2

Subject no	Age (yrs)	Body mass (kg)	Height (cm)	Skinfolds Sum of 7 (mm)
1	23	58.2	164.8	78.4
2	26	50.1	153.6	69.9
3	22	70.2	173.3	113.7
4	25	59.1	164.4	63.7
5	25	70.2	174.5	83.8
6	23	47.4	159.0	63.5
n	6	6	6	6
mean	24.0	60.0	164.9	77.9
sd	1.5	8.6	8.4	19.4

Table A3

Test 1

Performance data during a ten second sprint test. 10 sec bike sprint

Subject	Peak Power (W)	Peak Power ($W.kg^{-1}$)	Time to peak (s)	Work done (kj)	Rest Hla ($mmol.l^{-1}$)	Hla (1) ($mmol.l^{-1}$)	Hla(3) ($mmol.l^{-1}$)	Hla (5) ($mmol.l^{-1}$)
1	746	12.6	5.3	5.5	-	7.8	-	8.3
2	677	13.3	6.6	4.7	-	6.3	-	7.8
3	858	12.6	4.2	6.7	-	10.4	-	11.4
4	708	11.7	4.7	5.2	-	7.5	-	7.2
n	4	4	4	4	-	4	-	4
mean	747	10.1	5.2	5.5	-	8.0	-	8.7
sd	79	0.7	1.0	0.9	-	1.7	-	1.9

Table A4

Test 2

Performance data during a ten second sprint test.

Subject	Peak Power (W)	PeakPower ($W.kg^{-1}$)	Time to peak (s)	Work done (kj)	Wk done ($mmol.l^{-1}$)	Rest Hla ($mmol.l^{-1}$)	Hla (1) ($mmol.l^{-1}$)	Hla(3) ($mmol.l^{-1}$)	Hla (5) ($mmol.l^{-1}$)
1	879.	15.1	4.9	7.6	130.6	-	8.2	8.9	8.8
2	763.	15.2	6.4	6.7	133.7	1.4	9.4	8.4	8.1
3	1071.	15.2	4.4	7.8	111.1	0.9	7.3	8.7	7.7
4	794.	13.4	4.4	6.8	115.0	1.1	9.9	8.9	7.1
5	1125.	16.0	5.0	9.4	133.9	1.3	9.1	9.7	9.3
6	707.	15.0	4.9	6.0	126.5	0.9	8.6	9.1	8.2
n	7	7	7	7	7	7	7	7	7
sd	171.	1.0	0.7	1.2	9.8	0.23	0.9	0.4	0.8
mean	912	15.2	5.0	7.3	123.0	1.1	8.8	9.2	8.2

Table A5

Test 1

Peak workrate, respiratory and cardiovascular data during maximal incremental exercise.

Subject	HR (bts.min^{-1})	RER	$\dot{V}e$ (litres)	$\dot{V}O_2Max$ (ml.kg^{-1} min^{-1})	Max (l.min^{-1})	Hla 1' (mmol.l^{1})	Hla 3' (mmol.l^{-1})	Hla 5 ' (mmol.l^{-1})
1	180	1.10	127	51.0	3.04	13.3	-	12.3
2	192	1.16	94	57.0	2.90	12.0	-	11.6
3	190	1.12	103	46.3	3.20	13.5	-	12.7
4	178	1.15	103	46.7	2.79	12.8	-	12.4
n	4	4	4	4	4	4	-	4
mean	185	1.13	107	50.3	2.98	12.9	-	12.3
sd	7.02	0.03	14	5.0	0.18	0.7	-	0.5

Table A6

Test 2 $\dot{V}O_2$ Max test

Peak workrate, respiratory and cardiovascular data during maximal incremental exercise.

Subject	HR (bts.min^{-1})	RER	$\dot{V}e$ (litres)	$\dot{V}O_2$ Max (ml.kg^{-1} min^{-1})	Max (l.min^{-1})	Hla 1' (mmol.l^{-1})	Hla 3' (mmol.l^{-1})	Hla 5 ' (mmol.l^{-1})
1	182	1.10	127.7	51.0	2.99	12.6	12.8	12.0
2	188	1.14	85.8	53.7	2.69	10.1	10.7	10.1
3	190	1.12	103.3	46.3	3.20	13.5	-	12.7
4	178	1.15	103.4	46.7	2.79	12.8	-	12.4
5	184	1.15	125.0	55.2	3.78	12.1	12.5	11.9
6	187	1.05	109.1	54.6	2.62	10.9	11.3	10.0
7	192	1.27	130.3	55.3	3.57	11.3	11.6	11.0
n	7	7	7.0	7	7	7	7	7
mean	185.9	1.1	112.1	51.8	3.1	11.9	11.8	11.4
sd	4.8	0.1	16.3	3.9	0.5	1.2	0.9	1.1

Table A7
Intermittent sprint test performance data.

