THE PHYSIOLOGICAL LOAD IMPOSED ON BASKETBALL PLAYERS DURING GAME PLAY

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ABSTRACT

The purpose of this study was to investigate the intensities of work and the patterns of play during men's basketball and, in addition, to investigate the exercise metabolism that meets the energy demands of participation. Eight (8) male basketball players participating in the 1992 National Basketball League (NBL) were monitored during practice games and Victorian Basketball Association games. Each subject was videoed during competition and had his HR monitored at 15 second intervals throughout the game. In addition, arterialised blood samples were obtained at various stages throughout the game and analysed for lactate concentration.

The results of this investigation were divided into data obtained during "Total Time" (TT) and during "Live Time" (LT). Live Time denotes actual playing time or game time whilst TT includes LT in addition to all stoppages in play such as time-outs and free-throws. Total Time does not include the breaks between quarters or the time when the subject was substituted out of the game.

The movement patterns of the players during competition were analysed using video-editing equipment which allowed for multiple viewing and analysis of the play at various speeds. The analysis technique was found to be moderate to highly reliable for all categories of movement except that of backwards running (Run B), which was due to the small percent of time spent in this category of movement and the difficulty found in determining the intensity of backwards movement. The time-motion analysis revealed that the majority of TT (approximately 75%) was spent engaged in low intensity activity. The majority of LT, however, was spent engaged in activities of greater intensity than walking (60% of LT). High intensity activity was found to represent 10% of TT and more than 15% of LT. An average total of 1007 events were recorded during the games. The average duration of each movement category was less than 3 seconds whilst there was a change in event, on average, every 2.2 seconds during LT.

The average HR's for the entire game were 164.9 $bts.min^{-1}$ (86.8% of HRpeak) during TT and 168.4 $bts.min^{-1}$ (88.7% HRpeak) during LT. The average maximum HR recorded was 188.1 $bts.min^{-1}$ (99.1% of HRpeak). An average of 65% of TT and 75% of LT was spent with a HR response of greater than 85% of HRpeak.

The average Bla concentration was 6.8 $mmol.l^{-1}$. The highest Bla concentration recorded was 13.2 $mmol.l^{-1}$. These lactate concentrations suggest that anaerobic glycolysis is likely to be an important energy source during some periods of play in basketball.

The conclusion of this investigation was that the physiological loads imposed on the basketball players during competition were high. The movement patterns of the players, the HR responses to competition and the blood lactate concentrations suggest that participation in basketball places considerable demands on the cardiovascular and metabolic capacities of players during competition. It is proposed that higher physiological requirements are likely to be associated with more important competition, such as actual NBL games. The external structures of the game, including time-outs, free-throws and other stoppages in play, appeared to reduce the overall physiological requirements of participation by allowing considerable periods of recovery from previous activity.

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CHAPTER 1

1.1 INTRODUCTION

The majority of studies reporting the physiological loads imposed on athletes have been concerned with the sports of running, cycling and rowing. This is most likely due to the ease with which the physiological demands of participation in these activities can be accurately reproduced and measured in a laboratory setting. Various physiological parameters investigated have included heart rate (HR), oxygen consumption ($\dot{V}O_2$) and blood lactate (Bla). The responses of these parameters to participation can be used to help describe the physiological loads imposed on athletes during competition.

Comparatively little research, however, has been conducted on many team sports that require intermittent or interval-type activity, such as soccer, Australian rules football, rugby football, ice hockey and basketball. These sports require athletes to reproduce short bursts of high intensity activity interspersed with periods of low intensity activity or rest. The lack of research is surprising considering the potential benefits to coaches and players in possessing a clear understanding of the movement patterns during competition and the physiological requirements of participation in these sports. Knowledge regarding these aspects of participation would enable the development of training programs that are highly specific to the demands of play and which would assist in the preparation of athletes for competition (Allen 1989, McKenna et al. 1988, Withers et al. 1982).

The lack of research investigating the physiological requirements of participation in the intermittent teams sports (ITS) is related to the difficulty in both monitoring the responses to competition and in accurately reproducing the demands placed on participating athletes in a laboratory setting. The movement patterns are largely unpredictable and result from the spontaneity of the player and the demands of play. In addition it is unrealistic to encumber athletes with awkward measurement devices likely to restrict the athletes movements during actual competition. Furthermore, most ITS involve a critical interplay between the lower body and upper body musculature at varying intensities further complicating a laboratory replication and measurement of the physiological demands of competition. These difficulties, combined with the problems of relating laboratory based measurements to successful performances during ITS, have resulted in coaches and athletes being sceptical of the value of scientific investigations and physiological measurements.

Currently there is an inadequate understanding of the movement patterns and exercise metabolism during ITS upon which to base training programs for athletes. Coaches and athletes are, therefore, forced to base much of their training methods on anecdotal or observational information, much of which has been passed on by other coaches and athletes. In many cases this may have resulted in training programs not specific to the requirements of participation and which have inadequately prepared athletes for competition.

In recent years coaches and athletes have begun to realise the importance of implementing training programs that are highly specific to the demands of competition. In many instances sports scientists and exercise physiologists have been able to assist in the analysis of the patterns of play and the physiological requirements of participation (Green et al. 1976, McKenna et al. 1988). The results obtained have been used to develop more specific training programs and testing protocols designed to accurately monitor the fitness levels of players (Douge 1982, Montpetit et al. 1979).

Despite the popularity of basketball throughout the world and the recent growth in Australia there has been very little interest in the game from a sports science perspective. Whilst other ITS such as soccer and ice hockey have recently been subjected to physiological investigations (Van Gool et al. 1988, Bangsbo et al. 1991, Montgomery 1988) basketball has remained largely uninvestigated. In 1983 Riezebos, Paterson, Hall and Yuhasz recognised the need 'for study of the energy demands of basketball.....to more fully understand the energy requirements of the sport'. More recently, Smith and Thomas (1991), have suggested that training recommendations for basketball could be improved through a time-motion analysis of the movement patterns of players during competition and physiological measurements during games. Despite this, little progress has been made towards achieving a greater understanding of the physiological demands of participation in basketball.

At present there exists a dearth of research examining the physiological loads imposed on male basketball players during competition. Little is known regarding the movement patterns of players during play and the physiological responses to participation including HR, $\dot{V}O_2$ and Bla. The importance and interactions of the various energy sources in meeting the physiological demands of participation are, therefore, poorly understood. According to Bompa (1990) familiarity with the contribution ratio of the various energy systems for a sport or athletic event is of importance in identifying the needs and aspects that should be emphasised in training. As such research examining the physiological demands of participation in men's basketball is overdue from a coaching perspective as well as a scientific perspective.

1.2 RATIONALE

The development of game-specific training programs and testing protocols designed to both adequately prepare athletes for competition and evaluate the effects of training are important aspects of preparation for ITS. The structure of these programs and protocols should be based on objective evidence relating to the movement patterns of players during competition and the exercise metabolism that meets the energy demands of participation. The rationale behind this investigation is to provide information relating to the movement patterns of players during basketball and the physiological requirements of competition. These aspects of participation can be examined using video recording of players' movements, by monitoring intensity through recording the players' heart rates and by obtaining blood samples for lactate analysis. Information on these aspects of participation can be used as the basis for the development of training programs and testing protocols specific to the demands of competition.

1.3 THE PURPOSE OF THE STUDY

The purpose of this study is to investigate the intensities of work and the patterns of play during men's basketball and, in addition, to investigate the exercise metabolism that meets the energy demands of participation.

1.4 LIMITATIONS

Limitations to this study were imposed by the:

1. The performance and accuracy of the HR recording equipment.

2. The amount of playing time allotted to each subject by the coach.

3. The physical dimensions of the different playing stadiums and the influence of this on videotaping capability.

4. The different game plans and tactics employed by the coach and the effect of this on the movement patterns and physiological requirements of participation.

5. The quality of the game and the opposition.

6. The uncontrolled diet of the subject the day before and on the day of the game and the possible effect of this on match performance.

7. The intensity and volume of training undertaken by the subject the day before the game.

8. The different environmental conditions under which the games were played.

9. The fitness levels of the subjects and the effect of this on movement patterns and physiological responses.

1.5 DELIMITATIONS

1. The study was delimited to include players from two men's basketball teams competing in the 1992 Australian National Basketball League (NBL) competition.

2. Monitoring of the players was conducted during 1992 Victorian Basketball Association (VBA) competition games and NBL practice games only.

1.6 DEFINITIONS OF TERMS

Intermittent exercise: Activity requiring alternating periods of activity and rest, ie. varying intensity as distinct from activity at a constant intensity.

Intermittent team sports: Team sports that require intermittent exercise.

1.6.1 Time based terms

Live Time: Time during which the game clock was running. This is the time that the ball was in play.

Total Time: The total time during which the player was on the court. This time includes Live Time as well as all stoppages in play (such as fouls, free-throws, time-outs and substitutions) when the player was officially "in the game" (ie 1 of the 10 players on court). Total Time does not include the time during which the player was seated on the bench or the time between quarters.

1.6.2 Movement pattern terms

Rest: A type of relief period where minimal activity is evident. It includes standing still and walking.

Work: Activity of greater intensity than walking.

Stand/Walk: Minimal intensity activity or no activity.

Jog: Activity (forwards or backwards) requiring a greater intensity than Walking but less than Running. The movement is without urgency and the metabolic requirements are low.

Run: Forwards movement at an intensity greater than jogging and a moderate degree of urgency (and moderate metabolic requirements) but which does not approach an intense level of movement.

Backward running: Backwards movement at a moderate intensity. The metabolic demands are greater than those required for backward movement at a low intensity or forward jogging.

Stride/Sprint: Forwards movement at an intensity greater than Running. It indicates intense movement characterised by elongated strides, effort and purpose at or close to maximum. The metabolic requirements for stride/sprint are considered to be from high to maximal.

Shuffle: Movement generally in a sideways or backward direction using a shuffling action of the feet.

Low Shuffle: Shuffling at a low intensity.

Medium Shuffle: Shuffling at a moderate intensity

High Shuffle: Shuffling at a high intensity.

Jump: The time from the initiation of the jumping motion until the landing is complete. Jumping is considered to be high intensity activity.

High Intensity Activity: This includes all categories of movement that are considered to involve activity of a high intensity. The categories of Stride/Sprint, High Shuffle and Jump are considered to be high intensity activities.

1.6.3 Physiological terms

$\dot{V}O_2$ peak: The maximal volume of oxygen consumed during a continuous 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: Oxygen consumption expressed as a percentage of the subjects' $\dot{V}O_2$ peak.

Heart rate: The number of times the heart beats in 1 minute.

Peak heart rate: The highest HR value (HRpeak) recorded for each subject whilst either completing the $\dot{V}O_2$ peak test in the laboratory or during actual competition.

1.7 ABBREVIATIONS AND ACRONYMS.

ADP: Adenosine diphosphate

AMP: Adenosine monophosphate

ATP: Adenosine triphosphate

Bla: Blood lactate

CP: Creatine phosphate

CV: Coefficient of variation

FFA: Free fatty acid

FT: Free throw

HIA: High Intensity Activity

HR: Heart rate

ICC: Intraclass correlation coefficient

ITS: Intermittent team sports

LT: Live Time

ME: Method Error

OOP: Out of play

Run B: Backward running

S/W: Stand/Walk

TO: Time-out

TT: Total Time

$\dot{V}O_2$: Oxygen consumption

CHAPTER 2

REVIEW OF LITERATURE

Most of the literature reviewed concerns research that has been conducted on ITS, including soccer, Australian rules football, rugby union, ice-hockey, netball and field hockey. Whilst these ITS clearly differ from basketball in a number of aspects such as the size of the playing area, the number of players on each team, the duration of the games and the skill requirements of participation, they all require intermittent work where the intensity of activity varies according to the pattern of play. As such, despite the limitations of relating other ITS to the physiological demands of basketball, all of the sports are of use in understanding the physiological requirements of intermittent exercise, the responses to competition and the exercise metabolism that meets the energy demands of participation.

The literature is divided into 3 sections: 2.1 Characteristics of play in intermittent team sports, 2.2 Physiological responses to participation in intermittent team sports: Heart rate and $\dot{V}O_2$ and 2.3 Exercise metabolism in the intermittent team sports.

2.1 Characteristics of play in intermittent team sports.

An analysis of the movement patterns of players during competition in any ITS is important in an examination of the physiological requirements of participation. This form of movement analysis, referred to as "time-motion analysis", enables a qualitative and/or quantitative description of the movement characteristics of players during actual competition. This can include estimations of the distances travelled by athletes during a game, categorisation of the intensity of activity according to either the total distance travelled or the total game time, the work-to-rest ratios (work:rest) and the average durations and frequencies of various types of activity.

2.1.1 Methodogical aspects.

For the data obtained from such analyses to be of value to athletes, coaches and physiologists the methodology for measurement must be as reliable and objective as possible. Most of the earlier studies employing time-motion analysis used "trained observers" to follow the movements of players during competition (Nettleton and Sandstrom 1963, Brooke and Knowles 1973, Reilly and Thomas 1976). This methodology is limited in terms of both the volume of data and accuracy of the data that can be collected (MacLean 1984). Many studies have only analysed segments of the game varying from a few minutes (Saltin 1973) to a quarter (Jaques and Pavia 1974) or one half (Pyke and Smith 1975, Mayhew and Wegner 1985, Docherty et al. 1988) and extrapolated the results for application to the entire game. Results from these investigations should be viewed with caution as it may be erroneous to assume that the movement characteristics of players will remain the same throughout a game and not be affected by fatigue.

Often the studies failed to report the accuracy or methodology of measurement (Vinnai 1973, Wade 1962). According to Ohashi et al. (1988) data from many of these studies was most likely derived from gross observations whose technique was not precisely devised. More accurate procedures of conducting time-motion analysis have been developed (Hughes et al. 1989, Patrick and McKenna 1988) and current methods now involve video recordings of individual players to enable a more complete and accurate analysis (Bangsbo et al. 1991, Hahn et al. 1979, Withers et al. 1982). Some investigations have also used computers to assist in the collection and collation of data (Van Gool et al. 1988, McKenna et al. 1988). With the aid of current techniques most studies are able to report both satisfactory objectivity and reliability coefficients for their methodology (Mayhew and Wegner 1985, Withers et al. 1982).

2.1.2 Distance covered.

An estimation of the total distance covered by players during ITS provides a crude indication of the total energy expenditure during competition and the overall demands of participation (Reilly and Thomas 1976). Calculations of the distances travelled by players has involved the use of ground markings and cues (Pyke and Smith 1975, Reilly and Thomas 1976), stride length and frequency (Withers et al. 1982) or time spent in each category of movement velocity (Bangsbo et al. 1991). Others studies have utilised computers to assist the calculation of distance travelled (Van Gool et al. 1988, Ohashi et al. 1988). The distances travelled by athletes during competition in various ITS are summarised and presented Table 2.1.

The average ground covered by players during a game of soccer appears to be 8-13km (Withers et al. 1982, Saltin 1973, Smith 1988, Bangsbo et al. 1991, Ohashi et al. 1988, Van Gool et al. 1988). Similar distances have been reported in Australian rules football players (Hahn et al. 1979, Jaques and Pavia 1974). However, more recent estimates have suggested distances of 18.4 km (Baker and Taylor 1984) or as much as 28km (Jones, personal communication). This may reflect the increased physiological requirements of present day Australian rules football compared to that of 15 years ago (Jones and Laussen 1988). The distance travelled by players during both games appears to be related to the position played (Reilly and Thomas 1976, Bangsbo et al. 1991, Pyke and Smith 1975, Jaques and Pavia 1974, Hahn et al. 1979).

Similar distances to those of soccer players have been reported for "attack" players in lacrosse (Romas and Isles 1986) whilst estimates for rugby union (Reid and Williams 1974, Williams 1976), touch rugby (Allen 1989) and field hockey (Wein 1981) suggest smaller distances. The distances covered by rugby players, however, is likely to be related to the duration of the game, where the ball may be in play for less than 30 minutes (Morton 1978, Reilly 1990).

Although the overall distance travelled during ITS provides a general indication of the overall physiological load imposed on players during competition, more specific information can be obtained by categorising the intensities of movement. This allows for the data to be expressed as a percentage of the total distance travelled or the total game time. In categorising the movements according to the distance travelled most studies have chosen the categories of "backwards", "walking", "jogging", "striding" and "sprinting" (Van Gool et al. 1988, Reilly and Thomas 1976, Withers et al. 1982, Docherty et al. 1988). Although the descriptions for the requirements of these categories vary depending on the particular

Table 2.1: Distances travelled by players during various Intermittent Team Sports

Authors (Year)	Subjects	Distance (km) Range	Average
Soccer			
Reilly and Thomas (1976)	English 1st Division (n=40)	7.1-10.9	8.7
Bangsbo et al. (1991)	Danish 1st and 2nd Division (n=9)	—	10.8
Van Gool et al. (1988)	Belgian University (n=7)	9.4-11.0	10.2
Ohashi et al. (1988)	Japanese national and international (n=4)	9.3-11.6	10.3
Saltin (1973)	Swedish professionals (n=5)	—	12.0
Withers et al. (1982)	Australian national league (n=20)	10.2-12.0	11.5
Australian rules football			
Jaques and Pavia (1974)	South Australian state league (n=20)	4.6-14.9	9.6
Hahn et al. (1979)	West Australian state league (n=2)	10.4-10.9	10.6
Pyke and Smith (1975)	South Australian state league (n=2)	10.0-13.0	11.5
Jones (1991 personal communication)	Victorian state league (n=1)		28
Baker and Taylor (1984)	Victorian state league (n=5)	—	18.4
Field Hockey			
Wein (1981)	Defenders Midfielders	max = 8.82	5.14 6.36
Rugby Union			
Morton (1978)	centre (n=1)	—	5.8
Reid and Williams (1974)	—	4.8-9.6	—
Williams (1976)	—	—	5.5
Touch Rugby			
Allen (1989)	Australian state and national (n=12)	3.1-3.6	3.4
Lacrosse			
Romas and Isles (1986)	Victorian state attack (n=4) midfield (n=4)	— —	10.9 7.4

study, "backwards", "walking" and "jogging" are usually defined as low to moderate intensities of activity, whilst "stride" and "sprint" represent high to maximum intensities. Table 2.2 summarises the results of a number of studies that have expressed the movement patterns as a percentage of distance travelled at each intensity during the game.

Table 2.2: Intensities of activity as a percentage of distance travelled during Intermittent Team Sports.

Authors (Year)	Categories of movement (% of total distance)					
	Backwards	Walk	Jog	Stride	Sprint	Other*
Soccer						
Reilly and Thomas (1976)	6.7	24.8	36.8	20.5	11.2	
Withers et al. (1982)	2.6	31.4	47.1	13.1	5.8	
Van Gool et al. (1988)	---	43.0	49.5	<u>7.5</u>		
Smith (1988)	11.7	20.9	38.6	17.5	9.3	2.0
Australian rules football						
Hahn et al. (1979)	---	26	55	<u>19</u>		
Rugby football						
Morton (1978)	---	37	29	<u>34</u>		
Allen (1989)	---	25.8	65.6	---	8.6	
Lacrosse						
Romas and Isles midfielders	3	23	45	18	7	4
(1986) attack	7	45	29	10	4	5

* "Other" includes sideways and shuffling
<u>Underlined</u> values indicate combined percentages from the 2 categories.

The majority of distance travelled by players during ITS has been reported to be at low intensities. Soccer players (Van Gool et al. 1988, Withers et al. 1982), Australian rules football players (Hahn et al. 1979), lacrosse players (Romas and Isles 1986) and touch rugby players (Allen 1989) all covered 80% or more of the total distance by walking and jogging. Less than 20% of the distance was covered by intensities greater than jogging

(Hahn et al. 1979, Romas and Isles 1986, Van Gool et al. 1988) and less than 10% by sprinting (Romas and Isles 1986, Withers et al. 1982, Smith 1988). However, there were significant differences in the patterns of activity between the positions of play in soccer (Reilly and Thomas 1976, Van Gool et al. 1988, Smith 1988) and lacrosse (Romas and Isles 1986). Compared to other ITS, rugby players covered a larger percentage of the game distance by high intensity activity of striding or sprinting (Morton 1978).

2.1.3 Time-based analyses.

A number of studies have expressed the intensities of activity as a percentage of the total game time rather than total distance travelled. According to McKenna et al. (1988) this may be an easier, equally reliable and more objective measure of activity patterns than expressing the intensities of activity as a percentage of distance travelled. A summary of the available data is presented in Table 2.3.

A common characteristic of movement patterns in all ITS is that the players are engaged in low intensity activity such as walking and jogging for the majority of time during competition. Soccer and Australian rules football players have been reported to spend approximately 80-85% of the game time walking and jogging (Mayhew and Wegner 1985, Yamanaka et al. 1988, McKenna et al. 1988, Jaques and Pavia 1974), 4-5% running or striding (McKenna et al. 1988, Jaques and Pavia 1974) and, as in the case of soccer, as little as 3% or less sprinting (Ali and Farrally 1991, Bangsbo et al. 1991, Brodowicz et al. 1990). The amount of time spent standing appears to represent 5-10% of the game time (Ali and Farrally 1991, Yamanaka et al. 1988) though it has been reported as being as much as 17.1% (Bangsbo et al. 1991) or as little as 0.5% (Brodowicz et al. 1990), possibly indicating large differences between the games, the individual movement characteristics or the positions of play. Both sports appeared to require different movement patterns for the different positions played (Brodowicz et al. 1990, Bangsbo et al. 1991, Jaques and Pavia 1974). The data presented by Docherty et al. (1988) reveals that rugby union players spent a greater percentage of the game time standing. However this is likely to be due to the reduced amount of time for which the ball is actually in play.

Table 2.3: Intensities of activity as a percentage of game time.

Authors (Year)	Categories of activity (% of total game time)					
	Stand	Walk	Jog	Stride	Sprint	Other*
Soccer						
Mayhew and Wegner (1985)	2.3	46.4	38.0	11.3		2.0
Ali and Farrally (1991)	7	56	30	4	3	
Bangsbo et al. (1991)	17.1	40.4	35.1	5.3	2.8	
Yamanaka et al. (1988)	4-10	83-88		7-10		
Brodowicz et al. (1990)	10.5	55.2	43.5	10.5		
Australian rules football						
Jaques and Pavia (1974)	12.5	63.8	19.6	4.5		
McKenna et al. (1988)	8.8	44.5	40.9	4.1		2.5
Rugby Union						
Docherty et al. (1988)	37.7	31.0	16.4	3.8	2.0	9.1

* "Other" includes sideways, backward running, jumping, shuffling and tackling.
Underlined values indicate combined percentages from the 2 categories.

A problem with many of the studies examining the movement patterns during ITS is that according to the definitions of movement there would appear to be a large difference in intensity between jogging and striding. If jogging is considered to be low intensity exercise and striding as high intensity exercise (Jaques and Pavia 1974, McKenna et al. 1988), then the difference in intensity between the two categories may be too large in order to gain a clear understanding of the physiological requirements of competition. It is possible that much of the game time will be spent in activities where the intensity is between these two categories. As such an additional category of intensity may be required. Although including an additional category may adversely affect the reliability of movement analysis (McKenna, personal communication) it may be necessary in order to gain a more complete understanding of the movement patterns and physiological requirements of participation in ITS.

2.1.4 High intensity efforts.

It is clear from the available literature that the majority of distance covered by a player during ITS is at low to moderate intensities of activity such as walking and jogging. The majority of game time is also spent engaged in these intensities of activity. Although the periods of high intensity work account for only a small percentage of the game time and overall distance travelled, they are likely to be an important factor in determining the success of a team. According to Yamanaka et al. (1988), regarding soccer, "running and sprinting are attempted during the phases which are decisive and directly related to play...the ability a player displays during these phases is directly connected to the scoring potential of his team and may be the deciding factor in the game." For the purpose of understanding the physiological requirements of participation in ITS and in developing specific training programs it is important to understand the characteristics of the higher intensity work bouts, including time and distance covered during each effort.

Table 2.4 presents the characteristics of the high intensity (sprint) periods assembled from a number of studies. A characteristic common to all the ITS was the short duration of the high intensity work periods. The mean duration of high intensity activity in soccer is reported as 3.7 seconds (Withers et al. 1982), 4.4 sec (Mayhew and Wegner 1985), 2.0 sec (Bangsbo et al. 1991) or as little as 1.9 sec (Brodowicz et al. 1990). Similar durations have been reported for Australian rules football (Hahn et al. 1979, McKenna et al. 1988), rugby union (Docherty et al. 1988), touch rugby (Allen 1989) and lacrosse (Romas and Isles 1986).

The average distance travelled during the high intensity work periods has been reported as 10.4 m (Brooke and Knowles 1973), 15 m (Reilly and Thomas 1976) and 22.4 m (Withers et al. 1982) for soccer players, 12 and 19 m for Australian rules footballers (Hahn et al. 1979) and 10.14 m for Touch rugby players (Allen 1989). As well as this most of the sprints in all ITS were less than 5 sec in duration (Withers et al. 1982, Hahn et al. 1979, Otago 1983) and players usually covered less than 30m (Withers et al. 1982, Romas and Isles 1986).

Table 2.4: Characteristics of the high intensity (sprint) periods in various ITS.

Authors (Year)	High Intensity activity Average Distance (m)	Average duration (sec)
Soccer		
Withers et al. (1982)	22.4 75% < 28.3 max = 105	2.9 75% < 4.8 max = 24.3
Mayhew and Wegner (1985)	---	4.4
Reilly and Thomas (1976)	15	---
Bangsbo et al. (1991)	---	2.0
Brooke and Knowles (1973)	10.4	---
Brodowicz et al. (1990)	---	1.85
Australian rules football		
Hahn et al. (1979)	12 and 19 (n=2)	65% < 4 80% < 6
Douge (1982)	30% < 5 57% < 10 78% < 20	---
McKenna et al. (1988)	---	2.7 max = 10.4
Rugby football		
Morton (1978)	---	56% < 10 85% < 15
Docherty et al. (1988)	---	2.1
Allen (1989)	10.14	3-4
Netball		
Otago (1983)	---	55% < 4 37% 4-10 8% > 10
Allison (1980)	---	1.7
Lacrosse		
Romas and Isles (1986)	28% < 10 58% < 20 25% 45-100	---

N.B. % refers to the percentage of the total <u>number</u> of sprints.

According to Mayhew and Wegner (1985) the ratio of high intensity:low intensity activity during soccer was 1:7 and for every 4 sec spent running hard approximately 28 sec was spent in activities more aerobic in nature. The players monitored by Reilly and Thomas (1976) were found to sprint once every 90 sec whilst they ran at a high intensity once every 30 sec. Similar characteristics are evident in Australian rules football. McKenna et al. (1988) reported that, on average, players engaged in high intensity running (sprinting) once every 73 sec. Similarly Hahn et al. (1979) reported that high intensity efforts were not, on average, required more frequently that once every 50 seconds.

Brooke and Knowles (1973) estimated the ratio of walking to jogging to sprinting in soccer to be 3:5:1. By pooling the data for striding and sprinting Withers et al. (1982) reported a corresponding ratio of 3:5:2. In order to examine whether players were required to work at high intensities for several minutes without much recuperative low intensity work, Withers et al. (1982) isolated those instances where there were 2 or more consecutive ratios for high intensity/low intensity work that were more stressful than 1:9. Only 28.9% of the ratios fell in this category and of these, 60% involved only 3 consecutive ratios more stressful than 1:9. The most physiologically demanding situation involved 11 consecutive ratios for a midfielder who had an average high intensity/low intensity work ratio of 1:3.1 over a period of 178.2 sec.

In addition to the field ITS of soccer, Australian rules football and rugby the patterns of play during netball and ice hockey have been investigated. Netball may be of particular relevance to the demands of basketball because of the similarities between the games. The size of a netball court is almost identical to that of a basketball court (465 square meters for netball compared to 428 for basketball) and therefore no player is ever far from the play. Similar to basketball, the game is divided into 4 quarters of 15 minutes duration or 2 halves of 20 minutes duration depending on the level of competition. The physiological demands placed on participating athletes and the patterns of play may, therefore, be similar to those of basketball.

Otago (1983) monitored the movements of 24 netball players who participated in an international test series where the games consisted of two 20 minute halves. On average the players were found to be active for only 20.6% of the total playing time (the range for the different positions was 16.6-28.9%). Of this active time, 38.0% (range 19.6-58.3%) was spent shuffling, 19.2% (6.7-31.6%) sprinting and 16.6% (4.5-36.3) jogging, though there were large variations in the movement patterns depending on the position played. In addition Otago (1983) reported that of the total work periods an average of 55% were less than 4 sec in duration, 37% were between 4 and 10 sec and only 8% lasted longer than 10 sec.

Similar movement characteristics have been reported by Steele and Chad (1991) for Australian State level netball players. Less than 30% of the game was spent in activity of greater intensity than walking, 2.1% of the game was spent running with no sprinting. The remainder of the game was spent shuffling, jumping, catching, passing, guarding and defending. Similar to the results reported by Otago (1983), there were significant differences in the movement patterns between the different positions. According to Steele and Chad (1991) these differences are not currently being reproduced by coaches during training.

Allison (1980) reported on the sprint efforts of netball players according to position. The number of sprints per game ranged from 82 for the Goal shooter and Keeper to 336 for the Wing Attack with an average of 200 for all positions. The average duration of each sprint was 1.72 seconds (range 1.43-1.84). The percentage of game time spent sprinting was 4.1% for the Goal Shooter and Keeper, 5.9% for the Goal Attack, 11.8% for the Centre and 16.3% for the Wing Attack and Defence.

Netball, therefore, is characterised by short work periods of less than 10 seconds (and usually less than 4 sec) and overall work to rest ratios of 1:3 or greater. According to Allison (1980) whilst it is obvious that not all players will be involved in every sequence of play and that the intensity of a sequence will not always be maximal, netball could be described as a series of short sprints interspersed with short recovery periods.

Although the sport of ice hockey does not involve running, the game requires non-continuous or intermittent-type activity and as such the physiological requirements of play are relevant to this investigation. Green et al. (1976) monitored and recorded the movement patterns of 8 members of a university team during the 1971-1972 season. The distance travelled by players averaged 5535 m. Seliger et al. (1972) reported similar distances of 4860-5620 m with an average of 5160 m. Each 20 min period of play usually consisted of 5-6 "on-ice shifts", each lasting 150-200 sec (Green et al. 1976, Thoden and Jette 1975, Paterson 1979). During each shift players performed intense activity for periods of 30-40 sec, followed by periods of inactivity lasting approximately 30 sec, repeated 2-3 times (Green et al. 1976, Paterson 1979). The on-ice work:rest ratio was approximately 1:1. The overall pattern of play involved players being on ice for 2.5-3.5 minutes followed by off-ice inactive rest periods of 3-4 minutes (Thoden and Jette 1975, Green et al. 1976). Therefore the overall work:rest ratio was approximately 2:3.

Summary of the characteristics of play in Intermittent Team Sports.

The characteristics of activity evident from the analysis of players' movement patterns during competition in ITS are similar. Although there appear to be significant differences between the various positions of play, most ITS require players to cover moderate to large distances during the game. Most of the distance is covered by low intensity activity of walking and jogging. The periods of high intensity activity usually last less than 5 sec with players covering less than 30 m and are most often not required more than once every 30 sec. As such ITS can be described as requiring short bursts of high intensity activity (sprinting) interspersed with longer periods of rest or low to moderate intensities of activity (jogging or walking).

2.1.5 Movement patterns during basketball.

The patterns of play in basketball have not been subjected to significant investigation. In 1941 Ray Blake measured the distances travelled by male college basketball players in different types of defense in order to assess whether a player covered less ground during zone defense than during man-to-man defense. Distances were estimated by having observers pursue the movements of the players with a small tracing wheel on a scale model of the court. One revolution of the wheel represented a distance of 6 feet and by recording the number of revolutions the distances could be estimated. Data from 44 games was used and the figures reported represented only the distances travelled during defense when the ball was in play. The mean distance travelled by players in the "man-to-man" defense was 1.97 km while players in the "zone defense" travelled 1.85 km. The range in the distance travelled for the games was 1.34 km to 2.43 km. In each type of defense the guards travelled the greatest distance with forwards travelling the least.

Although the accuracy of the methodology is unknown and the study is over 50 years old, the results of Blake (1941) indicated that players travel approximately 2 km during defense. It appeared that the position of guard demanded greater physiological requirements than centre or forward. However, the distance travelled by players only provides an indication of the total volume of work required and is of little use in understanding the physiological requirements of participation in basketball. MacLean (1984) videoed the movements of female college basketballers during competition and reported an average of 13.6 sprints during a game, each being 1-4 seconds in duration. The average work time was 11.7 seconds while the average rest time was 17.4. Overall the work to rest ratio (calculated from play during actual game time only) was 1:1.7. As well as this MacLean (1984) reported that players ran backwards an average of 8.2 times per game and jumped 26.7 times. However this study did not report the frequencies or durations of other activities such as jogging or walking. There are no other studies reported in the literature.

It is clear that an investigation of the movement patterns of players during basketball is required in order for coaches to be able to develop training programs specific to the requirements of competition. From the literature reviewed it appears that the most accurate method involves video recording of the players during actual competition. Following this an analysis should be undertaken that categorises the movement patterns according to the percentage of the game time spent in different intensities of activity. In addition, an analysis of the characteristics of the high intensity exercise bouts will provide information relating to the exercise metabolism that meets the energy demands of competition.

2.2 Physiological responses to participation in the Intermittent Team Sports: Heart rate and oxygen consumption.

The physiological responses to participation in athletic events, including HR and $\dot{V}O_2$ have been used for many years to describe the metabolic demands imposed on athletes during competition. In most cases, however, the use of HR and $\dot{V}O_2$ have been limited to athletic events including running, rowing and cycling where the demands imposed on participating athletes can be accurately simulated in a laboratory setting. Examining the physiological responses to participation in ITS during actual competition has only recently been possible with the advent of small HR recording equipment. Heart rate has been used as a direct indicator of exercise intensity (Reilly 1990) or as a means of estimating oxygen consumption and, therefore, the metabolic demands (Van Gool et al. 1988, Paterson 1979). The use of HR to estimate $\dot{V}O_2$ is based on the linear relationship between HR and $\dot{V}O_2$ during steady state submaximal workloads (Christensen et al. 1983, Morgan and Bennett 1976, Malhotra et al. 1963). This relationship, however, is not always evident at high or maximal workloads (Åstrand and Rodahl 1977). In addition HR may be affected by such factors as emotional state (Ramsey et al. 1970, Tumilty 1993), upper-body exercise (Green et al. 1976, Montgomery 1988), non-steady state conditions (Paterson 1979, Balsom et al. 1992a) and heat (Williams 1962). Significant errors are therefore possible when attempting to estimate $\dot{V}O_2$ from HR during ITS (Paterson 1979). Despite this the use of HR remains the easiest means by which the physiological demands of competition can be examined (Paterson 1979).

2.2.1 Heart rate responses to Intermittent Team Sports.

Table 2.5 contains the results of a number of studies examining the HR responses to participation in ITS. The average HR recorded during soccer appears to be 160-170 bts.min^{-1} (Van Gool et al. 1988, Cochrane and Pyke 1976, Seliger 1968a, Seliger 1968b) representing approximately 85% of HRmax (Cochrane and Pyke 1976, Van Gool et al. 1988). A higher average value of 175 $bts.min^{-1}$ has been reported by Agnevik (1970 as cited by Reilly 1990). MacLaren et al. (1988) reported an average HR of 172 $bts.min^{-1}$ for one player during 4-a-side soccer. Estimated $\dot{V}O_2$ during soccer has been reported to represent 75-80% of $\dot{V}O_2$ max (Van Gool et al. 1988, Ekblom 1986).

As the work rates differ between the positions on the field it is reasonable to expect that these differences will be reflected in the HR responses. Van Gool et al. (1983) reported that the HR values of the forward and midfielder were 171 and 170 $bts.min^{-1}$ respectively, while those of the centre-back and full back were only 155 $bts.min^{-1}$ each. Similar characteristics have been reported by Smodlaka (1978).

Although average HR provides an indication of the overall physiological demands imposed on athletes during ITS, it gives little indication of varying demands that occur during the game. In addition many studies reported only the absolute HR value, rather than the value relative to the players' maximums. A HR of 165 $bts.min^{-1}$ may indicate different intensities of play for athletes with different maximum HRs. Smodlaka (1978) reported the HRs of several players during the first half of a soccer match according to the time that the HR was within selected intervals. The averages for all the players indicated that the HR was maintained in the zones of 65-80% of their maximum for 37.5% of the total game time, 80-90% for 47.75% of the time, 90-95% for 11.75% of the time and 95-100% for 2.65% of the time.

From the limited amount of literature the physiological demands of soccer, as reflected by HR are fairly high. The average HR during play appears to be approximately 165 $bts.min^{-1}$ representing 80-85% max, although much higher individual averages have been reported. A players HR may remain above 80% of their maximum for 60% of the game. Oxygen consumption is generally estimated to represent 75-80% of $\dot{V}O_2$ max, though this is likely to vary depending on the level of competition (Ekblom 1986). Therefore, despite the observation that most of the game time is spent in low to moderate intensities

Table 2.5: Heart rate values during Intermittent Team Sports.

Authors (Year)	Subjects	Average HR (bts.min^{-1})	Estimated $\dot{V}O_2$ (%$\dot{V}O_2$ max)
Soccer			
Agnevik (1970 as cited by Reilly 1990)	Swedish national (n=1)	175 game max = 189	
Seliger (1968a)	Unspecified (n=16)	165	
(1968b)	Unspecified	160	
Cochrane and Pyke (1976)	Australian national (n=2)	165 (86% max[a]) max = 184 (94%)	
Van Gool et al. (1983)	Unspecified		
	centre-back (n=1)	155	
	full-back (n=1)	155	
	midfielder (n=1)	170	
	forward (n=1)	171	
Van Gool et al. (1988)	Belgian University (n=7)	1st half 169 (86.7% max) 2nd half 165 (84% max)	78% 74%
Field Hockey			
Boyle et al. (1992)	English International (n=9)	159 (range 145-174) 65% time > 85% max	78%
Cibich (1991)	South Australian state league	60% time > 85% max	
Australian rules football			
Pyke and Smith (1975)	West Australian		
	rover (n=1)	178	
	half back flank (n=1)	160	
Hahn et al. (1979)	West Australian rovers (n=2)	164 159	
Rugby			
Morton (1978)	Unspecified level rugby union backline	161	
Allen (1989)	Australian state		
	Touch rugby (n=4 males)	152 (82% max)	
	(n=4 females)	179 (92% max)	
Netball			
Woolford and Angove (1991)	Australian State players (n=3)	22% of time > 95%max 50% of time 85-95%max 20% of time 75-85%max 8 % of time < 75%max	
Ice Hockey			
Green et al. (1976)	Canadian University (n=6)	173 (87-92% max)	70-80%
Paterson et al. (1977)	Minor league (aged 10)		
	n=14 competitive	182 (92% max)	81%
	n=14 recreational	188 (95% max)	88.5%
Seliger (1968b)	n=15 Czech junior	177	
Seliger et al. (1972)	Czech national (n=13)	152 (72% max)	66%
Wilson and Hedberg (1975)	Unspecified (n=1)	178 (78% max)	

of activity, the physiological demands, as reflected by HR and estimated $\dot{V}O_2$, are high. It is likely, therefore, that the high intensity efforts are stressful enough and repeated often enough to place considerable demands on the cardiovascular capacities of the players.

The HR responses of Australian rules football players have not been extensively studied. This is likely to be due to the body-contact nature of the sport. Pyke and Smith (1975) reported an average HR for 1 quarter of 160 $bts.min^{-1}$ for a "Half Forward Flank". Values of 170-180 $bts.min^{-1}$, representing 90-95% of HRmax, were recorded during the passages of intense play while the HR dropped below 140 $bts.min^{-1}$ during some periods of the game. An average of 178 $bts.min^{-1}$ was recorded by a player in the position of Rover. In addition the HR of this player oscillated between 170 and 185 $bts.min^{-1}$ for most of the game and did not fall below 150 $bts.min^{-1}$. The differences in the HR responses between the two players reflect the observations of McKenna et al. (1988) that rovers spend less time standing still and walking and more time jogging than the more stationary positions of Half Back Flank.

Hahn et al. (1979) monitored the HR values of two players who occupied nomadic positions on the team for an entire game. The average HRs for the two players were 164 $bts.min^{-1}$ and 159 $bts.min^{-1}$. Both players recorded lower HRs during the second half which may reflect the observation that they both ran less distance during this half. It is likely, however, that the increased physiological requirements associated with present day Australian rules football are likely to be reflected in higher HR responses to competition than those reported in the literature.

The contact nature of rugby also makes HR monitoring during competition difficult. As such there is limited information in the literature. Morton (1978) reported that a rugby union backline player will maintain a HR ranging from 135-180 $bts.min^{-1}$ during a game with an average of approximately 161 $bts.min^{-1}$. Allen (1989) monitored a total of 12 touch rugby players that included 4 Open males, 4 females and 4 males over 35 years of age. The average HRs reported were 152.3 $bts.min^{-1}$ (82.27% of HRmax) for the Open males, 179.0

bts.min^{-1} (92.11% HRmax) for the females and 159.9 bts.min^{-1} (87.35% HRmax) for the Over 35 males.

The HR responses to field hockey have been measured by Boyle et al. (1992) and Cibich (1991). Boyle et al. (1992) reported an average value of 159 bts.min^{-1} for all players with the range of the averages being 145-174 bts.min^{-1}. Cibich (1991) reported that hockey players spend 60.5% of the game time at a HR of greater than 85% of HRmax.

The HR responses to elite level netball have been reported by Woolford and Angove (1991). They reported that more than 70% of the game time was spent with a HR response of greater then 85% of HRmax. In addition, 22%, or 1 minute and 7 seconds, was spent with a HR response of greater than 95% of HRmax. These results suggest that, although only a small percentage of the game is spent in activities of greater intensity than jogging (Steele and Chad 1991), the physiological demands reflected in the HR responses are high. Heart rate values above 85% of a players maximum can be expected for as much as 75% of the game time.

The HR responses to ice hockey are relatively well documented. Green et al. (1976) monitored the HRs of University players during competition and reported an average HR of 173 bts.min^{-1} (87-92% max) during the on-ice shifts. Oxygen consumption was estimated to be 70-80% of $\dot{V}O_2$ max. Similar average HR values have been reported by Seliger (1968b) and Wilson and Hedberg (1975) though higher values have been reported by Paterson et al. (1977) for minor league players. Paterson et al. (1977) estimated the average $\dot{V}O_2$ during the on-ice shift for the competitive and recreational minors to represent 81% and 88.5% of their respective maximums. Peak $\dot{V}O_2$ during competition was estimated to be 88.5% and 95.5% of their respective maximums, indicating high intensity periods of play for these minors. It is questionable, however, whether HR/$\dot{V}O_2$ relationships established by running on a treadmill are valid for estimating $\dot{V}O_2$ during ice skating. Wilson and Hedberg (1975) have shown that the HR during ice skating is higher than the HR obtained during treadmill running when $\dot{V}O_2$ is the same. However, according to Montgomery (1988), when both the HR and $\dot{V}O_2$ are expressed as a percentage of maximum there is very little difference between HR during ice skating and HR on a treadmill.

Seliger et al. (1972) attempted direct measurement of the oxygen uptake of 13 Czech national team players during practice games. The on-ice $\dot{V}O_2$ averaged 32 $ml.kg.^{-1}min^{-1}$ (66% of $\dot{V}O_2$ max) and the average HR was 152 $bts.min^{-1}$. It is conceivable, however, that the equipment the players were required to wear hampered their movements causing them to modify their play, reducing the intensity at which they worked. This is likely given the low average HR when compared to other values reported in the literature. With the equipment presently available it is not possible to directly measure $\dot{V}O_2$ during ITS without detracting from the performance of the athletes. As such any data obtained by this method is not likely to be a valid representation of the physiological responses to serious competition.

2.2.2 Heart rate responses to basketball.

The HR responses of players to participation in basketball have not been extensively studied. In particular, the last 10 years has seen no work reported in the literature. The limited number of studies that have monitored the HR responses to participation in basketball are summarised in Table 2.6.

McArdle et al. (1971) monitored the HR responses of 6 members of the 1969-70 Queens College Women's varsity basketball team for at least one quarter but no longer than one half during a number of games. A few of the players were monitored more than once giving a total of 11 sets of data. Since a considerable drop in HR occurred during time-outs, the HR values were analysed under playing conditions. This included actual play, out-of-bounds and foul shots. The overall average HR for all the games was 172 $bts.min^{-1}$ which represented 89% of the average maximum HR recorded in the laboratory. There were, however, large variations in the average HRs between the players. One player recorded an average value of just 154 $bts.min^{-1}$ (which represented 81% of her HRmax) whilst another player who was monitored during 3 separate games recorded average HRs of 190, 192 and 195 $bts.min^{-1}$

Table 2.6: Heart rate responses to basketball.

Authors (Year)	Subjects		Mean heart rate ($bts.min^{-1}$)
McArdle et al. (1971)	n=6 college women		172 (89% max)
Kerr (1968)	n=5 women		169
Seliger (1968b)	n=25 men and juniors		170
Ramsey et al. (1970)	n=1 college male		170
Skubic and Hodgkins (1967)	subject #1	forward	142
		guard	156
		rover	195
	subject #2	forward	143
		guard	142
		rover	177
Higgs et al. (1982)	n=10 female college		183

(representing 93, 94 and 95%HRmax). In addition, this particular subject recorded maximum HRs of 197, 201 and 204 $bts.min^{-1}$ during the three games indicating periods of intense play. The estimated $\dot{V}O_2$ ranged from 1.48 $l.min^{-1}$ to 2.44 $l.min^{-1}$ with an overall average of 1.88 $l.min^{-1}$. Whilst the individual values were not presented as a percentage of $\dot{V}O_2$ max, the average $\dot{V}O_2$ max for the 6 players was 2.19 $l.min^{-1}$. Therefore, the average $\dot{V}O_2$ during the games represented 86% of $\dot{V}O_2$ max. According to McArdle et al. (1971) the HR responses to participation indicated that the position of guard was the most physiologically demanding position.

Other studies have reported similar HR responses to McArdle et al. (1971). Kerr (1968) reported an average HR of 169 $bts.min^{-1}$ for 5 women players. Skubic and Hodgkins (1967) reported the values of 2 subjects who played in each of the positions of forward, guard and rover. Subject 1 recorded an average HR of 142 $bts.min^{-1}$ in the position of forward, 156 $bts.min^{-1}$ whilst playing guard and 195 $bts.min^{-1}$ in the position of rover. The maximum HR recorded by the subject was 228 bts.min^{-1}. The other subject recorded values of 143 bts.min^{-1}, 142 bts.min^{-1} and 177 bts.min^{-1} respectively. According to Skubic and Hodgkins (1967) the oxygen uptake for each subject, although not reported, indicated that the roving player required a significantly greater expenditure of energy than a forward or guard.

Seliger (1968b) monitored the HR responses of 15 men and 20 junior males to a 10 min basketball game. The $\dot{V}O_2$ of the players was also directly measured by a respirometer carried on their backs. It is likely, therefore, that the limitations associated with requiring subjects to wear the device would be no different to those that were evident in the studies of soccer and ice hockey. The average HR, however, was similar to that reported by McArdle et al. (1971) with a value of 170 bts.min^{-1}. The average $\dot{V}O_2$ was calculated to be 40 ml.kg^{-1}.min^{-1}. Although not expressed as a percentage of $\dot{V}O_2$ max, according to Reilly (1990) a value of 40 ml.kg^{-1}.min^{-1} would represent a demand of approximately 70% $\dot{V}O_2$ max for an elite basketball player.

Ramsey et al. (1970) studied the HR response of a male basketball player during a college game. The values recorded ranged from 155 bts.min^{-1} to 190 bts.min^{-1} with an average of approximately 170 bts.min^{-1}. During the time-outs, which lasted for approximately 1 minute, and the foul shots, which lasted 30 to 40 sec, not taken by the player, the HR only dropped to 155-160 bts.min^{-1}. During the foul shots which were taken by the player the HR remained elevated. According to Ramsey et al. (1970) this was most likely due to the physical and emotional involvement of taking the shot.

The highest HR values recorded are reported by Higgs et al. (1982). An average HR of 183 bts.min^{-1} was reported for 10 female college players. This value indicates a higher average intensity during competition and may be related to the increased physiological requirements compared to earlier studies.

From the available literature it appears that the HR during basketball averages approximately 170 bts.min^{-1} though higher values have been reported. Maximum values during competition may be in excess of 200 bts.min^{-1}. There appear to be significant differences between the positions with guards exhibiting higher HRs than those of forwards or centres. The work rate of this position is clearly high. However the literature is far from adequate. Similar to most other studies reporting the HR responses to ITS there has been no investigation of the percentage of game time spent within various HR intervals. The majority of the studies have also concentrated on the HR responses of women during basketball with only a few reporting male responses. Whilst Seliger (1968a) monitored 15 male players they were required to wear respirometers on their backs and this may have reduced the intensity at which they worked. The study of Ramsey et al. (1970), is limited in that only one college male was monitored during one game.

There is a need to further examine HR and $\dot{V}O_2$ responses of males to participation in basketball, particularly at the elite level, in order to understand the intensity of play. It is unlikely, however, that coaches will allow their players to be monitored during serious match play irrespective of how small the measurement device may be. As such any investigation will most likely be confined to practice matches or less serious competitions. Most data will, therefore, be limited in the extent to which it represents the true physiological responses that would be evident during serious competition. Despite this, it will still be of value in attempting to understand the physiological responses and requirements of men's competitive basketball.

2.3 Exercise metabolism in the Intermittent Team Sports

2.3.1 The sources of energy during Intermittent Team Sports.

Understanding the sources of energy during participation in ITS is an important aspect of being able to develop training programs and fitness protocols specific to the demands of competition (Bompa 1990). A number of authors have sought to classify the extent to which each of the metabolic pathways that supply energy for muscular contraction are utilised during participation in ITS (Table 2.7).

Table 2.7 Estimations of the utilisation of metabolic energy pathways during ITS

Author (Year)	Position	Estimated contributions to the energy demands ATP-CP	Lactic	Aerobic
Soccer				
Dal Monte (1983)		60-80	20	20
Fox and Mathews (1976)	Wingers/Striker	80	20	--
	Halfback	60	20	20
Australian rules football				
Pyke and Smith (1975)	Rover	30	20	50
	Others	70	15	15
Rugby Union				
Morton (1978)	Winger/Fullback	70	15	15
	Forward	10	35	55
Dal Monte (1983)		40-70	10-20	30-50
Ice Hockey				
Fox and Mathews (1976)		80	20	--
Dal Monte (1983)		80-90	5-20	--
Seliger (1972)		~ 66		~ 33
BASKETBALL				
Dal Monte (1983)		80	20	--
Fox and Mathews (1976)		85	15	--

It is clear that most authors consider the ATP and CP metabolic systems are the most active and the aerobic pathway to be the least active during participation in ITS. It is likely, therefore, that most estimations have concentrated on the energy requirements associated with the high intensity work periods as, in the authors opinion, it is unlikely that the aerobic contribution to soccer and ice hockey is zero as suggested by Fox and Mathews (1976).

In addition, the estimations in Table 2.7 provide no information regarding the interactions of the different pathways in meeting the energy demands of participation in ITS. In order to further understand metabolism during ITS it is necessary to consider more closely the characteristics of activity evident from the time motion analysis literature previously reviewed. A common characteristic of most ITS is the short duration of the high intensity work periods. Sprints are usually not longer than 5-6 seconds in duration and are required approximately once every 30-60 seconds.

The sources of muscular energy during relatively short bouts of maximum intensity exercise of 30 sec duration have been extensively studied. The role and importance of intramuscular stores of Adenosine Triphosphate (ATP), Creatine Phosphate (CP) and glycogen for exercise of this duration are relatively well understood (Boobis et al. 1982, Jones et al. 1985, McCartney et al. 1986, Cheetham et al. 1986). In contrast the contribution of these energy sources to the demands of maximal intensity exercise of a shorter duration such as those common in ITS are less clear. Boobis et al. (1982) reported that a 6 sec sprint on a cycle ergometer resulted in a 9% reduction in ATP and a 35% reduction in CP. Gaitanos et al. (1993) reported slightly greater reductions with a 13% decrease in ATP and a 53% decrease in CP. Hirvonen et al. (1987) examined metabolism during 40, 60, 80 and 100 metre sprints in highly trained sprinters. During the 40 m sprint (approximately 5.5 sec) the levels of ATP and CP were reduced by 35% and 63% respectively in the 3 fastest sprinters whilst the reductions were only 6% and 46% in the 4 slowest athletes. In addition 88% of the CP used in the 100 m sprint (11 sec) by the 3 fastest athletes was used in the first 5.5 sec. According to Hirvonen et al. (1987) sprinting ability is related to the speed at which the stores of ATP and CP can be used and most of the CP stored in the muscle is used during the first few seconds of the acceleration phase of a sprint.

Many of the early studies examining the metabolic responses to exercise of only a short duration concluded that the energy for muscular contraction lasting less than approximately 10 sec was derived almost *entirely* from the breakdown of intramuscular stores of ATP and CP (Keul and Doll 1973, Margaria et al. 1969). The anaerobic breakdown of glycogen was thought to commence only after the intramuscular store of CP had been depleted or reached a critically low level (Keul and Doll 1973, Margaria et al. 1969). Such assumptions were usually based on the observation that Bla did not rise significantly after 10 seconds of "maximal" exercise (Saltin and Essen 1971). These observations, however, were usually in response to exercise at an intensity equivalent to that of maximal aerobic power rather than maximum intensity exercise.