	Work done (kj)					Work (J/kg)					Peak Power (watts)					Peak Power (watts /kg)					Hla 1	Hla 3	Hla 5
No	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	mm	mm	mm
1	4.2	4.2	3.8	3.9	3.4	72.1	72.1	65.3	67.0	58.4	820	830	794	812	784	14.1	14.3	13.6	14.0	13.5	13.3	13.7	
2	3.5	3.3	3.2	3.3	3.0	69.9	65.9	64.0	65.9	60.0	704	677	636	660	643	14.0	13.5	12.7	13.2	12.8	12.4	12.4	12.5
3	4.8	4.4	4.3	4.0	3.9	70.6	64.8	63.3	58.9	57.4	931	868	840	803	797	13.3	12.4	12.0	11.4	11.3	13.7		14.0
4	3.8	3.6	3.5	3.3	3.3	64.3	60.9	59.2	55.8	55.8	771	715	687	682	665	13.0	12.1	11.6	11.5	11.2	13.7	13.3	13.0
5	5.7	5.1	4.9	4.7	4.7	81.1	72.6	69.8	67.0	67.0	1065	1005	945	920	920	15.2	14.3	13.5	13.1	13.1	12.8	13.0	13.3
6	3.4	3.0	2.9	2.9	2.9	71.7	63.3	61.2	61.2	61.2	665	605	590	568	581	14.1	12.8	12.5	12.0	12.3	12.6	13.0	13.2
n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5
mean	3.7	3.9	3.8	3.7	3.6	60.2	66.6	64.9	62.3	61.4	699	782	755	738	736	142.3	13.2	12.8	12.5	12.5	13.1	13.0	13.3
sd	1.0	0.9	0.9	0.8	0.8	28.3	4.8	5.0	4.4	4.7	176	175	158	152	149	1.0	1.0	0.8	0.8	0.9	0.6	0.2	0.4

Appendix 3

Activity patterns of elite women hockey players during competition

Table A8 -13. Summary of activity patterns for individual subjects during a game of field hockey, n=6.

Table A8. Summary of activity patterns for subject 1 during a game of field hockey.

Subject 1	Stationary	Walk	Jog	Sideways	Sprint/Stride	Shuffle
n	111.0	355.0	410.0	62.0	175.0	102.0
Time (secs)	434.4	1708.9	1376.9	85.8	475.3	153.1
mean	3.9	4.8	3.4	1.4	2.7	1.5
SD	6.8	4.9	2.6	0.6	2.1	0.8
Min	0.8	0.8	0.1	0.8	0.8	0.8
Max	40.4	31.5	13.7	4.5	12.4	6.6
% n	9	29	34	5	14	8
%Time	10	40	33	2	11	4

Table A9. Summary of activity patterns for subject 2 during a game of field hockey.

Subject 2	Stationary	Walk	Jog	Sideways	Sprint/Stride	Shuffle
n	53.0	286.0	451.0	131.0	225.0	186.0
Time (secs)	181.6	1453.2	1450.0	203.8	589.3	230.0
mean	3.4	5.1	3.2	1.6	2.6	1.2
SD	4.4	4.6	2.9	1.0	2.1	0.5
Min	0.8	0.8	0.0	0.8	0.8	0.2
Max	21.6	22.4	25.8	8.9	11.0	4.5
% n	4	21	34	10	17	14
%Time	4	35	35	5	14	6

Table A10. Summary of activity patterns for subject 3 during a game of field hockey.

Subject 3	Stationary	Walk	Jog	Sideways	Sprint/Stride	Shuffle
n	120.0	341.0	362.0	57.0	156.0	144.0
Time (secs)	334.0	1905.1	1178.4	84.9	505.0	204.0
mean	2.9	5.2	3.3	1.6	3.4	1.4
SD	2.9	5.6	2.7	0.7	2.4	0.9
Min	0.8	0.8	0.6	0.8	0.8	0.8
Max	15.0	44.2	14.8	4.0	11.6	7.8
% n	10	29	31	5	13	12
%Time	8	45	28	2	12	5

Table A11. Summary of activity patterns for subject 4 during a game of field hockey.

Subject 4	Stationary	Walk	Jog	Sideways	Sprint/Stride	Shuffle
n	111.0	360.0	384.0	35.0	177.0	106.0
Time (secs)	285.9	2018.6	1151.4	43.5	590.5	135.1
mean	2.6	5.6	3.0	1.2	3.3	1.3
SD	3.4	5.7	2.3	0.3	2.7	0.5
Min	0.8	0.8	0.1	0.9	0.8	0.8
Max	20.6	40.2	14.4	2.1	18.3	3.0
% n	9	31	33	3	15	9
%Time	7	48	27	1	14	3

Table A12. Summary of activity patterns for subject 5 during a game of field hockey.

Subject 5	Stationary	Walk	Jog	Sideways	Sprint/Stride	Shuffle
n	100.0	340.0	385.8	62.6	176.2	119.8
Time (secs)	330.2	1890.6	1229.8	91.1	508.6	158.6
mean	3.4	5.5	3.2	1.4	2.9	1.3
SD	4.3	5.4	2.6	0.6	2.3	0.6
Min	0.8	0.8	0.3	0.8	0.8	0.7
Max	20.1	36.3	16.7	4.5	12.7	4.9
% n	9	29	33	5	15	10
%Time	8	45	29	2	12	4

Table A13. Summary of activity patterns for subject 6 during a game of field hockey.

Subject 6	Stationary	Walk	Jog	Sideways	Sprint/Stride	Shuffle
n	105.0	358.0	322.0	28.0	148.0	61.0
Time (secs)	415.0	2367.0	992.1	37.6	383.0	70.9
mean	4.0	6.6	3.1	1.3	2.5	1.2
SD	4.0	6.2	2.6	0.5	2.0	0.4
Min	0.8	0.8	0.8	0.8	0.9	0.8
Max	2.8	43.4	14.6	2.8	10.4	2.4
% n	10	35	32	3	14	6
%Time	10	55	23	1	9	2

Appendix 4

Physiological responses from heart rate monitoring

Table A14-A15. HR and percentage of HR peak data averaged over the five minute intervals preceding the following blood sampling times during a game of field hockey. All data Mean ± SD; n = 6

Table A 14

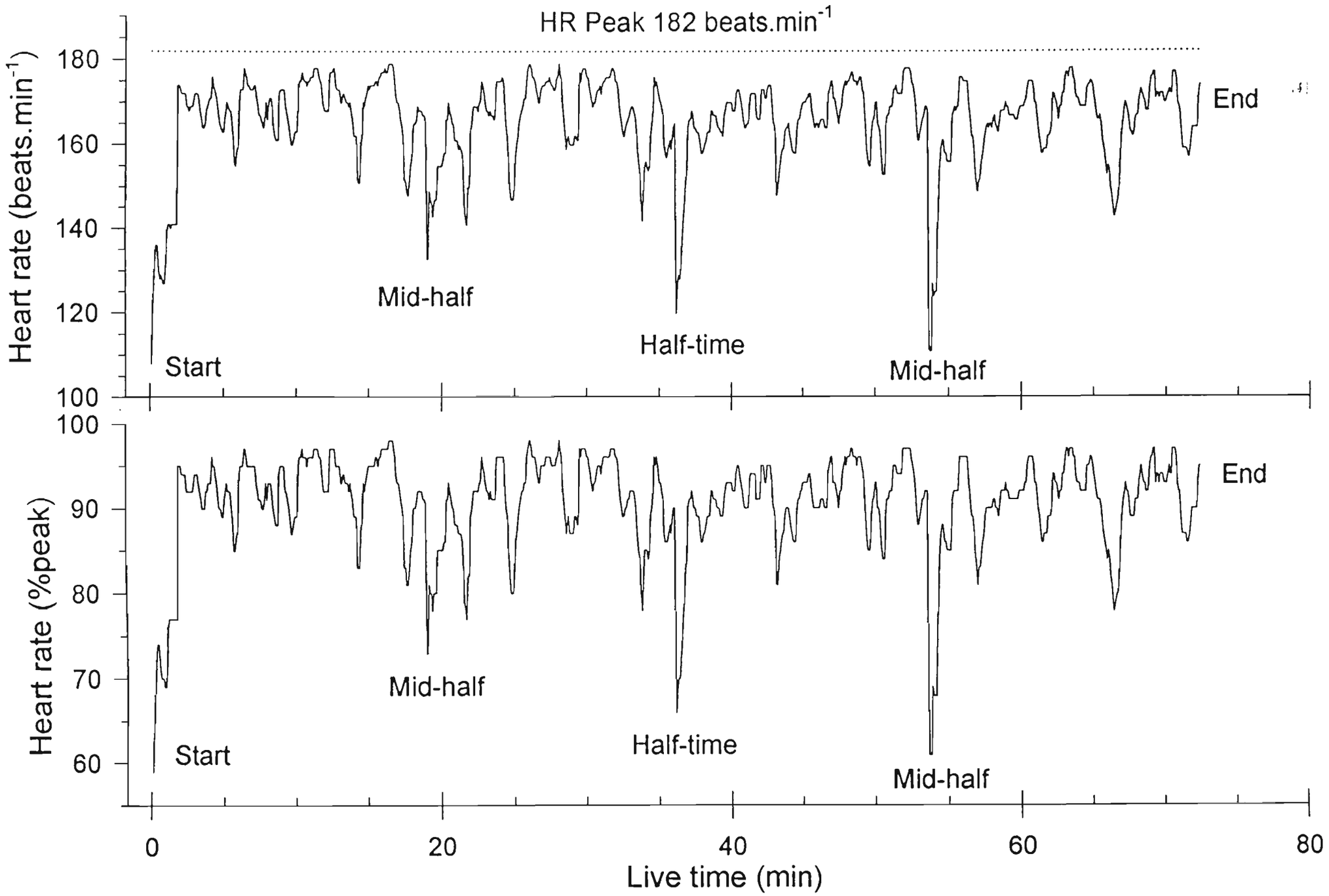
Game time (mins)	12- 17	30-35	47-52	65-70	Mean
1	168 ± 9	166 ± 9	168 ± 7	169 ± 5	168± 8
2	169± 10	165 ± 13	170 ± 11	170 ± 8	169 ± 11
3	165 ± 13	176 ± 5	168 ± 12	161 ± 7	167 ± 9
4	141 ± 13	156 ± 11	151 ± 9	136 ± 12	146 ± 11
5	168 ± 9	151 ± 14	162 ± 13	162 ± 10	161 ± 12
6	149 ± 11	145 ± 13	148 ± 11	145 ± 13	147 ± 12