More recent studies using higher intensities of exercise, such as those of sprinting, have reported that muscle lactate is substantially elevated following even brief exercise of less than 10 sec duration (Jacobs et al. 1983, Boobis et al. 1982). Jacobs et al. (1983) reported a 5-fold increase in resting muscle lactate following 10 seconds of maximum intensity cycling whilst Boobis et al. (1982) reported a 200% increase in muscle lactate following a 6 second sprint on a cycle ergometer. According to Boobis et al. (1982), glycogenolytic processes are initiated within the first 6 sec of maximal intensity exercise before stores of CP have been depleted.

Other studies have suggested an even earlier onset of anaerobic glycolysis. Hultman and Sjoholm (1983) estimated that 20% of the energy used in the first 1.26 sec of electrically stimulated muscle contraction was supplied by the degradation of glycogen to lactate, whereas between 1.28 and 2.56 sec of exercise glycolysis accounted for 50% of the ATP resynthesis. Hultman and Sjoholm (1983) suggest that the utilisation of stored glycogen begins within 1 sec of the onset of exercise and the main role of CP appears to be as a buffer for sudden changes in energy demand. According to Boobis (1987) it is likely that under conditions of supramaximal exercise the energy is supplied simultaneously by the breakdown of CP and glycogen. It is clear that the anaerobic breakdown of glycogen is an important energy source during high intensity exercise of less than 6 sec duration.

Based on these laboratory studies it can be concluded that the main sources of muscular energy for single high intensity exercise bouts common in many ITS are the intramuscular stores of ATP and CP, but CP in particular. This has been suggested by a number of authors (McKenna et al. 1988, Allen 1989, Docherty et al. 1988). It is also true, however, that the breakdown of glycogen will also play a much more important role than has previously been believed in providing energy for exercise of these durations. Boobis et al. (1982) reported a 14% reduction in glycogen levels following only 6 seconds of maximum intensity exercise.

Similar results have since been reported by Gaitanos et al. (1993). Longer exercise bouts have shown that muscle glycogen may be reduced by approximately 25% following 30 seconds of maximal intensity exercise (Boobis et al. 1982, Jacobs et al. 1983). The fast breakdown of glycogen in the muscle may be of particular importance for ITS athletes in terms of the effect that reduced glycogen stores could have on maximum intensity exercise performance (Jacobs 1987, Bangsbo et al. 1992).

Unlike laboratory controlled experiments employing a single exercise bout of maximum intensity the contributions of the metabolic pathways to the energy demands of participation in ITS depends not only the intensity and duration of the high intensity work periods but also the nature and durations of the low intensity recovery periods (Green 1979, Balsom et al. 1992a). Numerous investigations have reported that exercise of high or maximal intensity can only be maintained for a relatively short period of time before the effects of fatigue significantly reduce the work output (Metzger and Fitts 1987, Boobis 1987). When the high intensity exercise is performed intermittently, however, the volume of work achieved has been shown to be considerably higher (Åstrand et al. 1960). In addition the metabolic responses during intermittent exercise are more similar to continuous moderate intensity exercise than to high intensity exercise (Saltin and Essen 1971, Edgerton et al. 1975, Christensen et al. 1960). Essen and Kaijser (1978) reported that, at the same overall average power output, intermittent exercise resulted in less glycogen depletion and lactate accumulation than continuous exercise. The rest periods during intermittent exercise, therefore, play a number of important roles in regulating metabolism that allows a large volume of high intensity work to be achieved with a smaller decrease in glycogen and less lactate accumulation.

Inactive periods during intermittent exercise allow for the resynthesis CP and ATP and decreases in inorganic phosphate (Harris et al. 1976), ADP and AMP (Essen et al. 1977); increases in intracellular concentrations of FFA and citrate (Parmeggiani and Bowman 1963, Essen 1978, Saltin et al. 1976), and the restoration of resting intramuscular pH levels (Holmyard et al. 1988, Balsom et al. 1992a). These factors appear to be important in both delaying the onset of anaerobic glycolysis and in preventing prolonged and excessive dependence on anaerobic glycolysis which would otherwise result in an increase in lactate and hydrogen ions (Essen and Kaijser 1978, Saltin et al. 1976). Accumulation of hydrogen ions and the associated fall in pH of the muscle is believed to be a major cause of fatigue during high intensity exercise (Metzger and Fitts 1987, Tesch and Wright 1983).

Decreasing the length of the recovery periods during intermittent high intensity exercise has been shown to increase the physiological requirements for a given intensity and duration (Keul 1973, Margaria et al. 1969, Balsom et al. 1992a). Holmyard et al. (1988) studied the power output during sprint running on a non-motorised treadmill. Ten rugby union players completed 10 sprints of 6 sec duration with either 30 or 60 sec rest between each sprint. During the 60 sec rest protocol subjects were able to maintain a significantly higher mean power output after the 5th sprint. In addition there was a tendency for the heart rate to be higher with the 30 sec recovery. The same exercise protocol was employed by Wootton and Williams (1983) who reported significant differences in mean, peak and end power from the third sprint onwards. Balsom et al. (1992a) reported that 40 m sprint performance was significantly reduced when the rest interval between sprints was reduced from 60 seconds to 30 seconds. In addition, Bla and $\dot{V}O_2$ were higher when the rest period was only 30 seconds.

Other studies have shown that shortening the duration of the recovery periods increases HR (Keul 1973, Balsom et al. 1992a), Bla concentration (Keul 1973, Margaria et al. 1969) and $\dot{V}O_2$ (Margaria et al. 1969) during intermittent exercise. A possible explanation for the increased physiological requirements and decreased performance associated with decreased recovery intervals is that shorter recovery periods may not provide sufficient time for a significant resynthesis of CP, resulting in an increased reliance on anaerobic glycolysis during subsequent exercise bouts (Holmyard et al. 1988, Saltin et al. 1976, Essen 1978). As well as this the concentrations of ADP, AMP and inorganic phosphate (Pi) within the muscle will remain elevated after the rest period. This will remove the inhibitory effects of a high ATP/ADP ratio and a high intracellular CP concentration on phosphofructokinase

(PFK) and phosphorylase during subsequent exercise bouts (Essen and Kaijser 1978). The resultant increase in the glycolytic rate will contribute to a fall in pH of the muscle. Although the exact contribution of a low pH to fatigue is not clear (Bangsbo and Saltin 1993) it is believed to play a significant role (Boobis 1987).

Estimations regarding metabolic sources of energy during intermittent high intensity exercise have most often been made using lactate levels in the blood (Balsom et al. 1992a, Holmyard et al. 1988). A more recent study by Gaitanos et al. (1993) used muscle biopsies to investigate the sources of energy during 10 sprints of 6 seconds duration interspersed with 30 seconds of recovery. The contribution of anaerobic glycolysis to the energy demands was reported to decrease from 44.1% in the first 6 second sprint to 16.1% in the last. The contribution of CP, however, increased from 49.6% in the first sprint to 80.1% in the last. These results suggest that anaerobic glycolytic activity is reduced during repeated bouts of high intensity exercise. According to Gaitanos et al. (1993) this may be due to an inhibition of glycolysis and glycogenolysis with increasing acidosis in the muscle. This is likely to result in an increase in the contribution of CP as well as aerobic metabolism to the energy demands during repeated bouts of intense exercise. However, the 26.6% reduction in power output suggests that CP levels were not fully restored during 30 seconds of rest.

From the above studies it appears that the metabolic sources of energy for the sprint bouts during ITS will be derived predominantly from the CP stores within the muscle and from anaerobic glycolysis. The energy for lower intensity activity (such as jogging) is likely to be supplied by the aerobic pathway. In addition, the energy necessary to resynthesise CP is believed to be supplied predominantly through aerobic pathways (Sahlin et al. 1979). During intense play with relatively few rest periods anaerobic glycolysis may be inhibited by a fall in pH within the muscle. Under such conditions the stores of CP are likely to supply the majority of energy for the high intensity bouts. The aerobic contribution may also become increasingly important during such periods of play.

2.3.2 Blood lactate responses to Intermittent Team Sports.

Given the spontaneous nature of play during ITS the physiological requirements and thus the exercise metabolism that meets the energy demands may vary considerably during competition. In an attempt to understand the sources of muscular energy during competition a number of studies have obtained blood samples for lactate analysis following the completion of a quarter or a half and at the end of the game. The concentration of lactate in the blood is the net product of entry into the blood from exercising muscle and removal from the blood (Brooks 1985, Gollnick and Hermanssen 1973). As such blood lactate cannot be used to quantify the activity of anaerobic glycolysis. The concentration of lactate in the blood does, however, provide an indication of the activity of that energy pathway during ITS (Ekblom 1986, Bangsbo et al. 1991). Table 2.8 contains the results of a number of studies that have measured blood lactate concentration during ITS.

Blood lactate (Bla) concentrations reported during soccer range from 2.4 $mmol.l^{-1}$ (Tumilty et al. 1988), 4 $mmol.l^{-1}$ and 8 $mmol.l^{-1}$ (Gerisch et al. 1988, Rohde and Esperson 1988) up to 12.8 $mmol.l^{-1}$ (Ekblom 1986). The low Bla concentrations have been used to suggest that anaerobic lactic yield is of almost no significance during soccer (Rohde and Esperson 1988). However values of 8 $mmol.l^{-1}$ and up to 12.8 $mmol.l^{-1}$ reported by Ekblom (1986) suggest otherwise. In most cases, however, the blood samples were only obtained at the completion of each half and may not be representative of values achieved during other times of the game.

In addition to taking blood samples after the first and second halves of play, Bangsbo et al. (1991) obtained blood samples from soccer players in the First Division Danish League during actual play in a non-competitive match by substituting players out of the game. The average value after the competitive matches was 4.4 (range = 2.1-6.9) $mmol.l^{-1}$. The mean lactate concentration during the first half of the noncompetitive match was 4.9 $mmol.l^{-1}$,

Table 2.8: Blood lactate concentrations recorded during Intermittent Team Sports.

Authors (Year)	Average Blood lactate concentration (mmol.l^{-1})	Comments
Soccer		
Tumilty et al. (1988)	2.4	
Gerisch et al. (1988)	5.58	1st half
	4.68	2nd half
Rohde and Esperson (1988)	5.1	1st half
	3.9	2nd half
Ekblom (1986)	8.0 (range 2-13)	
Bangsbo et al. (1991)	4.4 (range 2.1-6.9)	competitive games
	1st half 4.9	non-competitive games
	2nd half 3.9	
Australian rules football		
Dawson et al. (1991)	range 3.0-9.0	generally higher values in first 2 quarters
Rugby		
Docherty et al. (1988)	2.8	post-game only
Allen (1989)	3.37	post game only
McLean (1991)	6.0 (range 3.6-9.8)	Average value represented 66.5% of peak Bla after treadmill test
Ice Hockey		
Green et al. (1976)	8.62	forwards 1st period
	7.41	2nd period
	5.51	3rd period
	8.86	defensive 1st period
	7.20	2nd period
	4.22	3rd period
Green et al. (1978)	6.16	forwards 1st period
	4.65	2nd
	5.63	3rd
	2.92	defensive 1st
	2.72	2nd
	3.12	3rd
Wilson and Hedberg (1975)	9.9	forwards 1st period
	9.9	2nd
	8.1	3rd

significantly higher ($p<0.05$) than the mean concentration of 3.7 $mmol.l^{-1}$ during the second half. Bangsbo et al. (1991) reported a significant relationship ($r=0.61$, $p<0.05$) between Bla concentration and the duration of the high-speed running and sprinting during the 5 minutes of play prior to the blood sampling. Accordingly, Bangsbo et al. (1991) suggest that Bla measurements taken during competition in ITS only indicate the type and intensity of activity performed for a short period prior to the sampling. Single Bla determinations during and after the match cannot, therefore, be considered representative of anaerobic glycolytic energy turnover during an entire match. Smith et al. (1993) suggest a similar limitation.

Dawson et al. (1991) obtained blood samples from four Australian Football League players during pre-season practice games and competition games and reported lactate values of 3.0-9.0 $mmol.l^{-1}$. According to Dawson et al. (1991) higher Bla values were generally recorded in the first two quarters and lower values in the second half, particularly in the last quarter. There are no other values reported in the literature.

Blood lactate concentrations during rugby football have been reported to be 2.8 $mmol.l^{-1}$ (Docherty et al. 1988) and 6.0 $mmol.l^{-1}$ (McLean 1991). Allen (1989) reported an average value of 4.0 $mmol.l^{-1}$ during touch rugby. The results reported by McLean (1991) conflict with the suggestions by Docherty et al. (1988) and Allen (1989) that anaerobic glycolysis is not a major energy source during rugby football. According to McLean (1991) the different Bla concentrations may be related to the timing of blood sampling as well as the different tempo of the games during which the blood samples were obtained.

Blood lactate concentrations during ice hockey have been relatively well documented. Most values are within the range of 5-10 $mmol.l^{-1}$ (Green et al. 1976, Green et al. 1978, Wilson and Hedberg 1975). According to Green et al. (1976) the four to five fold increase in the Bla concentrations suggests a significant anaerobic involvement. The lower values are most likely due to the shorter shifts evident from the analysis of the characteristics of play (Green et al. 1978).

Summary of blood lactate responses to Intermittent Team Sports.

The literature reporting blood lactate concentrations during ITS has produced equivocal results. Some authors suggest that the relatively low blood lactate levels observed indicate that anaerobic glycolysis is of very little importance during some ITS (Allen 1989, Rohde and Esperson 1988) whilst others suggest that it is significant (Ekblom 1986, Green et al. 1976, McLean 1991). Although research has assisted in gaining an understanding of the sources of muscular energy during competition in these respective sports, it is clear that further investigations are needed.

2.3.3 Exercise metabolism during basketball.

There has been very little work investigating the exercise metabolism during basketball. Little is known regarding either the importance of or the interactions between the aerobic and anaerobic energy systems in meeting the energy demands of participation. The estimations contained in Table 2.7 suggest significant ATP and CP activity, though both authors appear to concentrate on the energy sources during the high intensity bouts and do not report the significance of the aerobic contribution to the energy requirements of competition.

Blood lactate concentrations during basketball have not been reported in the literature. According to MacLaren (1990), given that game HRs often average over 170 $bts.min^{-1}$. and intensities over 75% $\dot{V}O_2$ max, a high Bla concentration may be observed. However, MacLaren (1990) suggests that the numerous interruptions to the game, such as time-outs and substitutions, may result in lower than expected Bla concentrations.

It is clear that investigations are required in order to obtain a better understanding of the sources of muscular energy during participation in basketball. Such information may be of use in the development of training programs specific to the metabolic requirements of the sport.

CHAPTER 3

METHODOLOGY

3.1 Research Design

This purpose of this investigation was to describe the physiological requirements of men's competition basketball. As such the methodology is predominantly of a descriptive nature. Variables were neither manipulated nor controlled. There was, therefore, no hypothesis to be examined.

Eight (8) male subjects agreed to participate in this investigation. The study required monitoring of the subjects during competition. This included obtaining a video recording of the movement patterns of each subject during a game, monitoring and recording HR responses and obtaining blood samples at various stages of the games to be analysed for lactate concentration. In addition, each subject completed a laboratory-controlled incremental $\dot{V}O_2$ peak treadmill test.

3.2 Subjects

Each of the eight subjects was a member of a team participating in the 1992 Australian National Basketball League (NBL). The subjects were informed on the purpose of the study and the requirements for their involvement before they gave informed consent.

For the purpose of comparing the movement requirements of the different positions of play in basketball, each subject was asked to nominate which of the three positions he had occupied for the majority of the game; Guard, Forward or Centre.

3.3 General Description of the data collection techniques

Six of the subjects were monitored during Victorian Basketball Association (VBA) games in which some NBL teams participate. One subject (subject number 8) was monitored during a practice game against an opposing NBL team. Another subject (subject number 1) was monitored during a game against a visiting American team. All games were played indoor under the Australian Basketball Federation rules and consisted of 12 minute quarters with a break of 2 minutes between the first and second quarters and the third and fourth quarters and a 20 minute break between the second and third quarters.

This investigation comprised three components: 1) video analysis of the movement patterns during competition, 2) monitoring of HR responses to competition and 3) analysis of Bla concentrations during competition. Data for all three components was obtained from only one subject during each game. Due to technical problems incomplete data was obtained for 2 subjects. These subjects were monitored during a second game. All quarters during which a complete data set was obtained were included in the results.

3.4 Specific data collection techniques

3.4.1 Video analysis of the movement patterns during competition.

a) Video recording of the subjects: The movements of each subject were videoed during an entire game using a National M-7 video camera. The video camera was positioned in the best possible location to permit the entire court to be easily covered and the individual subject to be followed. Where possible the camera was positioned well above eye level so as to provide an unobstructed view of the subject at all times of the game. Given that the games were played at different stadiums, the positioning of the camera was determined by the dimensions of the stadium. This resulted in different angles of view of the court and subject for the games. In addition, the presence of crowds at the games and in particular the use of reserved seating, often limited the available positions. Despite this, all video recordings provided a clear view of the subject during the entire game and therefore each location proved to be adequate for the purposes of this investigation.

The camera was set up at least 30 minutes before the game and the suitability was checked by observing the subject during the warm-up period. At the commencement of the game, or when the subject was substituted into the game, the video recording of the subject began. The camera operator followed the subject for the entire time that he was on the court including free-throws, out-of-bounds and time-outs. Recording stopped at the completion of the quarter or when the subject was substituted out of the game.

b) Analysis of the movement patterns during basketball: Video editing equipment available from Victoria University of Technology (Educational Development Department-Footscray Campus) was used to analyse the video recordings. The editing equipment consisted of a National Editing Controller NV-A960 linked to a National Cassette Recorder NV-8500. The video image was displayed on a Sony Trinitron (RX-20PS1) television.

Using the equipment, the video could be viewed frame by frame allowing the different activities to be timed to an accuracy of 1/25th of a second. The accumulated seconds and frames was displayed on a counter. In addition the video image could be directly controlled and easily viewed in reverse or forward direction at any chosen speed. This permitted multiple viewing and analysis of different movements to ensure accuracy of timing and classification. Both of these characteristics were considered important in deciding to use this equipment.

Before undertaking each analysis the entire game was viewed, allowing for familiarisation with each subject's individual movement peculiarities at varying intensities, particularly those associated with Sprinting and High intensity shuffling. This enabled a more accurate analysis to be completed.

The following categories were used to classify the form and intensity of movement: Stand/Walk (S/W), Jog, Run, Run B, Stride/Sprint, Low Shuffle, Medium Shuffle, High Shuffle and Jump. The characteristics of each of these categories is explained in the Definitions of Terms section of this thesis. No distinction was made between backwards or forwards jogging.

In order to analyse the movement patterns during Live Time (LT) as distinct from Total Time (TT), the sounds of the Referees' whistles were used to indicate when the game had officially stopped. To determine when the game was restarted, the hand signals of the referees or the ball itself (eg. when the ball was touched after being thrown) were used. In the event that the referee or ball was not in the picture then either the game clock/scoreboard at the stadium or the 30 second "shot-clock" located at each end of the court was used. In those instances when none of these were in the picture, the sound of the ball bouncing (ie. being "dribbled") was used to indicate when play had restarted. As this was not considered an accurate means of determining exactly when play had restarted, as the player receiving the ball may not start dribbling immediately, this was only used when no other means was available. It was only necessary 2-3 times each game.

The official clock/scoreboard located at the stadium was not used to determine LT. As such it is possible that differences may exist between LT determined from video analysis and actual playing time (when the game clock was running) at the game. In each case the clock/scoreboard at the stadium was operated by a person on the side-line who reacts to the whistle and hand signals of the Referees and stops and starts the game clock accordingly. This reaction time may have differed from the video analysis depending on the particular operator at the stadium. However, given that the scoreboard operators at games of this level of competition (ie. State and National) are experienced, any differences are likely to be very small (perhaps 2-3 seconds for a quarter) and, in the context of the entire game, were considered to be negligible.

c) Reliability of the movement analysis: The reliability of the time-motion analysis methodology was examined by repeating the movement analysis of 4 different quarters, 1 quarter from each of 4 subjects. This was completed at least 2 weeks after the original analysis without reference to the original results. The percent of LT spent in each of the categories of movement obtained during the repeat analysis was compared to the results obtained during the original analysis. In addition the frequency of occurrence for each activity category and the timing of each individual movement were compared with the original analysis for each subject.

Three statistical techniques were used to assess the reliability of measurement: Pearson's product-moment correlation, Intraclass correlation (ICC) and the Method Error (ME) technique proposed by Sale (1991). In addition, a Spearman's correlations coefficient was used to assess the reliability of the frequency data. The ICC technique and the ME technique have both been suggested to provide a more accurate assessment of reliability than Pearson's product-moment correlation (Sale 1991, Baumgartner 1989).

3.4.2 Recording the heart rate responses to competition.

In order to examine the intensity of competition, the subject being videoed had his heart rate (HR) monitored during the game using a Sports Tester PE-3000 Monitor (Polar Electro Finland) recording at 15 second intervals. This device consisted of a transmitter worn as a belt around the chest in alignment with the sub xiphoid and V5 positions. For additional support the belt was secured with tape normally used for ankle strapping. The ECG signals were transmitted via telemetry to a microcomputer receiver, in the form of a wrist watch, worn around the subject's non-shooting wrist. For protection a sweat band was placed over the watch and strapped down with tape.

Prior to the actual game each subject was given an opportunity to wear the HR monitor during a training session. This enabled the subject's to become familiar with the device and confident in the ability to play without modifying their movements.

Each subject was given at least 1 week notice prior to being monitored during competition. At least 30 minutes prior to the start of the game the subject was fitted with the device. Any problems with the device were rectified during the warm-up period.

Prior to the beginning of the game, but after the warm-up, the stop-watch on the HR monitor was started and the recording of the subjects HR began. At exactly the same time a stop-watch on the sideline was started in synchronisation with the stop-watch on the HR monitor. At the start of play in each quarter the exact time on the stop-watch on the sideline was noted. If the subject did not start the quarter or was re-entering the game after a break on the bench then the exact time was also noted. Having a watch on the side-line that was synchronised with the time on the HR monitor allowed the HR values to be matched to the video recording.

The HR monitor was checked a number of times throughout the game to ensure that the transmitter was still working and the stop-watch was still recording the subject's HR. As soon as possible after the game the monitor was removed and HR recording ceased. The HR values were retrieved from the watch at a later date.

The HR values were divided into those that were recorded during TT and those that were recorded during LT. This was achieved by matching the exact time that the HR value was recorded on the watch with the video recording of the player through the use of the synchronised watches. The TT values indicate all HR values recorded when the player was on the court and includes time-outs, free-throws and all stoppages in play. The LT values include those HRs recorded during LT (ie. when the game clock was running) or any value that was directly affected by LT (ie any play that occurred within the 15 seconds interval before the HR value was recorded). This often resulted in values being included in LT even though play may have commenced only 1-2 seconds before the HR value was recorded. Such values may be more reflective of the rest period rather than LT activity. However they were included in the LT data because they were recorded when the game was in progress and may have been affected by play. This method of dividing the HR values into TT and LT also meant that play may have stopped 13-14 seconds before the HR value was recorded. Although the value may have been affected by 13-14 seconds of inactivity they were included in LT data because play may have affected the HR value recorded.

In summary, the difference between TT and LT values is that LT values include all values where any amount of play occurred in the 15 seconds before the HR was recorded on the watch. Although this method may have resulted in values that were more indicative of rest HR or affected by a stoppage in play, it was considered the only possible way of including all values that may have been directly affected by play.

3.4.3 Analysis of blood lactate concentrations during competition.

In order to gain an indication of the metabolic sources of energy during participation in men's competition basketball arterialised blood samples were obtained during competition and analysed for lactate concentration. At a training session prior to the game each subject was informed of the purpose of the blood collection and the technique involved. This provided them with an opportunity to ask questions regarding the process of blood sampling.

In each case blood samples were obtained from the subject being videoed and having his HR monitored. At the end of the quarter, or when the subject was substituted out of the game, a blood sample was obtained where possible. As such, more than one blood sample may have been obtained during a quarter. As soon as the subject was seated after leaving the court a finger on the subject's non-shooting hand was swabbed with alcohol and pricked with an Auto-clix lancet. The first drop of blood was discarded, the finger dried and then the blood collected in a capillary tube containing anticoagulant and lysing agent. A band-aid was then placed over the wound so as to prevent blood being transmitted on to the ball or other players. The blood was mixed for at least 2 minutes before being capped and stored on ice.

In each case the blood sample was obtained as close as possible to the time that the subject came off the court at the completion of play. In most instances this was within 30 seconds of play being stopped. In a small number of cases, however, the delay in obtaining the sample was as much as 1 minute. In no instance was the sample obtained more than 1 minute after play had stopped.

The blood samples were stored at 1-4 degrees Celsius and analysed in duplicate within 12 hours using an Analox LM-P4 portable lactate analyser. The machine was calibrated prior to use (8 $mmol.l^{-1}$ lactate standard) and then 5 microlitres of the sample were injected in to the machine for analysis. The portable lactate analysis machine was calibrated after every 5 blood samples to ensure accuracy of analysis.

3.4.4 Laboratory testing of the subjects.

The aerobic power ($\dot{V}O_2$ peak) of each subject was measured on a motor-driven treadmill during a visit to the Exercise Physiology Laboratory located at Victoria University of

Technology, Footscray Campus. There was no attempt to keep the time between the monitoring of the subject during competition and the laboratory testing consistent. In all but one case, however, the test was completed within 2 months of the subject being monitored. As $\dot{V}O_2$ peak has been reported to remain the same throughout a competitive season (Hakkinen 1988) it is unlikely that the aerobic capacities of the subjects altered between the time of monitoring and the time of laboratory testing. One of the subjects (Subject 8) was injured after the game in which he was monitored and before being tested in the laboratory. This subject was tested at the beginning of the following season (1993 season). It is possible that the fitness of this subject may have altered between the time he was monitored and the testing in the laboratory. Any differences are, however, likely to be minimal, as $\dot{V}O_2$ peak is relatively insensitive to the training state of an athlete (Williams 1990). As such it is logical to conclude that the $\dot{V}O_2$ peak results obtained for subject #8 will not be significantly different to those that would have been obtained at the time of monitoring.

The subjects arrived at the lab at least 2 hours after their last meal and had their body mass and height recorded. They were then informed of the protocol of the test. In order to obtain steady state heart rates and oxygen consumption values each subject ran at each of 3 speeds (10, 12 and 14 km/h) for 3 minutes. Following this the speed of the treadmill was increased by 2 km/h for a further 1 minute and then the elevation was increased by 2% each minute until the subject terminated the test.

The $\dot{V}O_2$ peak tests were conducted using an on-line open-circuit spirometry system. Expired air volume was collected whilst the subject breathed through a Hans Rudolf two-way valve connected to a Pneumatic digital spirometer. Sampled expired air was analysed for O_2 and CO_2 content by Applied Electrochemistry Analysers. Calibration of the analysers preceded each test (C.I.G. Melbourne, Analytical Grade Gas). The Ventilometer was calibrated using a Medical Graphics Corporation 3 litre calibration syringe. An IBM PC linked via an A to D converter calculated the data directly from the instrumentation. Data was calculated and recorded every 30 seconds during the test.

Heart rate values were recorded every 30 seconds throughout the duration of the test using a Sports Tester PE-3000 HR monitor (the same monitor used during the games). The maximum HR recorded during the test was defined as HRpeak. The term "HRpeak" was preferred to the more commonly chosen term of "HRmax". This was because 2 of the subjects (subject 6 and subject 8) recorded higher heart rates during the game than the maximum value achieved during the $\dot{V}O_2$ peak test. In these instances the maximum value achieved during competition was considered to be the subject's HRpeak.

3.5 Statistical treatment of the data

Statistical analysis was performed using analysis of variance (ANOVA) procedure to determine if there were any significant differences between the physical characteristics of the subjects and the movement patterns between the 3 positions of play. In the event of a significant F-ratio, a Student-Newman-Keuls post-hoc test was employed. The same procedure was used to examine any significant differences between the positions for the percent of TT and LT spent in each of the HR categories of intensity.

For each of the above (excepting physical characteristics) the data from each quarter (as opposed to the data for the entire game) was used for statistical analysis.

The reliability of the time-motion analysis was examined using Pearson's product-moment correlation, an ICC analysis and the ME technique. In addition, a Spearman's correlation coefficient was also obtained for the frequency data.

An alpha level of 0.05 was adopted for all statistical analyses.

CHAPTER 4

RESULTS

The results obtained in this investigation will be presented in four sections; 4.1) Physical characteristics of the subjects, 4.2) Movement patterns during competition, 4.3) Heart rate responses to competition and 4.4) Blood lactate concentrations during competition.

4.1 Physical characteristics of the subjects

The physical characteristics of the subjects are presented in Table 4.1. The mean age of subjects was 23.5 years with no significant differences between the positions of play. The mean height of the subjects was 191.0 cm with Guards being significantly shorter than Forwards. Although the Centres were considerably taller than the Guards and Forwards the lack of statistical significance is most likely due to the small sample size (n=2) for Centres. The mean mass of the subjects was 90.8 kg with Centres and Forwards both being significantly heavier than Guards. The mean $\dot{V}O_2$ peak of the subjects was 5.5 $l.min^{-1}$ in absolute terms or 60.7 $ml.kg.^{-1}min^{-1}$ in relative terms. There were no significant differences in $\dot{V}O_2$ peak between the positions of play.

4.2 Movement patterns during competition

A total of 38 quarters of play were analysed for the movement characteristics of the subjects during actual competition. Each subject was analysed for at least 1 game (4 quarters) giving a total of 8 games or 32 quarters. Two subjects (subject 3 and subject 6) were analysed over 2 different games for 6 quarters and 8 quarters respectively. The second games were required following technical problems with video recordings and HR monitoring during the first game for both subjects. Complete data sets from each quarter are included in the results. Appendix A contains the results obtained for each quarter of play. Tables 4.3-4.7 contain the data collected from the entire game for each subject.

Table 4.1: Physical characteristics of the subjects

SUBJECT #	AGE (years)	HEIGHT (cm)	MASS (kg)	$\dot{V}O_2$ PEAK ($l.min^{-1}$)	$\dot{V}O_2$ PEAK ($ml.kg.^{-1}min^{-1}$)
GUARDS					
1	27	171.0	70.6	4.9	70.0
2	22	180.0	82.5	5.0	61.1
3	23	191.3	85.1	5.6	65.4
MEAN (±S.D.)	24.0 (2.7)	180.1 # (10.2)	79.4 #◆ (7.7)	5.2 (0.3)	65.5 (4.4)
FORWARDS					
4	21	195.7	89.6	6.4	71.9
5	24	194.8	94.5	5.9	62.0
6	27	196.4	93.2	4.8	51.6
MEAN (± S.D.)	24.0 (3.0)	195.6 * (0.8)	92.4 (2.5)	5.7 (0.8)	61.8 (10.2)
CENTRES					
7	18	199.1	108.2	6.1	56.2
8	26	199.3	102.4	4.9	47.5
MEAN (± S.D.)	22.0 (5.7)	199.2 (0.1)	105.3 *# (4.1)	5.5 (0.9)	51.8 (6.1)
MEAN ALL SUBJECTS (± S.D.)	23.5 (3.2)	191.0 (10.2)	90.8 (11.8)	5.5 (0.6)	60.7 (8.6)

* Significantly different from Guards.
\# Significantly different from Forwards.
◆ Significantly different from Centres.

4.2.1 Reliability of the movement analysis

Four quarters of play (mean TT 15 minutes 57 seconds, mean LT 8 minutes 46 seconds) were compared for the percent of LT spent in each category of movement (Table 4.2a), the accuracy of timing for each movement within each category (Table 4.2b) and the frequency of occurrence of each activity (Table 4.2c).

High Pearson's product-moment correlations (r) were obtained for the percent of LT spent in Jog, Run, Stride/Sprint, all intensities of Shuffle and Jump ($0.95 < r < 0.99$, $p<0.05$). Moderate correlations were obtained for S/W ($r=0.81$, $p=0.19$) and Run B ($r=0.93$, $p=0.08$). The ME technique, however, revealed a small variation between repeated measurement for S/W (CV=4.13%). The ME values for all other categories were low to moderate (4.0% < CV < 11.0%) except for Run B (CV=70.21%). The ICC values obtained for the percent of LT spent in the categories of movement were all high (0.94 < ICC < 0.99) except for S/W (ICC=0.68) and Run B (ICC=0.90).

Each of the 4 quarters used in the reliability analysis was assessed for the accuracy of timing for each individual movement. Each instance of S/W, Jog, Run, Run B, Stride/Sprint, Low intensity Shuffle, Medium intensity Shuffle, High intensity Shuffle and Jump was matched to the repeat analysis. The data obtained for each category of movement were compared using the 3 techniques listed above and the results are presented in Table 4.2b.

High Pearson's product-moment correlations were obtained for the accuracy of timing for all categories of movement ($r>0.90$, $p<0.05$) except Medium Shuffle ($r=0.86$, $p<0.05$). The ME technique revealed low to moderate coefficient of variation values for all categories (CV<12.00%) except Run B (CV=21.43%). High ICC values were obtained for all categories (ICC>0.88) except Run B (ICC=0.76) and Medium intensity Shuffle (ICC=0.81). These results indicate that the reliability of timing is high for all categories of movement except Medium intensity Shuffle ($r=0.86$, CV=10.86%, ICC=0.81) and Run B ($r=0.98$, CV=21.43%, ICC=0.76).

Table 4.2a: Reliability measurements for the percent of Live Time spent in the movement categories using 4 quarters of play from 4 subjects.

Movement category	Pearson's product-moment (r)* correlation	Method Error (CV)	Intraclass correlation coefficient**
Stand/Walk	0.81 (NS)	4.13%	0.68 (NS)
Jog	0.98	4.91%	0.98
Run	0.97	8.76%	0.97
Run B	0.93 (NS[a])	70.21%	0.90 (NS)
Stride/Sprint	0.98	5.63%	0.98
Low Shuffle	0.97	4.09%	0.97
Medium Shuffle	0.96	6.30%	0.95
High Shuffle	0.99	10.58%	0.99
Jump	0.96	8.93%	0.96

* All values significant at $P<0.05$ except Stand/Walk (NS) and Run B ([a]$P=0.08$).
** All values significant at $P<0.05$ except Stand/Walk and Run B.

Table 4.2b: Reliability analysis for accuracy of timing for each individual movement in the categories of activity. Values are the average for the 4 quarters.

Movement category	Pearson's product-moment (r)* correlation	Method Error (CV)	Intraclass correlation coefficient**
Stand/Walk	0.99	3.90%	1.00
Jog	0.93	8.92%	0.94
Run	0.97	7.92%	0.97
Run B	0.98 (NS[a])	21.43%	0.76 (NS)
Stride/Sprint	0.93	11.20%	0.93
Low Shuffle	0.91	9.84%	0.88
Medium Shuffle	0.86	10.86%	0.81
High Shuffle	0.92	8.01%	0.89
Jump	0.90	11.73%	0.95

* All values significant at $P<0.05$ except Run B ([a]$P=0.12$)
** All values significant at $P<0.05$ except Run B.

Table 4.2c: Reliability analysis for the frequency of each movement category for the 4 quarters.

Movement category	Pearson's product-moment (r)* correlation	Spearman's correlation coefficient*S	Method Error (CV)	Intraclass correlation coefficient**
Stand/Walk	0.99	1.00	3.92%	0.99
Jog	0.97	1.00	11.05%	0.96
Run	0.96	0.80 (NS)	11.82%	0.93 (NS)
Run B	0.94 (NS[a])	0.94	67.88%	0.85 (NS)
Stride/Sprint	1.00	1.00	9.48%	0.98
Low Shuffle	0.99	1.00	7.75%	0.91 (NS)
Medium Shuffle	0.95	1.00	6.27%	0.86 (NS)
High Shuffle	0.95	1.00	8.83%	0.87 (NS)
Jump	1.00	0.95 (NS[b])	3.96%	0.99

* All values significant at P<0.05 except Run B ([a] p=0.07)
*S All values significant at P<0.05 except Run (NS) and Jump ([b] P=0.051)
** All values significant at P<0.05 except Run, Run B, Low Shuffle, Medium Shuffle and High Shuffle

The third assessment of reliability compared the frequency of occurrence of each movement category between the original and repeat analysis for each quarter. The results are presented in Table 4.2c. Pearson's product-moment correlation were obtained using the square root of the frequency data. The square root transformation makes the frequency data approximately "normal", allowing Pearson's product-moment correlation to be used (Box et al. 1978 p.275). The correlation coefficient obtained for each category was high ($r>0.94$, $p<0.05$) excluding the category of Run B ($r=0.94$, $p=0.07$). The non-parametric Spearman's correlation (r_S) procedure was also used to examine the reliability of the frequency data. The values obtained for each category were high ($r_S>0.94$) except for Run B ($r_S=0.80$) which was not significant. The values obtained using the ME technique indicate only small variations (CV<12.00%) between the analyses for all categories excluding Run B (CV=67.88%). The large CV value for Run B is most likely due to the extremely small frequency (mean frequency=1.1). The ICC values were high (ICC>0.95) for S/W, Jog, Stride/Sprint and Jump. The values obtained for Run (0.93), Run B (0.85), Low Shuffle (0.91), Medium Shuffle (0.86) and High Shuffle (0.87) suggest some variations between the analyses.

4.2.2 Characteristics of movement during competition.

The TT on court and LT played are presented in Table 4.3. The results for subject number 6 are averaged for the 2 complete games monitored. The results for subject number 3 are only for 1 game and do not include the 2 quarters of data obtained during the incomplete game (game number 2). The mean TT on court for all subjects was 63 min and 25 seconds. The mean LT played was 36 min and 33 seconds. Each subject played at least half the game (24 minutes) but only one subject (subject number 4) played the entire game (48 minutes). The overall ratio of TT on court-to-LT played was approximately 7:4.

a) Frequency and duration of activity.

Table 4.4 contains the frequency of occurrence for each of the movement categories for the entire game. The mean frequency of all activities was 1007. Thus, with a mean frequency of 1007 over a mean TT of 3805 seconds, a change in event occurred, on average, every 3.8 seconds. Using the LT played of 2193 seconds it was calculated that there was a change in event every 2.2 seconds. The frequency of activity for each quarter was highly correlated to the LT played during the quarter using Spearman's correlation coefficient (r_S=0.94, $p<0.05$).

The mean frequency of S/W was 297. The mean frequency of Jog was 105 with a similar frequency for Run (106). The mean frequency of Run B was 6. The mean number of Stride/Sprints was 105, however there was a large range of values between the subjects (range 43-174). The mean number of Shuffles was 345. Of these Shuffles, an average of 168 were Low intensity, 114 were Medium intensity and 63 were High intensity. The mean number of Jumps for the entire time played was 44. The frequency of Jumps was moderately correlated to the LT played using Spearman's correlation coefficient (r_S=0.46 $p<0.05$).

Table 4.3: Total Time on court and Live Time played for each subject.

SUBJECT	TOTAL TIME ON COURT (MIN:SEC)	LIVE TIME PLAYED (MIN:SEC)
GUARDS		
1	75:45	37:04
2	64:28	35:35
3	68:38	43:34
MEAN (± S.D.)	69:37 (5:42)	38:44 (4:15)
FORWARDS		
4	77:50	48:00
5	57:30	34:52
6	57:23	34:35
MEAN (± S.D.)	64:13 (11:46)	39:09 (7:40)
CENTRES		
7	52:34	28:30
8	53:14	30:12
MEAN (± S.D.)	52:54 (0:28)	29:21 (1:12)
MEAN ALL SUBJECTS (± S.D.)	63:25 (9:52)	36:33 (6:28)

Table 4.4: Frequency of occurrence of each movement category during Total Time

SUBJECT #	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
GUARDS									
1	267	86	120	3	149	187	198	119	24
2	265	72	80	3	171	215	134	91	40
3	359	97	160	8	174	158	143	78	51
MEAN (± S.D.)	297 (54)	85 # (13)	120 (40)	5 (3)	165 #◆ (14)	187 (29)	158 #◆ (35)	96 #◆ (21)	38 (14)
FORWARDS									
4	392	178	119	0	88	184	116	53	54
5	310	109	83	6	76	140	76	62	60
6	285	159	89	4	60	197	102	33	37
MEAN (± S.D.)	329 (56)	149 * (36)	97 (19)	3 (3)	75 * (14)	174 (30)	98 *◆ (20)	49 * (15)	50 (12)
CENTRES									
7	259	71	104	19	43	127	67	12	53
8	235	71	89	1	76	133	76	59	35
MEAN (± S.D.)	247 (17)	71 * (0)	97 (11)	10 (13)	60 * (23)	130 (4)	72 *# (6)	36 * (33)	44 (13)
MEAN ALL SUBJECTS (± S.D.)	297 (54)	105 (42)	106 (27)	6 (6)	105 (52)	168 (33)	114 (44)	63 (33)	44 (12)

* Significantly different from Guards.
\# Significantly different from Forwards.
◆ Significantly different from Centres.

Statistical analysis using the results obtained from each quarter of play revealed a number of differences in the frequency of activity between the positions. Forwards recorded a higher frequency of Jog than Guards and Centres. Guards recorded a higher frequency of Stride/Sprint than Forwards and Centres. Guards also recorded a significantly greater number of Medium and High intensity Shuffles than Forwards and Centres. There were no significant differences between the positions of play for the frequency of S/W, Run B or Jump.

Table 4.5 contains the mean duration of the various activities for each subject for the entire game. The mean duration of S/W was calculated from LT data only and does not include those instances that the subjects were standing still or walking when the game clock was not running (such as free-throws and time-outs). Including these rest periods in the calculation would have elevated the average duration of S/W to a value rarely evident during the game, approximately 6-8 seconds.

The mean duration of activity for each category of movement was less than 3 seconds. The mean durations were 2.5 seconds for S/W, 2.5 seconds for Jog, 2.3 seconds for Run, 1.5 seconds for Run B and 1.7 seconds for Stride/Sprint. The mean duration of Shuffle was 1.8 seconds at Low intensity, 1.9 seconds at Medium intensity and 2.1 seconds at High intensity.

Statistical analysis using data obtained from each quarter revealed that the mean duration of S/W and Jog were greater for Forwards compared to Guards. There was a trend, which was not statistically significant, for Centres to S/W and Jog for longer than Guards. The mean duration of Run was significantly lower in Guards compared to both Forwards and Centres. There were no significant differences in the mean duration of activity between Forwards and Centres for any of the categories of movement.

Table 4.5: The mean duration (seconds) of the various activities.

SUBJECT #	MEAN DURATION OF ACTIVITY (SECS)							
	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH
GUARDS								
1	1.9	2.5	1.7	0.9	1.7	1.7	2.0	2.9
2	2.3	2.3	1.9	2.0	1.8	2.0	1.9	1.9
3	2.4	1.8	1.9	1.9	1.5	2.2	2.1	2.0
MEAN (± S.D.)	2.2 # (0.3)	2.2 # (0.4)	1.9 #◆ (0.1)	1.6 (0.6)	1.6 (0.2)	1.9 (0.3)	2.0 (0.1)	2.3 (0.6)
FORWARDS								
4	2.8	2.5	2.4	--	1.8	1.7	1.9	1.7
5	2.5	2.9	2.8	1.4	1.8	1.8	1.7	2.0
6	2.8	2.7	2.3	1.5	1.9	1.6	1.8	2.1
MEAN (± S.D.)	2.7 * (0.1)	2.7 * (0.2)	2.5 * (0.2)	1.5 (0.1)	1.8 (0.1)	1.7 (0.1)	1.8 (0.1)	1.9 (0.2)
CENTRES								
7	2.1	2.5	2.9	2.0	1.9	1.9	2.0	2.4
8	3.4	2.9	2.2	1.0	1.3	1.7	1.6	1.6
MEAN (± S.D.)	2.8 (0.9)	2.7 (0.3)	2.6 * (0.5)	1.5 (0.7)	1.6 (0.4)	1.8 (0.2)	1.8 (0.3)	2.0 (0.6)
MEAN ALL SUBJECTS (± S.D.)	2.5 (0.5)	2.5 (0.4)	2.3 (0.4)	1.5 (0.4)	1.7 (0.2)	1.8 (0.2)	1.9 (0.2)	2.1 (0.4)

* Significantly different from Guards.
\# Significantly different from Forwards.
◆ Significantly different from Centres.

b) Characterisitics of activity during Total Time.

The percent of TT spent in each category of movement is presented in Table 4.6 and Figures 4.1a-4.1d. Figure 4.1e illustrates each of the means for the 3 positions as well as the overall mean for all subjects.

The mean percent of TT spent in each category of movement was 61.9% for S/W, 7.1% for Jog, 6.9% for Run, 0.3% for Run B, 4.7% for Stride/Sprint, 8.5% for Low Shuffle, 5.8% for Medium Shuffle, 3.7% for High Shuffling and 1.1% for Jump. The standard deviations indicate that large variations in the percent of TT spent in each category of movement exist for all categories except S/W and Jog.

The percent of TT spent in the categories of activity was largely dependent on the position played. Guards spent a significantly smaller percent of the TT in S/W than Forwards and Centres and a smaller percent of time Jogging than Forwards. Guards also spent a significantly greater percent of TT Striding/Sprinting and Shuffling at all intensities (Low, Medium and High) than Forwards and Centres. The only significant difference between Forwards and Centres was that Forwards spent a greater percent of TT Jogging than Centres.

c) Characteristics of activity during Live Time.

The percent of LT spent in each of the categories of movement is presented in Table 4.7 and Figures 4.2a-d. Figure 4.2e illustrates the mean percentages for each position as well as the combined mean for all subjects.

The mean percent of LT spent in S/W was 35.5% for all subjects. The mean percent of LT spent Jogging was 11.3% similar to the percent of LT spent Running, 12.0%. Only 0.5% of the LT was spent in Run B. The mean percent of LT spent Striding/Sprinting was 8.1%. The mean percent of LT spent in Low intensity Shuffle was 14.7% while the values for Medium and High intensity Shuffling were 9.4% and 6.2% respectively. The time spent Jumping represented 1.9% of LT.

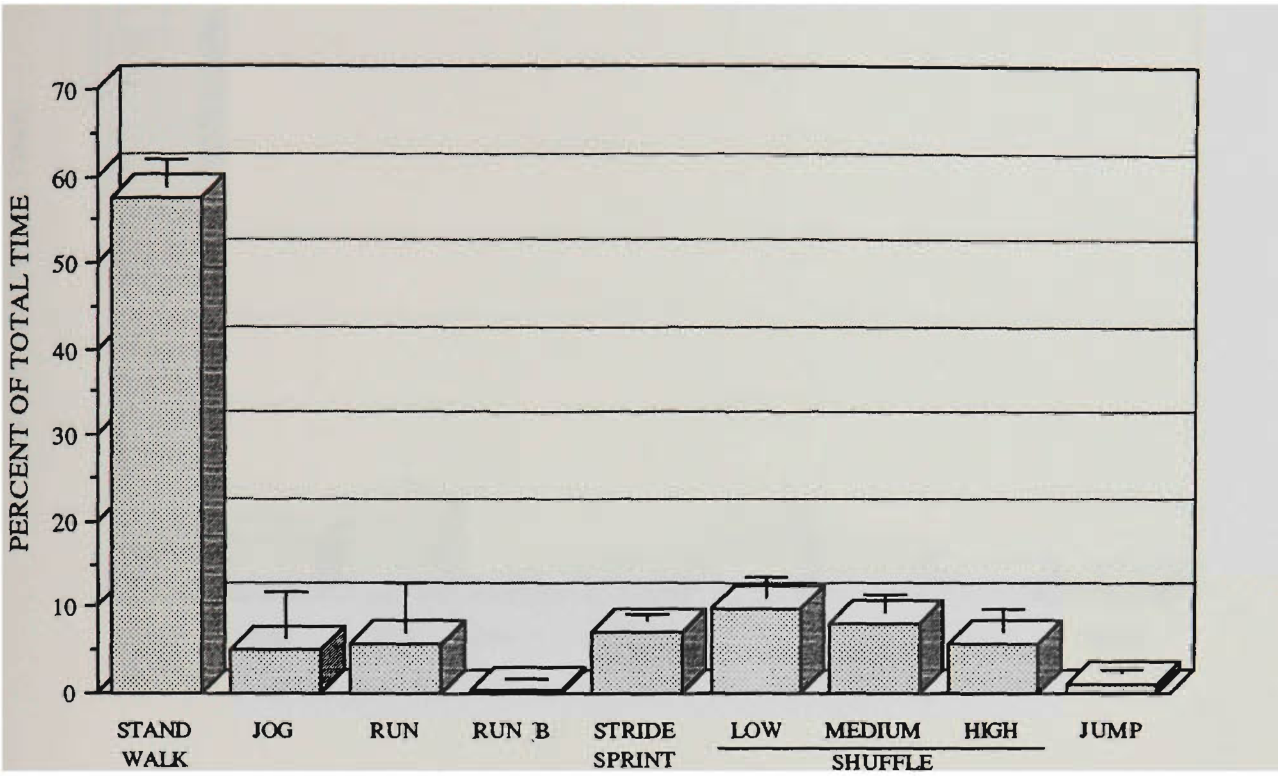
Table 4.6: Percent of Total Time spent in each category of movement.

SUBJECT #	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
GUARDS									
1	53.6	5.8	5.6	0.1	6.7	8.4	10.4	8.9	0.5
2	60.1	4.3	4.0	0.2	7.7	12.7	6.2	3.8	1.0
3	58.3	5.6	7.7	0.4	6.5	8.6	7.3	4.4	1.4
MEAN (± S.D.)	57.3 #◆ (3.3)	5.2 # (0.8)	5.8 (1.9)	0.2 (0.1)	7.0 #◆ (0.7)	9.9 #◆ (2.4)	8.0 #◆ (2.2)	5.7 #◆ (2.8)	1.0 (0.5)
FORWARDS									
4	64.4	9.9	6.4	0	3.8	7.1	4.9	2.5	1.0
5	63.7	8.6	6.9	0.3	3.9	7.2	3.9	3.8	1.6
6	63.2	8.7	6.2	0.2	3.4	9.2	5.4	1.7	1.0
MEAN (± S.D.)	63.8 * (0.6)	9.1 *◆ (0.8)	6.5 ◆ (0.4)	0.2 (0.1)	3.7 * (0.3)	7.9 * (1.2)	4.8 * (0.8)	2.7 * (1.1)	1.2 (0.3)
CENTRES									
7	63.5	7.3	11.3	1.1	2.6	7.5	4.2	1.1	1.6
8	68.1	7.0	6.7	0	3.2	7.2	3.9	3.0	0.9
MEAN (± S.D.)	65.8 * (3.3)	7.1 * (0.2)	9.0 # (3.3)	0.5 (0.8)	2.9 * (0.5)	7.4 * (0.2)	4.1 * (0.2)	2.0 * (1.4)	1.3 (0.5)
MEAN ALL SUBJECTS (± S.D.)	61.9 (4.4)	7.1 (1.9)	6.9 (2.1)	0.3 (0.4)	4.7 (1.9)	8.5 (1.9)	5.8 (2.2)	3.7 (2.4)	1.1 (0.4)

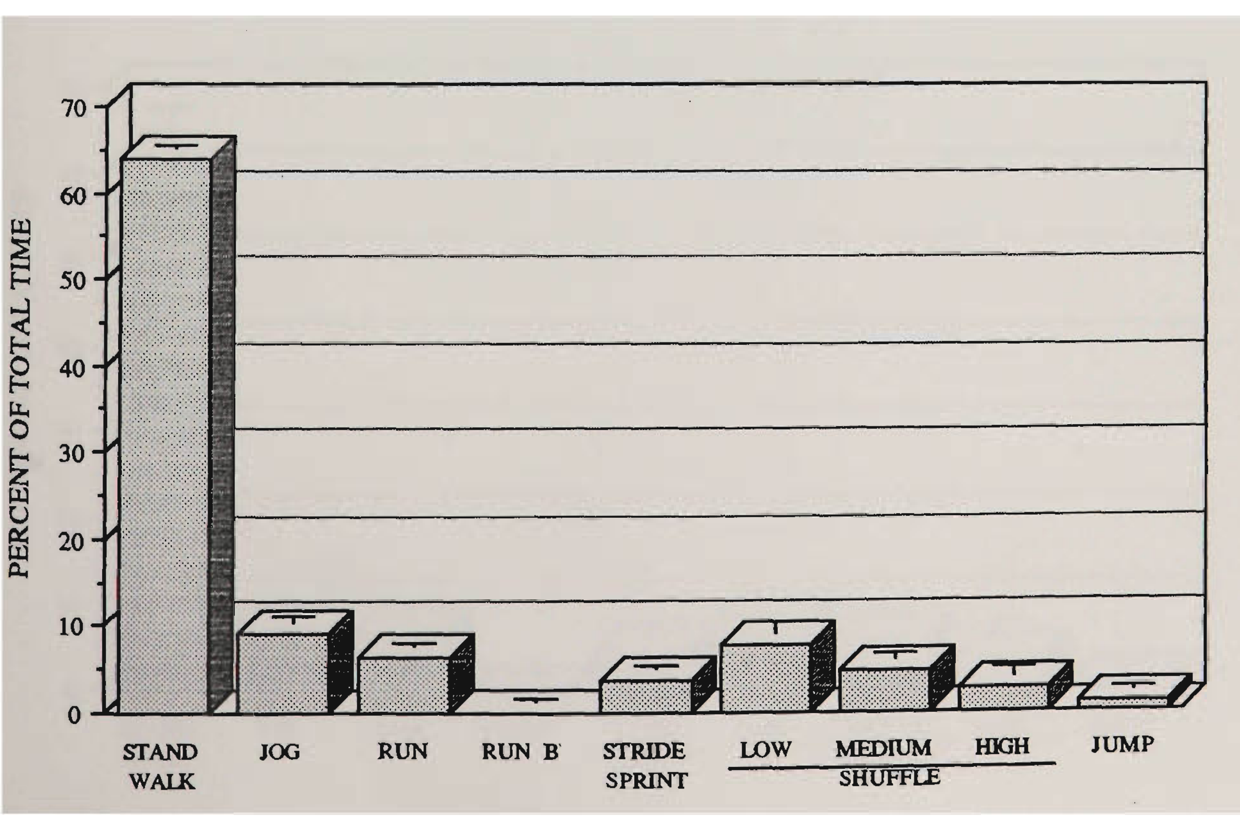
* Significantly different from Guards.
\# Significantly different from Forwards.
◆ Significantly different from Centres.