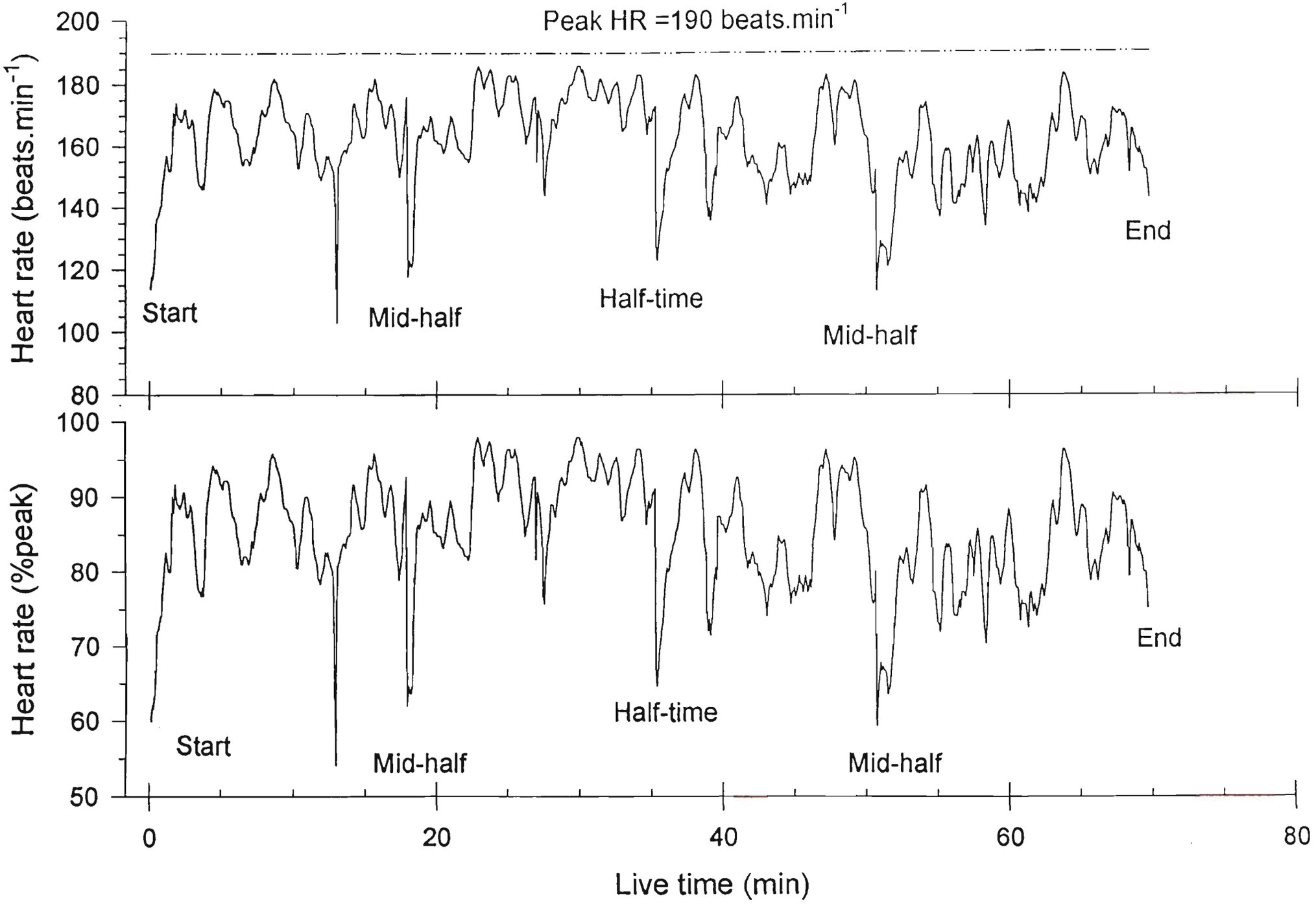
Table A15

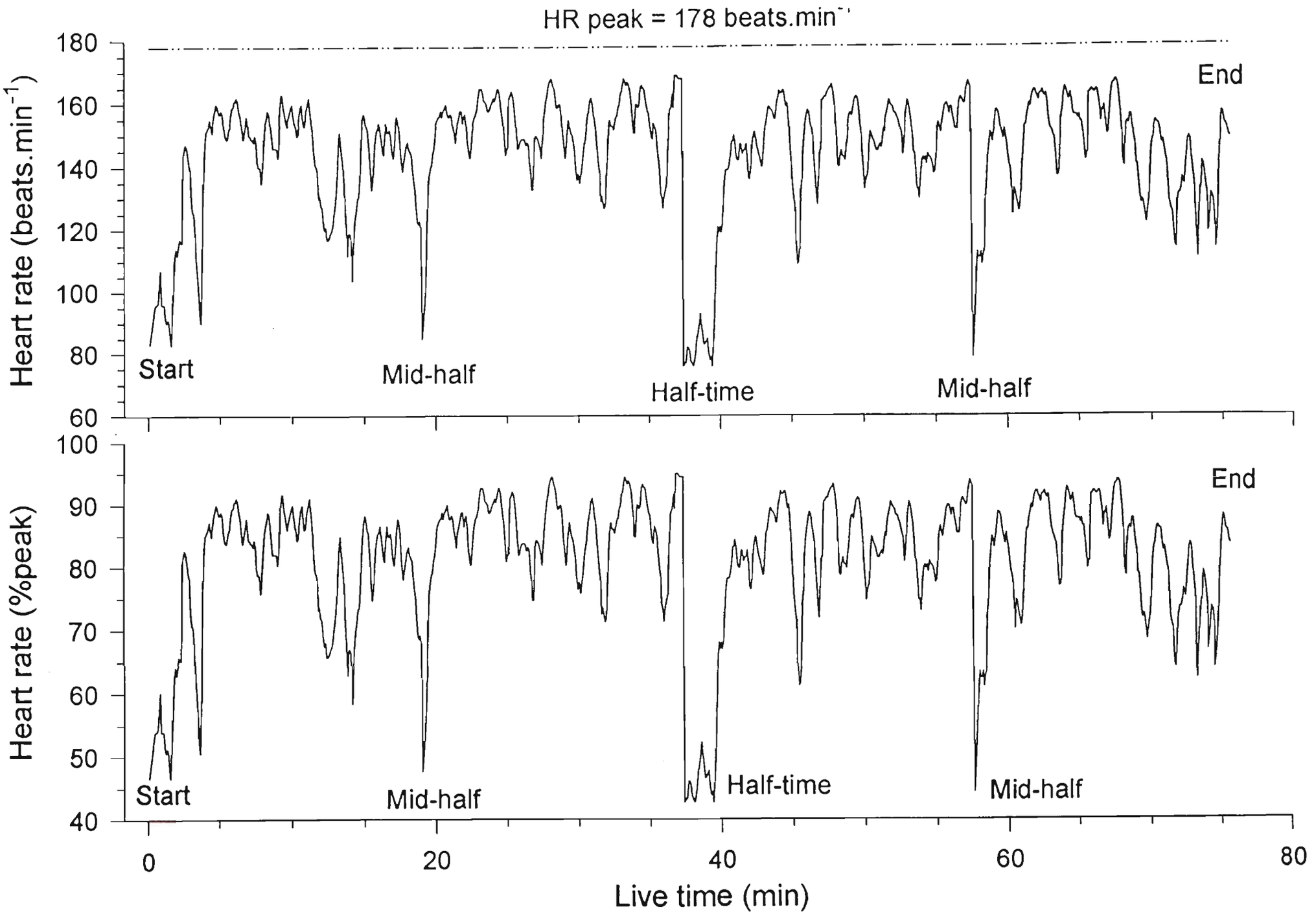
Game time (mins)	12- 17	30-35	47-52	65-70	Mean
1	92 ± 5	91 ± 5	92 ± 4	92 ± 3	92 ± 4
2	90 ± 5	88 ± 7	90 ± 6	91 ± 4	91 ± 4
3	87 ± 7	92 ± 3	88 ± 6	85 ± 4	88 ± 5
4	79 ± 7	88 ± 6	85 ± 5	76 ± 7	82 ± 6
5	92 ± 5	82 ± 8	88 ± 7	88 ± 5	87 ± 6
6	80± 6	77± 7	79± 6	78± 7	79± 7

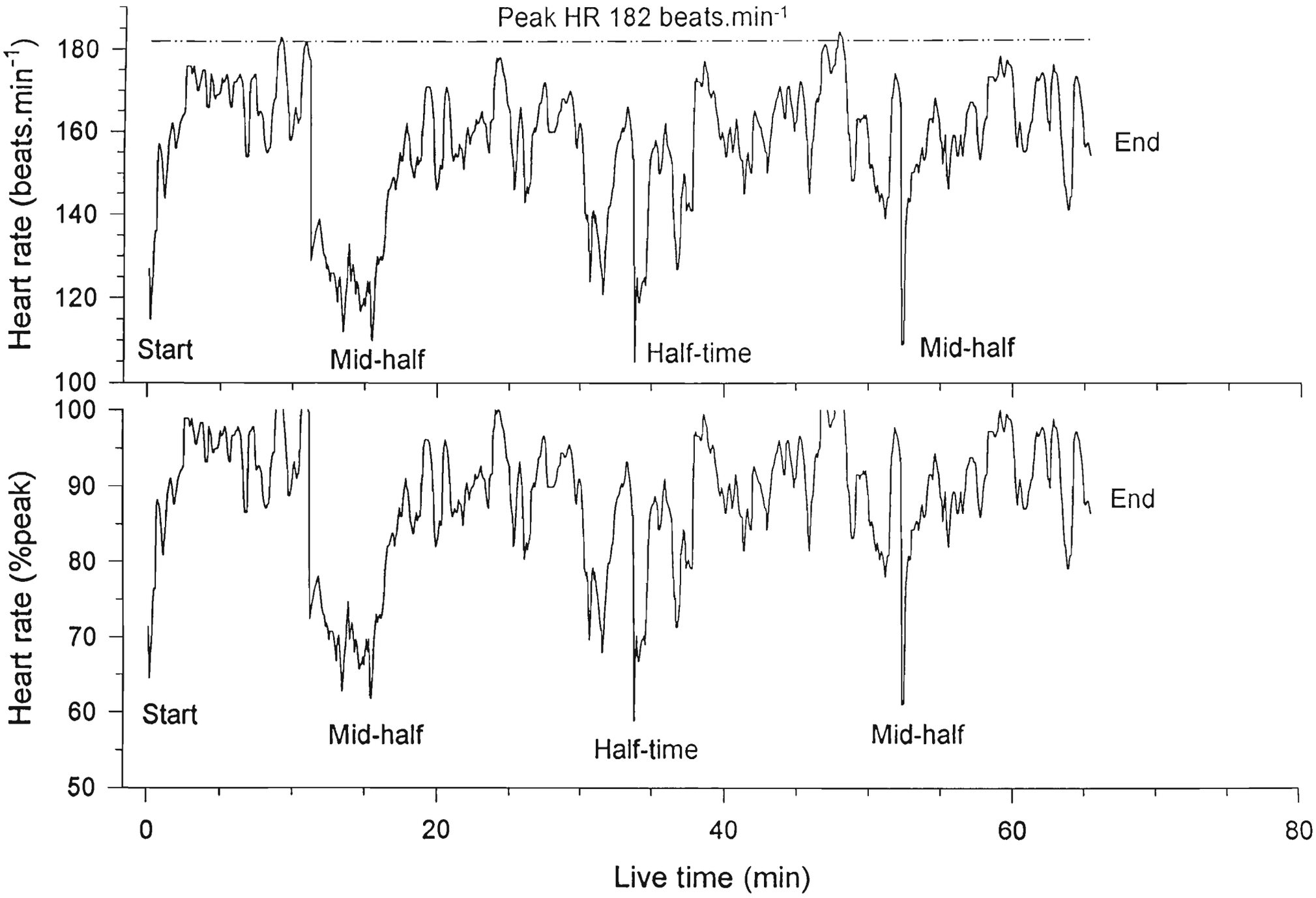
Table A16. Frequency of different categories of the percentage of HR peak during a game of field hockey. All data mean ± SD; n = 6