Figures 4.1, a-d: Percent of Total Time (mean ± S.D.) spent in the categories of movement for Guards (a), Forwards (b), Centres (c) and All Subjects (d)

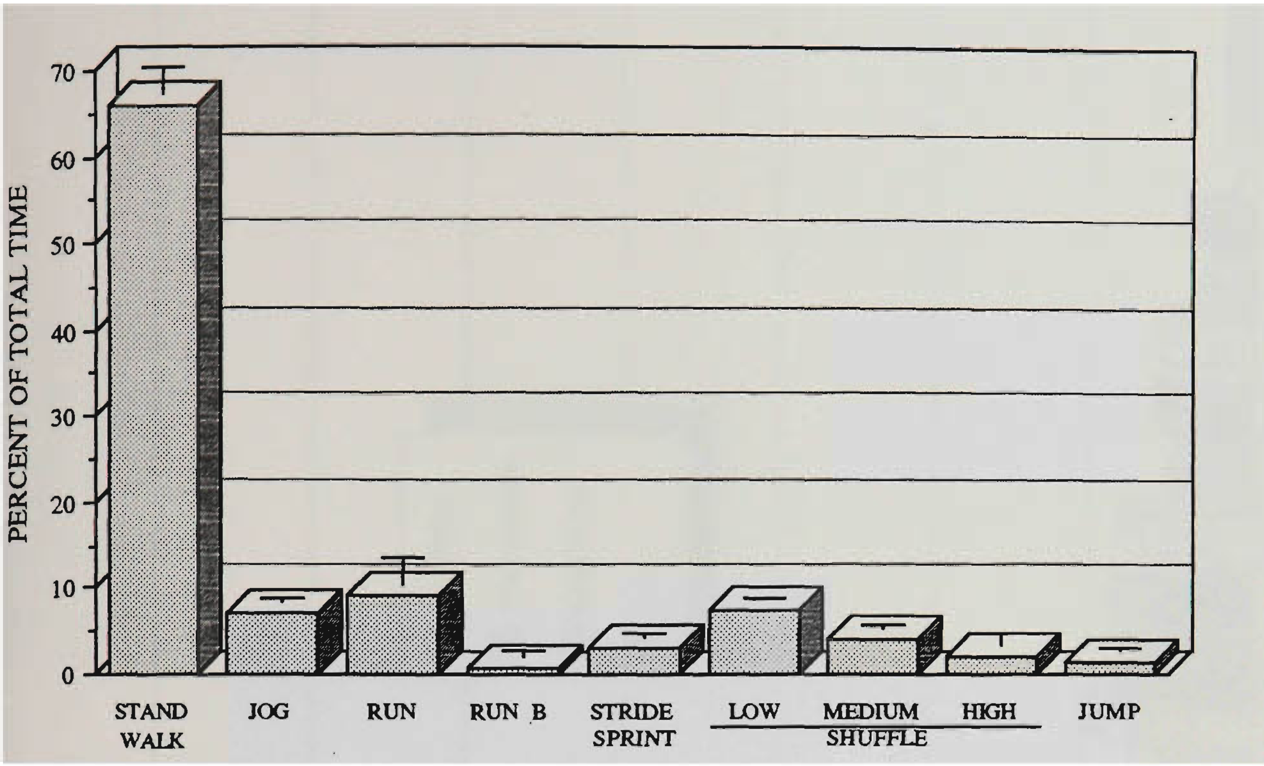
a: Guards



b: Forwards



c: Centres



d. All Subjects

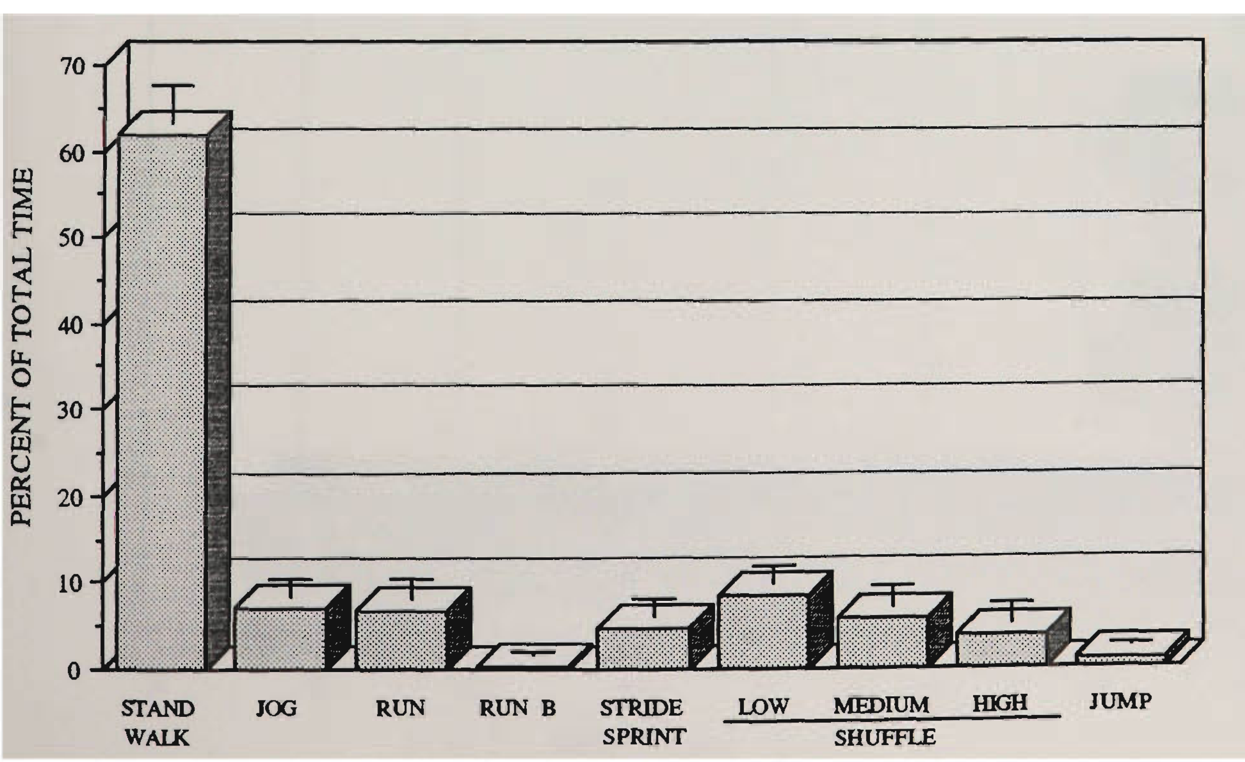


Figure 4.1e: Percent of Total Time spent in the categories of movement.

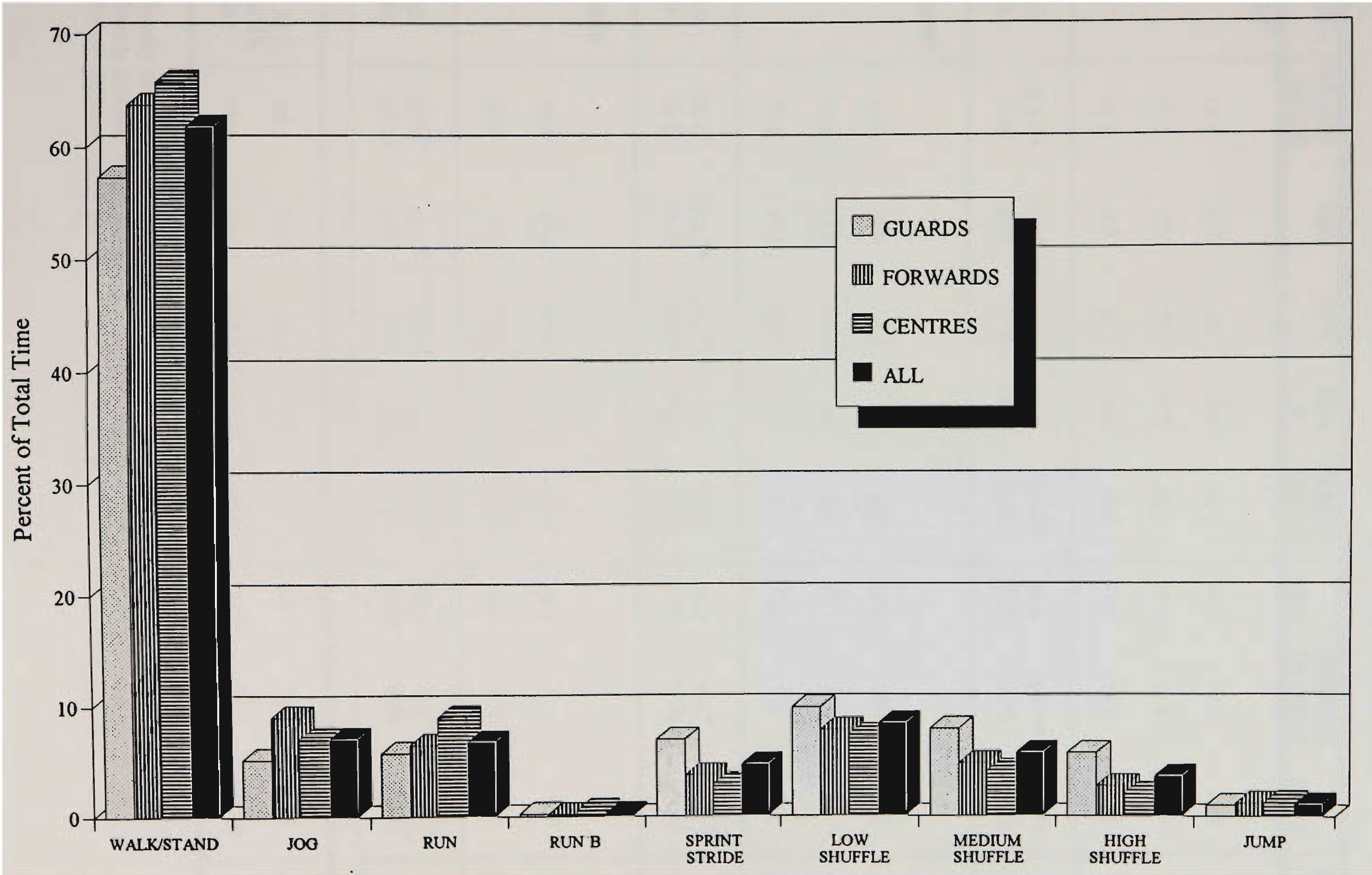


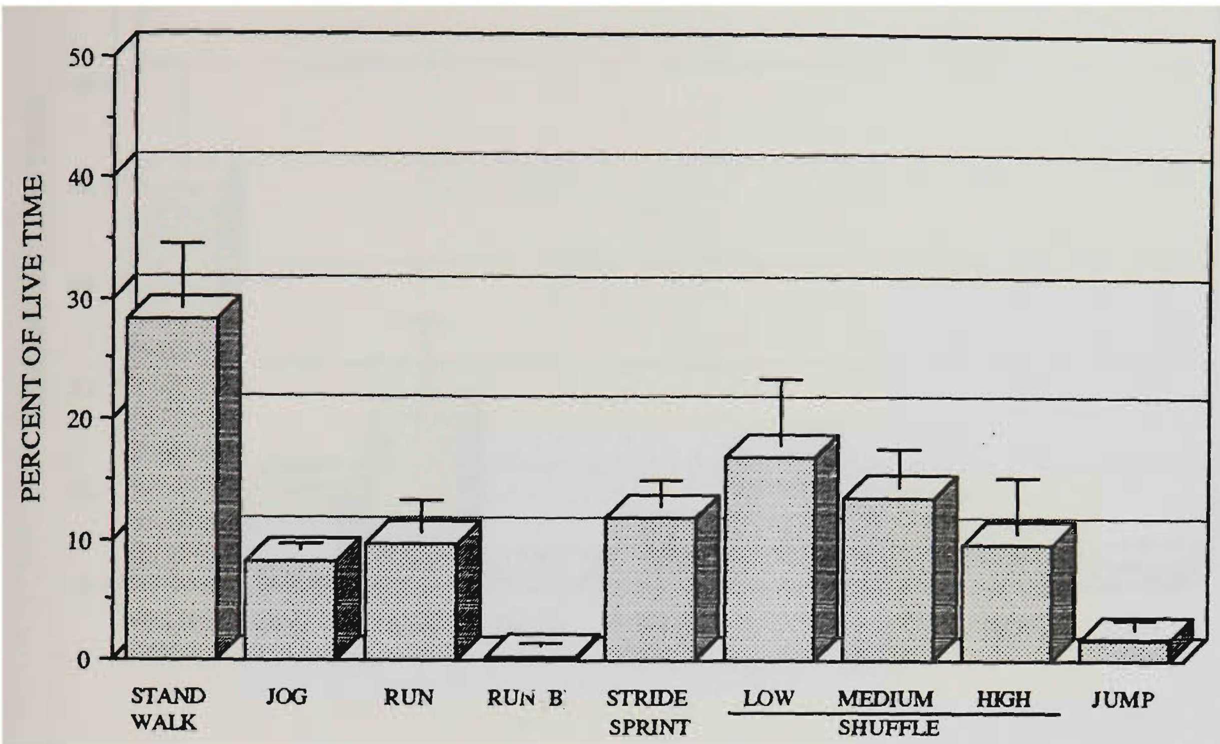
Table 4.7: Percent of Live Time spent in each category of movement.

SUBJECT #	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
GUARDS									
1	23.5	8.7	9.4	0.2	11.1	14.0	17.2	14.9	0.8
2	27.1	7.7	7.3	0.3	14.3	23.3	11.4	7.0	1.9
3	34.0	8.5	12.4	0.5	10.2	13.6	11.8	6.9	2.2
MEAN (± S.D.)	28.2 #◆ (5.4)	8.2 # (0.5)	9.7 (2.6)	0.3 (0.2)	11.9 #◆ (2.2)	17.0 (5.5)	13.5 #◆ (3.3)	9.6 #◆ (4.6)	1.6 (0.7)
FORWARDS									
4	40.5	16.5	10.7	0	6.2	11.9	8.3	4.2	1.7
5	39.1	14.5	11.6	0.5	6.6	12.2	6.6	6.4	2.6
6	39.5	14.6	10.4	0.4	5.7	15.6	9.2	3.0	1.6
MEAN (± S.D.)	39.7 * (0.7)	15.2 *◆ (1.1)	10.9 ◆ (0.6)	0.3 (0.2)	6.2 * (0.5)	13.2 (2.1)	8.4 * (1.3)	4.5 * (1.8)	1.6 (0.5)
CENTRES									
7	32.0	10.4	23.1	2.1	4.9	14.4	8.1	2.0	3.1
8	47.8	9.7	10.9	0	5.5	12.6	6.9	5.1	1.6
MEAN (± S.D.)	39.9 * (11.1)	10.1 # (0.6)	17.0 # (8.6)	1.0 (1.5)	5.2 * (0.4)	13.5 (1.2)	7.5 * (0.9)	3.5 * (2.2)	2.3 (1.1)
MEAN ALL SUBJECTS (± S.D.)	35.5 (7.9)	11.3 (3.4)	12.0 (4.7)	0.5 (0.7)	8.1 (3.4)	14.7 (3.7)	9.9 (3.5)	6.2 (4.0)	1.9 (0.7)

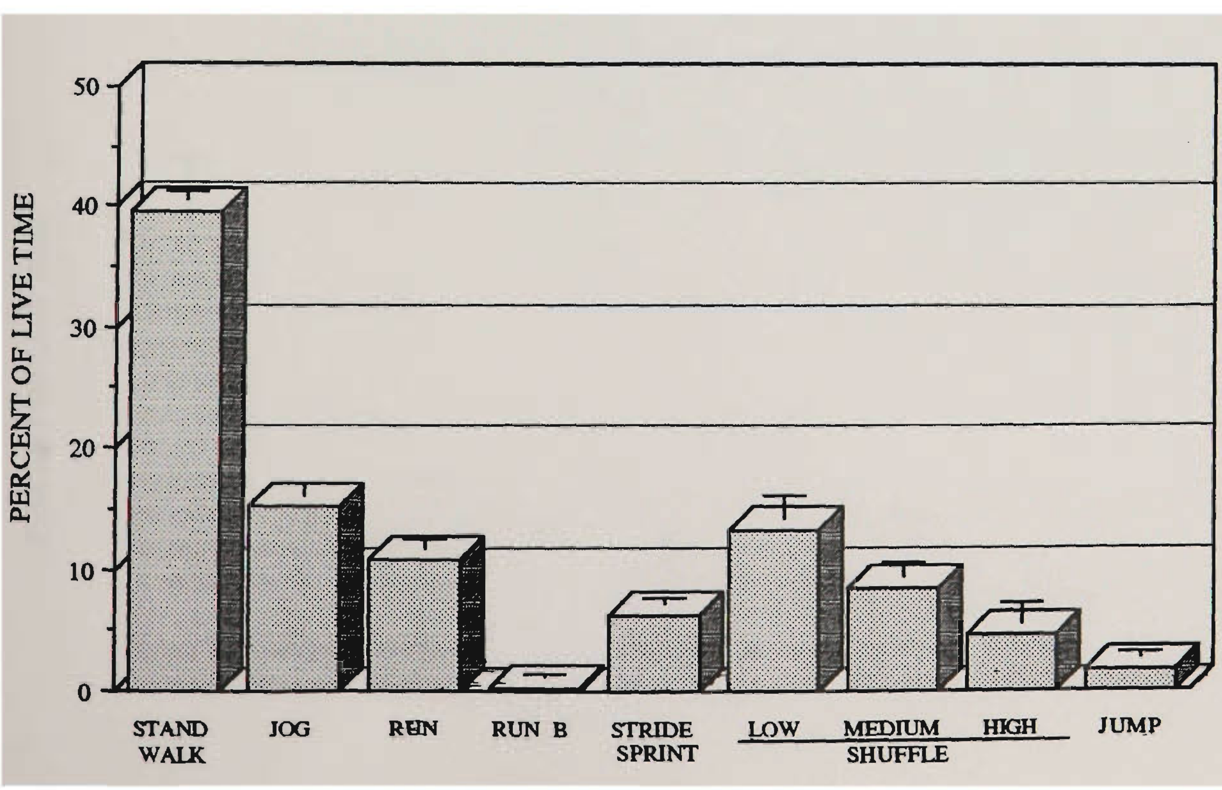
* Significantly different from Guards.
\# Significantly different from Forwards.
◆ Significantly different from Centres.

Figures 4.2 a-d: Percent of Live Time (Mean $\pm$ S.D.) spent in each of the categories of movement for Guards (a), Forwards (b), Centres (c) and All Subjects (d).

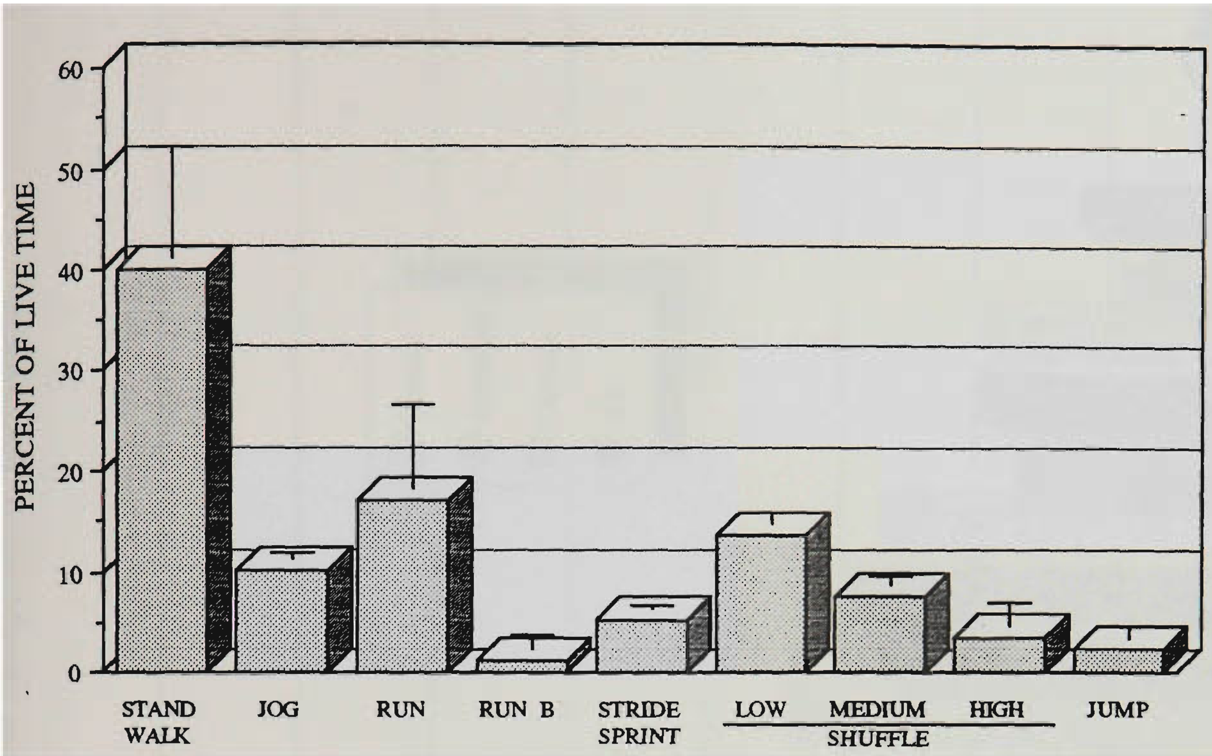
a: Guards



b: Forwards



c: Centres



d: All Subjects

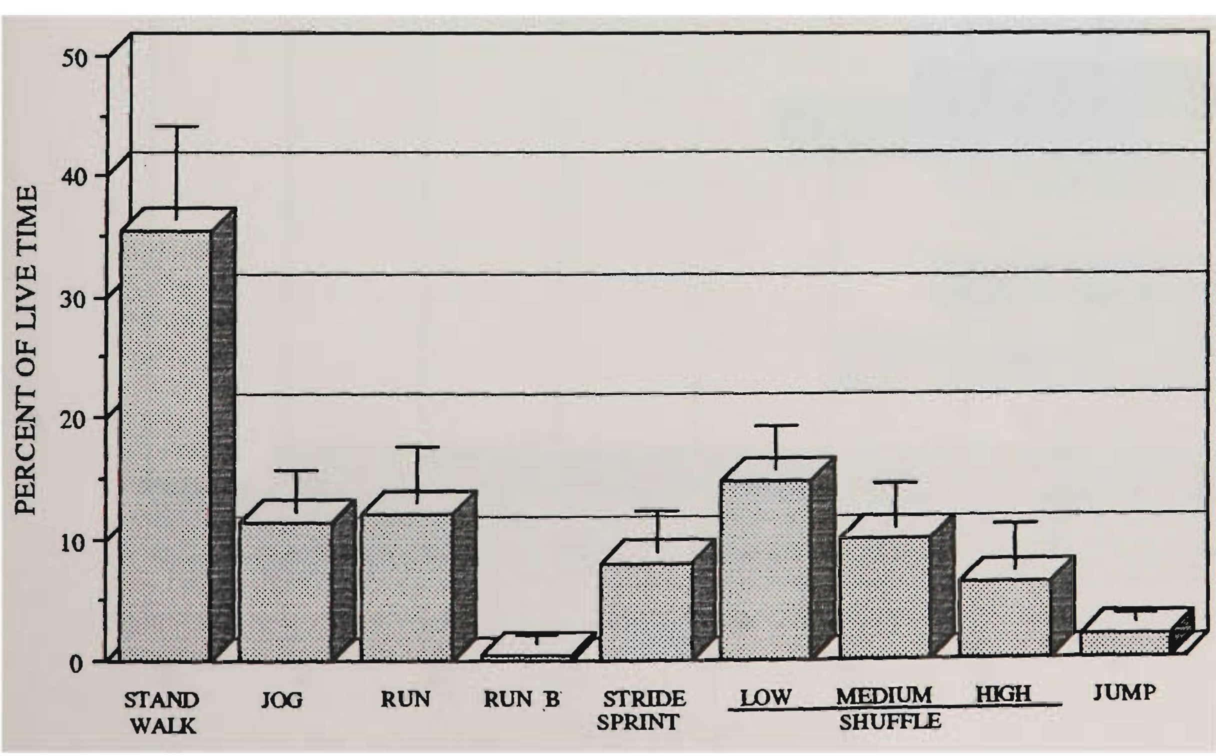
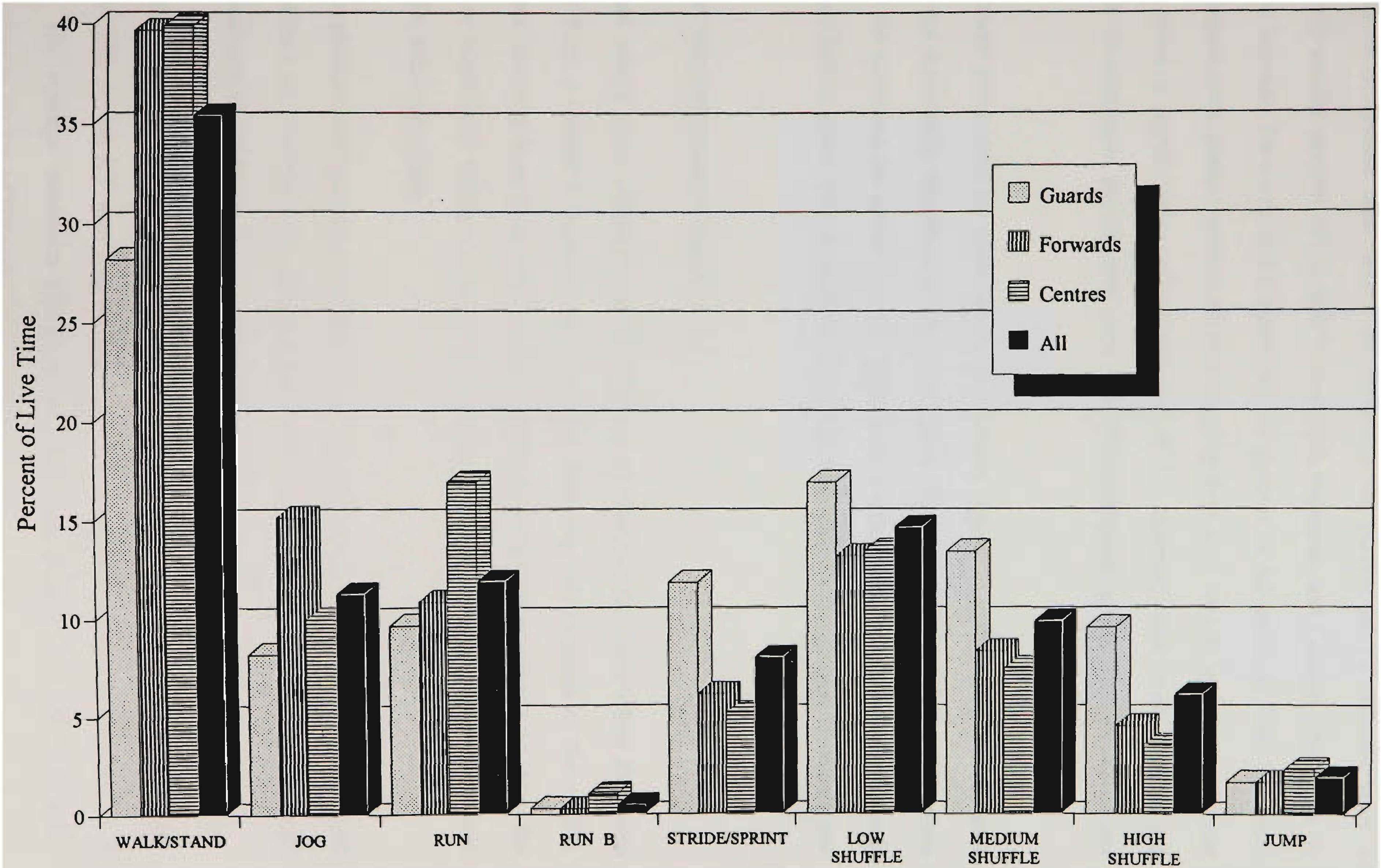


Figure 4.2e: Percent of Live Time spent in the categories of movement.



The significant differences between the positions of play for the percent of LT spent in the categories of movement were similar to those for the percent of TT. Guards spent a significantly smaller percent of LT in S/W than both Forwards and Centres. There was no difference between Forwards and Centres for the percent of LT spent in S/W. Forwards spent a significantly greater percent of time Jogging than both Guards and Centres whilst Centres spent a significantly greater percent of LT Running than both Guards and Forwards. Guards spent significantly more time Striding/Sprinting than both Forwards and Centres.

Though there was a trend for Forwards to spend more time Striding/Sprinting than Centres this was not statistically significant at the $p<0.05$ level. There were no significant differences between the positions for percent of LT spent Low intensity Shuffling. However Guards spent significantly more time in Medium and High intensity Shuffling than Forwards and Centres.

4.3 Heart rate responses to competition

Heart rate values were obtained for 32 quarters of competition. Incomplete data was available from a further 6 quarters, however this data was not included in the results. Incomplete data was most likely due to technical problems related to contact on either the receiver or transmitter. Similar problems have been reported in other investigations (Green et al. 1976, MacLean 1984).

The mean absolute and mean relative HR's during TT and LT are presented in Table 4.8 and Figures 4.3a-4.3d. The highest (maximum) HR recorded during the game for each subject are also included in Table 4.8.

The mean HR during TT was 164.9 $bts.min^{-1}$ representing 86.8% of the subjects' HRpeak. The mean HR during LT was slightly higher at 168.4 $bts.min^{-1}$ representing 88.7% of HRpeak. The average maximum HR recorded during the games was 188.1 $bts.min^{-1}$ corresponding to 99.1% of HRpeak.

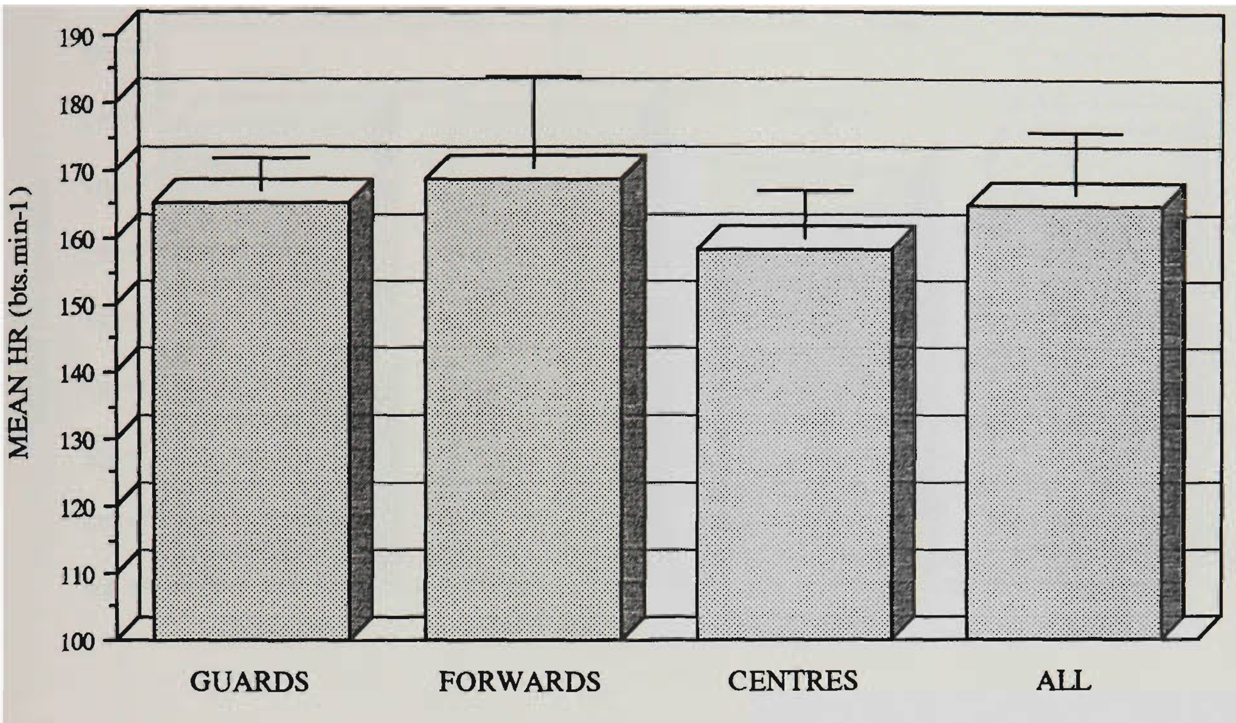
Table 4.8: Mean Absolute and Relative heart rates during Total and Live Time and maximum game heart rates.

SUBJECT #	MEAN HR (Total Time)	MEAN HR (%HRpeak) (Total Time)	MEAN HR (Live Time)	MEAN HR (%HRpeak) (Live Time)	MAXIMUM GAME HR	RELATIVE MAXIMUM (%HRpeak)
GUARDS						
1	170.7	87.6	176.0	90.2	190	97.4
2	161.5	86.8	165.7	89.1	184	98.9
3	163.4	87.8	166.1	89.3	184	98.9
MEAN (± S.D.)	165.2 (4.9)	87.4 (0.5)	169.3 (5.8)	89.6 (0.6)	186 # (3.5)	98.4 (0.9)
FORWARDS						
4	169.8	86.2	173.1	87.8	196	99.5
5	155.2	83.4	158.3	85.1	186	100.0
6	181.6	91.3	183.6	92.3	199	100.0
MEAN (± S.D.)	168.9 ◆ (13.2)	87.0 (4.0)	171.7 (12.7)	88.4 (3.6)	193.7 * (6.8)	99.8 (0.3)
CENTRES						
7	163.1	84.5	166.7	86.4	189	97.9
8	153.5	86.7	158.0	89.3	177	100.0
MEAN (± S.D.)	158.3 # (6.8)	85.6 (1.6)	162.4 (6.2)	87.8 (2.0)	183.0 (8.5)	99.0 (1.5)
MEAN ALL SUBJECTS (± S.D.)	164.9 (9.1)	86.8 (2.3)	168.4 (8.8)	88.7 (2.2)	188.1 (7.0)	99.1 (1.0)

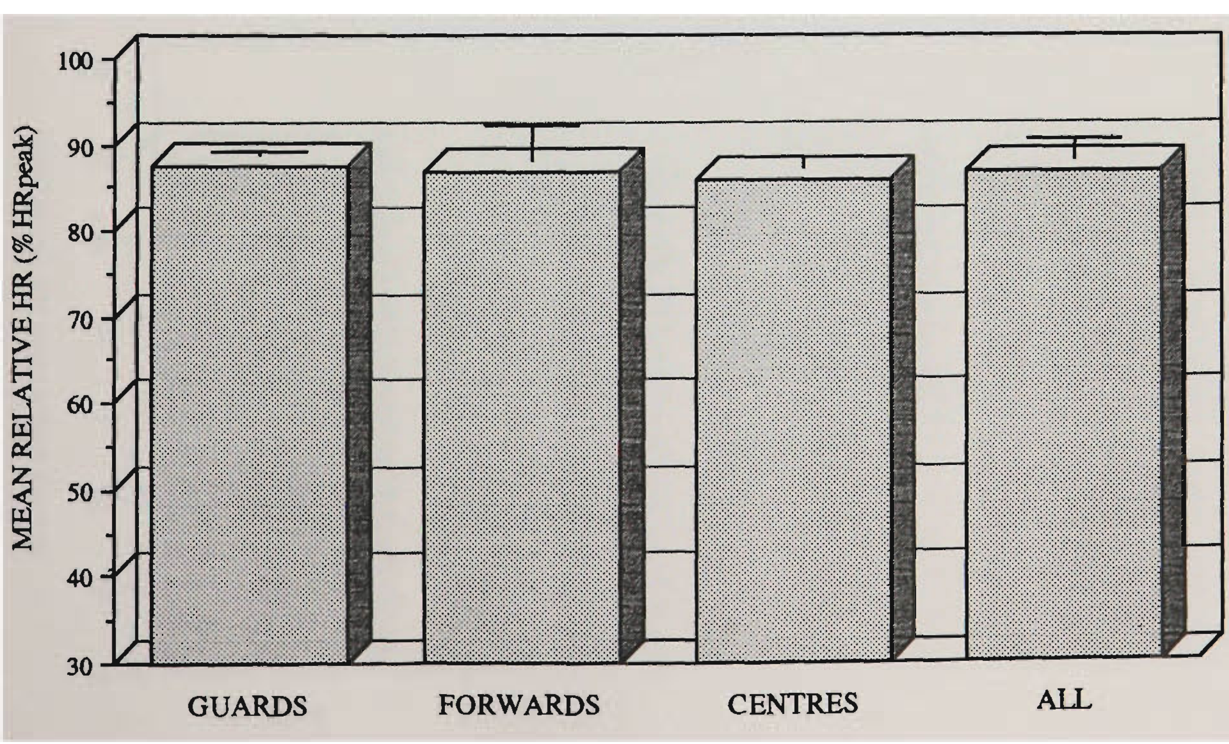
* Significantly different from Guards.
\# Significantly different from Forwards.
◆ Significantly different from Centres.

Figures 4.3 a-d: Mean (absolute and relative) HR's during Total and Live Time. Values are the average (± S.D.) for each position.

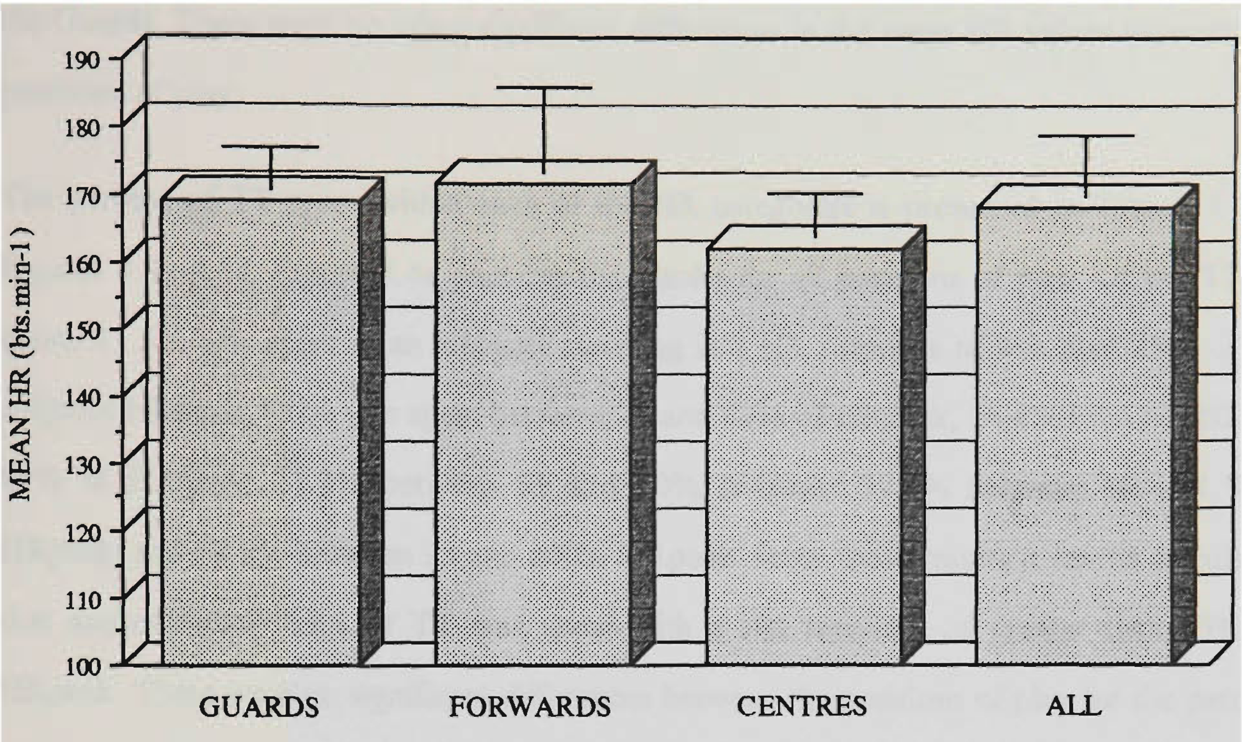
a. Absolute HR during Total Time



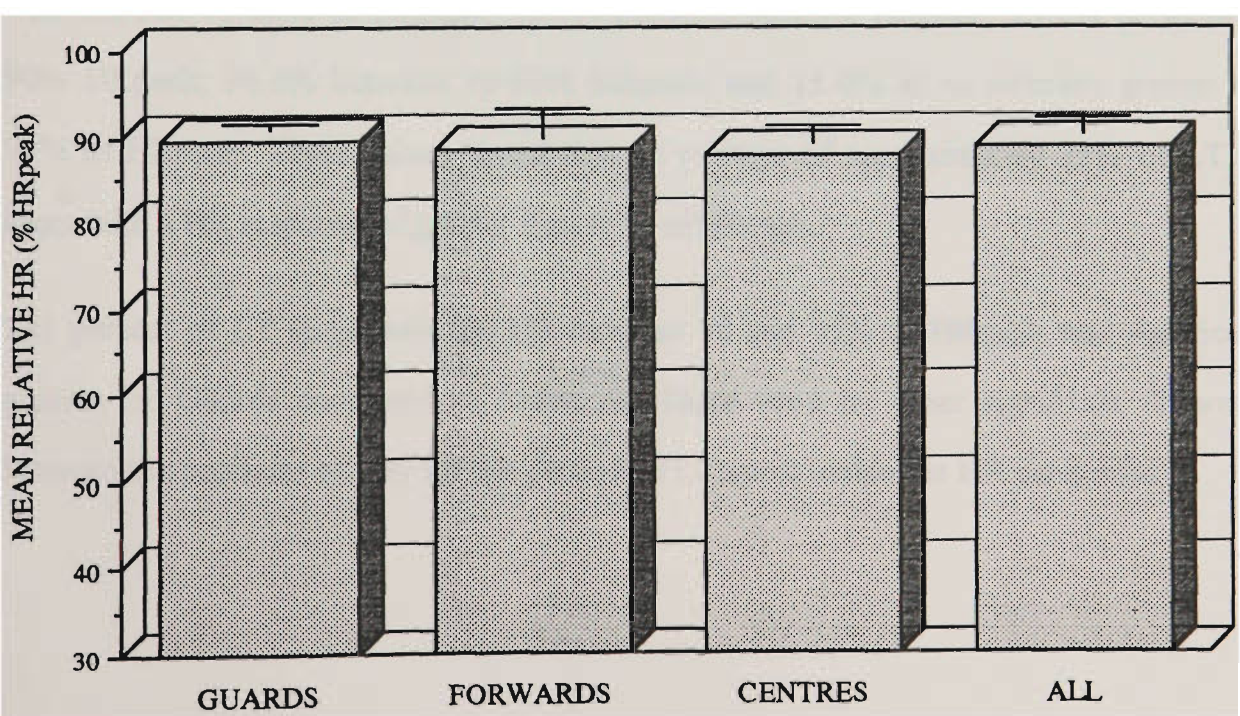
b. Relative HR during Total Time



c: Absolute HR during Live Time



d: Relative HR during Live Time



The mean HR of the Forwards during TT was significantly higher than that of the Centres. The mean maximum HR of the Forwards was also significantly higher than that recorded by the Guards. There were no other significant differences in the mean HR values between the positions of play.

The percent of TT spent within each of the HR categories is presented in Table 4.9 and Figures 4.4a-4.4d. Figure 4.4e contains the results for all positions of play. Of the TT on court, 11.3% was spent at an intensity resulting in a HR response of less than 75% of the subjects' HRpeak; 8.0% was spent between 75 and 80% of HRpeak; 14.4% between 80 and 85% of HRpeak; 21.8% between 85 and 90% HRpeak; 32.1% between 90 and 95% HRpeak; and 12.5% between 95 and 100% HRpeak. From these results it can be calculated that approximately 65% of TT was spent with a HR response of greater than 85% of HRpeak. There were no significant differences between the positions of play for the percent of TT spent within each of the HR categories of intensity.

The percent of LT spent within each of the HR categories is presented in Table 4.10 and Figures 4.5a-4.5d. Figure 4.5e contains the results for each position as well as the mean for all subjects. Of the LT played, 5.5% was spent with the HR less than 75% HRpeak; 6.1% with the HR 75-80% of HRpeak; 13.7% between 80-85% HRpeak; 23.2% between 85-90% HRpeak; 36.4% between 90-95% HRpeak; and 15.0% at an intensity greater than 95% of HRpeak. These values reveal that an average of approximately 75% of LT was spent with a HR response of greater than 85% of HRpeak.

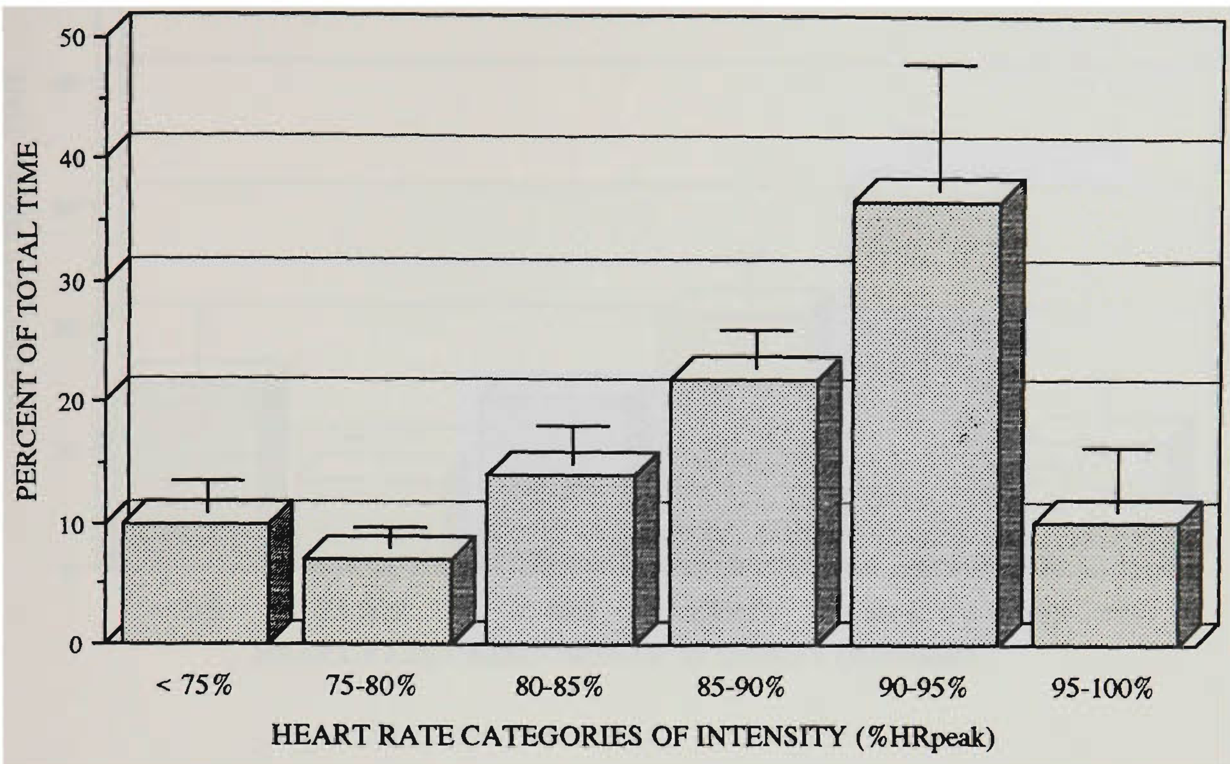
The percent of LT spent with the HR between 90 and 95% of HRpeak was significantly greater for Guards compared to Forwards. There were no other significant differences between the positions of play for the percent of LT spent within the HR categories.

Table 4.9: Percent of Total Time (excluding when substituted out of the game) spent within the heart rate categories of intensity.

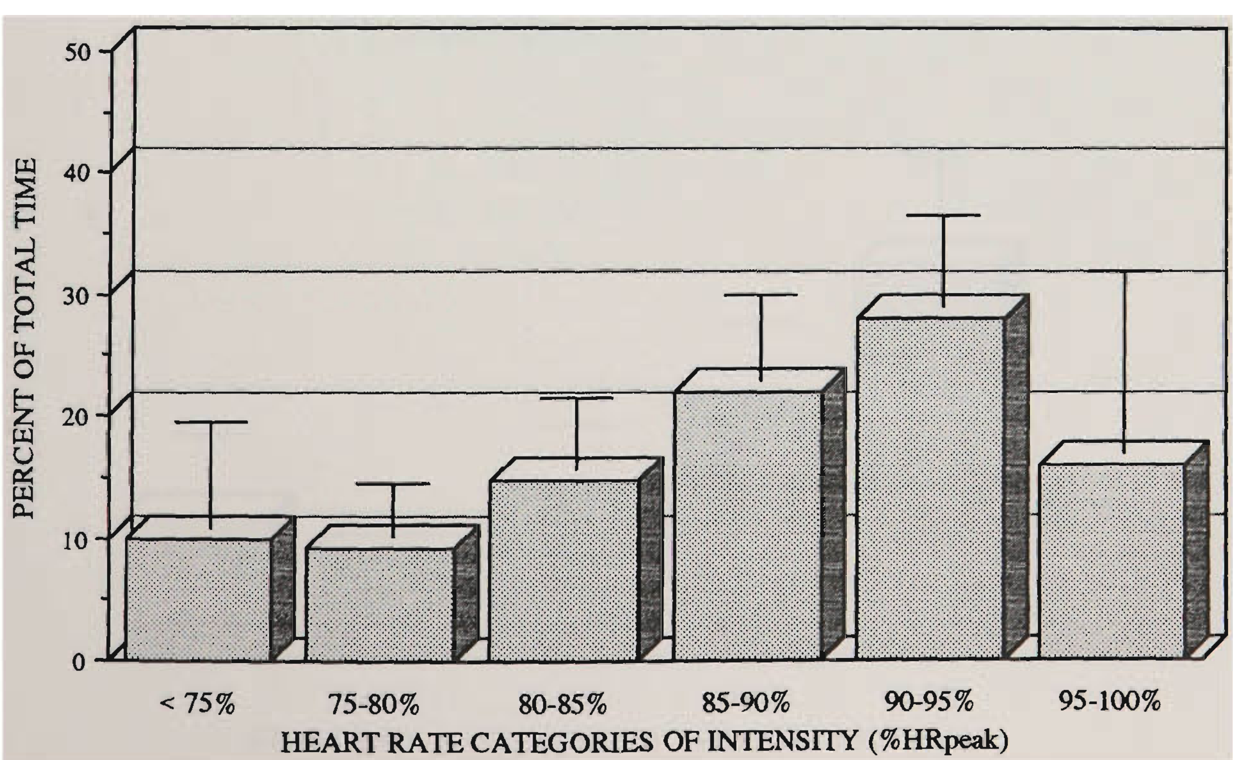
SUBJECT #	CATEGORIES (% HRpeak) < 75	75-80	80-85	85-90	90-95	95-100
GUARDS						
1	11.1	5.3	10.8	20.2	46.0	6.6
2	11.8	8.6	17.1	20.5	25.8	16.2
3	6.8	7.2	13.9	25.5	38.7	7.8
MEAN (± S.D.)	9.9 (2.7)	7.0 (1.7)	13.9 (3.2)	22.1 (3.0)	36.8 (10.3)	10.2 (5.3)
FORWARDS						
4	10.1	7.0	16.4	29.0	28.4	9.2
5	18.5	14.2	19.5	22.2	20.6	5.1
6	1.4	6.7	8.6	14.8	35.3	33.2
MEAN (± S.D.)	10.0 (8.5)	9.3 (4.3)	14.9 (5.6)	22.0 (7.1)	28.1 (7.4)	15.8 (15.2)
CENTRES						
7	19.2	5.8	14.8	18.3	34.3	7.6
8	11.1	9.4	13.6	24.0	28.0	13.9
MEAN (± S.D.)	15.2 (5.7)	7.6 (2.5)	14.2 (0.9)	21.2 (4.1)	31.2 (4.4)	10.8 (4.5)
MEAN ALL SUBJECTS (± S.D.)	11.3 (5.8)	8.0 (2.9)	14.4 (3.5)	21.8 (4.4)	32.1 (8.1)	12.5 (9.2)

Figures 4.4 a-d: Percent of Total Time (mean ± S.D.) spent within the HR categories for Guards (a), Forwards (b), Centres (c) and All Subjects (d).