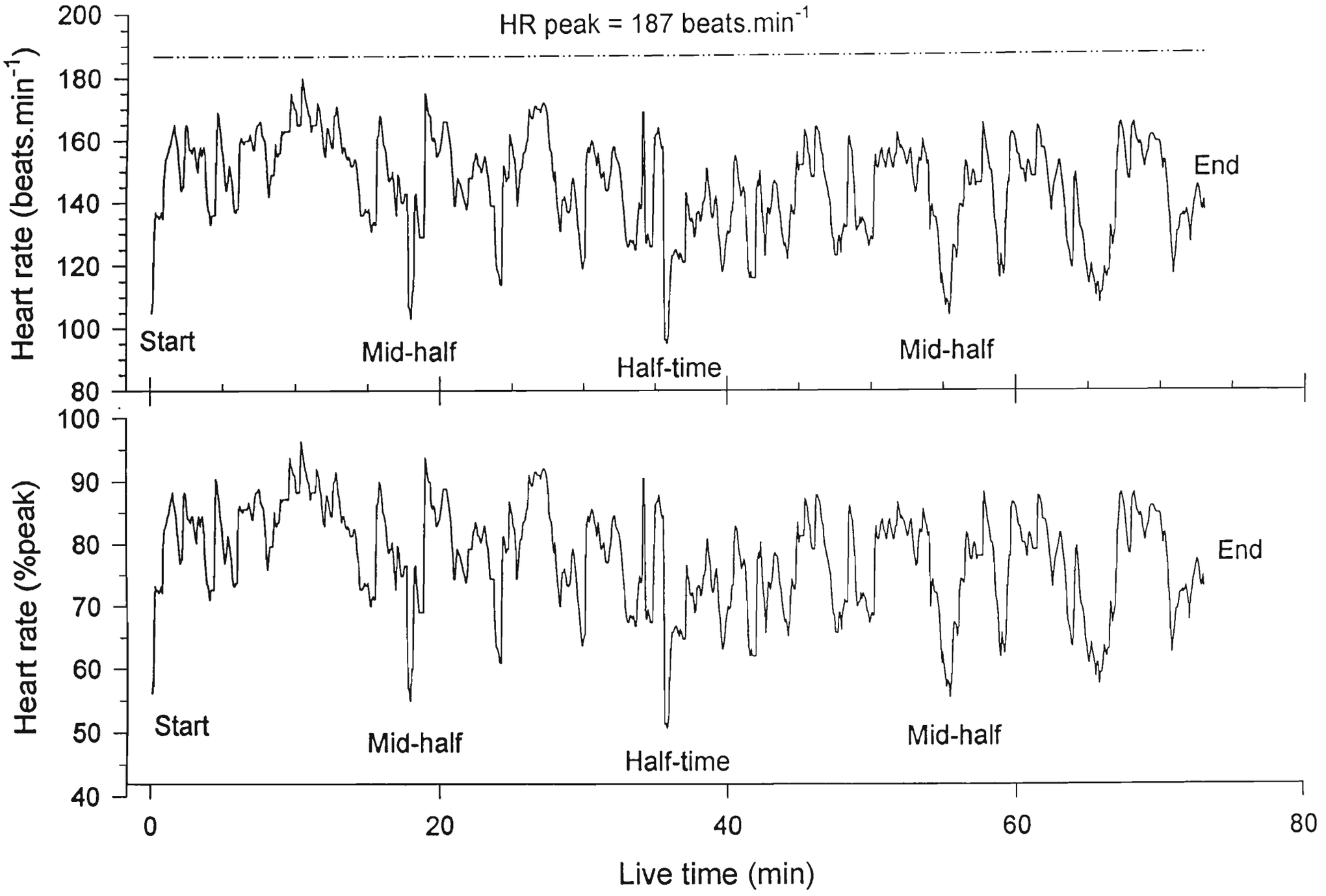
Subject	0-75	76-80	81-85	86-90	91-95	96-100
1	28	22	46	162	389	222
2	36	42	71	243	359	122
3	63	114	199	198	197	65
4	195	100	215	267	129	0
5	88	38	87	206	194	142
6	328	152	216	145	34	2
Mean	123.0	78.0	139.0	203.5	217.0	92.2
SD	117.2	51.6	79.1	46.4	135.6	86.7
Min	28.0	22.0	46.0	145.0	34.0	0.0
Max	328.0	152.0	216.0	267.0	389.0	222.0