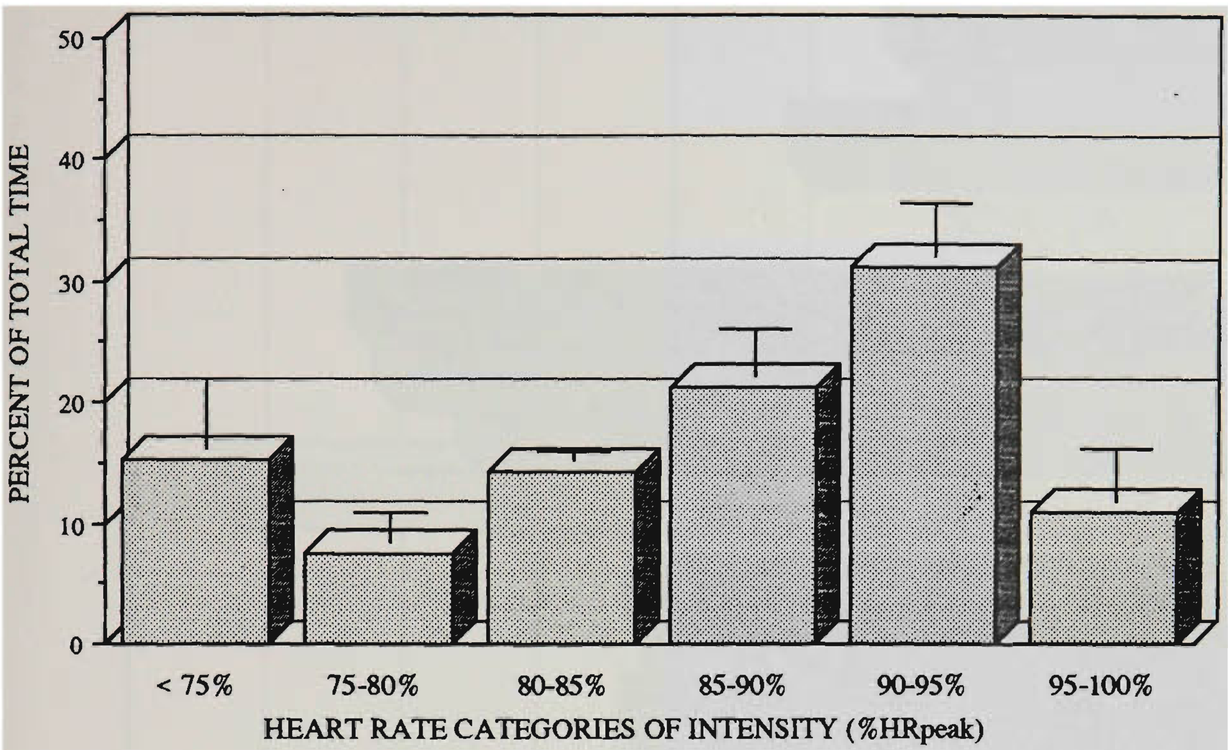
a: Guards



b: Forwards



c: Centres



d: All Subjects

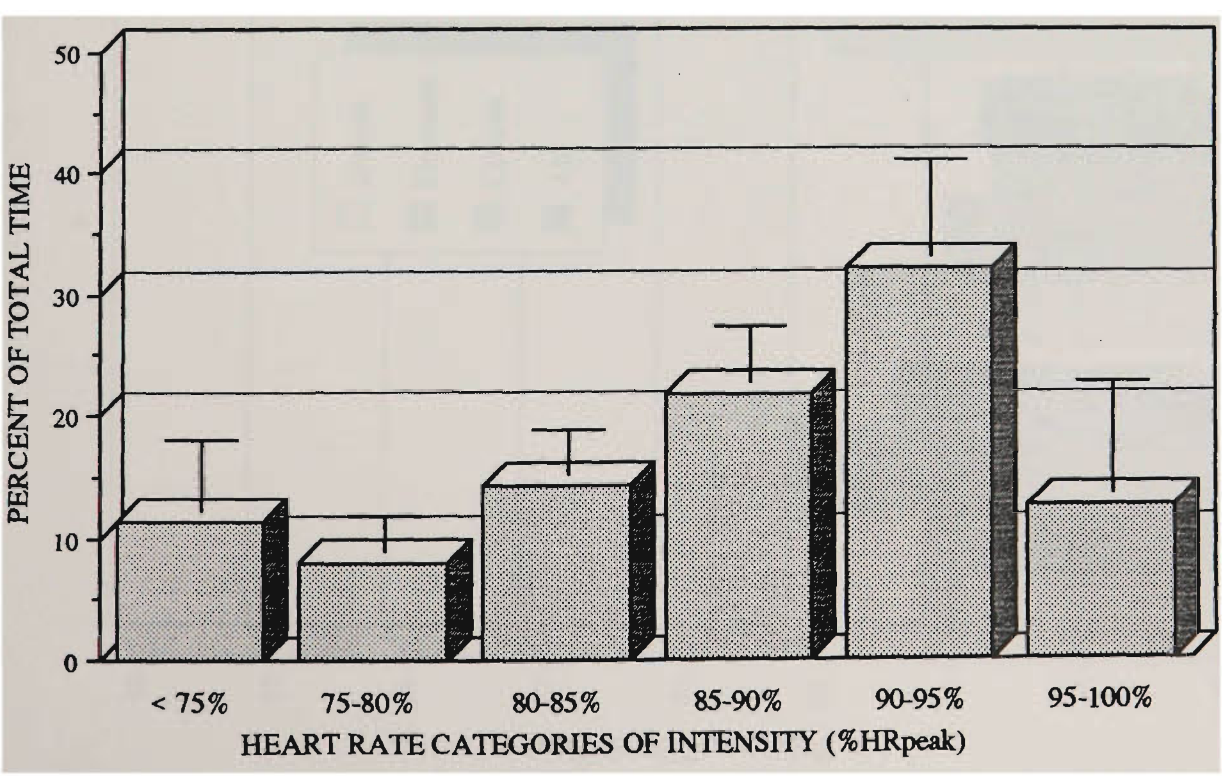


Figure 4.4e. Percent of Total Time spent in the Heart Rate categories.

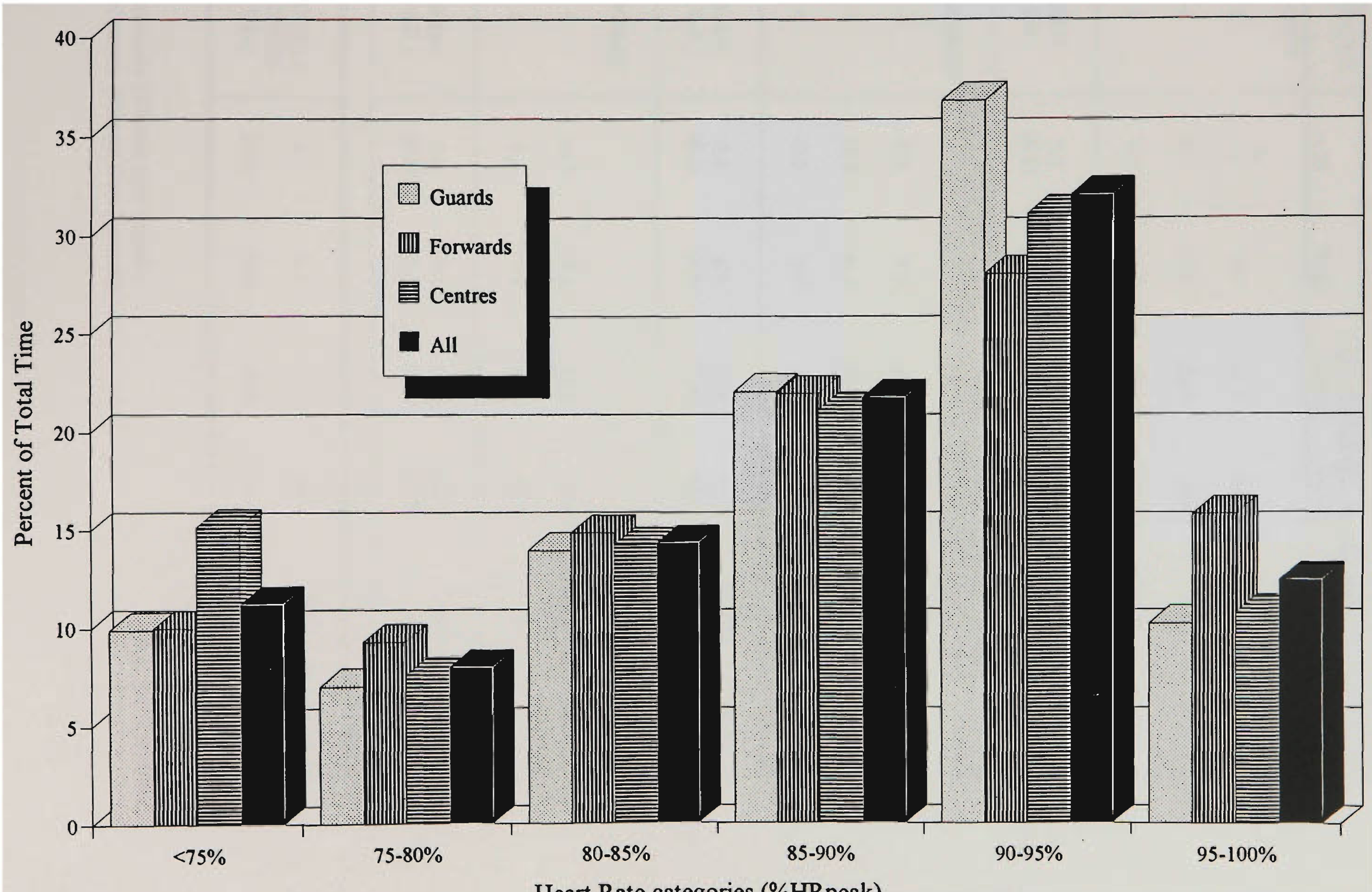
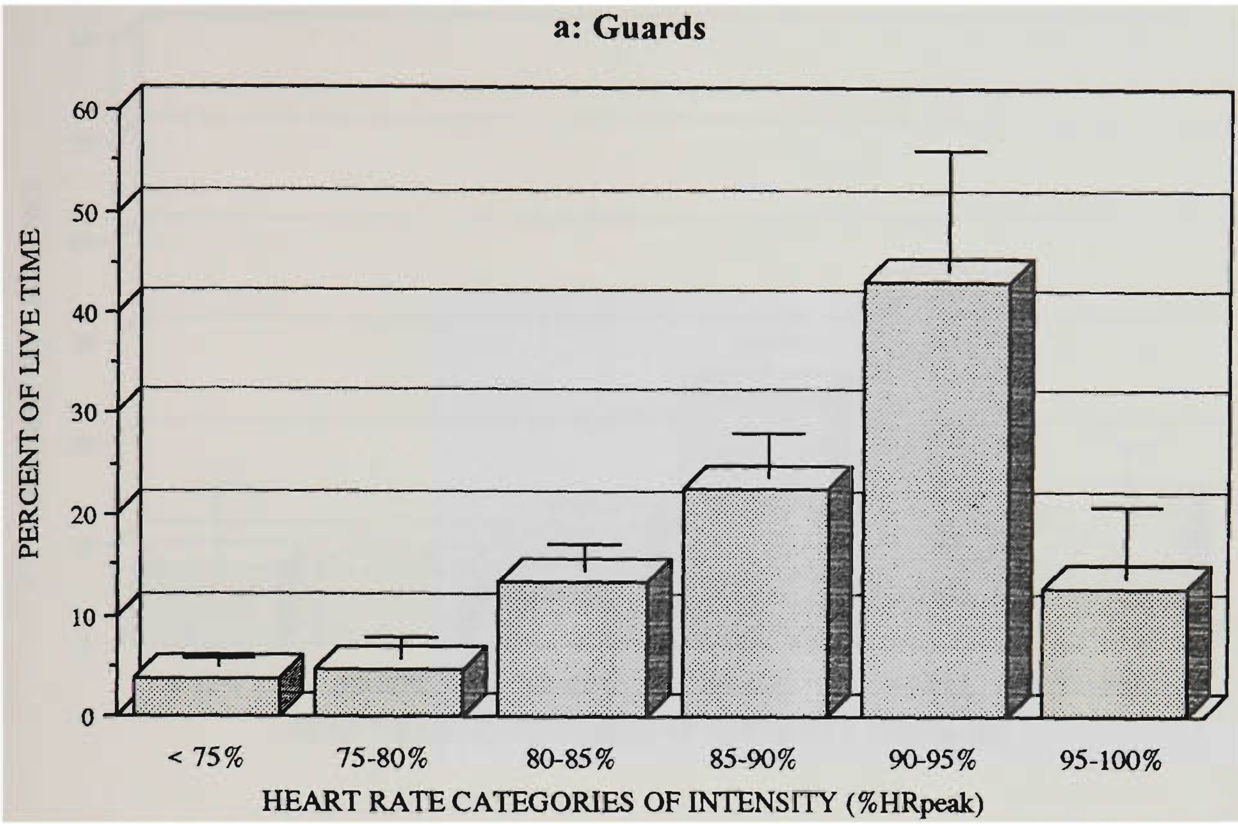


Table 4.10: Percent of Live Time spent within the heart rate categories of intensity.

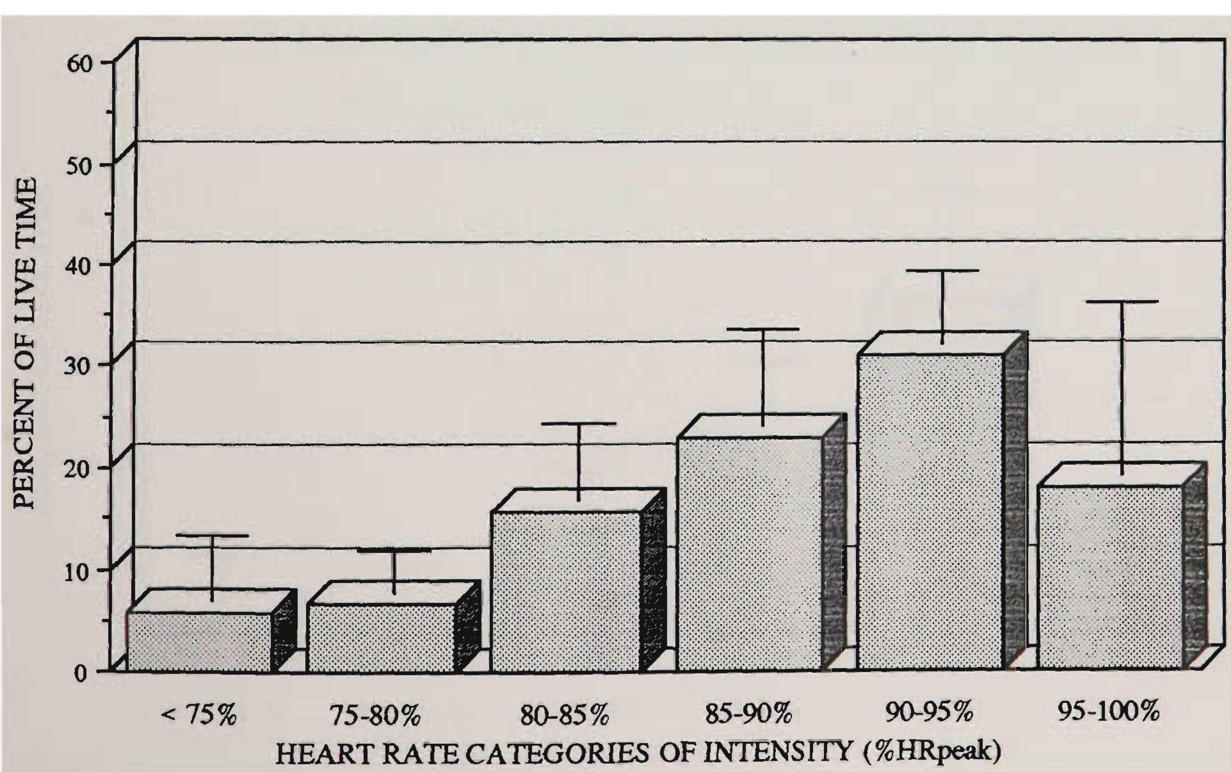
SUBJECT #	CATEGORIES (% HRpeak) < 75	75-80	80-85	85-90	90-95	95-100
GUARDS						
1	3.2	2.7	11.2	19.8	54.9	8.1
2	4.7	6.6	16.3	20.6	31.1	20.7
3	3.3	4.5	12.4	27.4	43.2	9.2
MEAN (± S.D.)	3.7 (0.8)	4.6 (2.0)	13.3 (2.7)	22.6 (4.2)	43.1 # (11.9)	12.7 (7.0)
FORWARDS						
4	4.2	5.0	18.4	31.7	30.9	9.9
5	12.8	11.4	21.4	24.4	23.6	6.4
6	0.4	3.9	6.9	12.8	38.3	37.7
MEAN (± S.D.)	5.8 (6.3)	6.8 (4.0)	15.6 (7.6)	22.9 (9.5)	30.9 * (7.3)	18.0 (17.1)
CENTRES						
7	12.7	7.3	11.9	21.6	36.3	10.2
8	3.1	7.2	11.3	27.7	33.3	17.4
MEAN (± S.D.)	7.9 (6.8)	7.3 (0.1)	11.6 (0.5)	24.7 (4.4)	34.8 (2.1)	13.8 (5.1)
MEAN ALL SUBJECTS (± S.D.)	5.5 (4.6)	6.1 (2.7)	13.7 (4.6)	23.2 (5.9)	36.4 (9.4)	15.0 (10.4)

* Significantly different from Guards.
# Significantly different from Forwards.

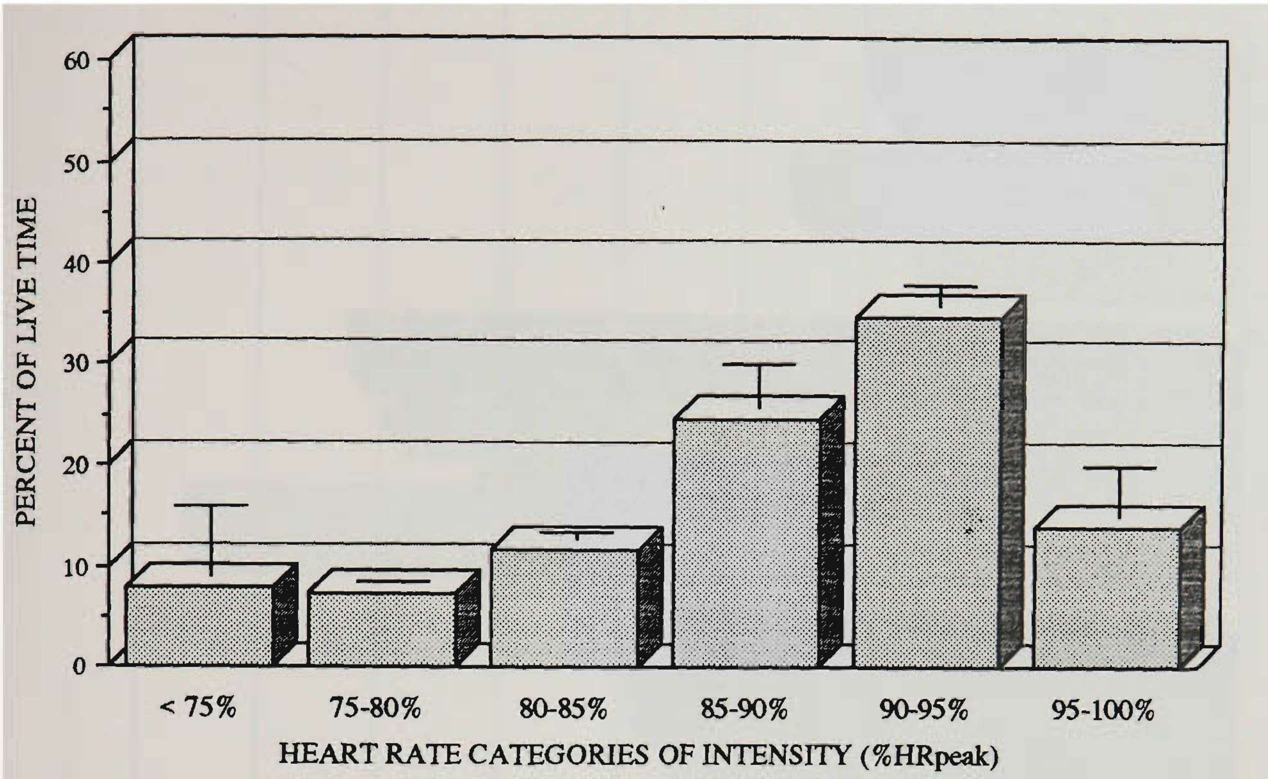
Figures 4.5 a-d: Percent of Live Time (mean ± S.D.) spent within the HR categories for Guards (a), Forwards (b), Centres (c) and All Subjects (d).



b: Forwards



c: Centres



d: All Subjects

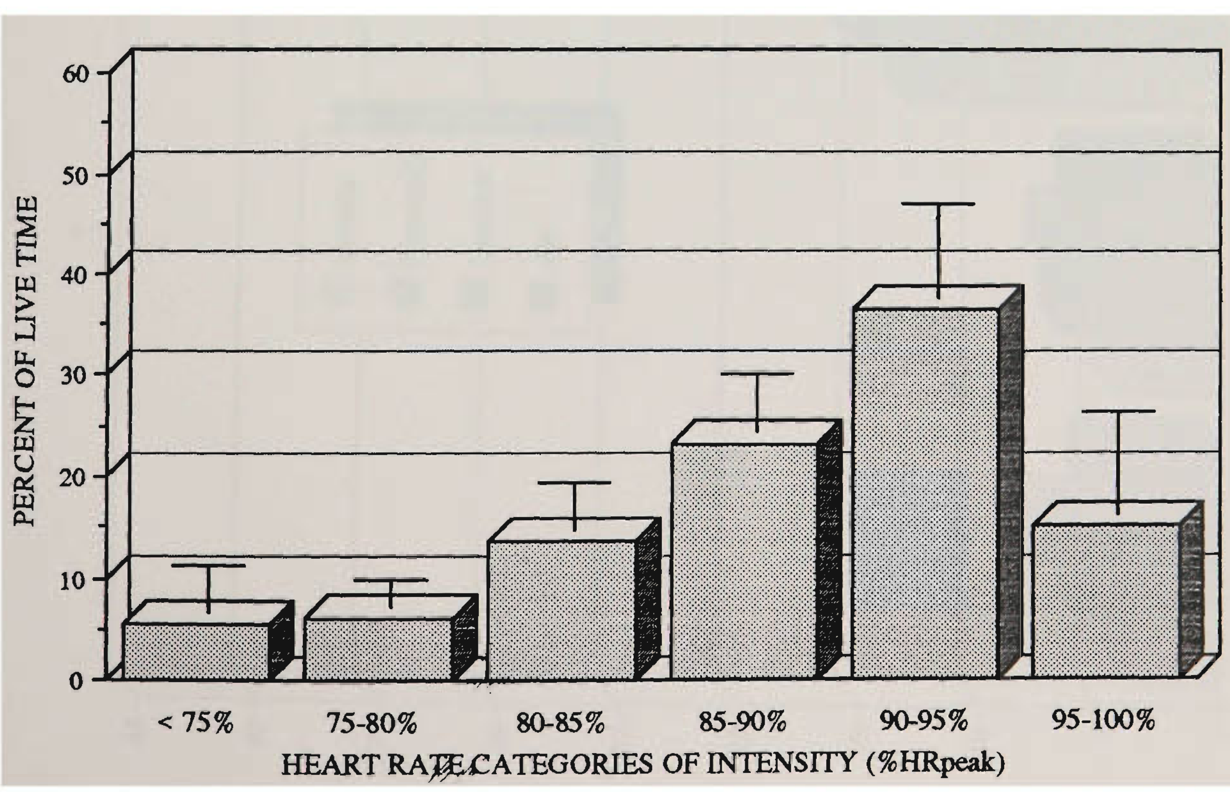
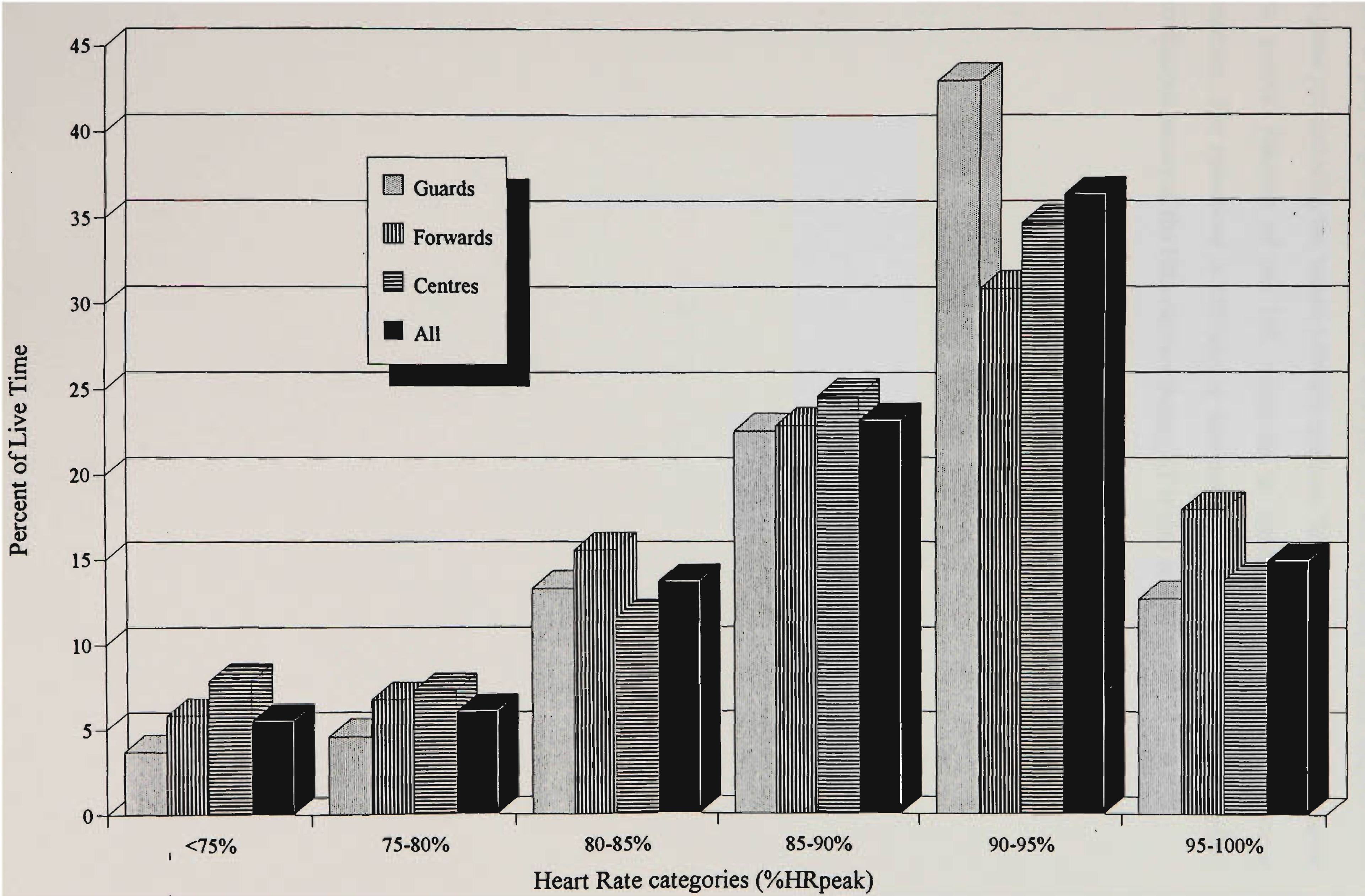


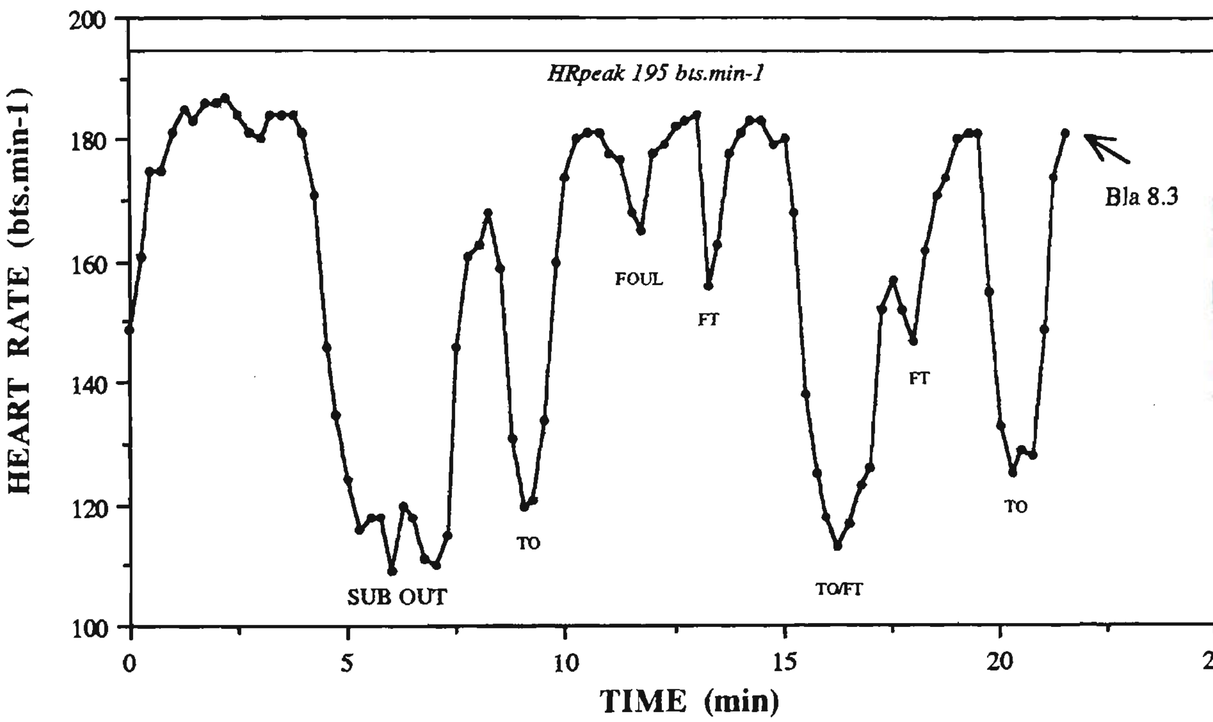
Figure 4.5e: Percent of Live Time spent in the Heart Rate categories.



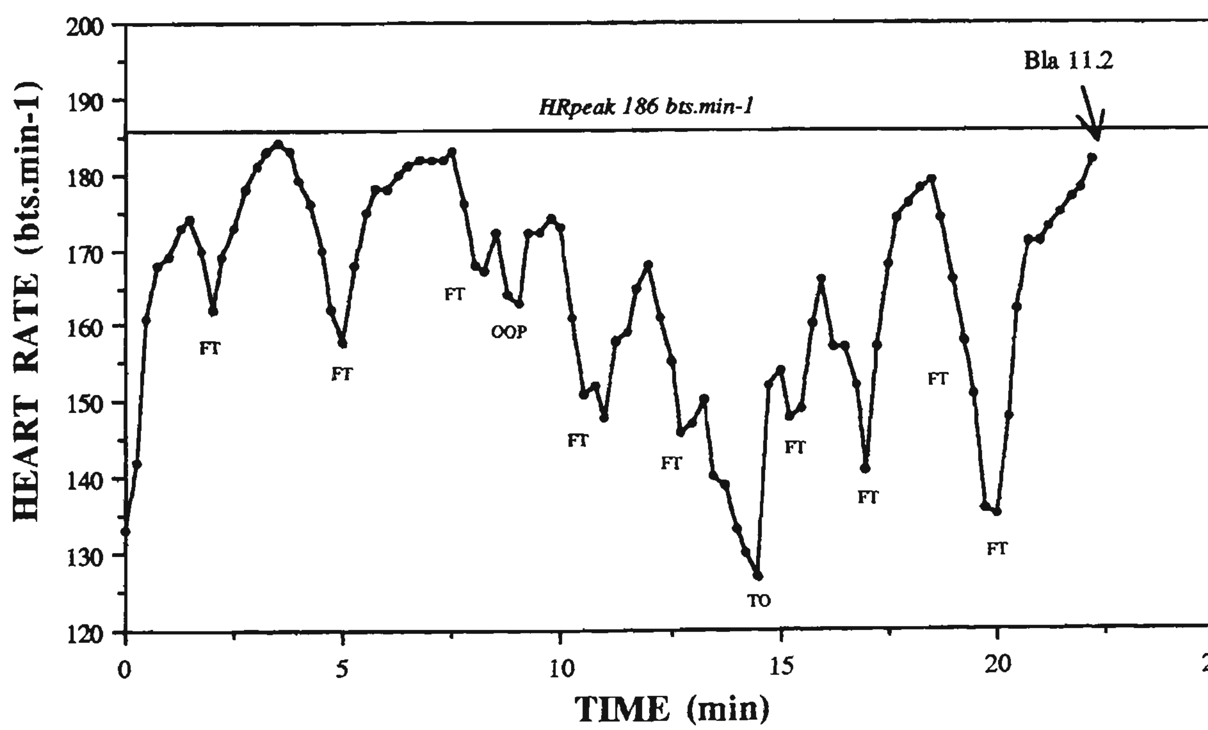
Figures 4.6a and 4.6b contain examples of the typical HR responses of two subjects to two quarters of play. Figure 4.7 contains an example the HR responses of one subject to an entire game not including the breaks between quarters. These figures provide an indication of the general patterns of the HR responses to basketball evident in the present investigation. The reductions in HR during time-outs and free-throws are clearly visible. The continuous nature of the HR response during LT is also evident.

Figure 4.6a-b: The HR responses of subject number 1 to the second quarter (a) and subject number 2 to the second quarter (b).

a: Subject number 1

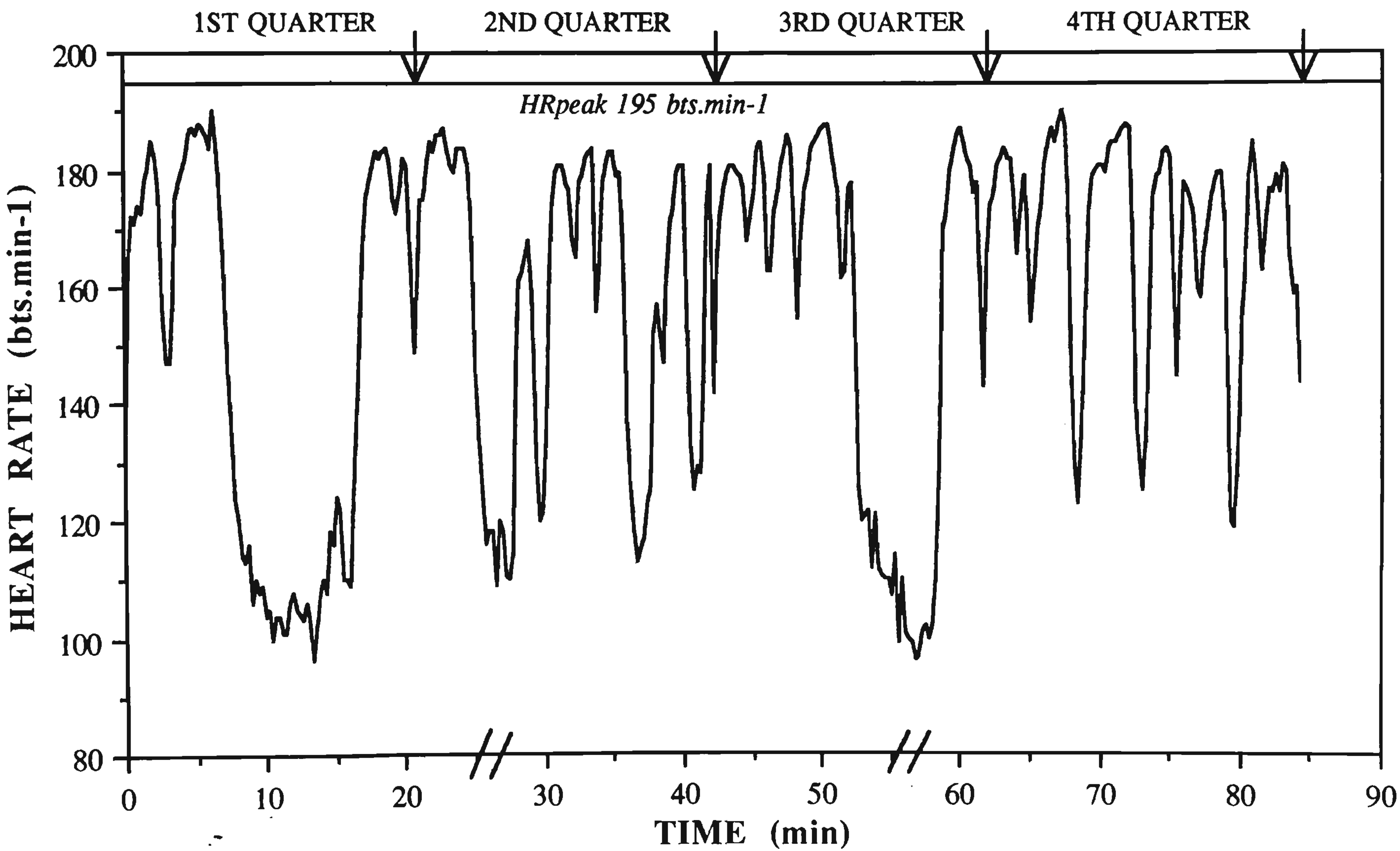


b: Subject number 2



* "TO" refers to a Time-out, "FT" refers to a free-throw, "OOP" refers to Out-Of-Play, "SUB OUT" refers to Substituted out of the game.

Figure 4.7: Heart Rate responses of subject number 1 to an entire game not including the breakds between quarters.



4.4 Blood lactate concentrations during competition

A total of 36 fingerprick blood samples were obtained during competition and analysed for lactate concentration. Blood samples were not obtained from every quarter of play due to technical problems as well as limited control over the subjects. More than one blood sample was obtained during some quarters of play where possible. For example, a subject may have been substituted out of the game but returned later in the quarter. In this instance it may have been possible to obtain blood samples following both periods of play.

A complete list of the blood lactate (Bla) concentrations obtained in this investigation is provided in Table 4.11. The mean Bla concentration recorded was 6.8 $mmol.l^{-1}$. The mean Bla concentrations for the different positions were 8.1 $mmol.l^{-1}$ for Guards, 6.6 $mmol.l^{-1}$ for Forwards and 5.2 $mmol.l^{-1}$ for Centres. There were no significant differences in Bla between the positions.

The Bla concentrations according to the quarter of play after, or during which the blood sample was obtained are illustrated in Figure 4.8. The results presented are according to the position of play. The average Bla value during the first quarter was 9.6 $mmol.l^{-1}$ for Guards, 7.0 $mmol.l^{-1}$ for Forwards and 5.8 $mmol.l^{-1}$ for Centres. The respective values were 7.9 $mmol.l^{-1}$, 7.4 $mmol.l^{-1}$ and 5.5 $mmol.l^{-1}$ for the 2nd quarter, 8.6 $mmol.l^{-1}$, 5.5 $mmol.l^{-1}$ and 6.0 $mmol.l^{-1}$ for the 3rd quarter and 2.6 $mmol.l^{-1}$, 6.6 $mmol.l^{-1}$ and 4.0 $mmol.l^{-1}$ for the 4th quarter. The mean Bla concentrations during each quarter of play for all subjects were 7.8 $mmol.l^{-1}$ during the first quarter, 7.3 $mmol.l^{-1}$ during the second quarter, 6.4 $mmol.l^{-1}$ during the third quarter and 5.0 $mmol.l^{-1}$ during the fourth quarter. There were no significant differences in Bla between the quarters.

The relationship between Bla concentration and the characteristics and intensity of activity 5 minutes prior to blood sampling were investigated using Pearson's product-moment correlation (Figures 4.9 a-c). A significant correlation ($r=0.64$, $p<0.05$) was found between the Bla concentration and the percent of TT spent in High Intensity Activity (HIA). High Intensity Activity included Stride/Sprint, High intensity Shuffle and Jump. A significant correlation was also found between the Bla concentration and the intensity of activity (according to the mean %HRpeak) for the 5 minutes of play preceding blood sampling ($r=0.44$ $p<0.05$). There was no significant relationship between the percent of TT spent in HIA and the mean %HRpeak ($r=0.24$, $p>0.05$).

Table 4.11: Movement analysis and mean %HRpeak for the 5 minutes of play preceding blood sampling.

SUBJECT #	QUARTER	PERCENT OF TIME SPENT IN HIGH INTENSITY ACTIVITY	%HRpeak	Bla ($mmol.l^{-1}$)
GUARDS				
1	1	23.9	90.7	13.1
	1	22.4	90.8	13.2
	2	11.6	80.8	8.3
	3	12.7	91.4	6.3
	4	16.0	83.9	-
2	1	14.0	88.7	10.5
	2	17.6	89.3	11.2
	3	23.3	94.3	10.9
	4	11.0	85.7	5.9
3 GAME 1	1	12.8	88.8	3.6
	2	18.7	88.1	4.1
	3	8.7	85.5	-
	4	4.7	83.4	2.0
3 GAME 2	1	13.5	-	7.6
MEAN (+ S.D.)		15.1 (5.6)	87.8 (3.8)	8.1 (3.8)

FORWARDS				
4	1	4.8	82.5	6.3
	2	9.2	91.4	11.0
	3	7.2	-	6.3
	4	-	-	8.7
5	1	4.8	78.8	4.3
	2	9.6	86.5	4.3
	3	10.1	84.8	5.9
	4	7.4	82.2	3.5
6 GAME 1	1	8.7	-	9.1
	2	3.5	91.0	7.8
	3	4.0	93.0	5.9
	4	-	90.2	7.7
6 GAME 2	1	5.3	94.4	8.4
	2	8.2	92.4	6.5
	3	1.4	92.8	3.8
	4	7.6	90.4	-
MEAN (+ S.D.)		6.5 (2.6)	88.5 (5.0)	6.6 (2.2)

Table 4.11 cont...........

Table 4.11 cont.

CENTRES				
7	1	4.8	83.4	4.2
	2	8.7	89.8	5.5
	3	3.5	85.1	4.3
	4	6.2	-	3.1
8	1	3.7	89.3	7.3
	1	7.6	86.8	5.9
	3	6.4	85.1	7.6
	4	6.0	88.6	4.2
	4	5.8	78.3	4.8
MEAN (+ S.D.)		5.9 (1.7)	85.8 (3.8)	5.2 (1.5)
MEAN ALL SUBJECTS (+ S.D.)		**9.6 (5.8)**	**87.6 (4.3)**	**6.8 (2.8)**

Figure 4.8: Blood lactate concentrations during each quarter of play.

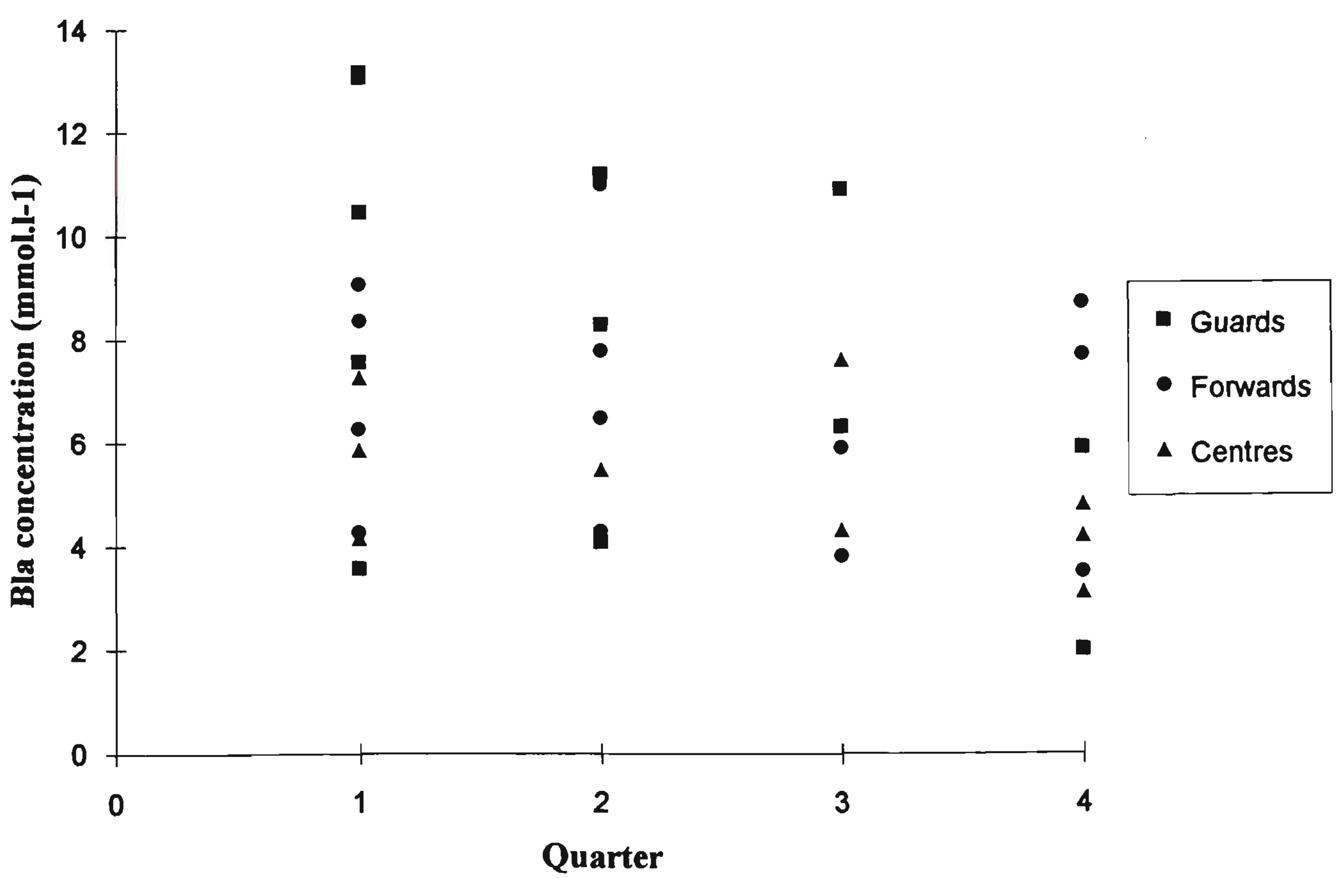
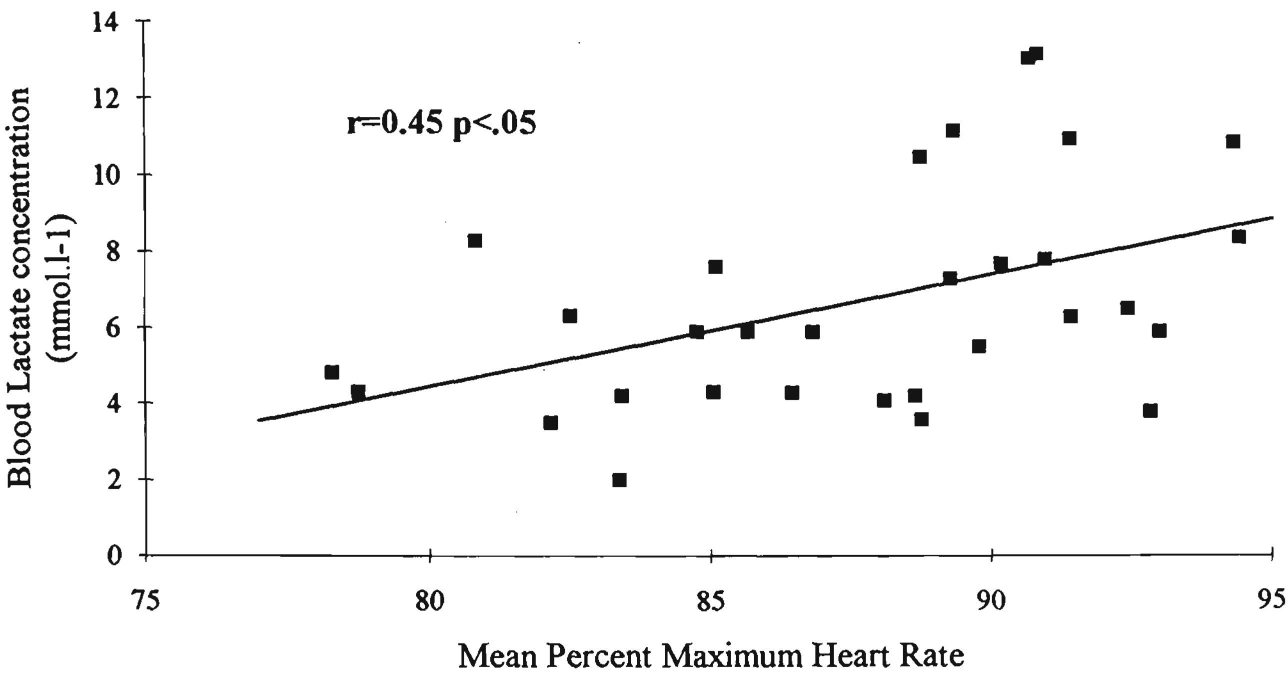
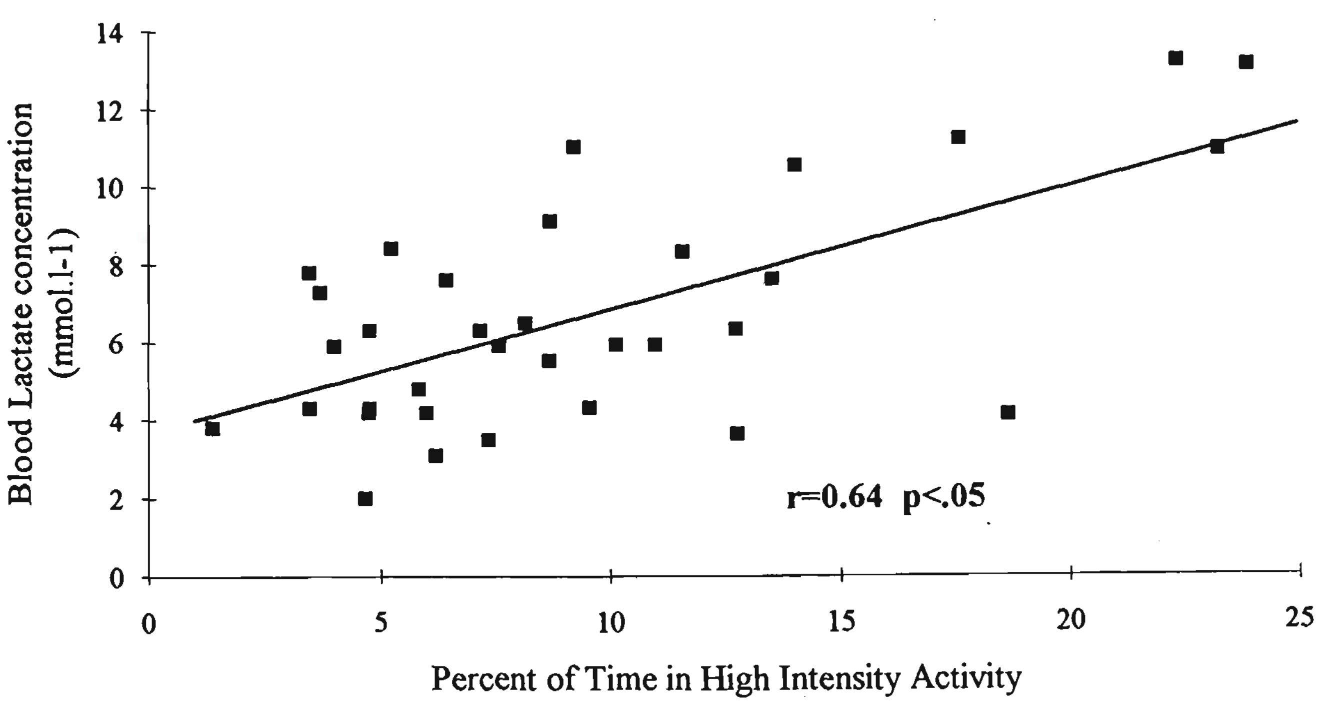


Figure 4.9 a-c: The relationships between Blood lactate, mean %HRpeak and percent of Total Time spent in High Intensity Activity for the 5 minutes of play preceding blood sampling.

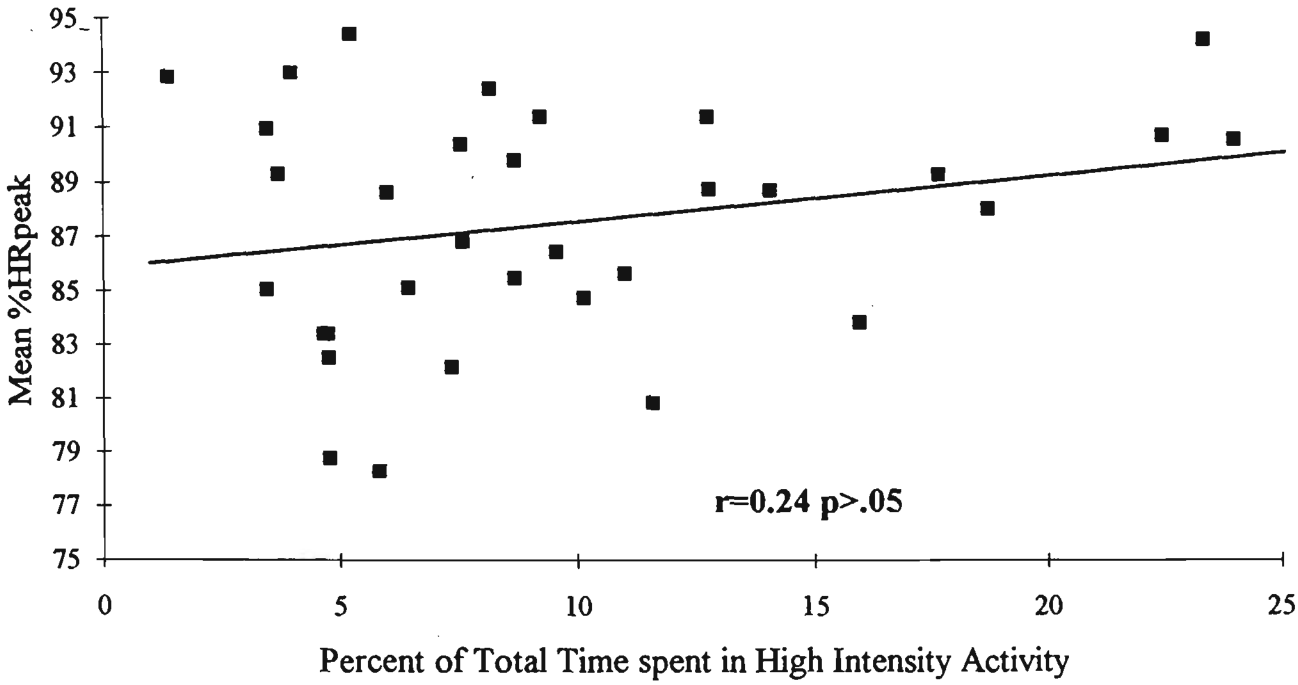
a: Blood lactate versus mean %HRpeak.



b: Blood lactate versus percent of Time in High Intensity Activity.



c: Mean %HRpeak versus percent of Time in High Intensity Activity.



CHAPTER 5

DISCUSSION

The development of training programs and testing protocols specific to the requirements of participation in basketball is an important aspect of adequately preparing athletes for competition. Information concerning the movement patterns of players during competition, and the physiological requirements of training and competing should form the basis of these programs. Training programs and testing protocols in the past have been based largely on anecdotal evidence relating to the demands of play and performance. The effectiveness of training programs devised in this manner remains questionable in the absence of supporting scientific and objective research.

The purpose of this study was to investigate the intensities of activity and the movement patterns of players during men's competition basketball. Information on these aspects of participation can be used to help describe the sources of metabolic energy during competition. This information may then be used to develop training programs specific to the requirements of basketball.

This discussion will be divided into four sections: 5.1) The reliability of movement analysis, 5.2) Movement patterns during competition basketball, 5.3) The intensity of activity during competition and 5.4) Exercise metabolism during basketball.

5.1 The reliability of movement analysis.

5.1.1 Assessment of reliability

The value of time-motion data generated through the analysis of the movement patterns of players during competition is dependant on its reliability and objectivity. Although this may appear relatively obvious, a review of the existing literature revealed that the techniques used to assess the reliability of such measurements were, in many cases, questionable. The reliability of most investigations, regardless of the technique used, has consistently been reported to be high (Reilly and Thomas 1976). Most commonly, the assessment of reliability has involved repeated recordings of various portions of play. The two sets of results obtained from the separate analyses of the same period of play are correlated using Pearson's product-moment correlation coefficient. High correlation coefficients are believed to be indicative of reliable time-motion analysis techniques. Although this method of assessing reliability has been used in a number of studies (Mayhew and Wegner 1985, Withers et al. 1982, McKenna et al. 1988, Steele and Chad 1991) the limitations associated with using Pearson's product-moment correlation have not always been acknowledged. As discussed by Sale (1991) and Baumgartner (1989), the magnitude of the correlation coefficient is affected by the homogeneity/heterogeneity of the data. Data that is homogeneous tends to deflate the magnitude of the correlation coefficient while heterogeneous data tends to inflate the value. The correlation coefficient is, therefore, sensitive to the range of values; the greater the range the more likely that a significant correlation will be obtained. As such, relatively high and relatively low correlation coefficients may be associated with a similar variation in the test-retest results (refer to Sale 1991, p78, Figure 3.25).

In addition, Pearson's product-moment correlation is a measure of the association between two different variables and not a measure of the agreement between repeated measures of the same variable (Kroll 1962). As such it is an inappropriate method of assessing test-retest reliability. For example, if a particular measurement increased by exactly 5% during each repeat analysis, a perfect correlation ($r=1.00$) would be obtained. This suggests high reliability despite the different values obtained during the repeated measurements.

With these limitations in mind, the reliability of the present investigation was examined using Pearson's product-moment correlation to enable comparisons to similar time-motion analysis investigations. In addition the Method Error (ME) technique proposed by Sale (1991) and the Intraclass Correlation Coefficient (ICC) technique were used. Both of these techniques have been suggested as alternatives to Pearson's product-moment correlation (Sale 1991, Baumgartner 1989). These techniques quantify the differences and assess the correlations between repeat analyses results. Sale (1991) has proposed that the ME technique may provide a more accurate indication of the reliability of measurement. This method calculates a coefficient of variation (CV) for the differences between the original and repeat analyses. Although the use of both the ME and ICC techniques in addition to Pearson's product-moment correlation technique does not provide a definitive answer on the reliability of the time-motion analysis techniques used in this investigation, collectively they provide a clearer picture regarding problems with the analysis methodology used.

5.1.2 Reliability of percent of Live Time spent in the categories of movement.

The reliability results obtained using Pearson's product-moment correlation for the percent of LT spent in each category of activity are consistent with those reported in other investigations (McKenna et al. 1988, Reilly and Thomas 1976), though higher correlations have been reported (Steele and Chad 1991). The values obtained in the present investigation ($r>0.95$) indicate high correlations between the repeat measurements for the categories of Jog, Run, Stride/Sprint, all intensities of Shuffle and Jump. The lower correlations for Run B ($r=0.93$) and S/W ($r=0.83$) indicated variability between the separate analyses.

The results obtained using the ME technique indicate small variations (CV<10.00%) in the separate analyses for all categories of movement except High intensity Shuffle (CV=10.58%) and Run B (CV=70.21%). Values of less than 10.00% are considered by the author to be acceptable for reliability. Values of greater than 10.00% are likely to indicate that these categories of movement are subject to a significant degree of variation. As such, the measurements of percent of LT spent in High intensity Shuffle and Run B were subject to some error.

The ICC values obtained for the percent of LT spent in all categories of movement were high (ICC>0.94) except for S/W (ICC=0.68). Intraclass Correlations of greater than 0.94 suggest that the results obtained for these categories of movement are reliable. Although the Pearson's product-moment correlation and ICC for the percent of LT spent in S/W are low ($r=0.81$ $p>0.05$, ICC=0.68) the use of the ME reveals that there was little variation (CV=4.13%) in the measurements. The low correlations are, therefore, most likely due to the small range of values obtained for percent of LT spent in S/W (range 35.20-43.15%). Similar to Pearson's product-moment correlation, the probability of obtaining a significant relationship using the ICC technique is partly dependent on the range of values (Baumgartner 1989). As such, the ME technique allows for the reliability to be examined without the range of values effecting the results obtained. A very low CV in the repeat analysis indicates that the percent of LT spent in S/W is a highly reliable measurement.

Although the ME revealed a higher degree of variation for the percent of LT spent in High intensity Shuffle (CV=10.58%) than all others categories except Run B, this degree of variation is equivalent to less than $\pm$ 1.50% of LT spent in High intensity Shuffle. A variation of this magnitude does not indicate considerable variation between the separate analysis. In addition, both correlations, and perhaps more importantly the ICC, reveal high relationships between the repeat measurements (r=0.99, ICC=0.99). It is therefore reasonable to conclude that all categories of movement, except Run B, are reliable for the percent of LT. The extremely large ME value for Run B (CV=70.21%) indicates substantial variation. The poor reliability value may be explained by both the small values obtained during the repeat analysis (less than 2.00% of LT) and the difficulty found in estimating the intensity of backward movement.

5.1.3 Reliability of timing measurements.

Reliability analysis for the accuracy of timing for each individual movement, although not frequently reported in the literature, was considered an important aspect of examining the reliability of the methodology used in this investigation. High Pearson's product-moment correlations ($r>0.96$) were obtained for S/W and Run while moderate values ($0.85 < r < 0.94$) for Jog, Stride/Sprint, all intensities of Shuffle and Jump indicate some differences between the measurements. The value for Run B ($r=0.98$) was not significant at $P<0.05$ and therefore suggests variations in the timing of this form of movement.

The ME values obtained for the accuracy of timing for each category suggest similar variations in the repeat measurements to those indicated by Pearson's product-moment correlations. The value for S/W (CV=3.90%) indicates extremely accurate timing of this category while the values obtained for Jog (CV=8.92%), Run (CV=7.92%), Low Shuffle (CV=9.84%), and High Shuffle (CV=8.01%) indicate some small variations between the separate analyses. The values obtained for Stride/Sprint (CV=11.20%), Medium Shuffle (CV=10.86%) and Jump (CV=11.73%) indicate the difficulty of accurately timing these forms of movement. The value for Run B (CV=21.43%) indicates that this category, for reasons discussed later, is not reliable for the timing of each occurrence.

The ICC values for the accuracy of timing indicate that S/W, Jog, Run, Stride/Sprint, and Jump are all reliable ($r>0.92$). The values obtained for Low Shuffle (ICC=0.88) and High Shuffle (ICC=0.89) indicate small differences between the repeat measurements. The values for Run B (ICC=0.76) and Medium Shuffle (ICC=0.81) suggest that these categories are subject to a significant degree of variation for the timing of each occurrence.

The 3 techniques used to assess the accuracy of timing for each category of movement suggest high reliability for S/W, Jog and Run. The results for Stride/Sprint, Low Shuffle, High Shuffle and Jump, although indicating that the timing of each movement is relatively reliable, suggest some variations between the measurements. The values obtained for Medium intensity Shuffle ($r=0.86$, CV=10.86%, ICC=0.81) indicate that this category may be subject to significant variations in the timing of each movement. However, the results obtained from the ME technique reflect variations of less than 0.3 seconds in timing. Variations of this magnitude are likely to be unavoidable when dealing with such small durations of activity. Based on this, it is reasonable to conclude that the category of Medium intensity Shuffle is relatively reliable though perhaps less so than the other categories of movement. The results obtained for the timing of each occurrence of Run B, however, suggest large and significant variations. It is likely that this category is not reliable for the timing of each movement.

5.1.4 Reliability of frequency measurements.

The reliability of the frequency of occurrence for each category of movement was examined using the 3 techniques above in addition to the calculation of Spearman's correlation coefficient (r_S). Spearman's correlation coefficient has been used in other investigations to assess the reliability of frequency (McKenna 1986). In the present investigation, high Spearman's correlation coefficients (r_S=1.00) were obtained for all categories except Run (r_S=0.80, p>0.05), Run B (r_S=0.94) and Jump (r_S=0.95, p=0.051). These values are generally higher than those reported by McKenna (1986). Correlations of r_S=1.00, although suggesting high reliability for the frequency data, may be equally reflective of the small sample size (n=4) used in the analysis. As such the use of Spearman's correlation coefficient may not provide a realistic assessment of the reliability of frequency measurement for the volume of data used in the present investigation.

In order to use the Pearson's product-moment correlation the frequency data was transformed using a square root transformation (Box et al. 1978, p.275). This procedure makes the data approximately "normal" and allows Pearson's product-moment correlation to be used. The results obtained indicate that all categories except Run B were reliable for the frequency of occurrence. High correlations (r>0.95) were obtained for all categories of movement except Run B (r=0.94, p>0.05).

The values obtained using the ME technique indicate that the categories of S/W, Stride/Sprint, Low Shuffle, Medium Shuffle, High Shuffle and Jump were reliable (CV<10.00%) for the frequency of occurrence. The values obtained for Jog (CV=11.05%) and Run (CV=11.82%) indicated some variability in the test-retest measurements. The large degree of variation between repeat analyses for Run B (CV=67.88%) indicates that this category was not reliable for the frequency of occurrence.

The ICC values indicate that the frequency data obtained for the categories of S/W, Jog, Stride/Sprint and Jump were extremely reliable (ICC>0.95). Moderate correlations (0.84 < r < 0.94) were obtained for Run, Run B, Low Shuffle, Medium Shuffle and High Shuffle.

Though these categories were subject to some degree of variation for the frequency of occurrence, the values obtained indicated moderate reliability. The differences in frequency for Low, Medium and High intensity Shuffle were most likely due to the variations in individual characteristics of movement during shuffling and the fact that shuffling constitutes many different forms and intensities of movement. Despite this, the results obtained indicated that the reliability for the frequency of all intensities of Shuffling may be considered moderate.

The methodology and statistical procedures used to assess the reliability of the time-motion analysis technique used in the present investigation reveal that the reliability is moderate to high for all categories except Run B, though some categories appear to be more reliable than others. The values obtained for Run B have been included in the results, however the data set obtained should be viewed with caution.

The poor reliability associated with the category of Run B is most likely due to the difficulty found in determining the intensity of backwards movement. In addition, the difficulty in classifying Run B may be due, in many instances, to the similarities in movement characteristics between Run B and Shuffle.

The reliability assessment in the present investigation included periods of play from only four of the eight subjects. Although this is likely to provide a more accurate indication of the reliability than those studies that have included the results from only one subject (Steele and Chad 1991, Reilly and Thomas 1976, Withers et al. 1982), the results obtained may be specific to the subjects included in the assessment of reliability. However, there is no obvious reasons why the reliability analyses for the other 4 subjects would differ from those in the present analysis.

5.1.4 Objectivity of movement analysis.

The objectivity of movement analysis is considered to be an important requirement of time-motion analysis investigations (Withers et al. 1982, Reilly and Thomas 1976). The objectivity of analysis can be assessed using independent analyses by separate testers.

Relatively high correlations (r>0.94) between the analyses by separate testers in a number of studies have indicated the objectivity of measurement (Mayhew and Wegner 1985, Withers et al. 1982, Yamanaka et al. 1988). In the present investigation, the time commitment necessary precluded analyses by separate testers. As such the objectivity of the present investigation was not examined. Similar problems have been reported by other authors (Reilly and Thomas 1976, McKenna 1986).

The use of pre-determined movement speeds of players at varying intensities of running may improve the objectivity of movement classification (Van Gool et al. 1988, Bangsbo et al. 1991). Generally, players are videoed before and/or after the game, running at a number of different intensities. From this, the speeds of the player can be used to assist in the classification of activity during the game if the speeds during the game can be estimated.

Using movement speeds may be relevant to basketball as the numerous markings on the court allow for a potentially accurate determination of speed. However, this was not undertaken in the present investigation due to limited control over the subjects' commitment to the investigation. In any event, the results obtained from the time-motion analyses indicate that the use of movement speeds is unlikely to assist in the classification of intensity during most instances of running. The mean durations of Run and Stride/Sprint in the current investigation were 2.3 seconds and 1.7 seconds respectively. As such the majority of time spent in each Run or Stride/Sprint will involve acceleration followed by deceleration. Players will only rarely achieve a steady speed and steady stride frequency and length from which pre-determined velocities can be used to classify the activity. As such the use of movement speeds is unlikely to be of considerable assistance in an analysis of the movement patterns during basketball.

The reliability results obtained for Low, Medium and High intensity Shuffle indicate that these categories of movement, although not unreliable, were subject to some variations. It is unknown how this category of movement could be improved as objective classifications of shuffling may not be possible. The intensity of shuffling in this investigation was based on an estimation of the energy requirements for the particular movement. This included the rate of foot movement as well as the stance and posture of the subject. It was not based on the movement speed of the subject as it was possible that there was no ground covered during the shuffling despite the energy requirements of the activity being obviously high. In addition the energy costs associated with sideways movement have been reported to be significantly higher than those associated with forwards movement at a given speed (Reilly and Bowen 1984). As such the use of movement speeds to classify the intensity of shuffling as either Low, Medium or High may not be possible.

Summary of the reliability assessment.

The reliability results obtained for the time-motion analysis techniques used in the present investigation reveal that all categories except Run B were reliable. The categories of S/W, Jog, Run and Jump were highly reliable. The categories of Stride/Sprint, Low Shuffle, Medium Shuffle and High Shuffle were moderately reliable. The objectivity of the analysis techniques was not examined in this investigation.

5.2 Movement patterns during basketball.

This investigation is believed to be the first thorough analysis of the movement patterns of basketball players during competitive games. As such the results cannot be widely compared to other investigations. They may, however, be used to compare the movement characteristics evident in basketball to those evident in other forms of ITS.

5.2.1 Distance covered.

The distances travelled by players during ITS have been used to estimate the overall energy expenditure during competition. The accuracy of these measurements, however, has been questioned (Reilly and Thomas 1976) as errors are likely to be evident due to few markings on the field of play from which distances can be estimated. The distances travelled by the subjects were not measured in the present investigation. In the author's opinion the distances travelled by players during basketball would provide relatively little information regarding the physiological loads imposed on the players, as a considerable percent of LT is spent in shuffling movements where players often cover very little ground, although the intensity of activity is often very high. As such an estimation of the distance travelled would severely underestimate the physiological demands of competition and may lead to incorrect conclusions regarding the overall volume of work evident during games. This has been suggested in soccer (Reilly 1990) and field hockey (Reilly and Borrie 1992) but is likely to be more apparent in basketball given the large proportion of LT (25-35%) spent in shuffling-type movements.

Furthermore, the large variations in the time spent on court during each game are likely to effect the distances travelled by players with LT played a direct determinant of distance travelled. For this reason, in addition to those mentioned above, the distances travelled by the subjects in present investigation were not measured.

Although the mean Total Time (TT) spent on court was 63 minutes and 25 seconds, the mean LT played was only 36 minutes and 33 seconds. The average ratio of TT on court to LT played was, therefore, approximately 7:4, similar to the off-ice:on-ice ratio of 3:2 reported in ice hockey (Green et al. 1976, Thoden and Jette 1975).

The mean time played by the subjects in the current investigation is considerably less than the playing time in other ITS such as soccer (90 minutes), Australian rules football (100 minutes), field hockey (70 minutes) and netball (60 minutes), but slightly more than the mean time played during rugby (approximately 30 minutes) and ice hockey (20-30 minutes).

5.2.2 Frequency and duration of activity.

The average number of discrete movements recorded by the subjects during play was 1007, similar to the number of movements reported for soccer (Reilly and Thomas 1976, Bangsbo et al. 1991) and for some players in Australian rules football (McKenna 1986). Lower frequencies have, however, been reported for soccer (Mayhew and Wegner 1985, Yamanaka et al. 1988) and rugby (Docherty et al. 1988). Steele and Chad (1991) reported a total of 1349 discrete movements during netball, though this may have reflected the 50%

greater playing time in netball. Using the total number of movements in relation to the LT played, it was calculated that a change in event occurred every 2.2 seconds during the basketball games, considerably less than the 5-7 seconds reported for soccer (Bangsbo et al. 1991, Reilly and Thomas 1976, Mayhew and Wegner 1985), Australian rules football (McKenna 1986) and rugby (Morton 1978), but similar to that reported for netball (Steele and Chad 1991).

Approximately 105 Jumps and 44 Stride/Sprints were recorded in the present investigation, 7 and 2 times greater than the number previously reported for female college basketball players (MacLean 1984). However, the category of sprint was considered by MacLean (1984) to be "all out, explosive" running. In the current investigation Stride/Sprint was considered to be of high intensity and not necessarily the maximum possible intensity. This may explain much of the differences in frequency. The reason for the large difference in the number of jumps between the present investigation and that reported by MacLean (1984) is unkown.

The mean duration of S/W in this investigation was 2.5 seconds, considerably less than that reported for soccer (Bangsbo et al. 1991, Mayhew and Wegner 1985), Australian rules football (McKenna et al. 1988), rugby (Morton 1978) and slightly less than that reported for netball (Steele and Chad 1991). The rest periods during actual play (LT) were, therefore, very short.

The mean durations of Jog and Run in basketball were less than those reported for other ITS (Morton 1978, Mayhew and Wegner 1985, McKenna et al. 1988) though greater than has been reported for netball (Steele and Chad 1991). The mean duration of Stride/Sprint (1.7 seconds) is also less than 2-5 seconds generally reported for most ITS (Mayhew and Wegner 1985, McKenna et al. 1988, Bangsbo et al. 1991, Withers et al. 1982, Morton 1978, Docherty et al. 1988). A similar duration, however, has been reported for netball (Allison 1980) though a much smaller value of 0.3 seconds has been suggested by Steele and Chad (1991). The ability to accurately classify the intensity of running from only 0.3 seconds of activity, however, is objectively doubtful.

MacLean (1984) reported that each sprint in female college basketball was 1-4 seconds in duration, similar to the values obtained in the current investigation. It is clear, therefore, that each instance of high intensity running during basketball consists almost entirely of acceleration followed by deceleration. Players will only rarely, if ever, achieve maximum velocity during a sprint effort. Similar characteristics associated with high intensity running bouts have been reported in other ITS (Mayhew and Wegner 1985, McKenna et al. 1988).

The mean duration of the shuffling movements was 1.8 seconds for Low intensity, 1.9 seconds for Medium intensity and 2.1 seconds for High intensity. These durations are similar to the average duration of 1.7 seconds reported by Steele and Chad (1991) for netball players.

Overall, the mean durations of activity for all categories of movement revealed that basketball involves frequent changes in intensity and very short rest (S/W) periods during LT. All categories of movement were extremely short (less than 3 seconds) and it is likely that players only rarely achieved a steady state running speed. These characteristics are similar to those of netball (Steele and Chad 1991). It is likely, therefore, that the movement characteristics evident in ITS are related to the size of the playing area. Basketball and netball are played on considerably smaller courts compared to the size of soccer, Australian rules football and rugby fields. These smaller courts will necessarily reduce the durations of running at constant speeds and will demand more changes in intensity.

The time-motion analysis conducted in the present investigation reveals that a great deal of the energy expenditure during basketball is likely to be due to overcoming inertia as well as the frequent need to decelerate the body mass. According to Reilly and Borrie (1992) the physiological costs associated with acceleration, deceleration and changing direction add to the physiological requirements of competition in field hockey. Green et al. (1976) suggest that changing acceleration and frequent turning add to the exercise intensity during ice hockey but are not evident from velocity analysis. Similar requirements of participation in ITS have been reported in other studies (Smodlaka 1978, Withers et al. 1982, Mayhew and Wegner 1985, McKenna 1986). However, given the shorter duration of each activity and the more frequent change in intensity when compared to other ITS, it is logical to conclude that there are increased energy demands associated with this characteristic of activity during participation in basketball.

5.2.3 Characteristics of activity during Total Time.

The percent of time spent in each of the categories of movement is expressed as a percent of TT and also as a percent of LT. The percent of TT spent in each category of movement reveals the overall movement characteristics of competition. Total Time, therefore, includes the individual movement patterns of the players during actual play (LT) in addition to the movement patterns imposed on the players as a result of the external structure of the game, such as time-outs, free-throws and other stoppages in play. The percent of TT spent in S/W (61.9%) in the current investigation is similar to that reported for soccer (Ali and Farrally 1991, Bangsbo et al. 1991, Brodowicz et al. 1990), Australian rules football (McKenna et al. 1988) and rugby union (Docherty et al. 1988), although lower values have also been reported for soccer (Mayhew and Wegner 1985) and higher values for Australian rules football (Jaques and Pavia 1974). Slightly higher percentages of game time spent standing and walking have also been reported for netball (Otago 1983, Steele and Chad 1991).

The percent of TT spent Jogging is similar to that reported for netball (Steele and Chad 1991) but considerably less than the values reported for most other ITS (Mayhew and Wegner 1985, Ali and Farrally 1991, Bangsbo et al. 1991, Brodowicz et al. 1990, McKenna et al. 1988). It is likely, therefore, that the dimensions of the playing area have a considerable impact on the percent of time spent jogging. The large playing areas in soccer and Australian rules football require players to cover large areas of ground at low intensity running speeds during the game (Reilly and Thomas 1976, Withers et al. 1982). There is not a similar requirement associated with participation in basketball.

A notable difference between the current investigation and many other time-motion analysis investigations, however, is the inclusion of the category of Run. The inclusion of this category of movement was based on the observation during pilot examinations that much of the running was at an intensity between low intensity jogging and high intensity running. In some investigations the category of "jogging" included all intensities of running below those associated with high intensities (Jaques and Pavia 1974, McKenna et al. 1988). The inclusion of an extra category of running intensity is, in the author's opinion, necessary in order to gain a clearer understanding of the movement requirements of basketball. However, if the results obtained for the categories of Run and Jog in the present investigation are combined, the percent of TT spent in these intensities of running (14.0%) is still smaller than that reported for soccer and Australian rules football, suggesting that participation in basketball does not require players to engage in large amounts of low to moderate intensities of running.

The percent of TT spent in Stride/Sprint in basketball is slightly less than has been reported for soccer (Mayhew and Wegner 1985, Brodowicz et al. 1990, Yamanaka et al. 1988). Similar values have, however, been reported for Australian rules football (Jaques and Pavia 1974, McKenna et al. 1988) and rugby union (Docherty et al. 1988). Values reported for netball have been both similar (Allison 1980) and lower (Steele and Chad 1991). A significant problem when comparing the various studies lies in the different descriptions of the stride or sprint movements. It does appear, however, that consistent with other ITS, only a small percent of the game time in basketball is spent in high intensity running.

Classifying shuffling movements according to intensity has not been attempted in any other investigation of the movement patterns during ITS. Although "shuffling" has been used in examinations of movement patterns during netball (Otago 1983, Steele and Chad 1991) and has been included as part of the category of "Other" in some ITS (Mayhew and Wegner 1985, McKenna et al. 1988), the varying intensity of shuffling has not been reported. Categorising the shuffling movements according to intensity was considered necessary in basketball because of the large percent of time spent in shuffling movements. In addition, pilot investigations indicated that there were large differences in metabolic demands of shuffling depending on the nature and intensity of the movement.

The percent of TT spent in all intensities of shuffling by the subjects in the current investigation (18.0%) is far greater than that reported for netball (Otago 1983, Steele and Chad 1991), and other investigations of ITS that have included shuffling in their analysis (Mayhew and Wegner 1985, McKenna et al. 1988). Of the total time spent shuffling in the current investigation, 47.4% was spent at Low intensity, 32.3% at Medium intensity and 20.4% at High intensity. It is clear that shuffling movements constitute a significant aspect of the movement requirements of basketball. In addition, the energy requirements associated with many of the shuffling movements are consistent with those of high intensity activity, such as Stride/Sprint. Shuffling is, therefore, likely to constitute a significant portion of the energy demands of participation in basketball at the level of competition examined in the current investigation.

The time spent Jumping represented only 1.1% of the TT in the present analysis. A similar value has been reported for netball (Steele and Chad 1991) and indicates that only a very small proportion of the game time in basketball is spent Jumping. Nevertheless, such an explosive activity as Jumping may still constitute a significant portion of the physiological demands of competition.

In the present investigation, the overall work:rest ratio during TT was 8:13. A higher ratio (approximately 8:8.6) has been reported for Australian rules football (McKenna 1986). The ratio of HIA-to-low/medium intensity activity during TT was approximately 1:9, slightly lower than the ratio (1:7) reported by Mayhew and Wegner (1985) for soccer but higher than the ratio calculated by McKenna (1986) for Australian rules football. Docherty et al. (1988) reported that rugby players spent 15% of the game time engaged in high intensity activity. In the present investigation 9.6% of TT was spent in HIA. Based on these comparisons it appears that the movement requirements of participation in basketball, as estimated from the categories used in the present investigation, may be slightly less demanding than those associated with other forms of ITS.

5.2.4 Characteristics of activity during Live Time.

The percent of LT spent in each of the categories of activity provides a clearer indication of the movement patterns during actual play. The patterns of activity during LT depend only on the movements of the players during competition rather than those characteristics of activity that are imposed on the players as a result of the external structure of the game, such as the frequency of time-outs, free-throws and other stoppages in play.

Compared to other ITS, a smaller percent of the actual game time in the present investigation was spent standing and walking and a similar percent jogging, running and striding/sprinting. A major difference between basketball and other ITS was the greater amount of game time in basketball spent shuffling. Overall the subjects in the present investigation spent more than 60% of the LT at an intensity of activity greater than walking. More than 15% was spent in HIA (Stride/Sprint, High intensity Shuffle and Jump). These values are generally greater than those reported for other ITS.

Comparing the total number of seconds spent in S/W during TT (2354 seconds) to that of LT (774 seconds) it can be calculated that more than 65% of the total time spent in rest periods (that is, activity of no greater intensity than walking) was due to stoppages in the game. Less than 35% of the total time spent in activity of no greater intensity than walking was during LT. Therefore, the format of the game and the frequency of stoppages during the game, plays a considerable role in reducing the overall movement demands and energy requirements of competition.

In the present study the overall work:rest ratio during LT was approximately 3:1. The work:rest ratio during actual play reported by MacLean (1984) was 1:1.7 recorded during women's college basketball. The corresponding ratio in the present investigation was considerably more demanding and may be related to the level of competition. The work:rest ratio for TT calculated in this investigation (8:13) was, however, similar to that reported by MacLean (1984). The ratio of HIA to low/medium intensity activity during LT in the present investigation was 1:5. This is considerably higher than the ratio of 1:9 recorded during TT and also the ratios reported for other ITS (Mayhew and Wegner 1985, McKenna 1986). It is clear, therefore, that the inclusion of the stoppages in play substantially decreases the work:rest ratios and the high:low/medium ratios compared to those during LT by providing the majority of rest/recovery time.

The percent of time that players were in possession of the ball was not measured in this investigation. Time-motion analysis studies conducted on soccer and Australian rules football have reported that only 2% of the distance covered during a game is whilst a player is in possession of the ball (Reilly and Thomas 1976, Douge 1988). Similar results may be evident in basketball though it is likely that the percent will vary between the positions. Guards tend to be those players who travel with the ball for much of the time whilst the other players tend to handle the ball only in the scoring area.

The movement characteristics evident during other ITS have been reported to be dependant on the fitness of the players. Significant relationships between the aerobic capacities of the players and the distances covered during competition have been reported for soccer (Reilly 1975, Smaros 1980, Bangsbo and Linquist 1992) and Australian rules football (Jaques and Pavia 1974). Given that distances covered by players were not measured in this investigation, the existence of such a relationship in basketball cannot be determined. However, a high $\dot{V}O_2$ max has been suggested by Higgs et al. (1982) and Riezebos et al. (1983) as being an important factor in meeting the energy demands of participation in basketball. According to Hakkinen (1988) a decrease in $\dot{V}O_2$ max throughout the season may influence negatively on playing capacity in basketball. Although the benefits of a high maximum aerobic power cannot be determined from this investigation, it is likely that a high $\dot{V}O_2$ max will not *disadvantage* the performance of any player.

The movement characteristics during soccer have been reported to be dependant on the level of competition, quality of the opposition, the importance of the game and the closeness of the game (Bangsbo et al. 1991, Ekblom 1986). In the present investigation the games analysed were, for the majority of subjects, state level competition. All of the subjects have, however, competed at the national level. Therefore, the games investigated were not as important as National level games. Furthermore, the quality of the opposition was, in most cases, slightly inferior. These factors may have resulted in reduced movement characteristics during play compared to more important competition.

A general observation of the games used in this investigation compared to National level games is that a greater percent of time appears to be spent in High intensity Shuffling during National level games. This cannot be supported by data in the absence of relevant time-motion analysis. However, it is logical to conclude that the movement patterns during more important games would be indicative of increased physiological requirements.

In comparing the movement patterns according to the position played it appears that the movement characteristics exhibited by Guards are different to those of both Forwards and Centres in terms of the amount of HIA. Guards engage in greater amounts of HIA, as determined from the movement categories selected, than both other positions of play. There is, therefore, likely to be an increased physiological load, as a result of increased lower body movement requirements, associated with playing this position during basketball. This has been suggested in other investigations (McArdle et al. 1971). The patterns recorded for Forwards and Centres, however, are very similar. Therefore, it can be concluded that the positions of Forward and Centre exhibit similar movement characteristics.

The results obtained concerning the differences in movement patterns between the positions should be viewed with caution. The subjects were analysed individually during different games. The different characteristics of the games alone may have effected the movement patterns of the subjects irrespective of playing position. For instance, the different quality of opposition and tactics employed by the coaches and players may have varied between the games subsequently effecting the movement patterns of the subjects. Although the analysis results obtained from one game in soccer have been suggested to be indicative of the time spent in high intensity activity in all games (Bangsbo et al. 1991), it is unknown whether a similar characteristic would be evident in basketball.

In order to gain a more accurate understanding of the differences in the movement patterns between the positions of play in basketball it would be necessary to analyse the movement patterns of each player during the one game. This was not attempted in the present investigation as technical considerations precluded all subjects wearing HR recording equipment and having blood samples obtained at various stages throughout the game.

Summary of time-motion analysis.

The movement patterns of basketball players in the present investigation involved a large number of discrete movements, frequent changes in intensity, very short rest periods during LT and a considerable amount of high intensity work. The addition of the stoppages in play due to time-outs, fouls, free-throws, out-of-bounds and substitutions appeared to play a considerable role in reducing the movement requirements of participation by providing longer periods of rest. Although activity patterns during Total Time provided an overall picture of the energy demands, Live Time data more accurately reflected the actual game demands. Overall, approximately 40% of the TT was spent in activities of greater intensity than walking whilst 10% was spent in HIA. The values for LT were approximately 65% and 15% respectively. The characteristics of movement in basketball are reasonably similar to those reported for other ITS with some small differences: a larger percent of time was spent shuffling and smaller percent of time was spent engaged in low to moderate intensities of running in the present investigation.

The movement patterns appeared to be partially dependant on the position played with Guards spending a significantly greater percent of LT in HIA than Forwards and Centres. The movement patterns of Forwards and Centres were similar.

5.3 The intensity of activity during competition.

The HR responses to participation in basketball have not been widely investigated. As such little is known regarding the intensity of activity during competition. The present investigation reveals that the intensity of competition during basketball is high and places considerable demands on the cardiovascular system.

5.3.1 Mean absolute and relative heart rates.

The mean HR calculated from TT for all subjects was 164.9 bts.min.-1. This is generally lower than the average HR responses to basketball reported in the literature. Kerr (1968), Seliger (1968a), Ramsey et al. (1970) and McArdle et al. (1971) all reported average values of 4-7 bts.min.$^{-1}$ higher than the value recorded in the present investigation, whilst Higgs et al. (1982) reported a substantially higher average value of 183 bts.min.$^{-1}$. However, by only including those HR values recorded during LT the mean HR was 168.4 bts.min.$^{-1}$. This value is similar to those reported by Kerr (1968), Seliger (1968a) and Ramsey et al. (1970).

The average HR values recorded in this investigation are similar to the values reported for soccer (Van Gool et al. 1988, Seliger 1968a, Cochrane and Pyke 1976), Australian rules football (Hahn et al. 1979) and rugby (Morton 1978). Higher average HR's have been reported for ice hockey (Green et al. 1976, Paterson et al. 1977). Based on these results it appears that the HR responses to basketball are generally similar to those associated with participation in other ITS.

The absolute mean HR values in the present investigation vary considerably between the subjects (mean 164.9 $\pm$ 9.1 bts.min.$^{-1}$ during TT and 168.4 $\pm$ 8.8 bts.min.$^{-1}$ during LT). The mean relative HR values, however, vary considerably less. The mean value for all the subjects was 86.8 $\pm$ 2.3% of HRpeak during TT and 88.7 $\pm$ 2.2% of HRpeak during LT. As such, expressing the HR values only as an absolute value may lead to incorrect conclusions regarding the intensity of play. Absolute HR values may correspond to different intensities of activity for players with different maximum HR's. The small standard deviations reveal that the overall intensity of competition is similar for each position of play. There were, in fact, no significant differences in the mean relative HR's between the positions of play.

In the present investigation the mean relative HR values during TT and LT are similar to those reported in other studies examining the intensity of basketball (McArdle et al. 1970) as well as other ITS (Cochrane and Pyke 1976, Van Gool et al. 1988, Green et al. 1976, Paterson 1979). The average maximum value recorded during competition in the present investigation was 188.1 bts.min.-1 representing an average of 99.1% of the subjects' HRpeak. These HR values suggest extremely high intensities of activity and near maximal cardiovascular responses during some periods of play in basketball. Similar maximum values have been reported for soccer (Reilly 1986), rugby (Maud 1983) and ice hockey (Paterson 1979). However, lower maximum game HR's have also been reported for soccer (Cochrane and Pyke 1976) and ice hockey (Paterson et al. 1977).

The use of the HR values to estimate oxygen consumption during participation in ITS has been reported in a number of studies (Van Gool et al. 1988, Boyle et al. 1992, Green et al. 1976). This has been suggested as providing an estimation of the energy requirements of participation (MacLaren 1990, Paterson 1979). This was not attempted in the present investigation as it was not considered to provide an accurate enough indication of the level of oxygen consumption that may be evident during competition.

Oxygen consumption rates during ITS have commonly been estimated from HR/$\dot{V}O_2$ relationships established during 3-5 minutes of steady rate treadmill exercise. The HR responses of the subjects during competition in the present investigation rarely, if ever maintained a steady rate, defined as $\pm$5 bts.min.$^{-1}$, for 2-3 minutes during competition. As such it was not considered appropriate to estimate the energy demands from relationships established in the laboratory. In addition the demands of basketball require intermittent work with frequent changes in intensity as well as upper-body exercise. Both are likely to alter the HR/$\dot{V}O_2$ relationship (Montgomery 1988, Paterson 1979). According to Balsom et al. (1992a) and Tumilty (1993), intermittent exercise may elevate HR disproportionately to oxygen uptake.

The effect of psychological arousal and emotion on HR response have been reported during basketball (McArdle et al. 1971, Ramsey et al. 1970) and other ITS (Hahn et al. 1979, Montgomery 1988, Tumilty 1993) and are also likely to effect the HR/$\dot{V}O_2$ relationship. According to Tumilty (1993), HR may not provide a true reflection of oxygen uptake during ITS. Similarly Balsom et al. (1992a) suggest that HR cannot be used to predict oxygen uptake during intermittent exercise. Furthermore, an increase in body temperature has been reported to increase the HR during prolonged exercise (Costill 1970) potentially altering the HR/$\dot{V}O_2$ relationship towards the latter part of the game in basketball.

Although the level of oxygen consumed during men's competition basketball may provide valuable information regarding the energy requirements of competition, the errors associated with predicting $\dot{V}O_2$ were considered numerous and may lead to incorrect conclusions regarding the intensity of activity. As such an estimation of oxygen consumption during basketball was not attempted in this investigation.

5.3.2 Heart rate responses according to percent of Total Time.

Mean HR values calculated from the entire game reveal little about the intermittent nature and the varying demands of competition during participation in ITS. Unfortunately most of the literature reporting HR values during participation in ITS have reported only this aspect of the HR responses to competition (Van Gool et al. 1988, Pyke and Smith 1975, McArdle et al. 1971, Green et al. 1976). In the present investigation, the HR values were categorised according to the percent of the subjects' HRpeak. The results were expressed as the percent of TT or LT spent within each of 6 categories of intensity. A similar method was employed by Woolford and Angove (1991) in netball. However in the present investigation the categories of HR response were divided into intervals of 5% of HRpeak rather than 10% of HRmax as used by Woolford and Angove (1991). An interval of 10% (or approximately 20 bts.min.-1) is considered by the author to be too large and is likely to result in HR values which reflect very different intensities of activity, being classified in one category. A variation of 5% of HRpeak (or approximately 10 bts.min-1) is likely to provide a more accurate indication of the varying intensities of activity.

The results of the present investigation reveal that the subjects spent more than 65% of TT with a HR value of greater than 85% of HRpeak. This is similar to results reported for netball (Woolford and Angove 1991), field hockey (Boyle et al. 1992) and soccer (Smodlaka 1978). A similar percent of time was also spent with the HR less than 75% of HRpeak and between 75% and 85% of HRpeak as that during netball (Woolford and

Angove 1991). A slightly greater percent of time in netball, however, was spent with a HR value greater than 95% of the players' maximum (Woolford and Angove 1991). It is unclear in the study by Woolford and Angove (1991) what time intervals were used for the HR recording. From this investigation, however, it appears that the HR responses to State level competition netball are similar to those of State level competition basketball. It is logical to conclude that the similarities in the movement patterns during competition are reflected in the similar HR responses of the players to competition.

5.3.3 Heart rate responses according to percent of Live Time.

The HR values recorded during LT provide a clearer indication of the intensity of actual play during basketball. The percentages obtained do not, however, vary widely from those for TT. Although in the present investigation approximately 33% of the HR values during LT were less than 85% of the subjects HRpeak, many of these HR values were recorded as the HR increased from resting levels to values reflective of the energy demands of the activity. As such it should not be assumed that one third of the game was played at an intensity that demanded less than 85% of the subjects' HRpeak. In addition the problems associated with determining the HR values that occurred during LT have been discussed in Chapter 3. Many of the HR values included in the LT data are more reflective of recovery periods than the intensity of competition.

The main difference between the HR values recorded during TT and those recorded during LT was that a greater percent of LT was spent with a HR response of greater than 90% of HRpeak (51.4% of LT compared to 44.6% of TT). Approximately 75% of the LT was spent with HR response of greater than 85% HRpeak. This is slightly higher than those responses reported for soccer (Smodlaka 1978), field hockey (Boyle et al. 1992) and netball (Woolford and Angove 1991) and suggests greater physiological demands of actual play in basketball. However, the percent of LT spent with a HR response of greater than 95% of HRpeak was lower than that reported for netball (Woolford and Angove 1991). In the present study, however, there was a large standard deviation in the results for this category of intensity (mean 15.0 $\pm$ 10.4 CV=69.39%). Two subjects (subjects number 2 and 6) recorded values of greater than 20% for the percent of LT spent with a HR response of greater than 95% HRpeak. These results indicate large variations in the percent of time spent with HR responses of greater than 95% of HRpeak.

Compared to TT a smaller percent of LT was spent with a HR response of less than 75% of HRpeak (5.5% for LT compared to 11.3% of TT). The numerous stoppages in play are, therefore, likely to play a significant role in reducing the overall cardiovascular demands of competition.

The HR responses to basketball indicate the often intense nature of movement during competition. More than 50% of LT resulted in a HR response of greater than 90% of HRpeak. This was equivalent to 18 minutes of LT. Approximately 15% of LT resulted in a HR response of greater than 95% of HRpeak. This corresponded to the percent of LT spent in HIA during competition (approximately 16% of LT). In addition the total number of minutes associated with this percent of LT (5 minutes) also appears to correspond to the total amount of time spent in HIA (6 minutes).

In the present investigation the maximum HR values obtained during competition were close to the peak values recorded during exhaustive laboratory testing and for two of the subjects actually exceeded the peak laboratory values. This indicates that the intensity of activity is high enough during some periods of play to result in a near maximum cardiovascular response. Paterson (1979) suggested that near maximal $\dot{V}O_2$ may be achieved during 2-3 minutes of high intensity play in ice hockey. A similar response may be evident in basketball during continuous periods of LT (2-3 minutes) where the intensity of competition is high.

Examples of the HR responses to participation in basketball (Figures 4.6a-b and Figure 4.7) reveal that the variations in the HR responses during actual play (LT) are small. The main reductions in HR only occurred during stoppages in play. The greatest reductions in HR occured during time-outs (approximately 90 seconds of inactivity) when the HR response decreased to approximately 60% of HRpeak and free-throws (approximately 30-60 seconds of inactivity) when the HR decreased to 70-75% of HRpeak. Smaller reductions often occurred as the result of other stoppages in play, such as when the ball was out-of-bounds.

A similar HR response to the rest periods in basketball has been reported by McArdle et al. (1971) and Ramsey et al. (1970). An interesting observation noted by Ramsey et al. (1970), was that the HR response of the player when attempting a free-throw did not decrease. They (1970) related this to the increased effect of arousal on HR response. This was not observed in the current investigation, possibly relating to the level of competition. More important competitions may result in increased psychological arousal during free-throw shooting, thus maintaining high HRs despite periods of relative inactivity. A unique requirement of participation in basketball may be related to the ability to successfully complete free-throws and yet recover during the associated rest period.

It is clear, however, that considerable reductions in the HR response to basketball only occurred during the longer stoppages in play. During LT the HR response remained relatively constant. A similar pattern of HR response has been reported for ice hockey (Paterson 1979) with small reductions during each on-ice shift but much larger reductions during off-ice recoveries between shifts. Graphical illustrations of the HR responses to ice hockey contained in Montgomery (1988) and Paterson (1979) show similar characteristics to those obtained in the present investigation for basketball.

The small reductions in the HR response of the subjects during LT may be explained by the small oscillations in HR response during intermittent exercise when both the work periods and exercise periods are less than approximately 30 seconds (Astrand et al. 1960, Saltin et al. 1976, Christensen et al. 1960). According to Saltin et al. (1976) the energy demands during intermittent exercise are averaged between the exercise and rest periods when the work:rest ratio is 1:1 and both are less than 60 seconds in duration. Large variations in HR appear to occur with work and rest periods of 60 seconds or longer (Astrand et al. 1960, Saltin et al. 1976). This would explain the small reductions in HR values during basketball with only short rest periods (such as those that occur during actual LT) whilst the longer rest periods (time-outs and free-throws) will result in considerable decreases in HR.

The only significant differences in the HR responses between the positions of play was that Guards spent a greater percent of LT than both Forwards and Centres with a HR response of 90-95% of HRpeak. This would appear to reflect the observation that the Guards spent a greater percent of LT engaged in HIA. However, Guards spent a smaller, though not statistically significant, percentage of LT with a HR response of greater than 95% HRpeak. Therefore, the increased percent of time spent in HIA for Guards is not reflected in the HR responses to competition. This may be explained by the smaller aerobic capacities ($\dot{V}O_2$ peak) of the Centres and Forwards, as Guards may be able to maintain a greater intensity of activity for a given cardiovascular response. As has been previously suggested, a high $\dot{V}O_2$ peak may be an important factor in meeting the physiological demands of basketball (Higgs et al. 1982, Riezebos et al. 1983).

It is also possible that the similar cardiovascular demands for the different positions of play may have been related to the amount of upper-body activity required for each position. Forwards and Centres may be required to involve considerably more upper-body musculature in order to "maintain position" whilst engaged in defensive and offensive manoeuvres. Upper-body involvement in ITS has been suggested to contribute to the cardiovascular and metabolic demands of competition in ice hockey (Green 1979, Montgomery 1988). In addition there may be greater energy requirements of these positions in order to maintain a low body position for stability. This has been suggested as a major energy requirement during volleyball (Heimer et al. 1988). No account of either of these forms of activity was made during the present time-motion analysis of basketball, though they are likely to contribute to the energy demands. As such the similar HR responses, despite the different movement patterns evident from the time motion analysis, suggest that the intensity of activity for each position is similar, though reflective of different movement requirements.

Heart rate responses to other ITS have been suggested to be dependant on the level of competition and quality of opposition (Forsberg et al. 1974 as cited by Montgomery 1988). It is likely that during more important games the HR responses of the subjects would be higher than the responses evident in the present investigation. As such the data obtained in this investigation is limited in the extent to which it provides an indication of the intensity of basketball at higher levels of competition. Although the equipment used in this investigation was of little inconvenience to the subjects, it is unlikely that HR recording will be permitted by coaches and players during more important games.

Summary of the HR responses to basketball.

The HR responses to basketball recorded in the present investigation indicate that the intensity of activity during LT was high. The HR responses of subjects were maintained above 85% of HRpeak for 75% of the LT and above 95% of HRpeak for 15% of the LT. During TT, however, the respective values were 65% and 12% of TT. The inclusion of the stoppages in play, therefore, substantially reduced the overall HR responses to competition.

The highest HR responses recorded approached, and for two of the subjects exceeded the peak HR values achieved during exhaustive laboratory tests. This suggests that the intensity of activity during some periods of play may have been equivalent to that evident during such laboratory testing. The HR responses during actual play did not oscillate to any great extent, suggesting that the rest periods during LT are too short to allow reductions in the HR values. Substantial reductions, however, did occur during extended rest periods such as those associated with time-outs and free-throws. These rest periods appeared to play a significant role in reducing the cardiovascular demands of competition.

5.4 Exercise metabolism during basketball.

Scientific knowledge relating to the exercise metabolism that meets the energy demands of competition in the ITS is an essential element of being able to develop training programs and testing protocols specific to the demands of competition (Mayhew and Wegner 1985). In the past the importance of the various energy sources during basketball has been estimated through the testing of the physiological characteristics of players (Riezebos et al. 1983, Vaccaro et al. 1980). The characteristics associated with high individual performances have been suggested to reflect the energy requirements of competition

(Riezebos et al. 1983). In addition the changes in the physiological characteristics of players throughout a competitive season have also been used to estimate the energy demands of training and competing (Hakkinen 1988). The value of any such estimations remains questionable in the absence of direct monitoring of the physiological responses to competition. In the present investigation estimations regarding the sources of muscular energy can be derived from the time-motion analysis results and the HR responses to competition. In addition Bla samples obtained at various stages of competitive play can also be used to indicate the sources of muscular energy.

Lactate is the end product of anaerobic glycolysis. The accumulation of lactate in the blood has been used as an indicator of the involvement of the anaerobic glycolytic turnover during ITS (Bangsbo et al. 1991). The limitations associated with the use of Bla in this way, however, need to be recognised. The concentration of lactate in the blood is the balance between entry into the blood from the exercising muscle and removal/clearance from the blood by other tissues in the body such as the liver or inactive muscle (Brooks 1985, Gollnick and Hermanssen 1973). An increase in Bla may, therefore, reflect increased entry into the blood as well as decreased removal from the blood. In addition a large percent of the lactate produced during anaerobic glycolysis and glycogenolysis will be metabolised within the muscle itself (Brooks 1985). According to Sahlin (1990), the glycolytic rate has been reported to increase 25 fold at an exercise intensity of 40% $\dot{V}O_2max$ without an increase in either muscle or blood lactate. As such, Bla cannot be used to quantify the activity of the anaerobic glycolytic pathway.

Despite these limitations the use of Bla to estimate the anaerobic glycolytic contribution to the metabolic demands of ITS has been defended on the grounds that, under some conditions, increases in Bla reflect increases in exercising muscle and can, therefore, be used to estimate the sources of energy. According to Gollnick and Hermanssen (1973) the concentration of lactate in the blood provides valuable information regarding the changes taking place in the muscle. Ekblom (1986) suggests that the anaerobic yield in soccer is reflected in the Bla concentration. As such blood lactate can be used to confirm that anaerobic glycolysis has been stimulated (Balsom et al. 1992a) and provides some indication of the glycolytic energy supply (Gollnick and Hermanssen 1973, Cheetham et al. 1986). Therefore, although the use of Bla is subject to the limitations discussed and provides only an indication of the metabolic sources of energy during activity, the relative ease of sampling provides an appropriate means of estimating the sources of muscular energy during basketball.

This study is believed to be the first to report the use of blood samples for the purpose of lactate analysis in basketball. The average lactate concentration obtained was 6.8 $mmol.l^{-1}$, similar to values reported for soccer (Ekblom 1986) though higher than values usually obtained during soccer (Bangsbo et al. 1991, Gerisch et al. 1988, Rohde and Espersen 1988, Tumilty et al. 1988). A similar average Bla concentration has been reported for ice hockey (Green et al. 1976) whilst both similar (McLean 1991) and lower (Docherty et al. 1988, Allen 1989) average values have been reported for rugby.

The highest Bla concentration recorded in the current investigation was 13.2 $mmol.l^{-1}$. The average peak value for all of the subjects was 8.9 $mmol.l^{-1}$. Similar maximum Bla concentrations of 10 $mmol.l^{-1}$ (Bangsbo et al. 1991), 12.4 $mmol.l^{-1}$ (Gerisch et al. 1988), 13 $mmol.l^{-1}$ (Ekblom 1986) and 11.6 $mmol.l^{-1}$ (Smith et al. 1993) have been recorded during soccer, suggesting a substantial involvement of the anaerobic glycolytic system during some periods of play (Ekblom 1986). The high values obtained in the present investigation also indicate the considerable involvement of the anaerobic glycolytic system in meeting the energy demands of some periods of play in basketball.

According to Ekblom (1986), higher Bla concentrations are evident during higher levels of competition in soccer, possibly reflecting an increased activity of anaerobic glycolysis during such play (Tumilty 1993). McLean (1991) suggests a similar response for rugby union. Blood lactate concentration has also been reported to be partly dependant on the calibre of opposition in ice hockey (Forsberg et al. 1974 as cited by Montgomery 1988). The level of competition in basketball is, therefore, likely to effect Bla. Nevertheless, the high values achieved in the present investigation suggest that anaerobic glycolysis plays a significant role in meeting the energy demands of competition in basketball. This supports the observation by Mueller and Steinhofer (1982 as cited by Hakkinen 1988) that basketball places considerable demands on anaerobic energy production.