HR Peak 182 beats.min-1
Heart rate (beats.min-1)
180
160
140
120
100
Start
Mid-half
Half-time
Mid-half
End
Heart rate (%peak)
100
90
80
70
60
Start
Mid-half
Half-time
Mid-half
End
0
20
40
60
80
Live time (min)


Peak HR =190 beats.min-1
Heart rate (beats.min-1)
200
180
160
140
120
100
80
Start
Mid-half
Half-time
Mid-half
End
Heart rate (%peak)
100
90
80
70
60
50
Start
Mid-half
Half-time
Mid-half
End
0
20
40
60
80
Live time (min)


HR peak = 178 beats.min-1
Heart rate (beats.min-1)
180
160
140
120
100
80
60
Start
Mid-half
Half-time
Mid-half
End
Heart rate (%peak)
100
90
80
70
60
50
40
Start
Mid-half
Half-time
Mid-half
End
0
20
40
60
80
Live time (min)


Peak HR 182 beats.min-1
Heart rate (beats.min-1)
180
160
140
120
100
Start
Mid-half
Half-time
Mid-half
End
Heart rate (%peak)
100
90
80
70
60
50
Start
Mid-half
Half-time
Mid-half
End
0
20
40
60
80
Live time (min)


HR peak = 187 beats.min-1
Heart rate (beats.min-1)
200
180
160
140
120
100
80
Start
Mid-half
Half-time
Mid-half
End
Heart rate (%peak)
100
90
80
70
60
50
40
Start
Mid-half
Half-time
Mid-half
End
0
20
40
60
80
Live time (min)

Appendix 6

Blood biochemical measures

Tables A17 - A28. Haematological data, derived fluid shifts and blood gas status in venous blood sampled before (Pre) at half time (Half) and at the end of the field hockey match (Post). All data mean ± SD, n = 5 for test 2.

Table A17

Test 1

Haemoglobin ($g.dl^{-1}$)

Subject	Pre	Half	Post 1	Post 5
1	14.1	13.2	13	12.4
2	14.9	14.8	14.8	-
3	13.8	13.5	13.5	-
4	15.3	15.1	15.5	-
mean	14.5	14.2	14.2	12.4
sd	0.7	0.9	1.2	0

Table A18

Test 2

Haemoglobin ($g.dl^{-1}$)

Subject	Pre	Half	Post
1	13.8	13.1	13.3
2	15.2	15	15.1
3	13.6	13.2	12.6
4	13.9	14.7	14.6
5	14.4	14.1	14.8
mean	14.2	14.0	14.1
sd	0.6	0.9	1.1

Table A19

Test 1

Haematocrit (%)

Subject	Pre	Half	Post 1	Post 5
1	41.5	39.2	-	37.9
2	43.4	43.4	41.9	-
3	42.8	42.0	44.0	42.7
4	43.9	45.2	44.7	42.7
mean	42.9	42.5	43.5	41.1
sd	1.0	2.5	1.5	2.8

Table A20

Test 2

Haematocrit (%)

Subject	Pre	Half	Post
1	41.4	39.7	39.6
2	44.3	43.8	44.5
3	41.4	40.4	39.7
4	39.5	43.2	40.6
5	42.2	42.4	42.9
mean	41.8	41.9	41.5
sd	1.7	1.8	2.2

Table A21

Test1

% Plasma volume changes

Subject	Pre	Half	Post
1	11.4	-1.3	
2	0.6	2.4	3.5
3	3.6	1.0	-0.3
4	-1.1	-1.8	-2.7
mean	3.6	0.1	0.2
sd	5.5	1.9	3.1

Table A22

Test 2

% Plasma volume changes

Subject	Pre	Half	Post
1	8.5	-1.3	6.8
2	2.3	-1.9	0.4
3	5.2	6.0	10.8
4	-11.1	5.3	-6.3
5	1.8	-5.5	-4.1
mean	1.3	0.5	1.5
sd	7.4	5.0	7.2

Table A23

Test 1

% Blood volume changes

Subject	Pre	Half	Post
1	6.8	1.5	8.5
2	0.7	0.0	0.7
3	2.2	0.0	2.2
4	1.3	0.7	-1.3
mean	2.8	0.6	2.5
sd	2.8	0.7	4.2

Table A24

Test 2

% Blood volume changes

Subject	Pre	Half	Post
1	5.3	-1.5	3.8
2	1.3	-0.7	0.7
3	3.0	4.8	7.9
4	-5.4	0.7	-4.8
5	2.1	-4.7	-2.7
mean	1.3	-0.3	1.0
sd	4.0	3.4	5.1

Table A25

Test 1

PO 2 Data (mmHg)

Subject	Pre	Half	Post
3	20.50	33.80	64.60
4	24.70	76.00	29.30
mean	22.60	54.90	46.95
sd	2.97	29.84	24.96

Table A26

Test 2

PO_2 data (mmHg)