In the present investigation Bla concentration was found to be significantly correlated to the percent of time spent in HIA for the 5 minutes of TT prior to blood sampling. A similar correlation has been reported in soccer by Bangsbo et al. (1991) for the duration of high intensity running 5 minutes prior to blood sampling. According to Ekblom (1986) and Bangsbo et al. (1991) the concentration of lactate in the blood during soccer is dependent on the type of activity prior to the blood sample being obtained. Single samples obtained at the end of a half or at the end of the game cannot be used to estimate the sources of muscular energy for the entire game (Smith et al. 1993, Bangsbo et al. 1991, Ekblom 1986). The results obtained in the present investigation support this observation.

A significant correlation was also found in the present investigation between the Bla concentration and the mean HR (%HRpeak) for the 5 minutes of play prior to blood sampling. As such Bla concentration appeared to be related to both the percent of time spent in HIA as well as the overall intensity of activity, reflected in the mean HR response.

The correlations found between Bla and percent of time spent in HIA and the overall intensity of activity (Figure 4.9a and 4.9b) in the present investigation indicate that the sources of energy during basketball were dependant on the patterns and intensities of play. In addition, the wide range of values recorded (refer to Figure 4.8) suggests that the activity of the anaerobic glycolytic pathway varied considerably between as well as during the games.

The low Bla concentrations recorded during some periods of play in the present investigation (2-4 $mmol.l^{-1}$) suggest that the predominant sources of energy during such periods of play were the ATP and CP stores and aerobic pathway. Given that more than 60% of the rest periods in basketball were due to stoppages in the game, it is likely that these low Bla values reflected frequent and extended periods of inactivity due to time-outs and free-throws. In fact, a significant negative relationship ($r=-0.69$, $p<0.05$) was obtained between the Bla concentration and the percent of time spent in S/W for the 5 minutes of play prior to blood sampling. The external formats of the games are, therefore, likely to partly determine the concentration of lactate in the blood.

Despite the low lactate values recorded following some periods of play, the rate of lactate production may still have been high during the actual activity. The duration of activity, however, may have been too short to result in accumulation of lactate in the blood, as has been suggested by Bangsbo et al. (1991). According to Saltin et al. (1976), the duration of the exercise periods during intermittent activity is the most critical factor in determining whether or not lactate accumulates in the blood. Results reported by Balsom et al. (1992a), Wootton and Williams (1983) and Holmyard et al. (1988) indicate that the Bla responses to 10 sprints of 6 seconds duration were similar despite recovery periods of different duration. Although the duration of the recovery periods may also be important (Saltin et al. 1976), the duration of the exercise bout may be the major determinant of Bla concentration during intermittent exercise. As such, the low concentrations of Bla observed during some periods of play in the present investigation, although suggesting little activity of anaerobic glycolysis, may have been equally reflective of short work periods.

In addition, the longer rest periods will allow for lactate to be removed from the blood (Saltin et al. 1976). MacLaren (1990) has suggested that the removal of lactate from the blood during time-outs and free-throws may result in lower Bla concentrations than might be expected during basketball. Furthermore, low intensity activity (such as jogging or walking) has consistently been shown to increase the removal of lactate from the blood when compared to no activity (Hermanssen and Stensvold 1972, Belcastro and Bonen 1975). Both of these factors are likely to reduce the concentration of lactate in the blood. A similar response has been suggested for rugby union (McLean 1991).

The low lactate concentrations may also be explained by the metabolic effects of the rest periods during basketball. Rest periods during intermittent exercise have been reported to play a significant role in regulating metabolism during intermittent exercise (Essen and

Kaijser 1978, Saltin et al. 1976). Rest periods of 1-2 minutes (such as those of time-outs) have been suggested to result in 70-90% resynthesis of CP levels (Harris et al. 1976, Sahlin et al. 1979) and increases in the ATP/ADP ratio (Jansson et al. 1990) in the muscle following high intensity exercise. Both of these factors have been reported to delay the onset of anaerobic glycolysis during subsequent exercise bouts (Essen and Kaijser 1978, Saltin et al. 1976).

Rest periods of 1-2 minutes will also result in increased free-fatty acid (FFA) and citrate concentrations within both the muscle and the cytoplasm (Saltin et al. 1976, Essen et al. 1977, Essen 1978). Increased use of FFA during intermittent exercise has been reported by a number of authors (Green 1979, McCartney et al. 1986). The inhibitory effect of FFA and citrate on anaerobic glycolytic rate has been well documented (Parmegianni and Bowman 1963, Saltin et al. 1976) though the effect of this during repeated bouts of exercise has been recently questioned (Bangsbo and Saltin 1993).

It is likely that the metabolic processes occurring during rest periods reduce the contribution of anaerobic glycolysis during subsequent work bouts (Saltin et al. 1976, Essen 1978). This will result in an increased proportion of energy supplied from the ATP and CP stores as well as aerobic metabolic pathways, reducing the activity of anaerobic glycolysis and decreasing the production of lactate (Saltin et al. 1976). If the work bouts are relatively short and rest periods relatively frequent, the levels and restoration rates of ATP, CP, FFA, and citrate are likely to partially regulate metabolism during basketball in this manner. This may explain the low concentrations of lactate in the blood during some periods of play, despite high intensity activity between the rest periods.

Shorter rest periods (30 seconds or less, such as those associated with free-throws, substitutions and other stoppages in play) may also result in increases in ATP, CP and FFA levels as well as a decrease in the ADP concentration. The restoration rate of CP has been suggested to have a half-time of 21-22 seconds (Edwards et al. 1972, Harris et al. 1976, Sahlin et al. 1979) and rest periods of 30 seconds may result in 60-65% restoration of CP (Green 1979). As such there may have been considerable resynthesis of CP during free-throws and other stoppages of approximately 30 seconds, which may have assisted in delaying the onset of glycolysis during further activity.

However, laboratory studies examining the metabolic sources of energy during intermittent high intensity exercise have generally concluded that rest periods of 30 seconds duration interspersed with 6 second period of sprinting are inadequate to sufficiently restore CP levels in the muscle (Wootton and Williams 1988, Balsom et al. 1992b, Jansson et al. 1990, Holmyard et al. 1988). In addition the small increases in FFA and citrate are unlikely to play a significant inhibitory role on glycolytic rate during such exercise. The increase in Bla concentrations observed during intermittent exercise is believed to indicate an increased activity of the anaerobic glycolysis pathway in meeting the energy demands of repeated maximal efforts (Holmyard et al. 1988, Wootton and Williams 1983, Balsom et al. 1992a).

A more recent study, however, using muscle biopsies has suggested that anaerobic glycolytic activity is reduced after a few 6 second sprints interspersed with 30 second recovery periods. Gaitanos et al. (1993) reported that the glycolytic contribution to the 6 second sprint was reduced from 44.1% in the first bout to 16.1% in the final bout. According to Gaitanos et al. (1993), this inhibition of anaerobic glycolysis is likely to be related to the increase in hydrogen ions after a few sprints. However, after only 4 of the 10 sprint bouts, there was a decrease in maximum power output. A similar reduction in power output after only 3 sprints was reported by Wootton and Williams (1983). Given that the rate of recovery of maximum force parallels the resynthesis rate of CP (Stull and Clarke 1971, Harris et al. 1976) and that a loss of maximum power output is related to an inadequate resynthesis of CP (Williams 1993) it is likely that CP levels are not sufficiently restored with 30 seconds of inactivity to maintain maximum levels of power output.

Although CP continues to make a considerable contribution to the energy requirements during high intensity intermittent exercise, the reduction in maximum power output is likely to reflect reduced stores of CP within the muscle (Williams 1993). Based on the above investigations it can be concluded that CP stores within the muscle cannot be adequately restored during 30 seconds of rest in order to reproduce maximum power outputs.

Although caution must be used when extrapolating the results from investigations examining the sources of energy during repeated exercise bouts of 6 seconds duration to the requirements of basketball, these investigations provide information relating to the regulatory role of rest periods common in basketball. The short rest periods of approximately 30 seconds or less during basketball, although allowing some degree of recovery from intense play, will most likely result in greater anaerobic glycolytic activity during subsequent activity than if longer rest periods were evident.

The rest periods during actual LT evident from the time-motion analysis were unlikely to be associated with significant recovery from preceding activity. Rest periods of 2-3 seconds (such as the average period of S/W) or slightly longer periods (such as those associated with periods of out-of-bounds or substitutions) will not allow for significant restoration of intramuscular ATP and CP levels (Saltin 1975), increases in pH or decreases in lactate concentrations (Sahlin and Ren 1989). It is likely that prolonged periods of intense play requiring multiple bursts of HIA without substantial rest periods resulted in considerable use of the CP stores in the muscle. According to Harris et al. (1977) lactate content is curvilinearly related to the decrease in CP stores. Similarly, Sahlin (1990) states that under most exercise conditions a high muscle lactate concentration is associated with a low CP level. The high Bla concentrations observed in the present investigation suggest that, at least during these periods of play, the CP stores of the muscle may have been reduced to low levels.

It appears, therefore, that prolonged periods of play without frequent stoppages due to time-outs or free-throws resulted in an increased dependence on anaerobic glycolysis and aerobic metabolism during basketball. This is likely to be reflected in high HR s of perhaps greater than 95% of HRpeak, and relatively high Bla concentrations. According to Gaitanos et al. (1993) a greater reliance on aerobic metabolism is possible during repeated bouts of high intensity exercise due to the inhibitory effect of a low pH on glycolytic metabolism. This has also been suggested by Spriet et al. (1989). It is also likely, therefore, that 2-3 minutes of continuous LT resulted in high levels of oxygen consumption during basketball.

During some periods of very intense play, oxygen consumption may have approach those levels associated with $\dot{V}O_2$ peak, as has also been suggested in ice hockey (Paterson 1979). Nevertheless, the intramuscular phosphagen stores are likely to remain an extremely important fuel source for participation in basketball, even during prolonged periods of intense play.

Creatine phosphate is the major energy source for explosive-type activities such as jumping. In addition, the average Stride/Sprint revealed from the time-motion analysis is less than 2 seconds in duration. Although it is believed that glycolysis will contribute significantly to the energy demands of a short bout of high intensity activity such as a 2-3 second sprint (Hultman and Sjoholm 1983, Boobis 1987), the predominant source of energy will most likely be the intramuscular ATP and CP stores (Hultman and Sjoholm 1983, Jones et al. 1985). In addition, the intramuscular stores of myoglobin will also contribute to the energy demands during short periods of activity (Åstrand et al. 1960, Jones et al. 1985) and intermittent activity (Christensen et al. 1960, Essen et al. 1977).

In addition to the energy requirements of movement during basketball there may be an increased requirement associated with dribbling the basketball. Increased $\dot{V}O_2$, HR, Bla and energy expenditure for a given running speed have been reported for dribbling a soccer ball (Reilly and Ball 1984) and a field hockey ball (Reilly and Seaton 1990). This is likely to be related to the complexity of the skill associated with controlling the ball whilst moving. Although no such studies have examined the cardiovascular and metabolic effects of dribbling a basketball, it is logical to expect increased energy requirements associated with the skill. Although no account was made of the percent of time spent in possession of the ball in the present investigation, it is likely that the energy requirements of those players who handle the ball the most (such as Guards) will be increased as a result of having to perform the skill whilst moving.

The energy costs associated with shooting and re-bounding may also contribute a significant amount to the energy demands of competition in basketball. Both activities require significant involvement of upper-body musculature, often at very high intensities. It is likely that these forms of activity will be associated more with the positions of Forward and Centre. In particular the re-bounding requirements associated with the position of Centre may explain the similar intensities reflected in the HR responses despite the reduced lower body movement requirements evident from the time-motion analysis.

Summary of exercise metabolism during basketball.

The high Bla concentrations recorded during competition indicate that anaerobic glycolysis is an important energy pathway during basketball. However, the metabolic sources of energy during basketball are dependent on both the intensity of competition and the movement requirements of play. In addition, the physiological requirements vary according to the nature of the stoppages in play. In particular, the frequency of time-outs and the longer rest periods associated with free-throws may play a role in regulating metabolism during basketball. Periods of play associated with few time-outs and free-throws are likely to result in increasing demands of both anaerobic and aerobic energy systems. This may be related to the prolonged use and subsequent depletion of intramuscular CP stores associated with 2-3 minutes of intense activity.

Prolonged periods of uninterrupted LT are likely to result in both considerable cardiovascular and metabolic demands. Oxygen consumption levels approaching $\dot{V}O_2$ peak and high Bla concentrations indicative of considerable anaerobic glycolytic activity may be associated with these particular periods of intense play. Periods of play interspersed with frequent stoppages due to time-outs and free-throws may be associated with increased use of CP stores and decreased reliance on anaerobic glycolysis.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. The time-motion analysis technique used in the present investigation was moderate to highly reliable for all categories of movement excluding Run B. The poor reliability results obtained for Run B may be explained by the small volume of data collected, the difficulty in determining the intensity of backward running and the similarities in movement characteristics between backward running and shuffling.

2. Similar to the movement patterns reported for other forms of ITS, the basketball players in the present investigation spent the majority of TT engaged in low intensity activity. Only a small proportion of the TT was spent in activities classified as high intensity. Of the LT played, the majority of time was spent engaged in activities of greater intensity than walking. Compared to TT, a greater percent of LT was spent in high intensity activity and a considerably smaller percent of time was spent standing and walking. The external structures of the game reduced the movement requirements of participation as determined by the movement categories used in the present investigation. The average duration of each activity and the frequent changes in intensity indicated the intermittent nature of basketball.

3. There were significant differences in the movement patterns between the three positions of play in the present investigation. Guards were found to spend a smaller percent of TT and LT standing or walking compared to Forwards and Centres. Guards also spent a greater percent of LT engaged in high intensity activity than Forwards and Centres. The only differences between the movement characteristics of Forwards and Centres was that Forwards spent a greater percent of LT Jogging whilst Centres spent a greater percent Running.

4. The HR responses of the subjects indicate that participation in basketball places considerable demands on the cardiovascular system. The highest HR values achieved during

competition were similar to the peak values recorded during an exhaustive laboratory test and suggest that the intensity of activity during competition was, at times, very high. Substantial decreases in the HR values were only evident during stoppages in the game due to free-throws and time-outs. Small decreases were evident during other breaks in the game, such as out-of-bounds. The HR responses of the players remained fairly steady during actual play suggesting that periods of standing and walking during LT did not allow substantial decreases in HR values and may only have played a minor role in allowing recovery from previous activity.

5. The only significant differences in the HR responses between the positions of play was that the Guards spent a greater percent of LT with a HR response of 90-95% of HRpeak. Guards did not spend a significantly greater percent of LT with a HR response of greater than 95% of HRpeak. Therefore, the HR responses of the subjects suggest that the differences in the movement requirements between the positions of play were not reflected in the HR responses to competition. It is likely, therefore, that other forms of movement not included in the time-motion analysis conducted in this investigation, such as upper body activity associated with re-bounding and maintaining position, contributed to the energy demands of the positions of Forward and Centre.

6. The average and maximum Bla concentrations obtained in the present investigation indicate that anaerobic glycolysis is an important energy source during basketball. The relationship found between the Bla concentration and the percent of time spent in HIA for the 5 minutes of play preceding blood sampling suggests that the activity of the anaerobic glycolytic pathway was related to the characteristics of movement and the patterns of play. During periods of play interrupted by frequent stoppages for time-outs and free-throws the main energy sources were most likely ATP, CP and anaerobic glycolysis. During periods of play without substantial rest periods the main energy sources were likely to be the aerobic pathways as well as anaerobic glycolysis, though intramuscular stores of ATP and CP are likely to have contributed to the energy demands during sudden bursts of high intensity activity.

6.2 Recommendations

1. There needs to be considerably more research undertaken to investigate the physiological requirements of participation in basketball at the elite level. Further investigations of the movement patterns of basketball players during competition should be conducted from video recordings of actual National Basketball League (NBL) competition games, as the information derived from these games is likely to be of greater value for coaches seeking to replicate the requirements of competition for training purposes. The objectivity of further time-motion analysis investigations may be improved through the development of computer programs, similar to those used in some investigations, which can be used to assist in the analysis of movement patterns during basketball. A more accurate indication of the differences between the positions of play may be obtained through an analysis of the movement patterns of all players during one game, rather than during different games, as was conducted in this investigation. In addition, changes in the movement patterns of players during the latter stages of NBL competition games may indicate the effects of fatigue on the physical performances of players.

2. In order to obtain a clearer understanding of the intensity of activity during basketball the HR responses of players need to be monitored during games more indicative of the intensity at which actual NBL competition games are likely to be played. Such games may include those played during the pre-season competition in addition to other pre-season practice games.

3. It is also recommended that further examinations be undertaken to investigate the sources of energy during basketball. This may involve obtaining arterialised blood samples during more important games including NBL games. Obtaining venous blood samples during competition may also provide valuable information relating to exercise metabolism during basketball. Venous blood samples could be used to describe the blood glucose, blood lactate and blood pH responses to basketball, providing information of the sources of energy and the interactions of the energy pathways during competition.

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APPENDIX A.1 Total Time on court and Live Time played.

SUBJECT #	QUARTER	TOTAL TIME ON COURT (MIN:SEC)	LIVE TIME PLAYED (MIN:SEC)
GUARDS			
1	1	19:54	7:28
	2	20:42	9:25
	3	12:42	8:51
	4	22:27	12:00
2	1	10:32	5:00
	2	22:11	12:00
	3	8:45	6:35
	4	23:00	12:00
3 GAME 1	1	17:15	12:00
	2	11:55	7:34
	3	17:02	12:00
	4	22:26	12:00
3 GAME 2	1	11:47	7:21
	2	6:16	5:15
MEAN (+ S.D.)		16:13 (5:46)	9:15 (2:46)

SUBJECT #	QUARTER	TOTAL TIME ON COURT (MIN:SEC)	LIVE TIME PLAYED (MIN:SEC)
FORWARDS			
4	1	18:40	12:00
	2	17:33	12:00
	3	21:52	12:00
	4	19:45	12:00
5	1	19:04	12:00
	2	11:59	6:59
	3	12:43	7:30
	4	13:44	8:23
6 GAME 1	1	16:07	9:53
	2	16:53	9:02
	3	10:31	7:22
	4	11:33	7:47
6 GAME 2	1	9:17	5:25
	2	19:17	11:17
	3	22:47	12:00
	4	9:26	6:27
MEAN (+ S.D.)		15:42 (4:25)	9:38 (2:29)

Appendix A.1 cont.......

Appendix A.1 Cont.

CENTRES			
7	1	11:00	5:39
	2	5:34	3:08
	3	13:00	7:43
	4	23:00	12:00
8	1	15:04	9:15
	2	11:04	5:25
	3	15:37	9:11
	4	11:28	6:21
MEAN (± S.D.)		13:13 (5:01)	7:20 (2:48)

MEAN ALL SUBJECTS (± S.D.)		**15:22** **(5:04)**	**8:50** **(2:44)**

APPENDIX A.2 Average durations of the various activities

SUBJECT #	QRTR	AVERAGE DURATION OF ACTIVITY (SECS) STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH
GUARDS									
1	1	1.76	2.40	1.73	1.04	1.68	1.60	2.01	3.64
	2	1.66	2.51	1.83	-	1.77	1.79	1.73	3.42
	3	1.82	2.47	1.73	0.76	1.47	1.51	2.23	2.10
	4	2.27	2.59	1.66	1.84	1.74	1.74	1.89	2.54
2	1	1.77	2.20	2.02	2.52	1.73	2.28	2.45	1.72
	2	1.94	2.20	1.78	-	1.77	2.19	1.73	2.11
	3	3.44	2.63	1.84	2.44	1.96	1.78	1.66	1.93
	4	1.85	2.24	1.93	0.88	1.56	1.78	1.90	1.71
3 GAME 1	1	2.72	1.59	1.96	-	1.44	1.83	1.54	1.78
	2	1.92	1.37	1.72	1.27	1.61	1.52	1.66	1.78
	3	2.77	2.41	2.13	2.52	1.41	3.13	2.82	2.81
	4	2.26	1.79	1.91	1.97	1.42	2.12	2.38	1.80
3 GAME 2	1	1.77	3.07	2.64	-	1.71	1.74	1.51	2.44
	2	3.05	2.41	2.27	-	2.01	1.29	1.70	1.28
MEAN (+ S.D.)		2.21 (0.56)	2.28 (0.44)	1.94 (0.26)	1.69 (0.72)	1.66 (0.19)	1.88 (0.45)	1.94 (0.39)	2.22 (0.68)
FORWARDS									
4	1	2.86	2.28	2.37	-	2.18	1.86	1.79	1.50
	2	3.04	2.83	2.39	-	1.81	1.69	1.69	1.68
	3	2.77	2.48	2.58	-	1.43	1.56	2.05	1.83
	4	2.45	2.36	2.21	-	1.60	1.81	2.02	1.90
5	1	2.75	2.23	2.91	2.25	1.70	1.81	1.73	1.83
	2	2.32	3.00	2.85	1.08	1.91	1.96	2.06	1.67
	3	2.44	3.64	1.95	1.10	1.54	1.74	1.62	2.89
	4	2.64	2.59	3.32	1.24	1.95	1.49	1.54	1.69
6 GAME 1	1	2.26	2.77	2.13	1.08	1.66	1.62	1.67	1.08
	2	2.11	2.22	2.56	-	1.41	1.53	1.48	1.55
	3	3.18	3.38	2.65	1.83	1.95	1.71	1.59	1.84
	4	3.28	3.00	2.52	-	1.87	1.30	2.23	1.54
6 GAME 2	1	2.15	2.40	2.34	0.80	1.71	2.12	2.28	2.17
	2	2.97	2.37	2.22	-	2.50	1.46	1.58	2.06
	3	3.31	2.95	2.14	2.34	2.14	1.66	1.77	1.92
	4	2.92	2.32	2.06	-	2.04	1.43	2.08	2.08
MEAN (+ S.D.)		2.72 (0.39)	2.68 (0.43)	2.45 (0.36)	1.47 (0.59)	1.79 (0.30)	1.67 (0.21)	1.82 (0.26)	1.83 (0.39)

Appendix A.2 cont.........

Appendix A.2 cont

CENTRES									
7	1	2.03	1.91	2.76	2.62	2.00	1.81	2.09	-
	2	1.86	2.55	2.56	-	2.51	2.37	2.26	1.88
	3	2.13	3.01	2.97	1.49	1.61	1.59	1.65	2.37
	4	2.39	2.36	3.34	1.77	1.44	1.90	1.94	3.04
8	1	3.75	2.62	2.31	-	1.69	1.50	1.36	1.85
	2	2.91	3.22	1.51	-	1.24	1.98	1.76	1.78
	3	3.58	2.75	2.48	1.04	1.03	1.65	1.58	1.37
	4	3.35	3.01	2.44	-	1.25	1.68	1.61	1.21
MEAN (± S.D.)		2.75 (0.75)	2.68 (0.42)	2.55 (0.53)	1.73 (0.67)	1.60 (0.48)	1.81 (0.28)	1.78 (0.30)	1.93 (0.62)

MEAN ALL SUBJECTS (± S.D.)		**2.54** **(0.59)**	**2.53** **(0.46)**	**2.28** **(0.45)**	**1.61** **(0.64)**	**1.70** **(0.31)**	**1.78** **(0.34)**	**1.86** **(0.32)**	**1.99** **(0.57)**

APPENDIX A.3 Frequency of activity for each quarter.

SUBJECT #	QRTR	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
GUARDS										
1	1	39	16	29	1	34	42	39	20	8
	2	68	24	36	0	31	49	46	25	4
	3	67	20	21	1	35	45	46	31	7
	4	93	26	34	1	49	51	67	43	5
2	1	37	11	7	1	26	10	35	24	11
	2	92	23	29	0	56	88	39	18	14
	3	40	8	14	1	24	40	21	19	9
	4	96	30	30	1	65	77	39	30	16
3 GAME 1	1	94	34	40	0	59	44	44	16	20
	2	69	17	33	3	39	39	26	21	5
	3	87	18	32	2	38	37	35	14	13
	4	109	28	55	3	38	38	38	27	13
3 GAME 2	1	50	23	19	0	29	38	27	22	19
	2	37	17	16	0	16	25	19	11	9
MEAN (+ S.D.)		69.85 (25.61)	21.07 (7.22)	28.21 (12.19)	1.00 (1.04)	38.50 (14.12)	44.50 (19.17)	37.21 (12.19)	22.93 (8.15)	10.93 (5.12)

SUBJECT #	QRTR	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
FORWARDS										
4	1	96	50	36	0	23	47	28	4	14
	2	93	53	32	0	23	33	22	10	15
	3	108	40	34	0	20	53	36	19	13
	4	95	35	17	0	22	51	30	20	12
5	1	105	44	31	2	29	49	20	10	23
	2	65	11	21	1	19	31	20	17	9
	3	66	20	14	2	16	26	22	20	7
	4	74	34	17	1	12	34	14	15	21
6 GAME 1	1	84	36	32	1	26	62	25	7	20
	2	82	34	31	0	17	56	30	10	15
	3	54	18	21	3	13	39	16	4	5
	4	57	24	12	0	20	42	23	4	8
6 GAME 2	1	44	16	15	1	8	28	23	7	5
	2	93	31	29	0	13	64	40	13	12
	3	100	37	25	3	14	66	30	19	5
	4	56	23	13	0	10	37	18	2	5
MEAN (+ S.D.)		79.50 (20.29)	31.63 (12.14)	23.75 (8.39)	0.88 (1.09)	17.81 (5.95)	44.88 (13.04)	24.81 (7.10)	11.31 (6.36)	11.81 (5.97)

Apendix A.3 cont.............

Appendix A.3 cont.

CENTRES										
7	1	58	18	28	2	9	17	16	0	15
	2	24	5	16	0	10	15	9	1	5
	3	70	14	30	6	11	46	13	4	12
	4	107	34	50	11	13	49	29	7	21
8	1	68	23	31	0	22	33	17	16	5
	2	45	9	14	0	18	24	17	17	8
	3	70	25	25	1	19	39	23	15	12
	4	52	14	19	0	17	37	19	11	10
MEAN (+ S.D.)		61.75 (24.02)	17.75 (9.35)	26.63 (11.41)	2.50 (4.00)	14.88 (4.76)	32.50 (12.74)	17.88 (6.08)	8.88 (6.83)	11.00 (5.35)

MEAN ALL SUBJECTS (+ S.D.)		**72.21 (23.56)**	**24.82 (11.43)**	**26.00 (10.46)**	**1.26 (2.08)**	**24.82 (14.22)**	**42.13 (15.95)**	**27.92 (11.76)**	**15.08 (9.29)**	**11.32 (5.41)**

APPENDIX A.4 Percent of Total Time spent in each category of movement.

SUBJECT #	QRTR	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
GUARDS										
1	1	35.89	6.65	8.66	0.18	9.88	11.61	13.64	12.58	0.99
	2	59.35	5.60	6.13	00	5.11	8.17	7.39	7.95	0.29
	3	48.18	6.74	4.97	0.10	7.04	9.26	14.03	8.90	0.77
	4	59.70	5.04	4.23	0.14	6.37	6.62	9.47	8.17	0.26
2	1	61.66	3.74	2.19	0.39	6.91	12.39	9.11	2.94	0.71
	2	60.09	3.92	4.01	00	7.70	14.94	5.23	2.95	1.15
	3	51.98	4.11	5.03	0.48	9.15	13.92	6.81	7.16	1.36
	4	62.37	5.00	4.33	0.07	7.65	10.26	5.53	3.84	0.97
3 GAME 1	1	58.07	5.59	8.00	00	8.63	8.20	6.89	2.90	1.68
	2	56.05	3.52	8.73	0.57	9.46	8.95	6.51	5.66	0.53
	3	57.04	4.27	6.73	0.50	5.25	11.40	9.74	3.88	1.17
	4	66.97	3.69	7.74	.44	3.97	5.92	6.65	3.58	1.06
3 GAME 2	1	50.69	10.11	7.18	00	6.61	9.48	5.84	7.70	2.39
	2	47.39	11.20	9.91	00	7.92	8.80	8.82	3.85	2.12
MEAN (+ S.D.)		55.39 (7.94)	5.66 (2.37)	6.27 (2.22)	0.21 (0.22)	7.26 (1.73)	9.99 (2.60)	8.26 (2.77)	5.86 (2.94)	1.10 (0.63)

SUBJECT #	QRTR	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
FORWARDS										
4	1	63.02	10.43	7.79	00	4.57	7.92	4.58	0.55	1.09
	2	60.64	14.50	7.40	00	4.02	5.39	3.59	3.26	1.20
	3	67.53	7.71	6.81	00	2.23	6.41	5.73	2.70	0.87
	4	65.40	8.01	3.64	00	3.42	8.93	5.87	3.69	1.05
5	1	64.02	8.73	8.04	0.41	4.38	7.89	3.07	1.63	1.81
	2	62.11	4.64	8.92	0.15	5.11	8.55	5.80	4.00	1.22
	3	64.03	9.66	3.62	0.29	3.27	6.00	4.73	7.68	0.70
	4	64.48	10.96	7.04	0.15	2..92	6.31	2.69	3.15	2.28
6 GAME 1	1	59.39	10.68	7.32	0.12	4.63	10.79	4.48	0.81	1.77
	2	65.48	7.72	8.12	00	2.46	8.79	4.55	1.59	1.28
	3	58.94	9.94	9.12	0.90	4.14	10.90	4.16	1.2	0.71
	4	61.41	10.71	4.49	00	5.58	8.12	7.64	0.92	1.14
6 GAME 2	2	68.04	6.43	5.64	00	2.86	8.17	5.53	2.35	0.98
	3	69.80	8.19	4.01	0.53	2.24	8.23	3.97	2.73	0.29
	4	64.12	9.58	4.80	00	3.66	9.49	6.72	0.75	0.88
MEAN (+ S.D.)		63.65 (3.16)	9.06 (2.28)	6.45 (1.85)	0.17 (0.25)	3.62 (1.05)	8.30 (1.70)	5.17 (1.76)	2.49 (1.77)	1.12 (0.49)

Appendix A.4 cont...............

Appendix A.4 cont.

CENTRES										
7	1	67.79	5.20	11.69	0.79	2.72	4.65	5.07	00	2.10
	2	56.92	3.88	12.45	00	7.63	10.83	6.20	0.57	1.52
	3	63.91	5.60	11.77	1.18	2.34	9.65	2.84	1.25	1.49
	4	65.50	5.90	12.26	1.40	1.37	6.88	4.14	1.56	1.46
8	1	67.90	7.34	8.50	00	4.06	5.75	2.67	3.30	0.47
	2	71.84	4.15	3.28	00	3.49	7.39	4.59	4.43	0.83
	3	67.14	9.06	7.05	0.11	2.17	6.99	4.01	2.36	1.10
	4	66.82	6.14	7.17	00	3.16	9.05	4.54	1.97	1.14
MEAN (+ S.D.)		65.98 (4.31)	5.91 (1.68)	9.27 (3.32)	0.44 (0.59)	3.36 (1.91)	7.65 (2.06)	4.26 (1.15)	1.93 (1.44)	1.26 (0.49)

MEAN ALL SUBJECTS (+ S.D.)		**61.10 (7.07)**	**7.14 (2.71)**	**6.98 (2.58)**	**0.24 (0.35)**	**4.91 (2.35)**	**8.79 (2.30)**	**6.12 (2.66)**	**3.61 (2.79)**	**1.15 (0.54)**

APPENDIX A.5 Percent of Live Time spent in each category of movement.

SUBJECT #	QRTR	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
GUARDS										
1	1	14.35	8.97	11.68	0.24	13.33	15.08	18.04	16.97	1.34
	2	21.09	9.50	12.29	00	9.95	16.38	14.37	15.94	0.58
	3	25.24	9.77	7.04	0.18	10.70	13.35	19.26	13.32	1.17
	4	29.57	7.11	7.47	0.26	11.09	11.94	17.12	14.97	0.49
2	1	20.95	7.71	4.51	0.80	15.24	25.48	18.79	6.05	1.47
	2	25.74	7.30	7.47	00	14.32	27.80	9.74	5.49	2.15
	3	35.87	5.49	6.71	0.64	12.21	18.59	9.10	9.57	1.82
	4	26.38	8.65	8.62	0.13	15.21	20.42	11.00	7.65	1.93
3 GAME 1	1	38.70	8.12	11.78	00	12.39	12.09	10.16	4.28	2.48
	2	31.71	5.25	13.53	0.91	14.47	13.94	10.35	8.99	0.84
	3	35.59	6.40	10.09	0.74	7.91	17.10	14.60	5.81	1.75
	4	35.44	7.21	15.12	0.85	7.74	11.56	13.00	7.00	2.07
3 GAME 2	1	20.44	16.32	11.58	00	10.66	15.30	9.42	12.42	3.85
	2	36.96	13.41	11.87	00	9.48	10.54	10.57	4.61	2.54
MEAN (+ S.D.)		28.43 (7.54)	8.66 (3.01)	9.98 (3.04)	0.34 (0.36)	11.76 (2.53)	16.40 (5.18)	13.25 (3.74)	9.51 (4.41)	1.75 (0.89)

SUBJECT #	QRTR	STAND/ WALK	JOG	RUN	RUN B	STRIDE/ SPRINT	SHUFFLE LOW	SHUFFLE MEDIUM	SHUFFLE HIGH	JUMP
FORWARDS										
4	1	40.40	16.81	12.56	00	7.37	12.85	7.37	0.88	1.75
	2	40.99	21.74	11.09	00	6.04	8.08	5.38	4.88	1.81
	3	41.72	13.85	12.22	00	4.00	11.51	10.29	4.85	1.56
	4	39.47	14.01	6.37	00	5.98	15.63	10.27	6.45	1.83
5	1	41.61	14.17	13.04	0.66	7.11	12.81	4.98	2.64	2.94
	2	34.33	8.04	14.59	0.26	8.85	14.82	10.05	6.94	2.12
	3	37.29	16.84	6.32	0.51	5.69	10.47	8.26	13.40	1.21
	4	40.71	18.30	11.76	0.26	4.88	10.53	4.49	5.26	3.81
6 GAME 1	1									
	2	33.95	14.77	15.54	00	4.71	16.83	8.71	3.03	2.45
	3	40.65	14.37	13.16	1.30	6.00	15.75	6.01	1.74	1.02
	4	41.92	16.12	6.76	00	8.39	12.22	11.50	1.38	1.71
6 GAME 2	1	30.21	12.25	11.21	0.26	4.36	18.91	16.75	4.83	1.22
	2	43.55	11.37	9.47	00	5.04	14.43	9.77	4.15	1.72
	3	45.09	14.89	7.29	0.96	4.09	14.97	7.23	4.96	0.52
	4	45.00	14.68	7.36	00	5.62	14.55	10.31	1.14	1.34
MEAN (+ S.D.)		39.32 (4.48)	15.00 (3.11)	10.69 (3.03)	0.28 (0.39)	5.99 (1.51)	13.90 (2.92)	8.68 (3.04)	4.24 (3.12)	1.87 (0.83)

Appendix A.5 cont..........

Appendix A.5 cont.

CENTRES										
7	1	35.20	10.45	23.50	1.60	5.47	9.36	10.19	00	4.23
	2	21.59	7.07	22.65	00	13.87	19.72	11.28	1.04	2.77
	3	35.31	9.98	21.09	2.11	4.20	17.30	5.09	2.25	2.66
	4	31.24	11.58	24.08	2.81	2.70	13.52	8.12	3.07	2.87
8	1	49.62	10.70	13.07	00	6.27	9.66	4.49	5.40	0.79
	2	43.14	7.41	6.94	00	7.09	15.61	9.28	8.78	1.75
	3	50.14	10.07	11.47	0.20	3.78	11.73	6.98	3.70	1.92
	4	45.77	9.49	10.24	00	5.57	15.40	8.02	3.49	2.02
MEAN (± S.D.)		39.00 (9.94)	9.59 (1.58)	16.63 (6.90)	0.84 (1.15)	6.12 (3.44)	14.03 (3.66)	7.93 (2.36)	3.47 (2.71)	2.38 (1.01)

MEAN ALL SUBJECTS (± S.D.)		**35.24 (8.64)**	**11.53 (4.09)**	**11.68 (4.77)**	**0.42 (0.64)**	**8.15 (3.64)**	**14.85 (4.10)**	**10.21 (3.92)**	**6.02 (4.42)**	**1.93 (0.90)**

APPENDIX B.1 Mean absolute and relative heart rates during Total and Live Time and maximum heart rates recorded during play.

SUBJECT #	QRTR	MEAN HR (Total Time)	MEAN HR (%HRpeak) (Total Time)	MEAN HR (Live Time)	MEAN HR (%HRpeak) (Live Time)	MAXIMUM GAME HR	MAXIMUM GAME HR (%HRpeak)
GUARDS							
1	1	175.17	89.83	176.96	90.75	190	97.44
	2	163.02	83.60	174.49	89.48	187	95.90
	3	176.01	90.26	176.87	90.70	188	96.41
	4	168.54	86.43	175.54	90.02	190	97.44
2	1	158.17	85.04	163.90	88.12	183	98.39
	2	171.85	88.13	168.40	90.54	184	98.92
	3	172.36	88.39	167.49	90.05	184	98.92
	4	159.40	85.70	162.56	87.74	182	97.85
3 GAME 1	1	165.60	89.03	166.32	89.42	179	96.24
	2	161.76	86.97	162.68	87.46	176	94.62
	3	165.00	88.71	167.51	90.06	184	98.92
	4	160.16	86.10	165.48	88.97	178	95.70
3 GAME 2	1	164.24	88.30	168.55	90.62	180	96.78
MEAN (+ S.D.)		166.25 (6.02)	87.42 (1.97)	168.98 (5.25)	89.53 (1.14)	183.46 (4.46)	97.19 (1.39)

FORWARDS							
4	1	164.16	83.33	170.23	86.41	190	96.45
	2	175.39	89.03	175.57	89.12	196	99.49
5	1	152.02	81.73	155.94	83.84	179	96.24
	2	151.66	81.54	154.12	82.86	178	95.70
	3	159.77	85.90	163.49	87.90	186	100.00
	4	156.61	84.20	159.46	85.73	179	96.24
6 GAME 1	2	182.07	91.49	184.47	92.70	196	98.49
	3	180.93	90.92	181.87	91.39	196	98.49
	4	182.82	91.87	185.07	93.00	194	97.49
6 GAME 2	2	181.85	91.38	183.10	92.01	199	100.00
	3	181.09	91.00	182.07	91.49	197	98.99
	4	180.81	90.86	185.03	92.98	199	100.00
MEAN (+ S.D.)		170.77 (12.83)	87.77 (4.12)	173.37 (12.13)	89.12 (3.68)	190.75 (8.15)	98.13 (1.64)

Appendix B.1 cont..........

Appendix B.1 cont.

CENTRES							
7	1	160.21	83.01	170.82	88.51	183	94.80
	2	159.24	82.51	156.23	80.95	186	96.37
	3	169.98	88.07	173.14	89.71	189	97.93
8	1	157.62	89.05	158.75	89.69	174	98.31
	3	155.05	87.60	158.33	89.45	177	100.00
	4	147.85	83.53	157.00	88.70	172	97.18
MEAN (+ S.D.)		158.33 (7.23)	85.63 (2.92)	162.38 (7.53)	87.84 (3.41)	180.17 (6.85)	97.43 (1.77)

MEAN ALL SUBJECTS (+ S.D.)		**166.46 (10.21)**	**87.21 (3.13)**	**169.40 (9.52)**	**89.04 (2.80)**	**185.65 (7.66)**	**97.60 (1.57)**

APPENDIX B.2 Percentage of Total Time (excluding when substituted out of the game) spent within the heart rate categories of intensity.

SUBJECT #	QRTR	CATEGORIES (% HRpeak) < 75	75-80	80-85	85-90	90-95	95-100
GUARDS							
1	1	2.44	7.32	4.88	26.83	48.78	9.76
	2	21.92	9.59	12.33	12.33	42.47	1.37
	3	3.85	1.92	9.62	21.15	55.77	7.69
	4	16.30	2.17	16.30	20.65	36.96	7.61
2	1	16.66	8.33	22.92	18.75	27.08	6.25
	2	7.69	10.99	14.29	16.48	30.77	19.78
	3	10.81	5.41	10.81	24.32	16.21	32.43
	4	11.83	9.68	20.43	22.58	29.03	6.45
3 GAME 1	1	1.47	5.88	13.24	29.41	41.18	8.82
	2	4.08	8.16	22.45	32.65	32.65	00
	3	1.45	5.80	15.95	23.19	42.03	11.59
	4	12.77	13.83	8.51	25.53	37.23	2.13
3 GAME 2	1	14.29	2.38	9.52	16.67	40.48	16.67
MEAN (+ S.D.)		9.66 (6.68)	7.04 (3.60)	13.94 (5.53)	22.35 (5.59)	36.97 (10.12)	10.04 (8.76)

FORWARDS							
4	1	18.67	5.33	20.00	28.00	25.33	2.67
.	2	1.43	8.57	12.86	30.00	31.43	15.71
5	1	25.97	11.69	18.18	22.08	20.78	1.30
	2	20.41	20.41	18.37	26.53	12.24	2.04
	3	15.38	5.77	17.31	21.15	25.00	15.38
	4	12.07	18.97	24.14	18.97	24.24	1.72
6 GAME 1	2	1.51	10.61	6.06	13.64	36.36	31.82
	3	2.33	00	6.98	23.26	55.81	11.63
	4	2.08	8.33	4.17	14.58	33.33	37.50
6 GAME 2	1	00	00	9.68	16.13	45.16	29.03
	2	00	3.95	18.42	17.11	23.68	36.84
	3	00	6.67	5.56	12.22	25.56	50.00
	4	2.63	10.53	10.53	7.89	36.84	31.58
MEAN (+ S.D.)		8.54 (9.38)	9.24 (5.86)	13.55 (6.72)	19.62 (6.79)	29.22 (10.87)	19.85 (17.00)

Appendix B.2 cont..........

Appendix B.2 cont.

CENTRES							
7	1	22.22	4.44	24.44	17.78	31.11	00
	2	14.29	7.14	14.29	17.86	42.86	3.57
	3	21.15	5.77	5.77	19.23	28.85	19.23
8	1	3.28	4.92	18.03	26.23	27.87	19.67
	3	10.94	12.5	7.81	20.31	32.81	15.63
	4	19.15	10.64	14.89	25.53	23.40	6.38
MEAN (± S.D.)		15.17 (7.23	7.57 (3.29)	14.21 (6.81)	21.16 (3.78)	31.15 (6.57)	10.75 (8.50)

MEAN ALL SUBJECTS (± S.D.)		**10.29 (8.06)**	**7.99 (4.54)**	**13.84 (6.05)**	**21.06 (5.78)**	**32.84 (10.23)**	**13.97 (13.09)**

APPENDIX B.3 Percentage of Live Time spent within the heart rate categories of intensity.

SUBJECT #	QRTR	CATEGORIES (%HRpeak) < 75	75-80	80-85	85-90	90-95	95-100
GUARDS							
1	1	2.94	00	8.82	23.53	52.94	11.76
	2	2.04	6.12	16.33	14.29	59.18	2.04
	3	4.55	00	6.82	20.45	59.09	9.09
	4	3.23	4.84	12.90	20.97	48.39	9.68
2	1	6.06	6.06	21.21	21.21	36.36	9.09
	2	1.59	9.52	11.11	15.87	34.92	26.98
	3	6.25	3.13	12.50	21.88	18.75	37.50
	4	4.69	7.81	20.31	23.44	34.38	9.38
3 GAME 1	1	1.67	5.00	10.00	31.67	41.67	10.00
	2	5.00	5.00	22.50	30.00	37.50	00
	3	1.72	1.72	15.52	24.14	43.10	13.79
	4	1.52	10.61	7.58	28.79	48.48	3.03
3 GAME 2	1	6.45	00	6.45	22.58	45.16	19.35
MEAN (± S.D.)		3.67 (1.91)	4.60 (3.53)	13.23 (5.54)	22.99 (5.01)	43.07 (11.13)	12.43 (10.35)

FORWARDS							
4	1	6.78	3.39	22.03	32.20	32.20	3.39
	2	1.64	6.56	14.75	31.15	29.51	16.39
5	1	18.03	11.48	21.31	24.59	22.95	1.64
	2	17.07	14.63	19.51	31.71	14.63	2.44
	3	9.76	2.44	17.07	21.95	29.27	19.51
	4	6.38	17.02	27.66	19.15	27.66	2.13
6 GAME 1	2	00	6.82	4.55	11.36	40.91	36.36
	3	2.63	00	5.26	18.42	60.53	13.16
	4	00	5.13	2.56	17.95	35.90	38.46
6 GAME 2	2	00	2.00	18.00	12.00	26.00	42.00
	3	00	2.94	4.41	10.29	26.47	55.88
	4	00	6.67	6.67	6.67	40.00	40.00
MEAN (± S.D.)		4.79 (6.52)	6.08 (5.36)	13.24 (8.31)	19.55 (8.47)	33.54 (12.07)	22.77 (18.27)

Appendix B.3 cont............

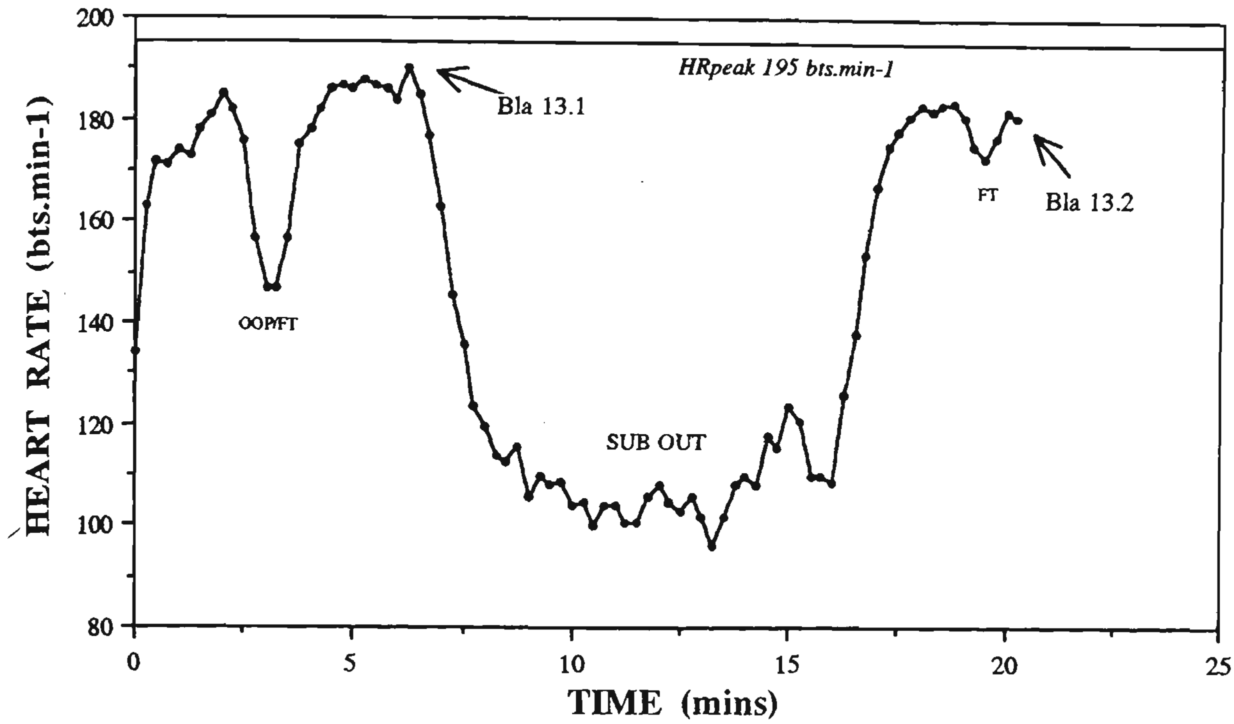
Appendix B.3 cont.

CENTRES							
7	1	10.34	6.90	20.69	24.14	37.93	00
	2	20.00	10.00	10.00	20.00	45.00	5.00
	3	7.69	5.13	5.13	20.51	35.90	25.64
8	1	4.00	4.00	12.00	28.00	30.00	22.00
	3	2.08	14.58	6.25	20.83	35.42	20.83
	4	3.13	3.13	15.63	34.38	34.38	9.38
MEAN (+ S.D.)		6.21 (3.61)	7.29 (4.32)	11.62 (5.87)	24.64 (5.65)	36.44 (4.96)	13.81 (10.43)

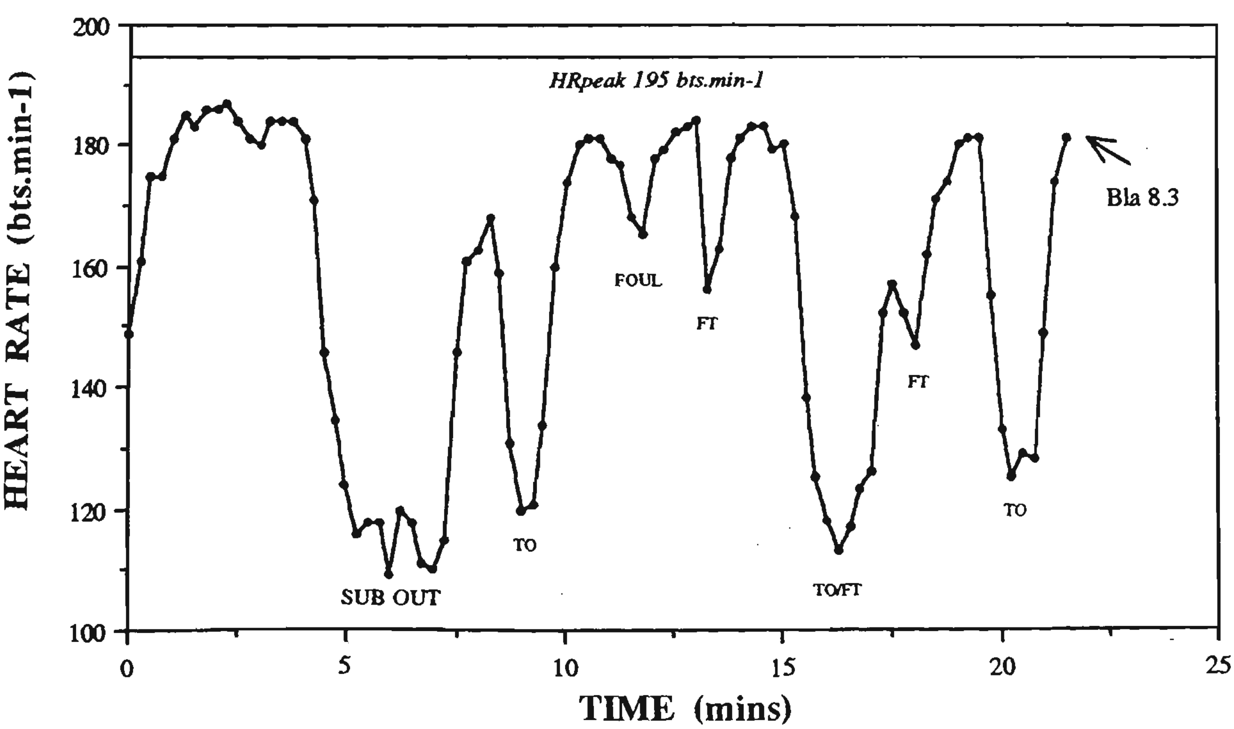
MEAN ALL SUBJECTS (+ S.D.)		**4.60 (4.56)**	**5.71 (4.47)**	**12.93 (6.67)**	**21.90 (6.85)**	**37.96 (11.31)**	**16.90 (14.59)**

APPENDIX C.1A. Heart Rate responses of subject #1.

1st quarter.

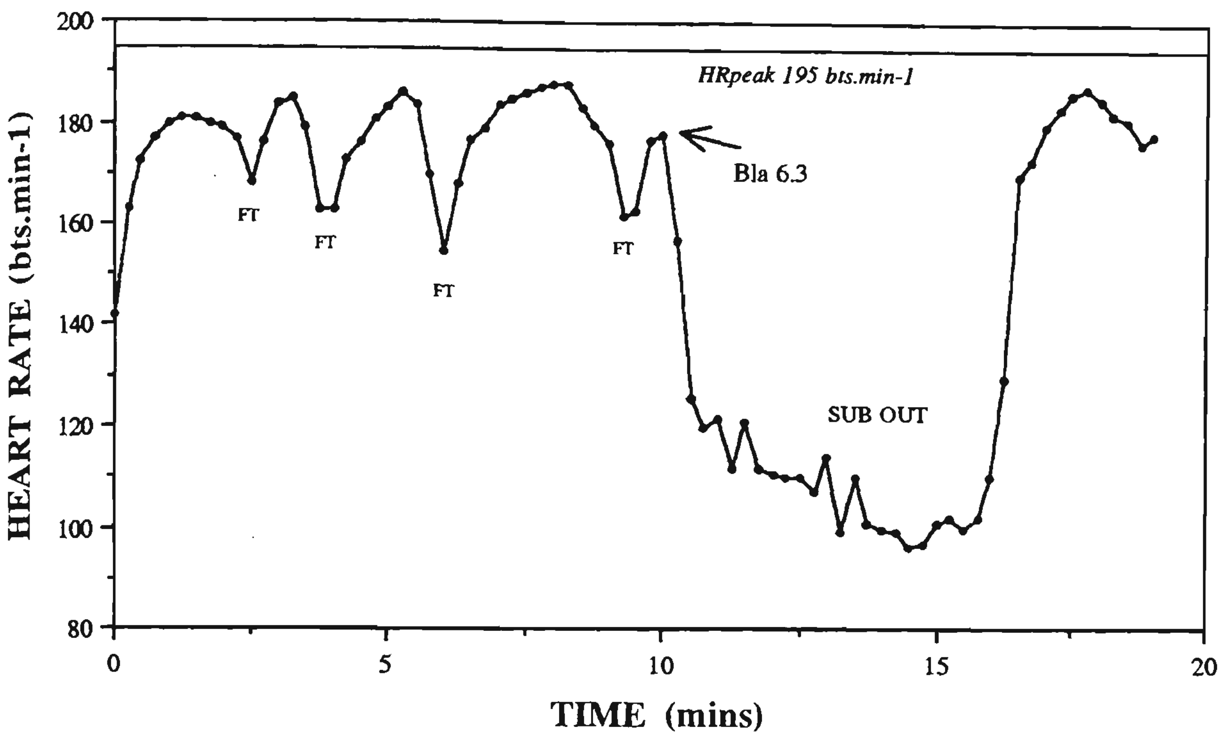


2nd quarter.

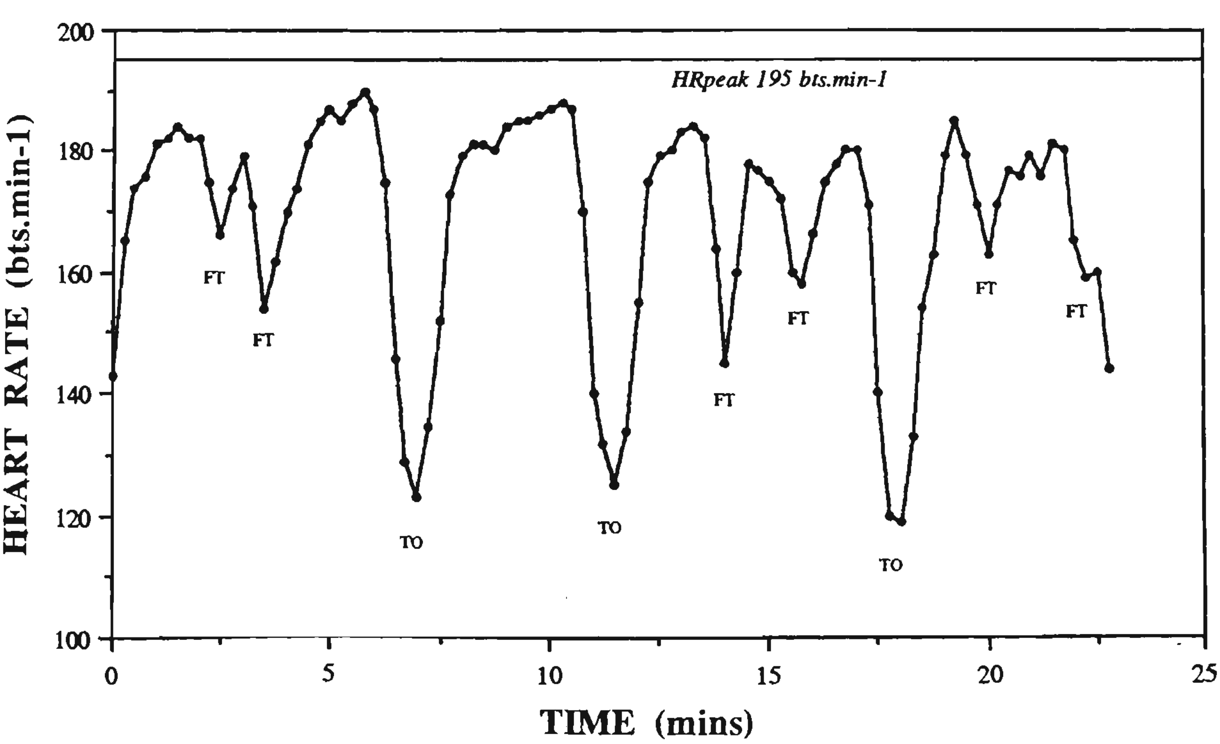


APPENDIX C.1A. cont.

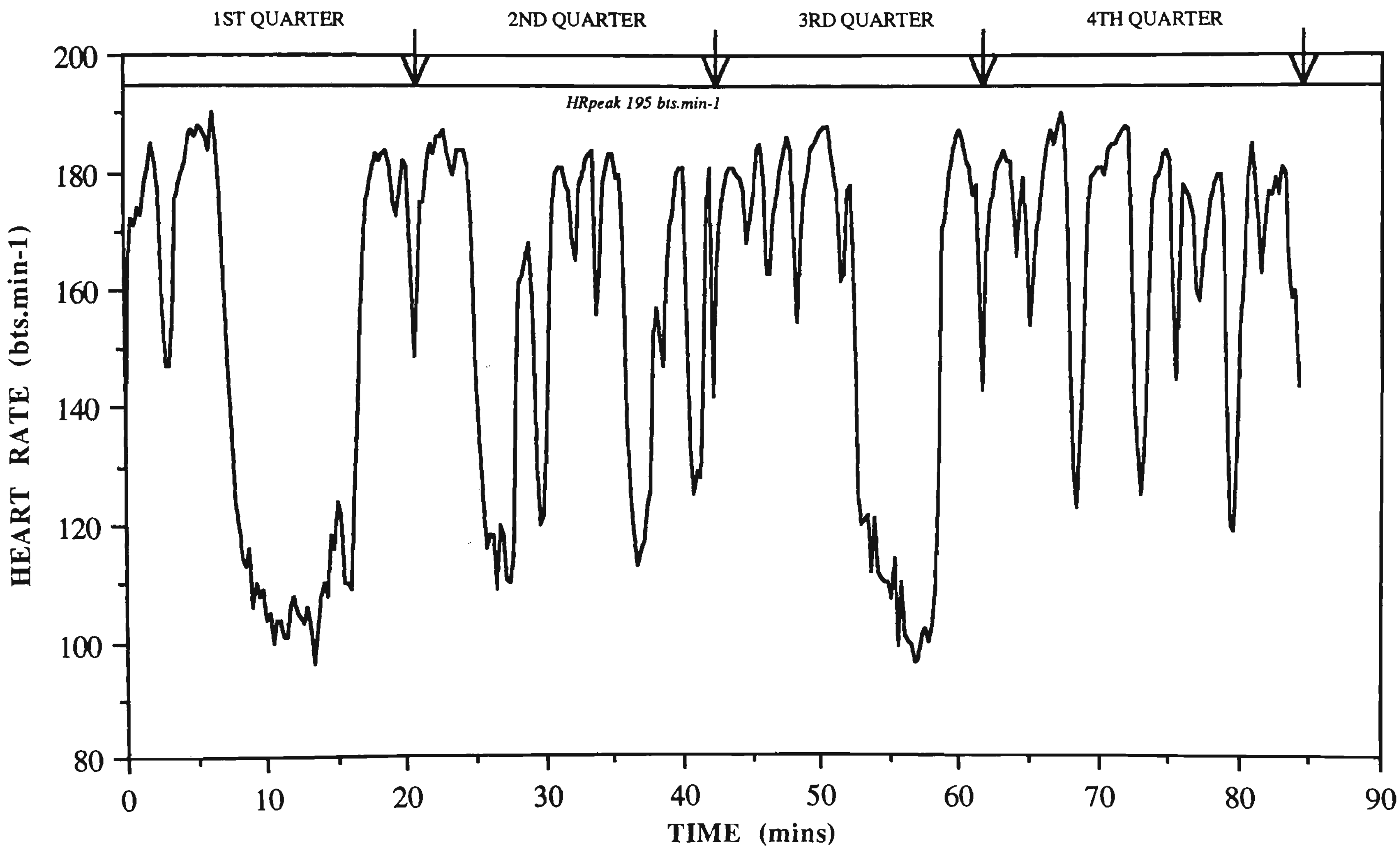
3rd quarter.



4th quarter.

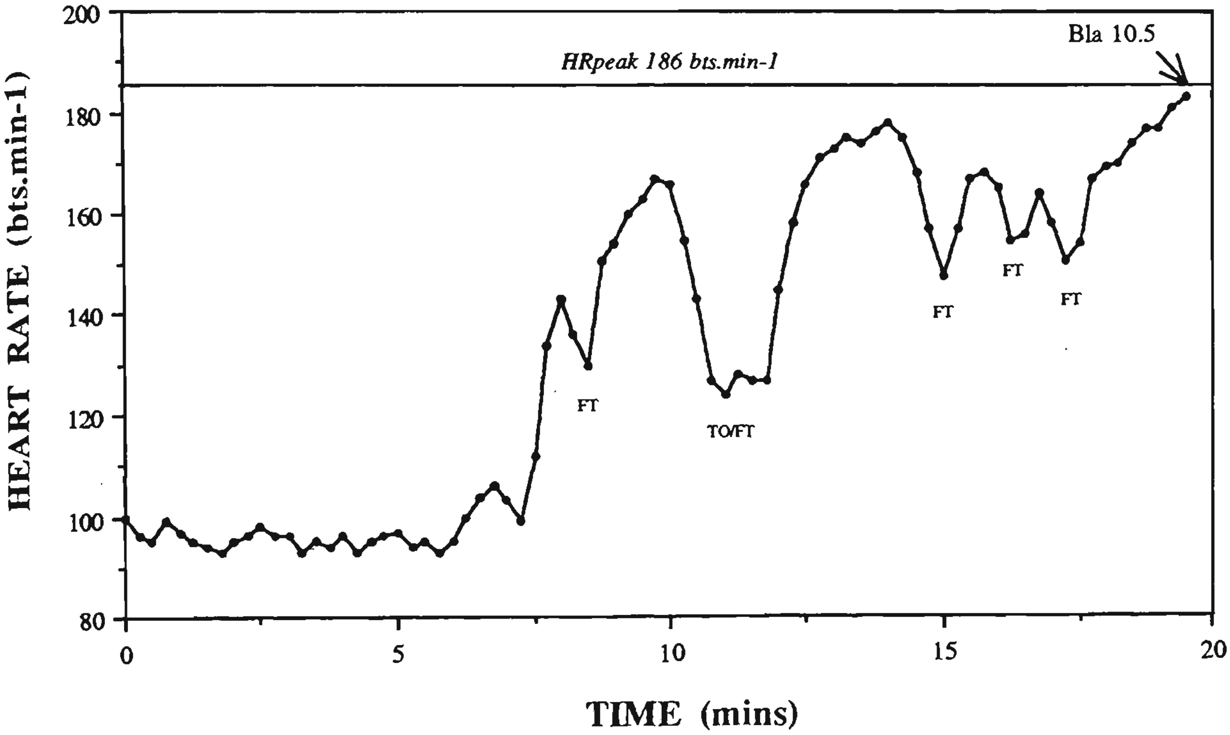


APPENDIX C.1B. Heart Rate responses of subject #1 to the entire game not including the breaks between quarters.

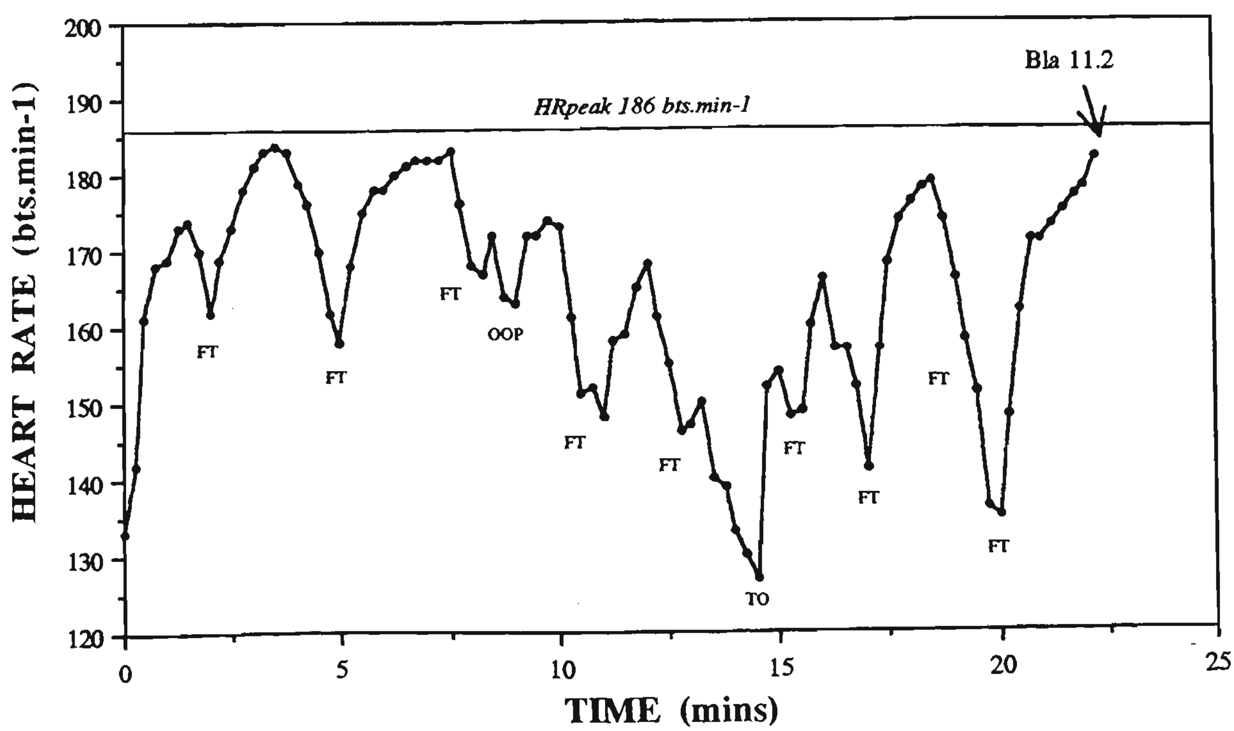


APPENDIX C.2A. Heart Rate responses of subject #2.

1st quarter.

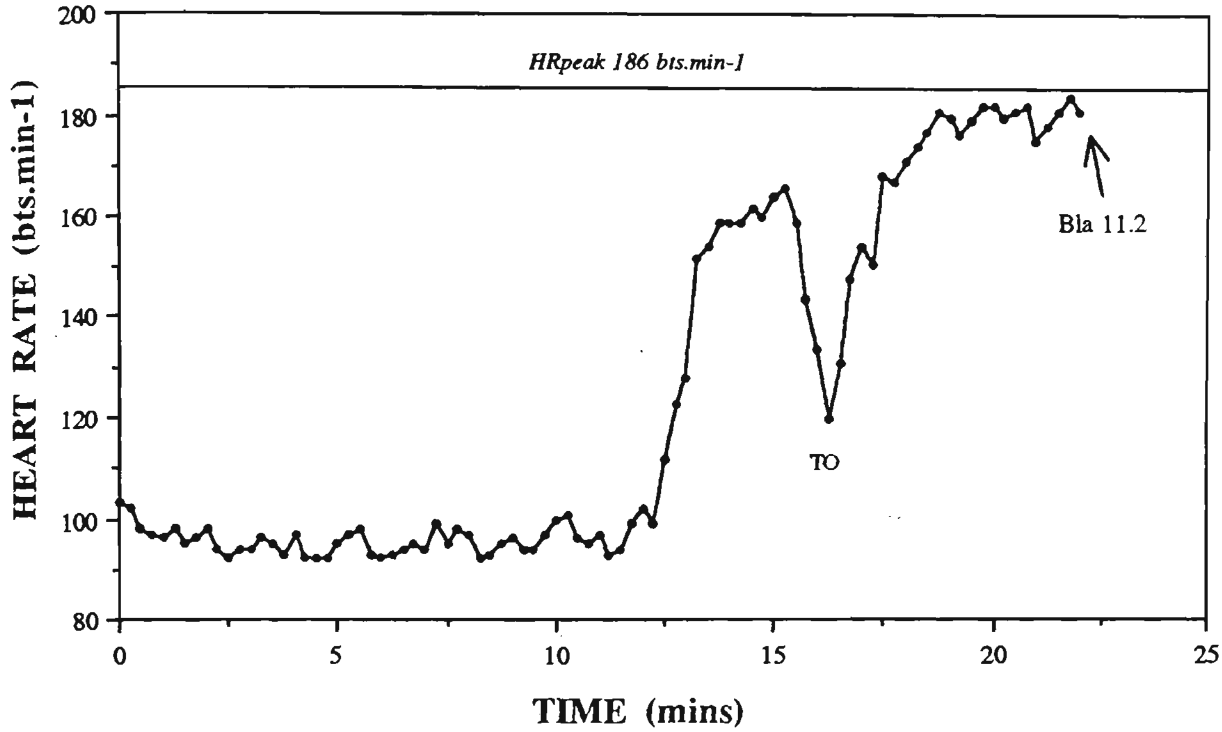


2nd quarter.

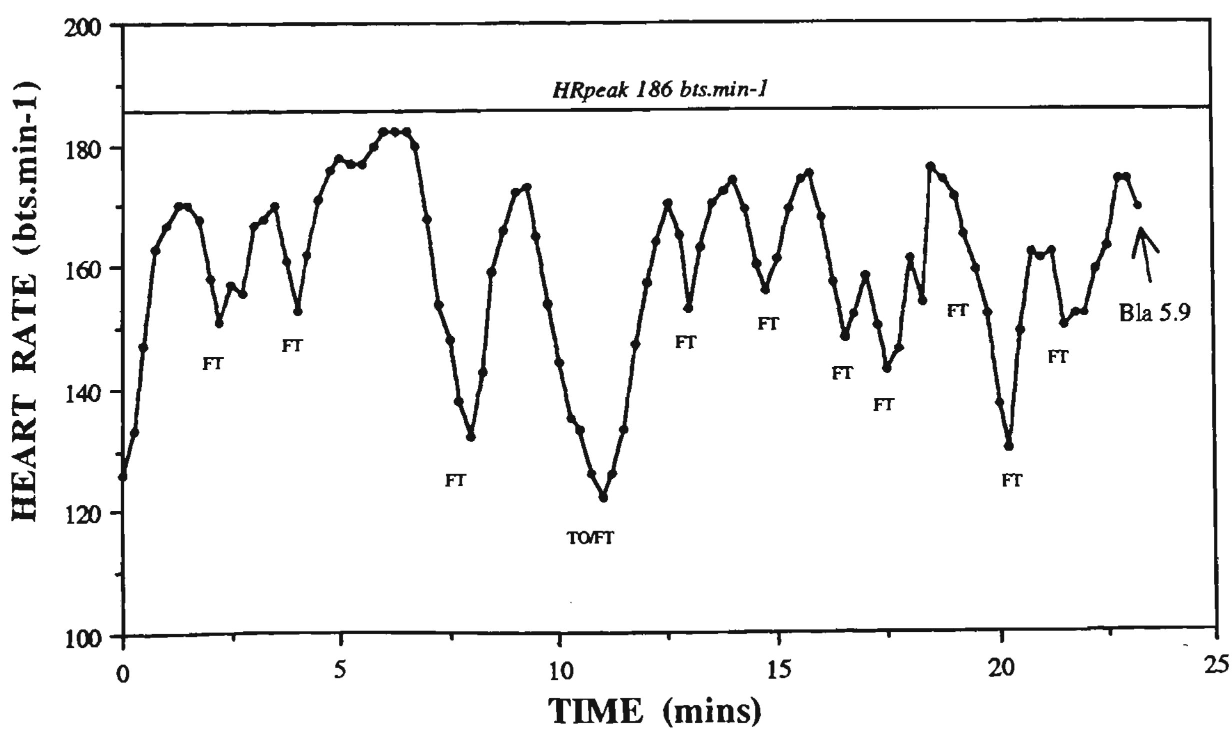


APPENDIX C.2A. cont.

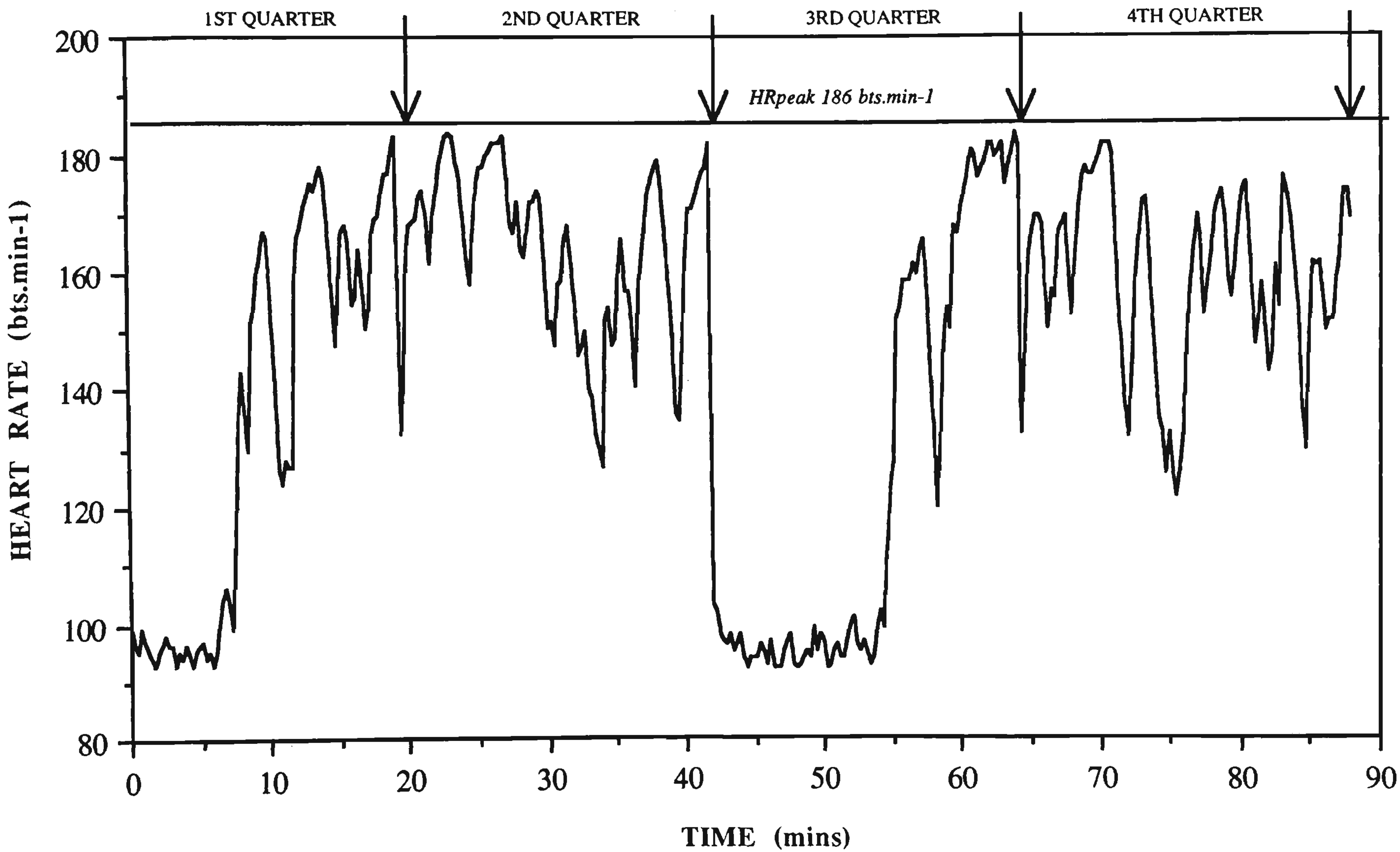
3rd quarter.



4th quarter.

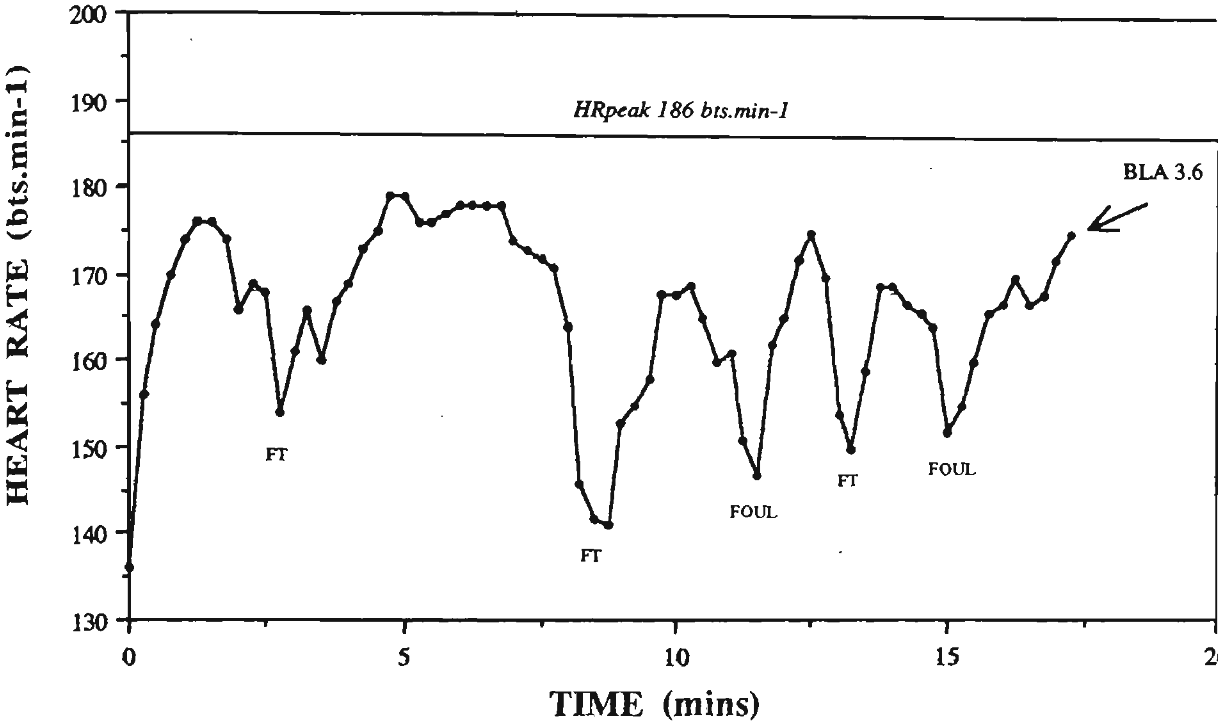


APPENDIX C.2B. Heart Rate responses of subject #2 to the entire game not including the breaks between quarters.

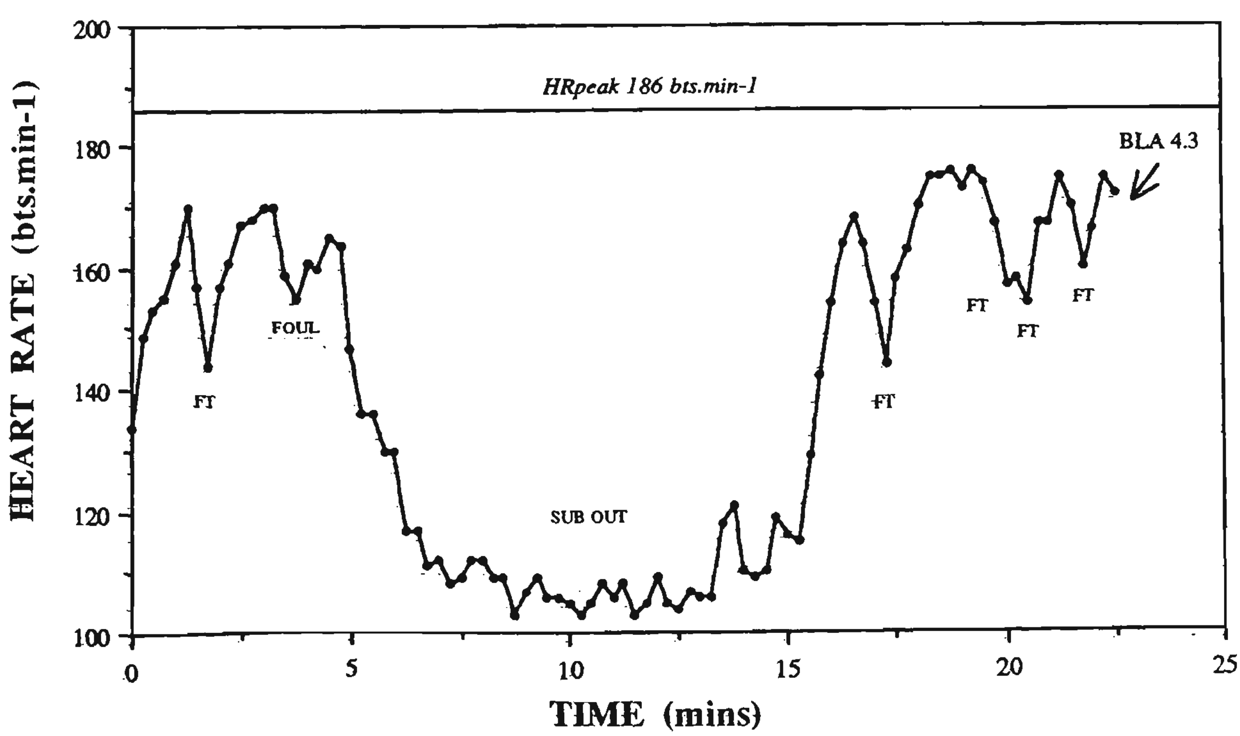


APPENDIX C.3A. Heart Rate responses of subject #3 to game #1.

1st quarter.

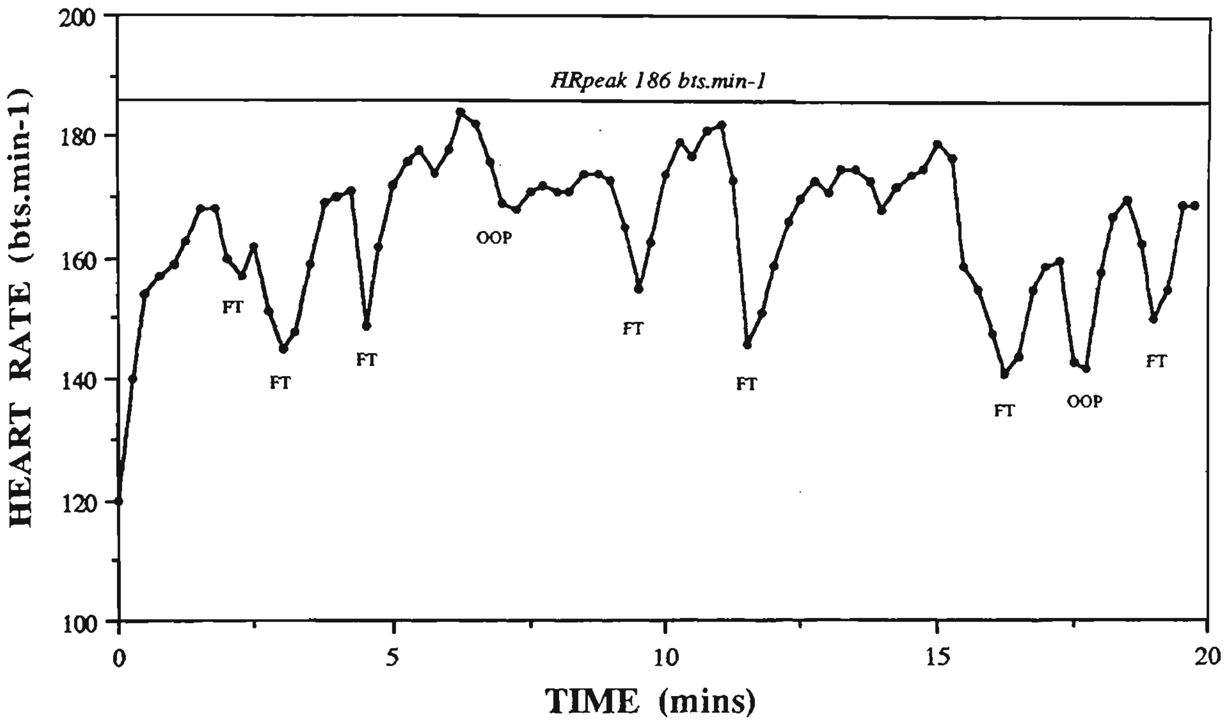


2nd quarter.

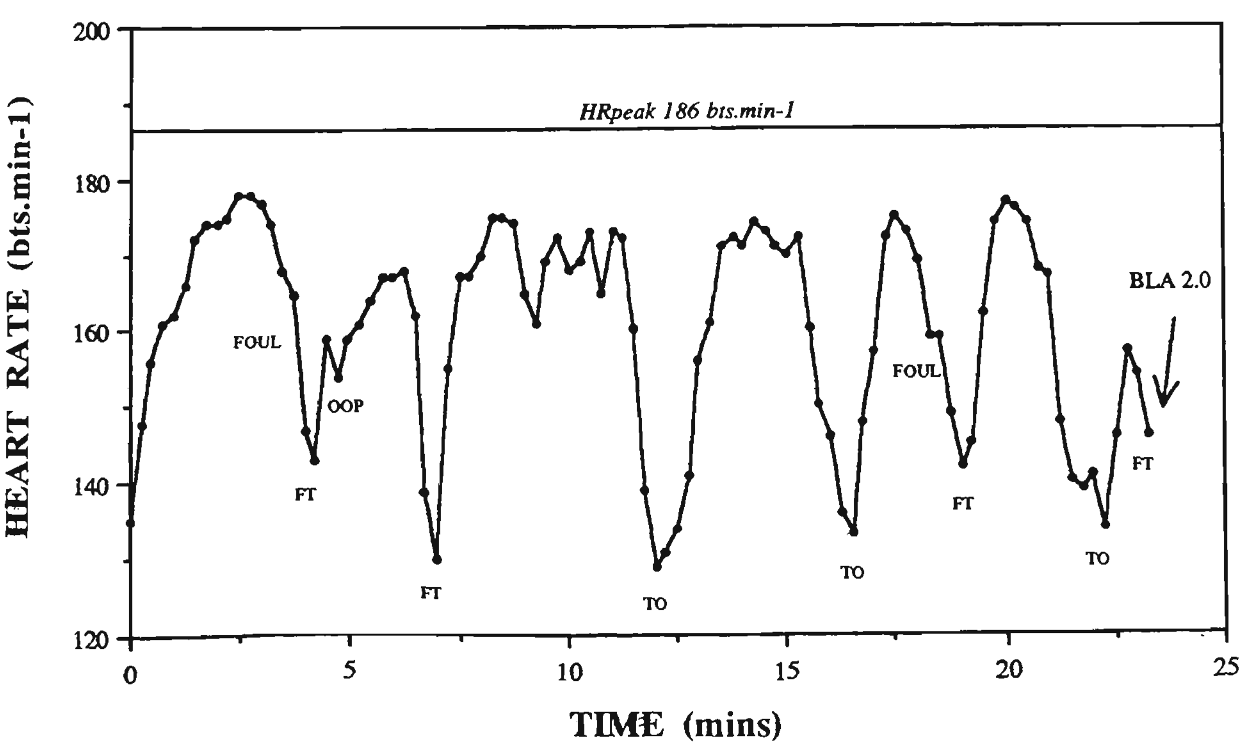


APPENDIX C.3A. cont.

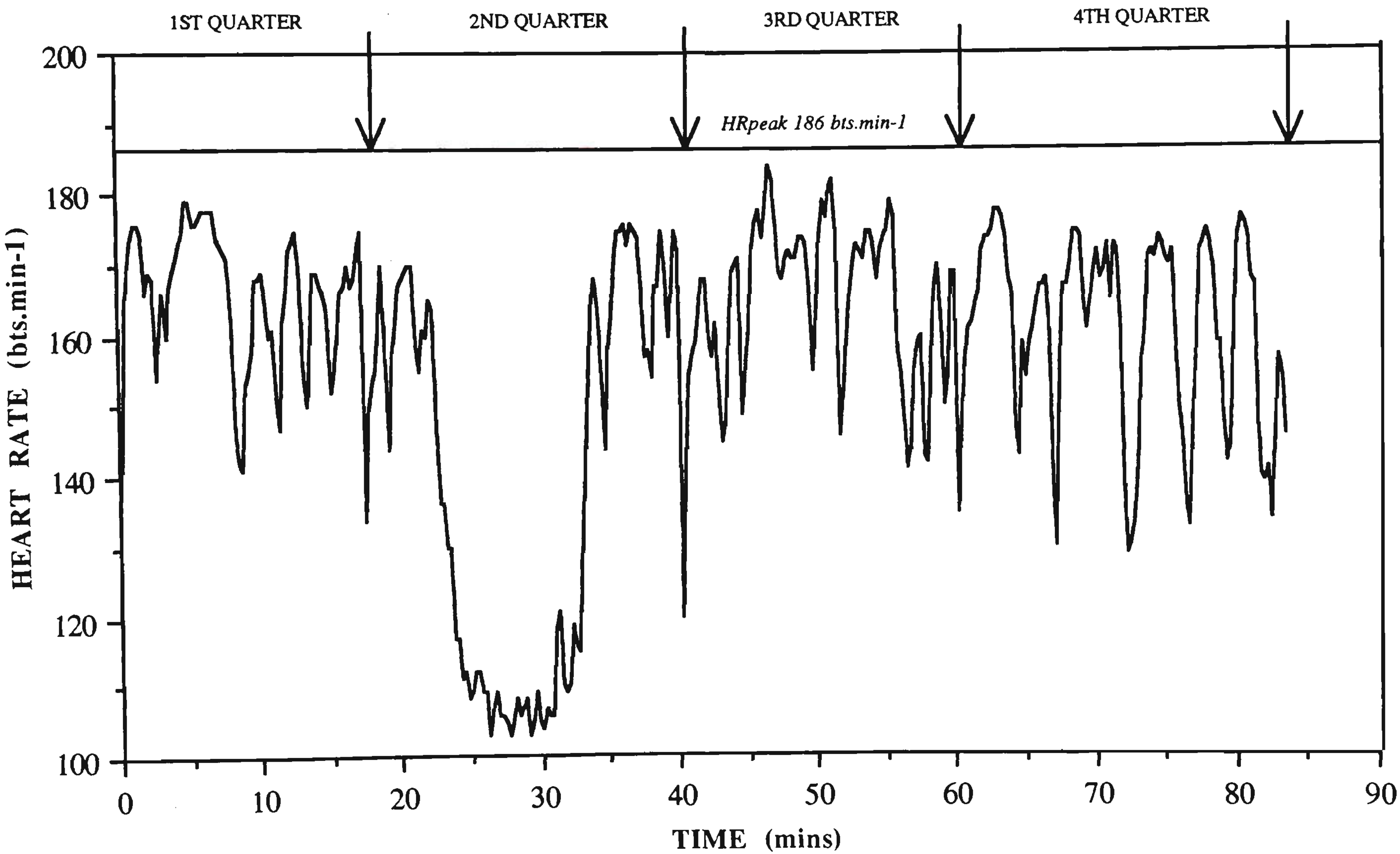
3rd quarter.



4th quarter.

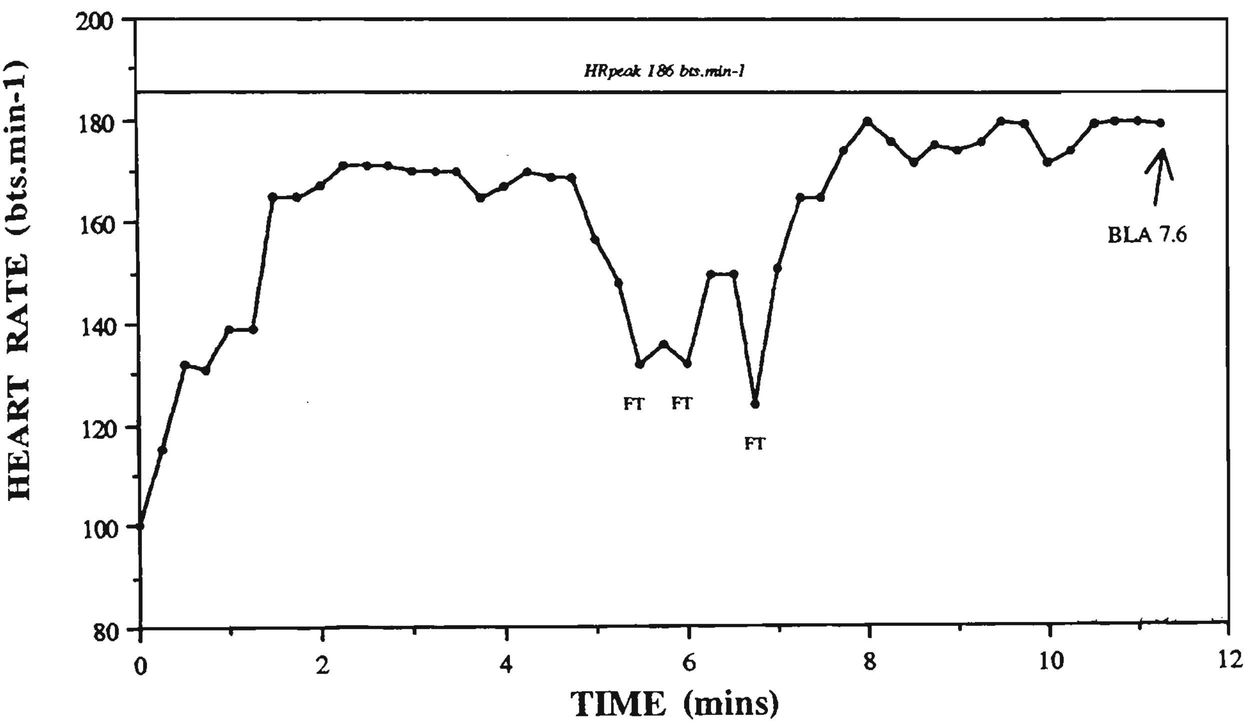


APPENDIX C.3B. Heart Rate responses of subject #3 to game #1 not including the breaks between quarters.



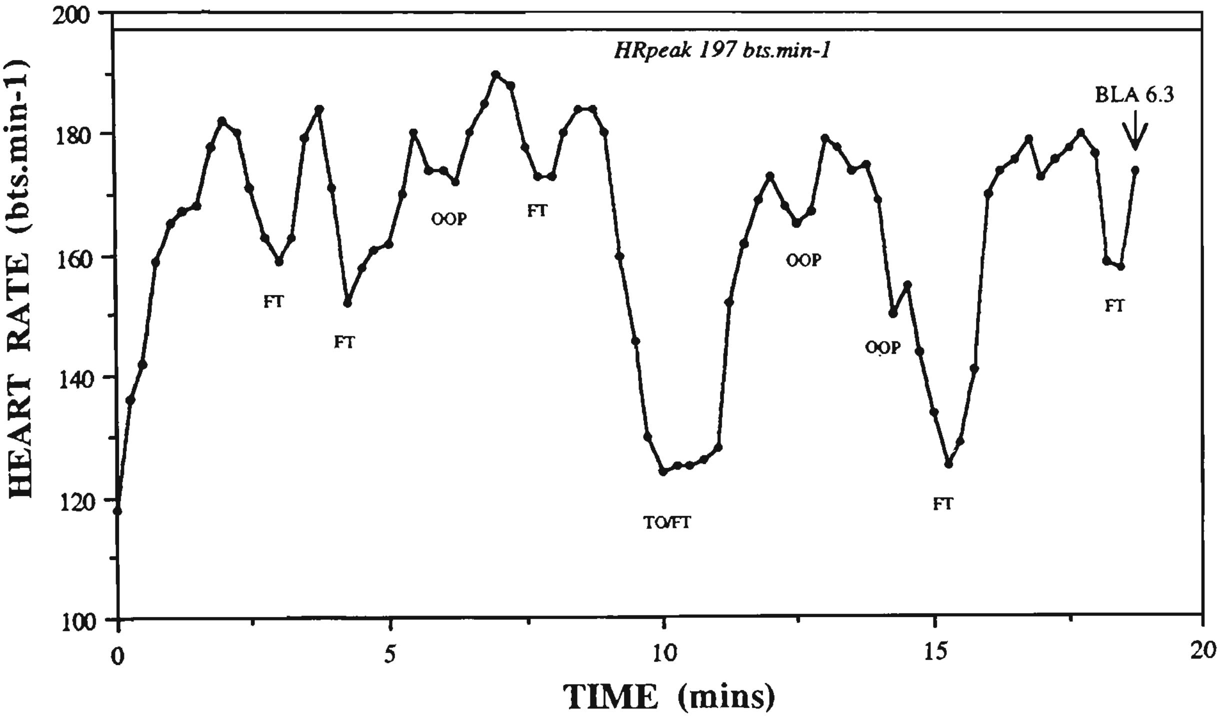
APPENDIX C.3C. Heart Rate responses of subject #3 to game #2.

1st quarter.

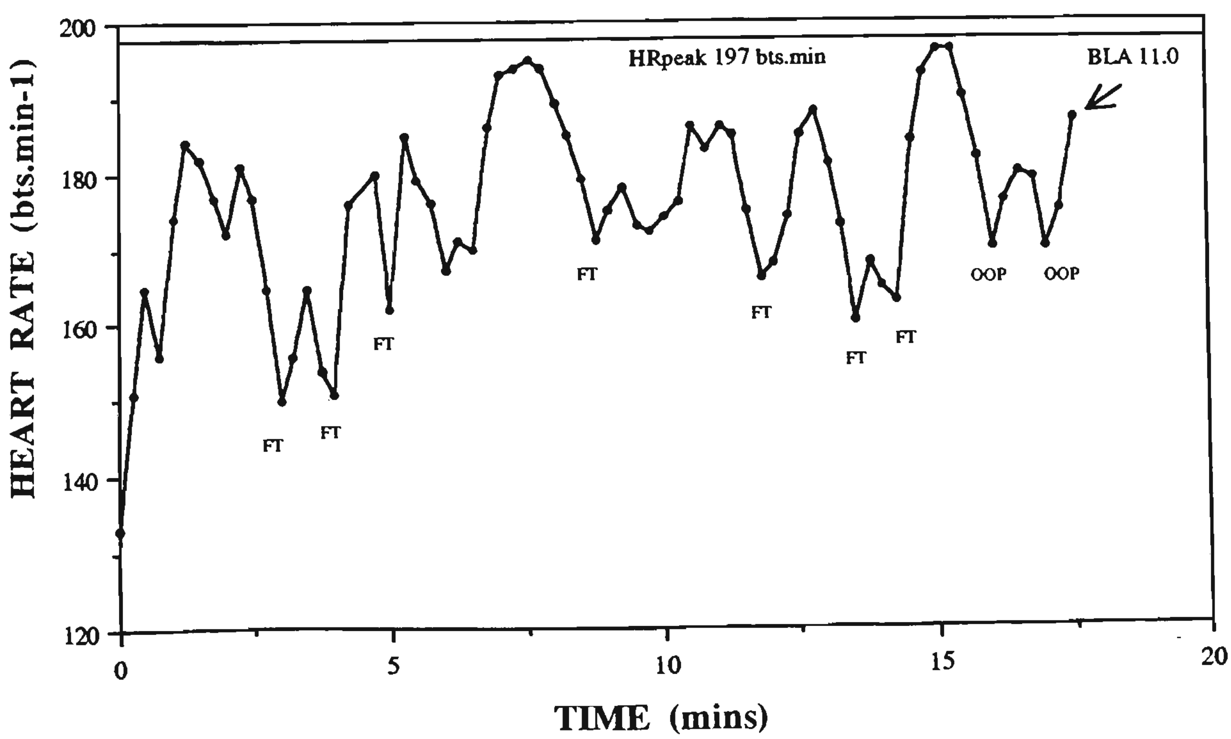


APPENDIX C.4A. Heart Rate responses of subject #4.

1st quarter.

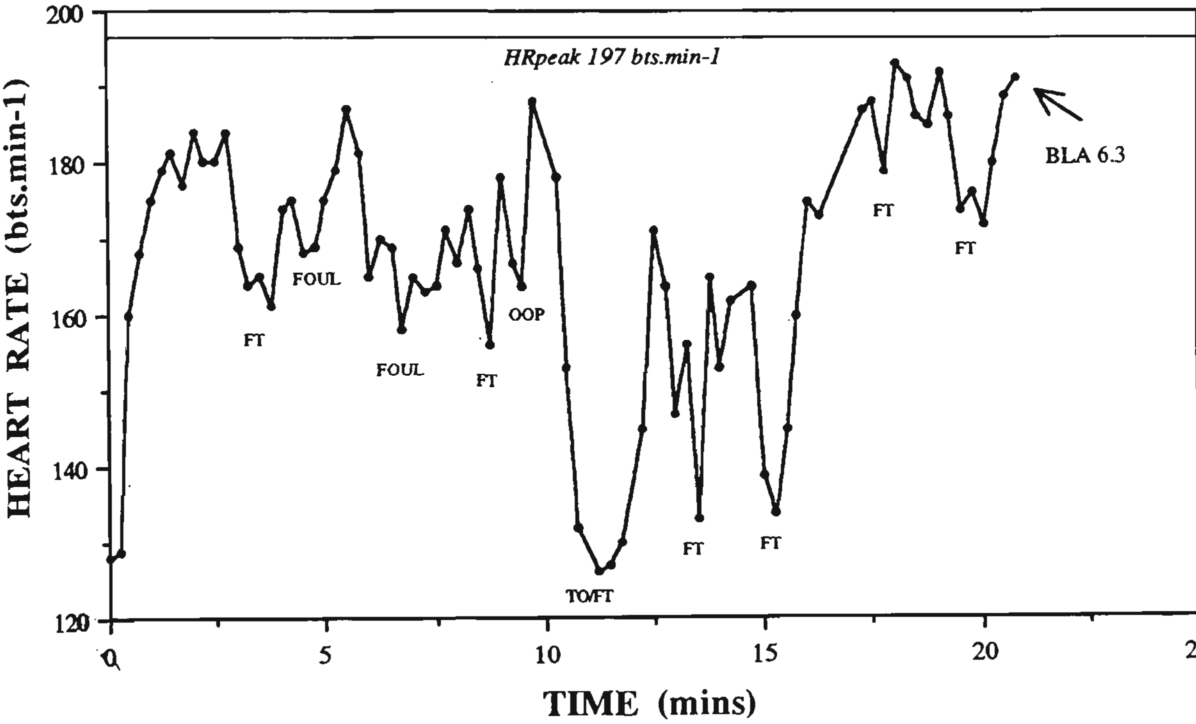


2nd quarter.

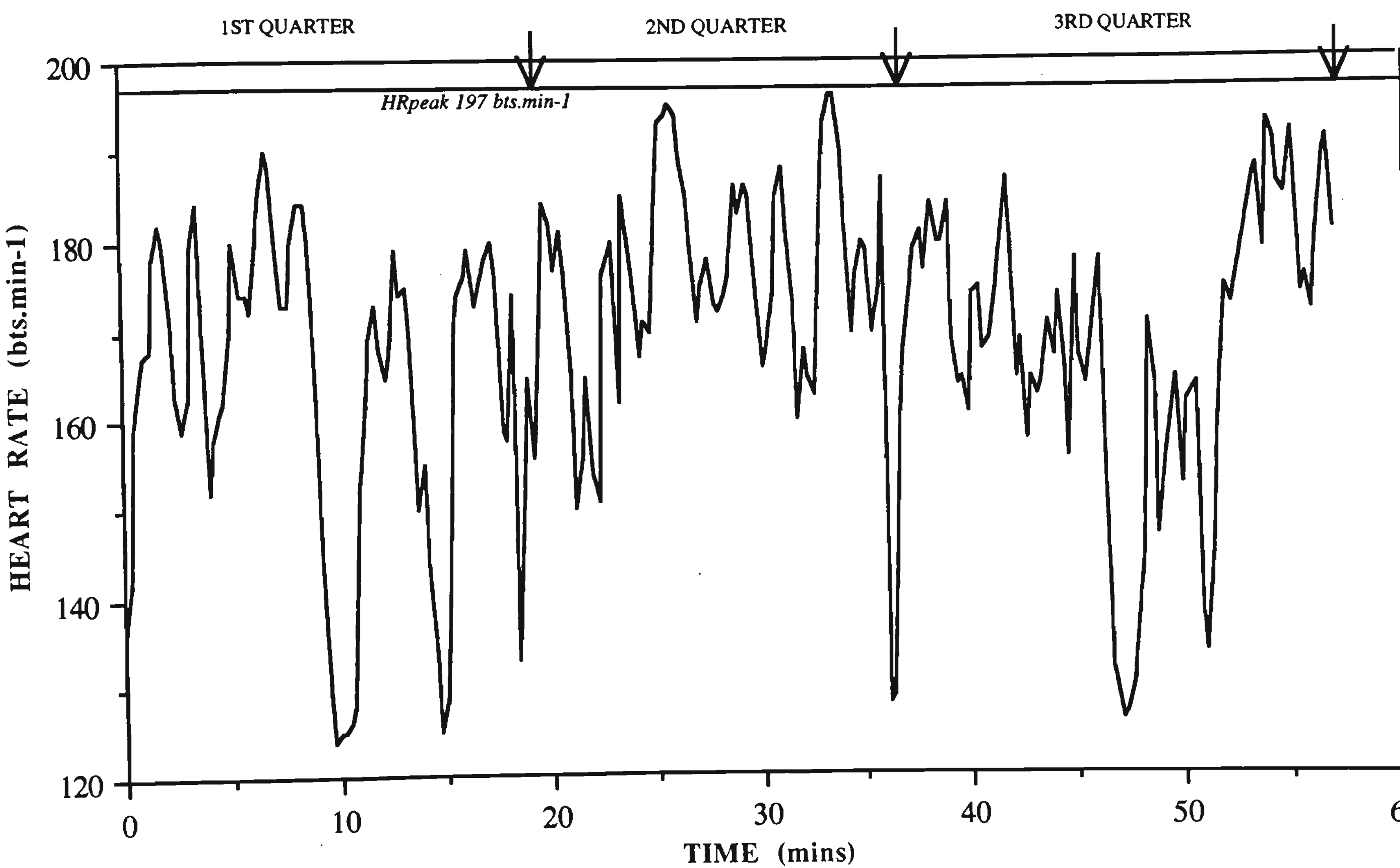


APPENDIX C.4A cont.