Subject	Pre	Half	Post
1	17.10	65.70	34.40
2	13.60	37.40	26.60
3	21.10	34.70	39.40
4	17.20	60.30	31.70
5	22.70	65.20	46.10
mean	17.25	49.53	33.03
sd	3.06	15.75	5.34

Table A27

Test 1

Saturation (%)

Subject	Pre	Half	Post 1	Post 5
1	47.5	90.0	96.6	99.2
2	46.3	66.3	34.0	-
3	27.0	59.5	92.6	-
4	49.5	95.8	50.8	-
mean	34.9	63.1	55.6	-
sd	10.5	17.7	31.0	-

Table A28

Test 2

Saturation (%)

Subject	Pre	Half	Post
1	21.2	92.2	55.5
2	19.6	68.4	51.4
3	35.2	65.0	74.9
4	33.4	86.5	61.2
5	35.7	94.3	80.5
mean	29	81.3	64.7
sd	7.9	13.7	12.5

Table A29-30. Capillary blood $[Lac^-]_{cap}$ before, during (17, 52 min) and following (70 min) a game of field hockey. All data mean ± SD, n=6 for test 2.

Table A 29

Test 1

Capillary blood lactate data ($mmol.l^{-1}$)

Game time (mins)	0	17	35	52	70
Subject					
1	1.6	11.0	-	5.6	-
2	1.4	9.1	-	11.3	-
3	-	14.1	-	11.3	-
4	-	8.7	-	5.7	-
Mean	1.5	10.7	-	8.5	-
SD	0.1	2.5	-	3.3	-

Table A 30

Test no 2

Capillary lactate data ($mmol.l^{-1}$)

Game time (mins)	0	17	35	52	70
Subject					
1	1.9	6.9	6.4	5.9	5.2
2	1.6	4.8	2.4	9.7	-
3	2.1	6.4	5.3	6.2	4.7
4	1.7	2.6	8.4	4.5	4.2
5	1.8	4.6	2.5	6.8	4.3
6	2.4	4.6	2.5	2.8	5.0
Mean	1.9	6.0	4.6	6.0	4.7
SD	0.3	1.5	2.5	2.3	0.4

Table A31-39. Plasma electrolyte, lactate, glucose and protein concentrations in venous blood sampled before (PRE), at half time (HALF) and at the end of the field hockey match (POST). All data mean ± SD; n=5.

Table A31

Test 2

Plasma lactate ($mmol.l^{-1}$)

Subject	Pre	Half	Post
1	1.3	5.3	4.7
2	2.2	4.6	7.2
3	1.0	1.3	2.8
4	1.5	2.3	2.8
5	1.4	10.4	4.9
n	5.0	5.0	5.0
Mean	1.5	4.8	4.5
SD	0.5	3.6	1.8

Table A32

Test 2

pH

Subject	Pre	Half	Post
1	7.406	7.333	7.299
2	7.294	7.315	7.219
3	7.325	7.377	7.377
4	7.343	7.218	7.314
5	7.294	7.39	7.362
mean	7.332	7.327	7.314
sd	0.046	0.068	0.062

Table A33

Test 2

H+ ($nmol.l^{-1}$)

Subject	Pre	Half	Post
1	3.90	4.60	5.02
2	5.08	4.84	6.04
3	4.73	4.20	4.20
4	4.54	6.05	4.85
5	5.08	4.07	4.35
Mean	4.67	4.75	4.89
SD	0.49	0.79	0.73

Table A34

Test 2

HCO_3 ($mmol.l^{-1}$)

Subject	Pre	Half	Post
1	26.1	17.9	21.4
2	32.1	26	25.3
3	28.6	23.2	23.7
4	25.3	15.7	21.4
5	27.5	22.8	23
Mean	27.9	21.1	23.0
SD	2.7	4.2	1.7

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Table A 35

Test 2

Plasma sodium ($mmol.l^{-1}$)

Subject	Pre	Half	Post
1	139	141	141
2	141	-	139
3	138	142	138
4	140	137	140
5	138	130	138
mean	139	138	139
sd	1.3	5.4	1.3

Table A36

Test 2

Plasma potassium ($mmol.l^{-1}$)

Subject	Pre	Half	Post
1	4	3.6	3.7
2	4.9	-	3.5
3	4.7	3.7	3.5
4	4.1	3.7	3.9
5	3.4	3.6	3.4
mean	4.2	3.7	3.6
sd	0.6	0.1	0.2

Table A37

Test 2.

Plasma chloride ($mmol.l^{-1}$)

Subject no	Pre	Half	Post
1	104	100	106
2	104		103
3	107	107	105
4	109	106	109
5	104	100	106
mean	106	103	106
sd	2	4	2

Table A38

Test 2

Plasma protein ($g.l^{-1}$)

Subject	Pre	Half	Post
1	74	72	73
2	71	-	71
3	74	79	74
4	70	76	75
5	69	71	76
mean	72	75	74
sd	2	4	2

Table A39

Test 2

Blood glucose ($mmol.l^{-1}$)

Subject	Pre	Half	Post
1	4.2	8.0	5.6
2	4.5	5.4	5.1
3	5.5	8.0	6.4
4	3.9	5.5	5.1
5	3.6	5.6	5.6
mean	4.3	6.5	5.6
sd	0.7	1.4	0.5

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