3rd quarter.

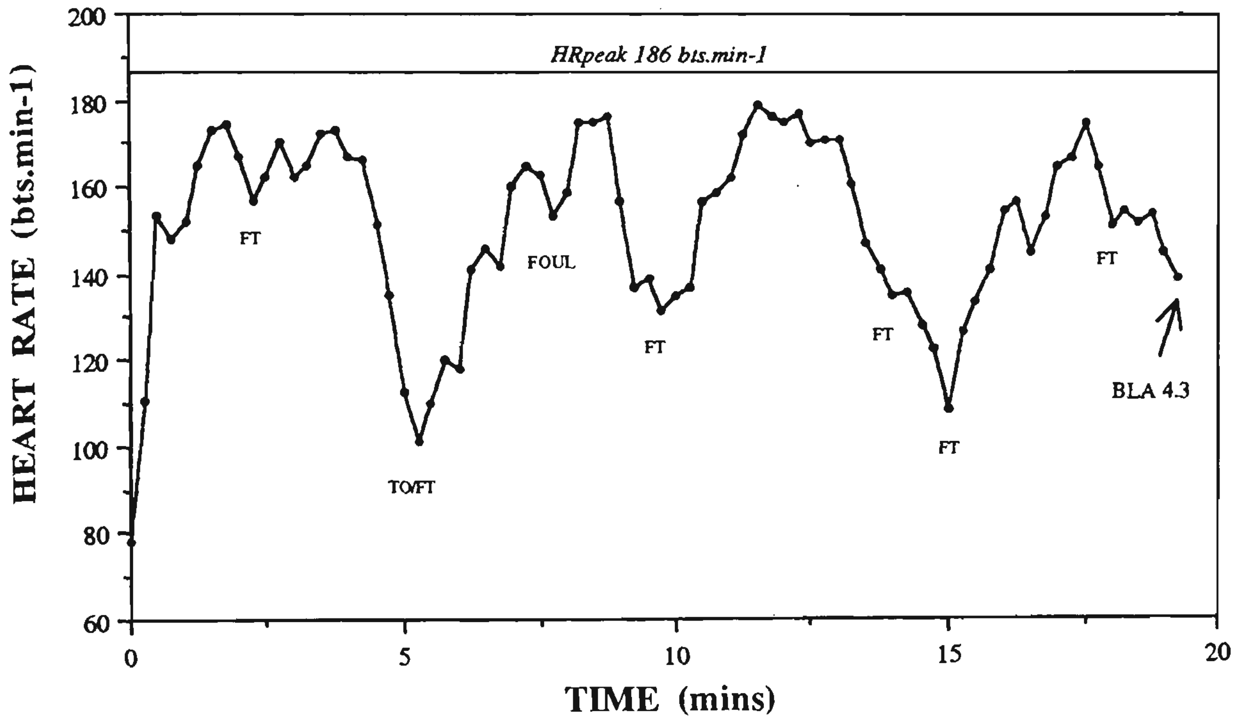


APPENDIX C.4B. Heart Rate responses of subject #4 to the entire game not including the 4th quarter and the breaks between quarters.

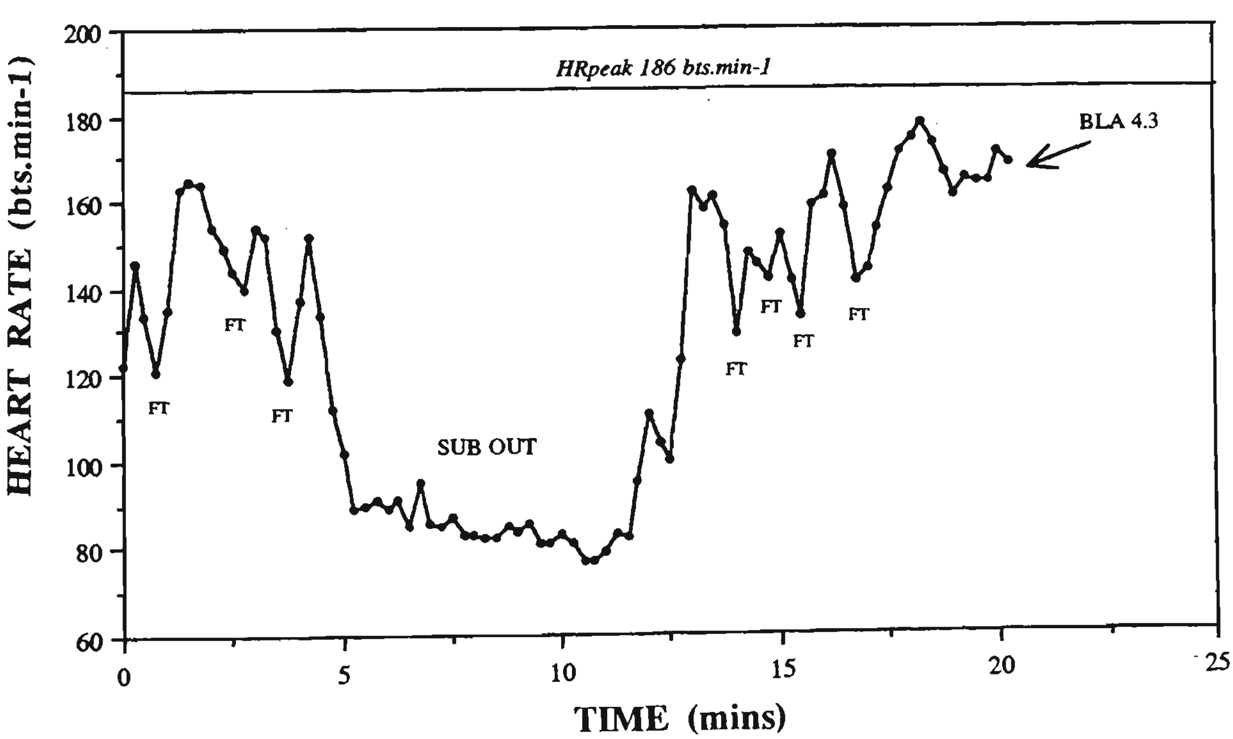


APPENDIX C.5A. Heart Rate responses of subject #5.

1st quarter.

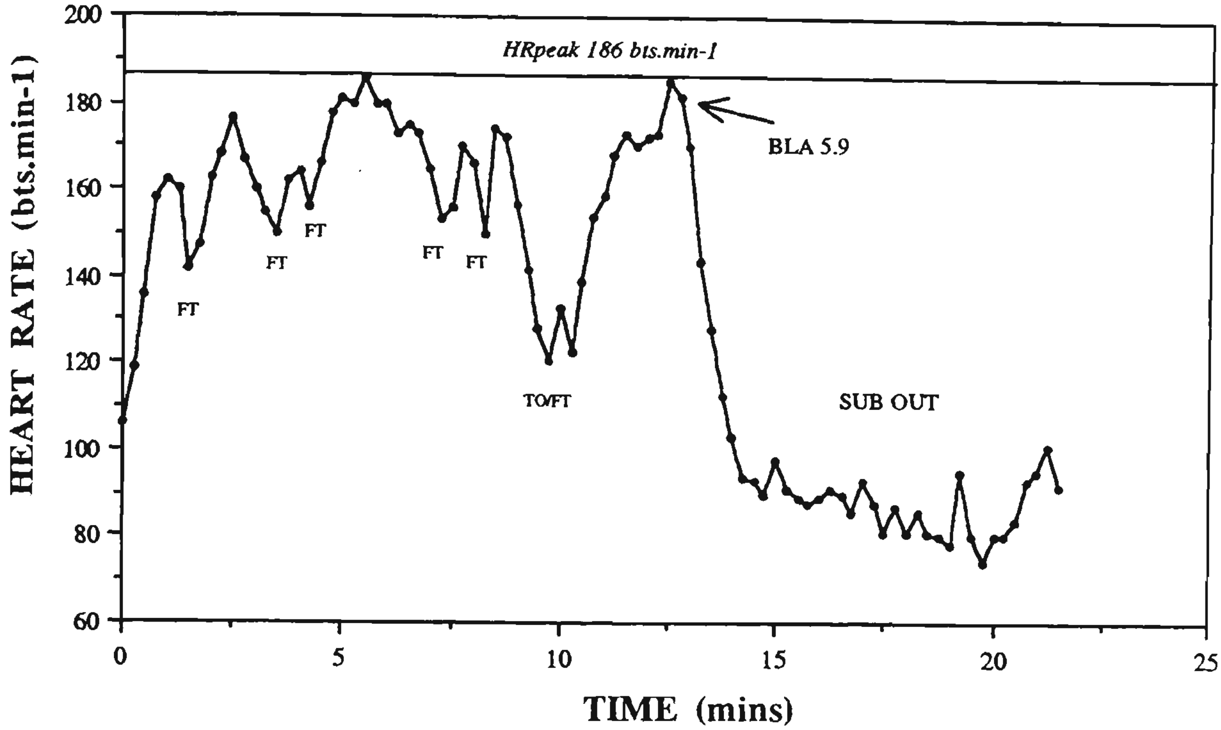


2nd quarter.

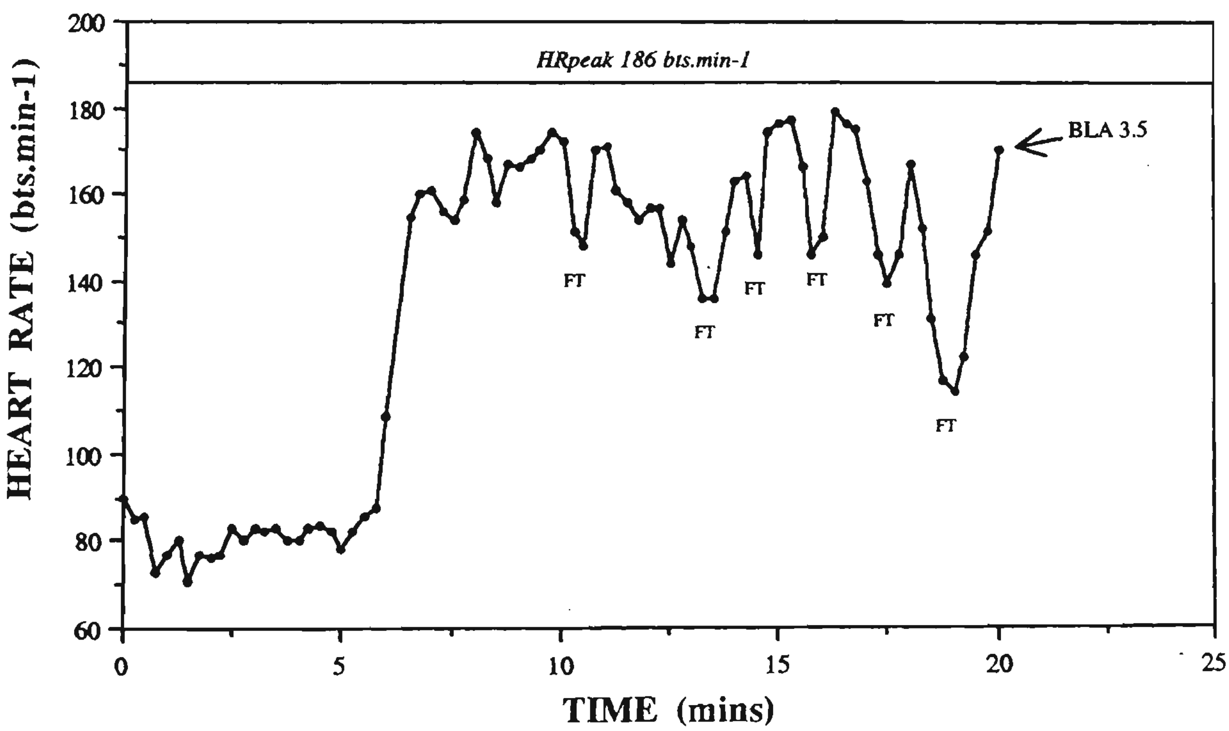


APPENDIX C.5A. cont.

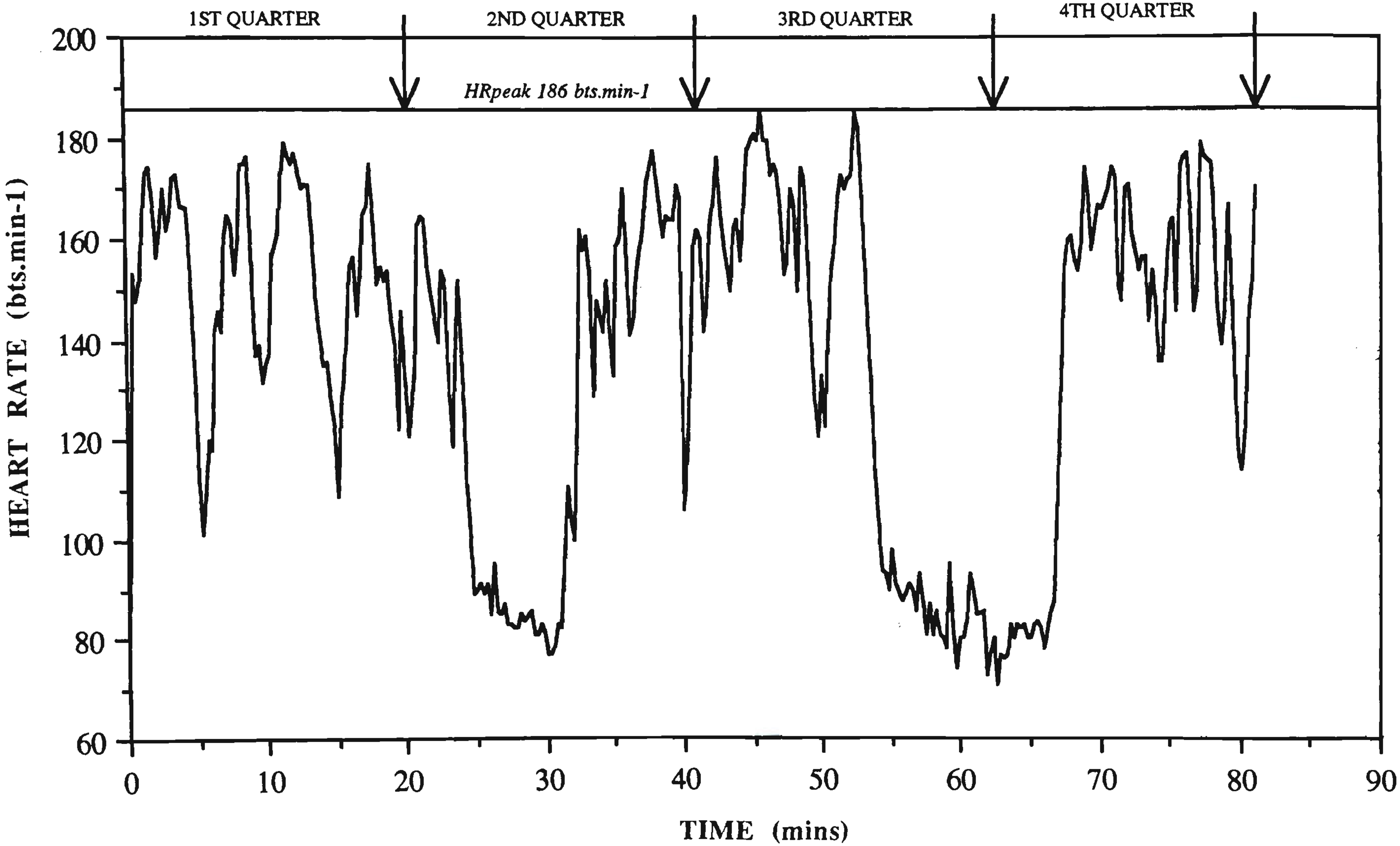
3rd quarter.



4th quarter.

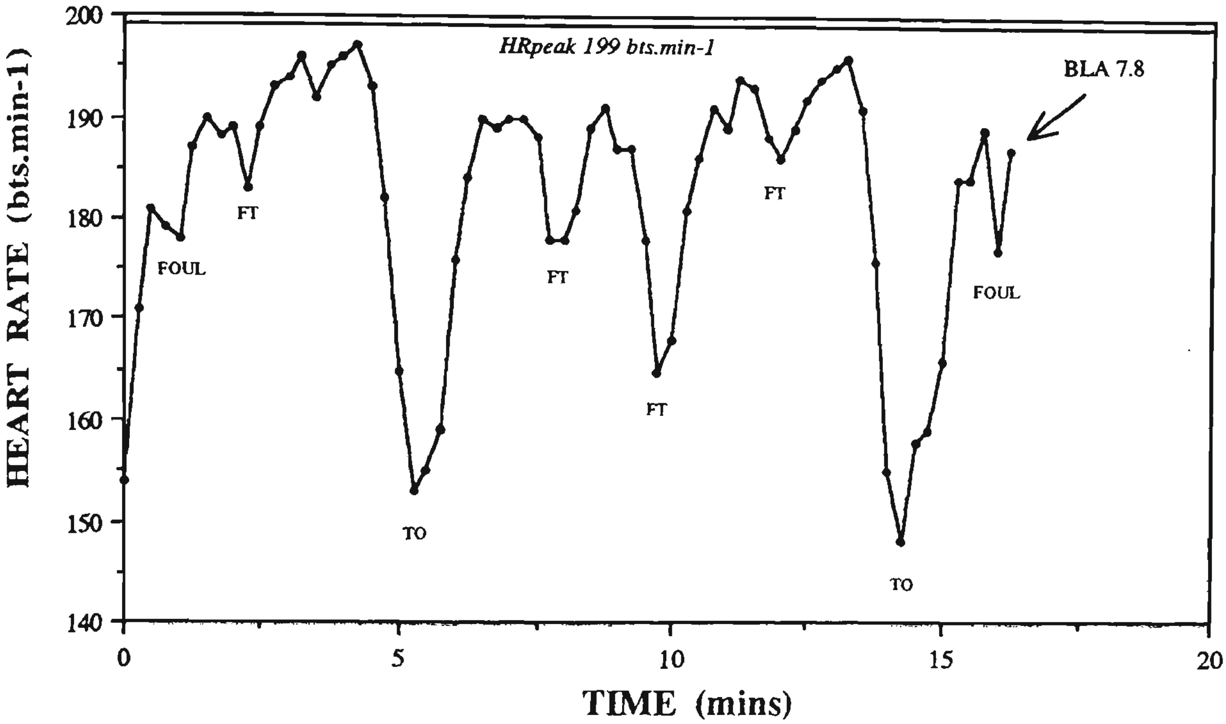


APPENDIX C.5B. Heart Rate responses of subject #5 to the entire game not including the breaks between quarters.

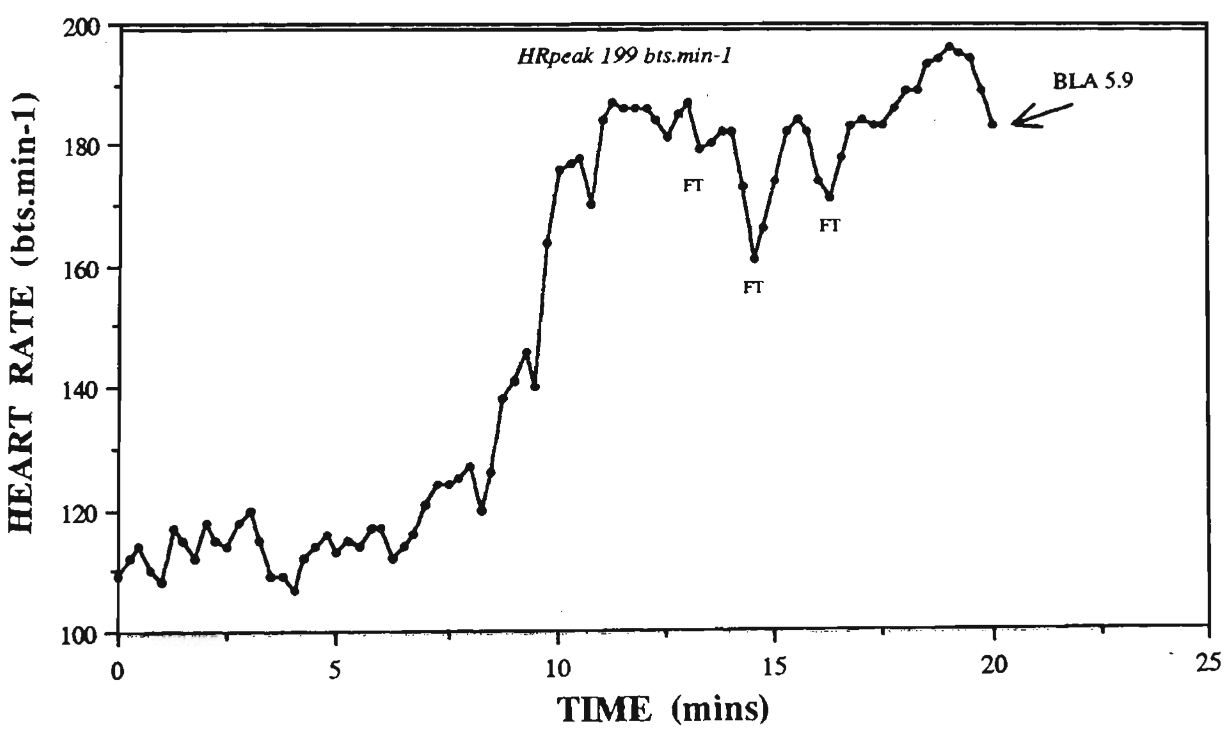


APPENDIX C.6A. Heart Rate responses of subject #6 to game #1.

2nd quarter.

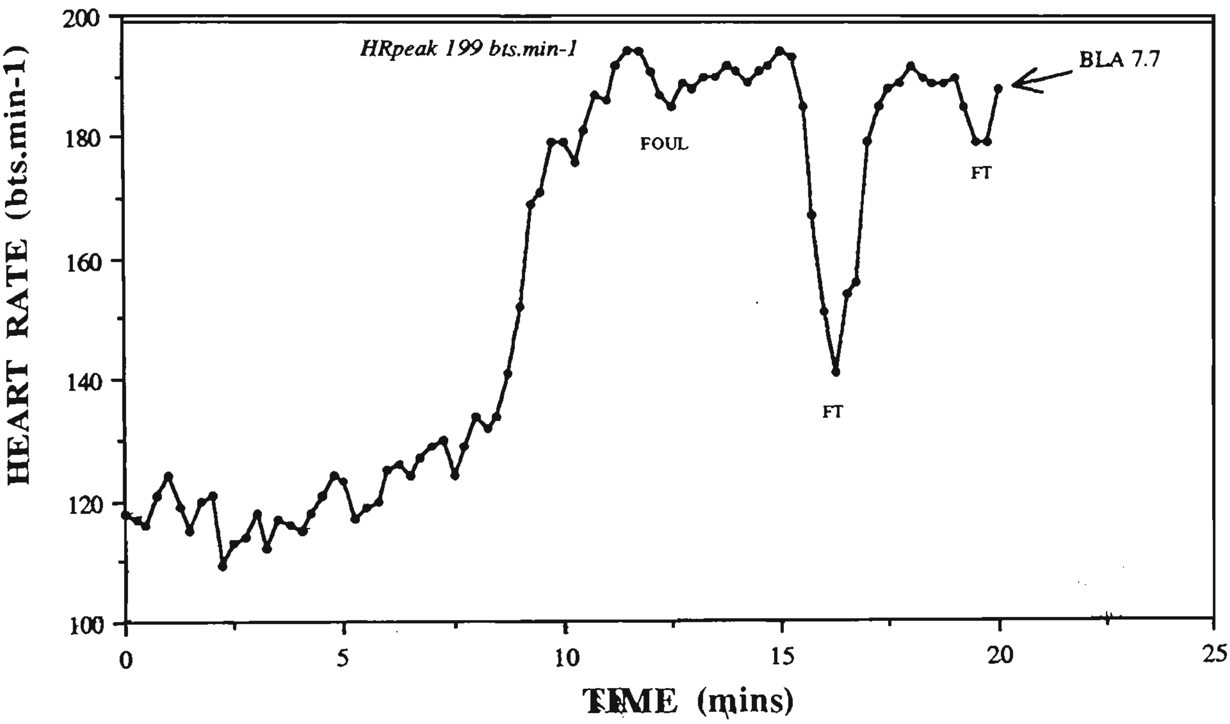


3rd quarter.

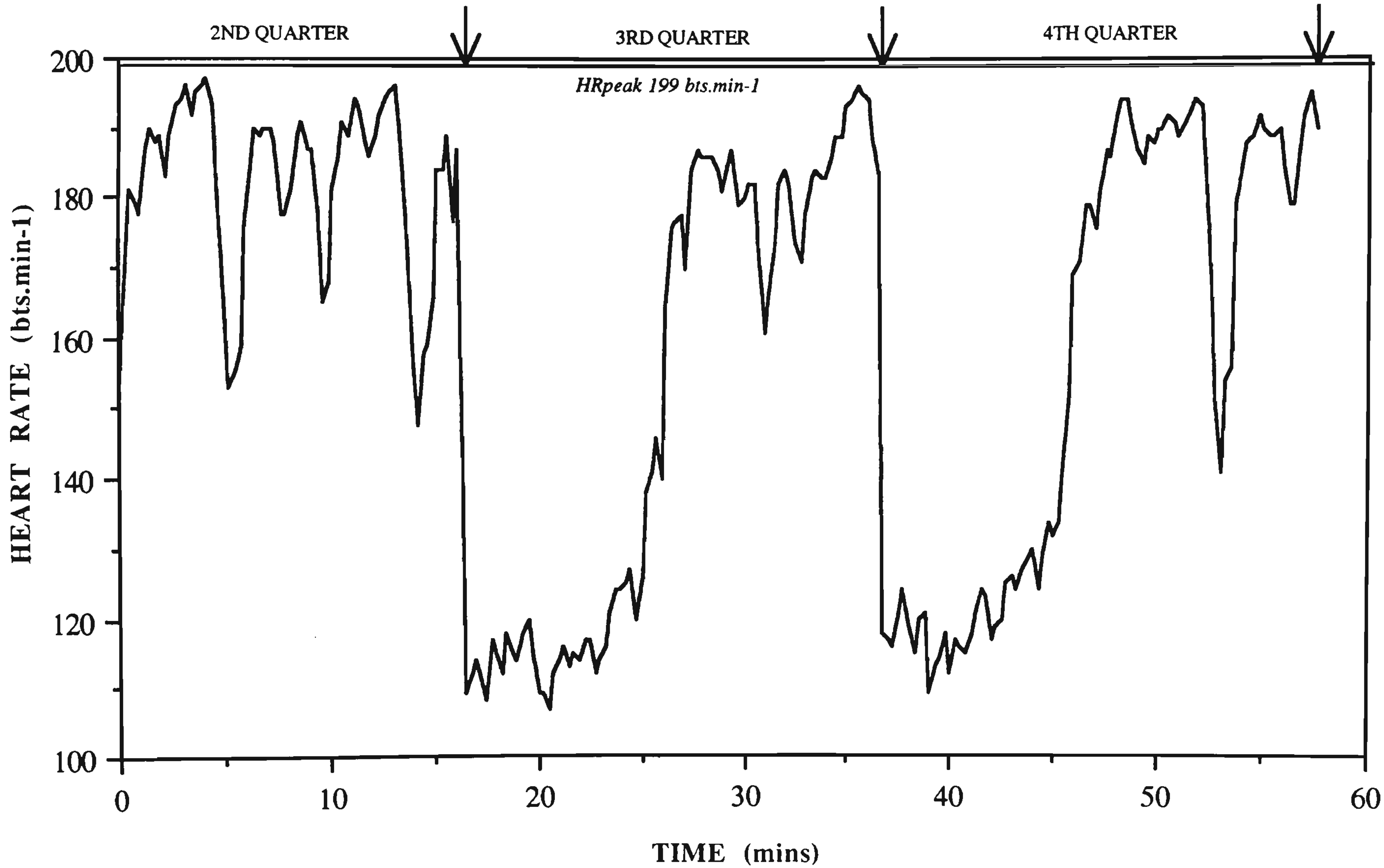


APPENDIX C.6A. cont.

4th quarter.

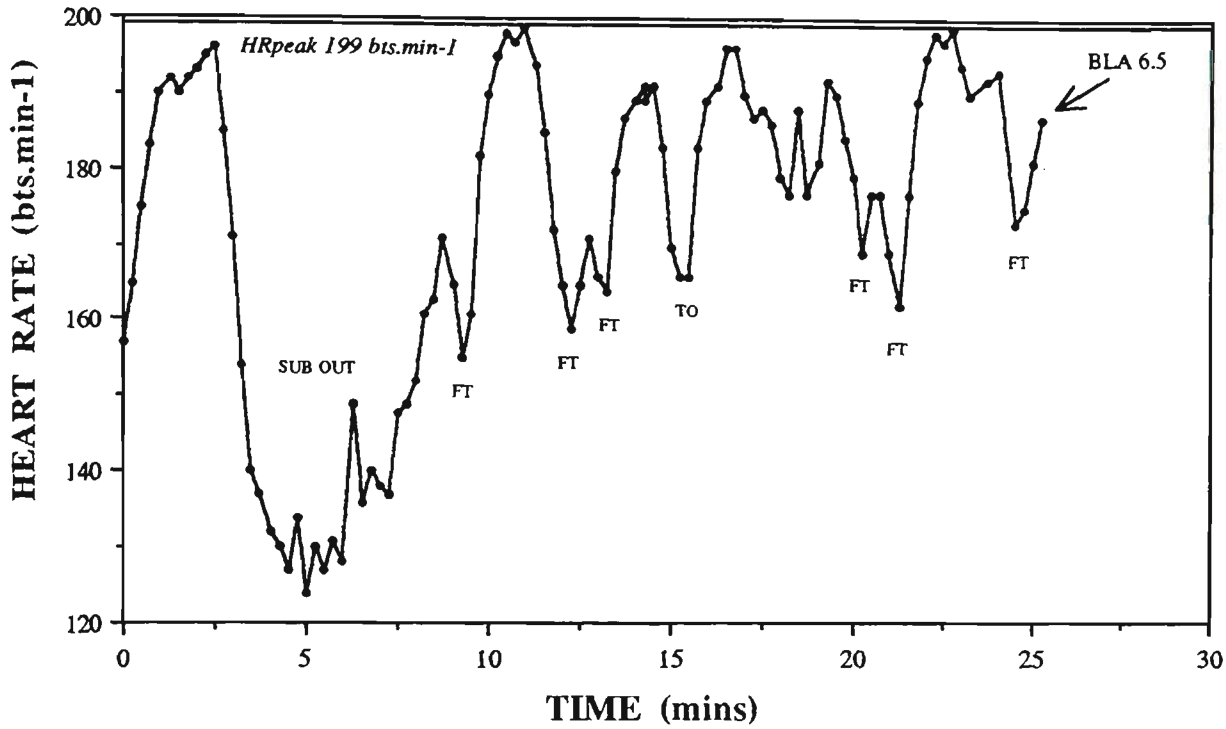


APPENDIX C.6B. Heart Rate responses of subject #6 to the game #1 not including the 1st quarter and the breaks between quarters.

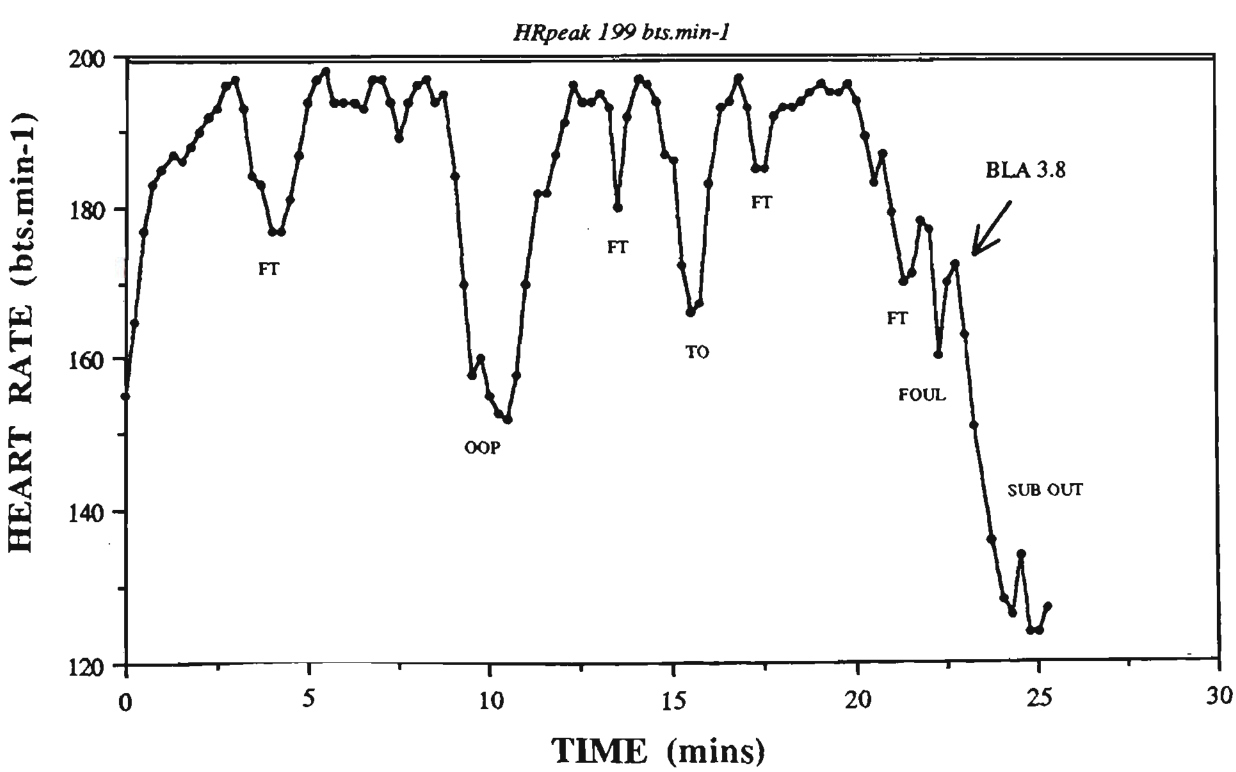


APPENDIX C.6C. Heart Rate responses of subject #6 to game #2.

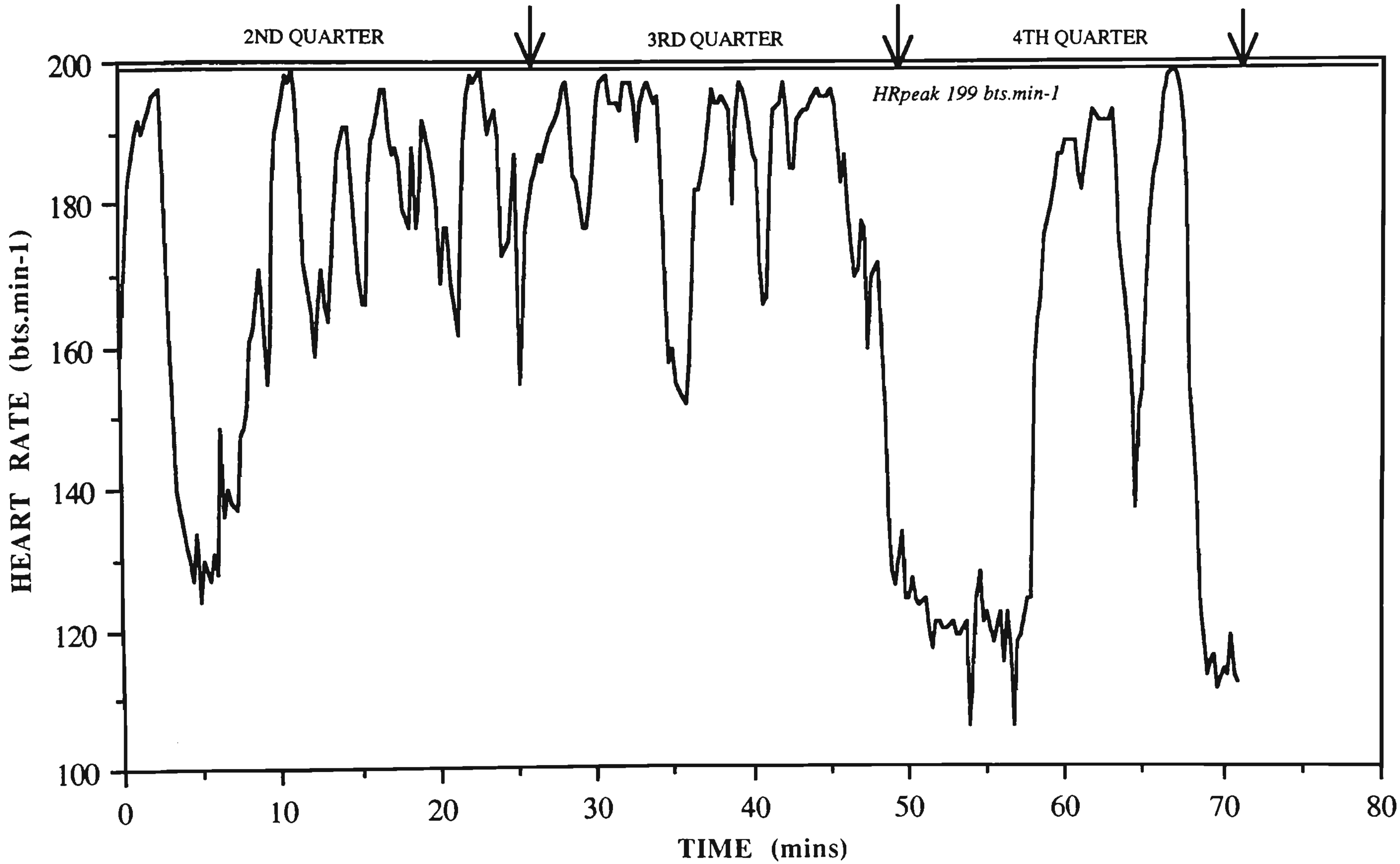
2nd quarter.



3rd quarter.

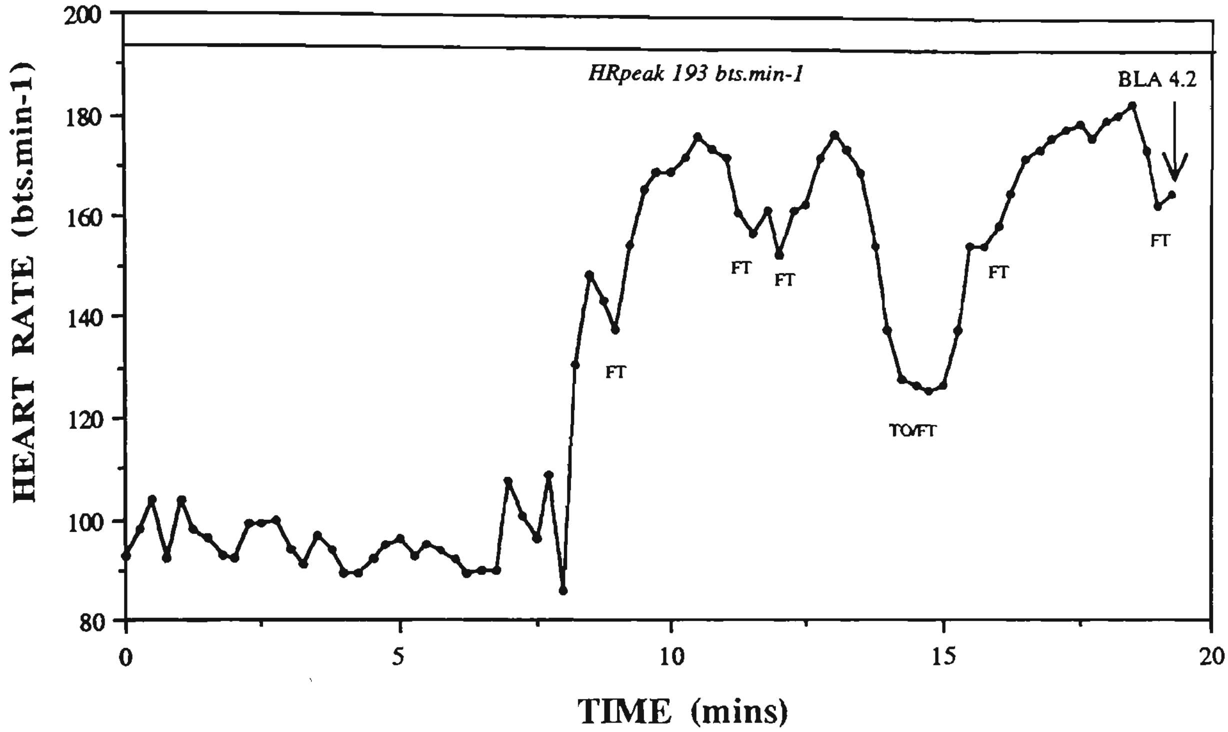


APPENDIX C.6D. Heart Rate responses of subject #6 to game #2 not including the 1st quarter and the breaks between quarters.

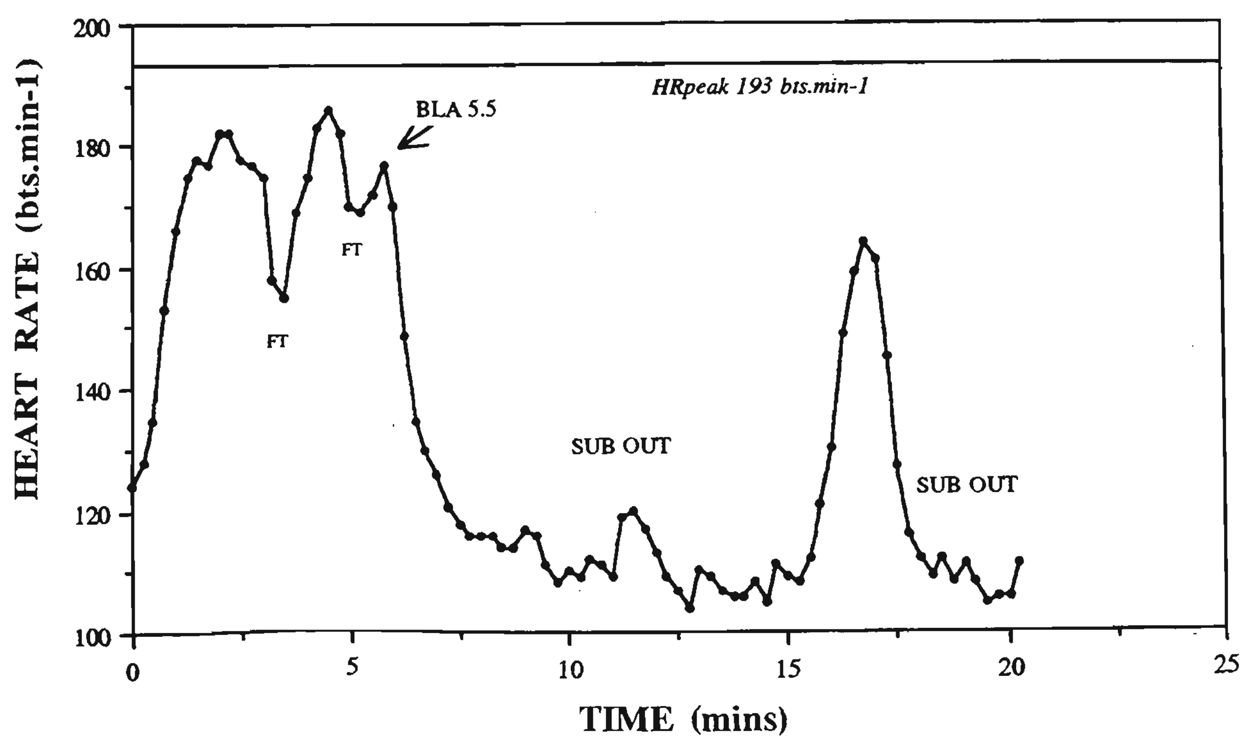


APPENDIX C.7A. Heart Rate responses of subject #7.

1st quarter.

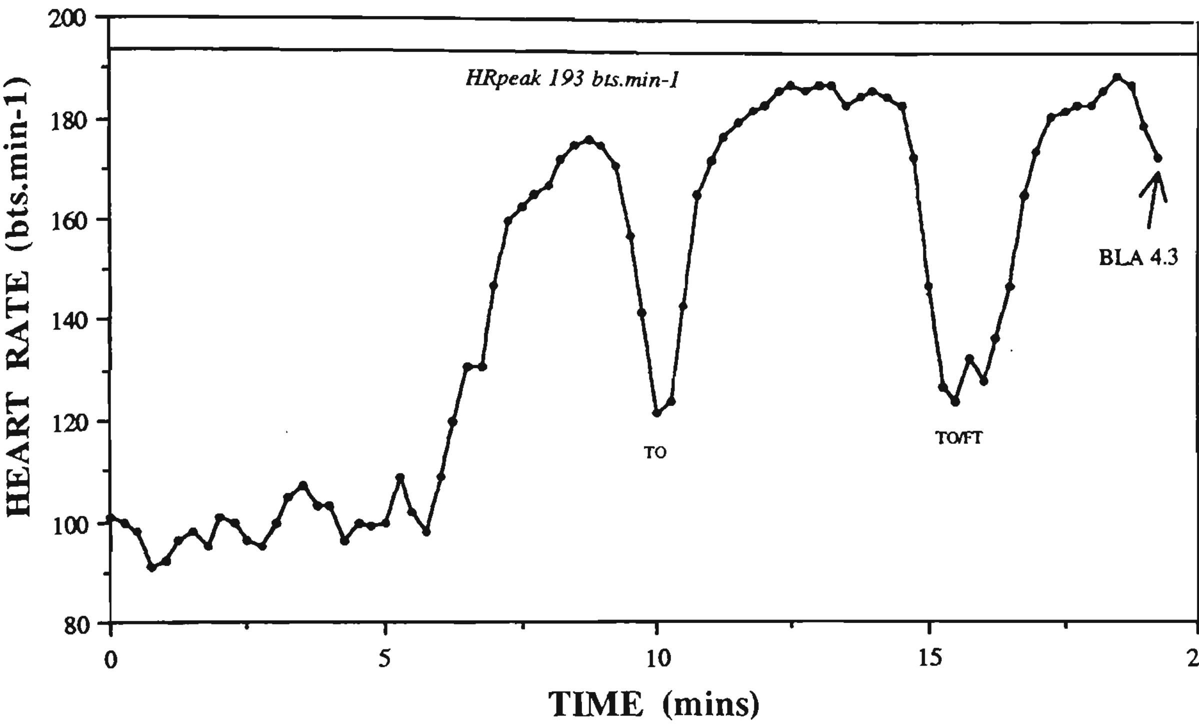


2nd quarter.

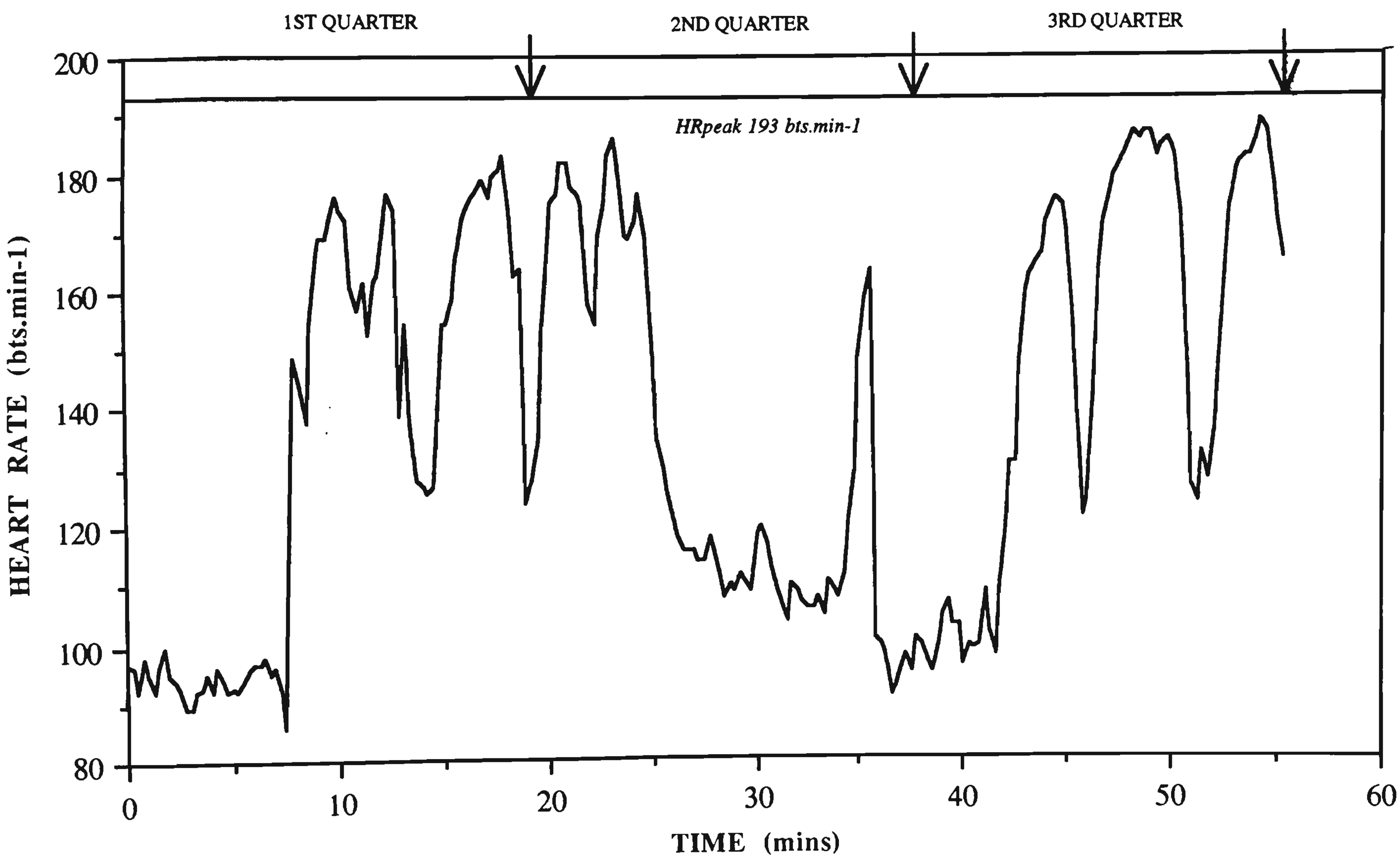


APPENDIX C.7A. cont.

3rd quarter.

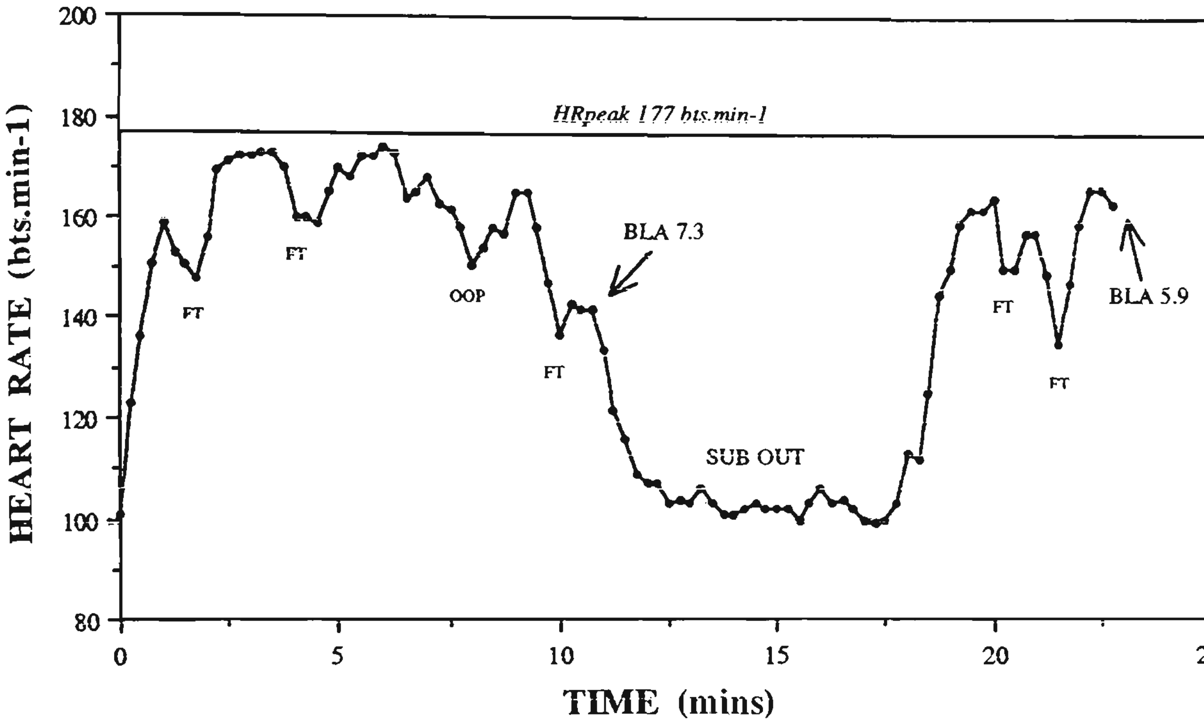


APPENDIX C.7B. Heart Rate responses of subject #7 to the entire game not including the 4th quarter and the breaks between quarters.

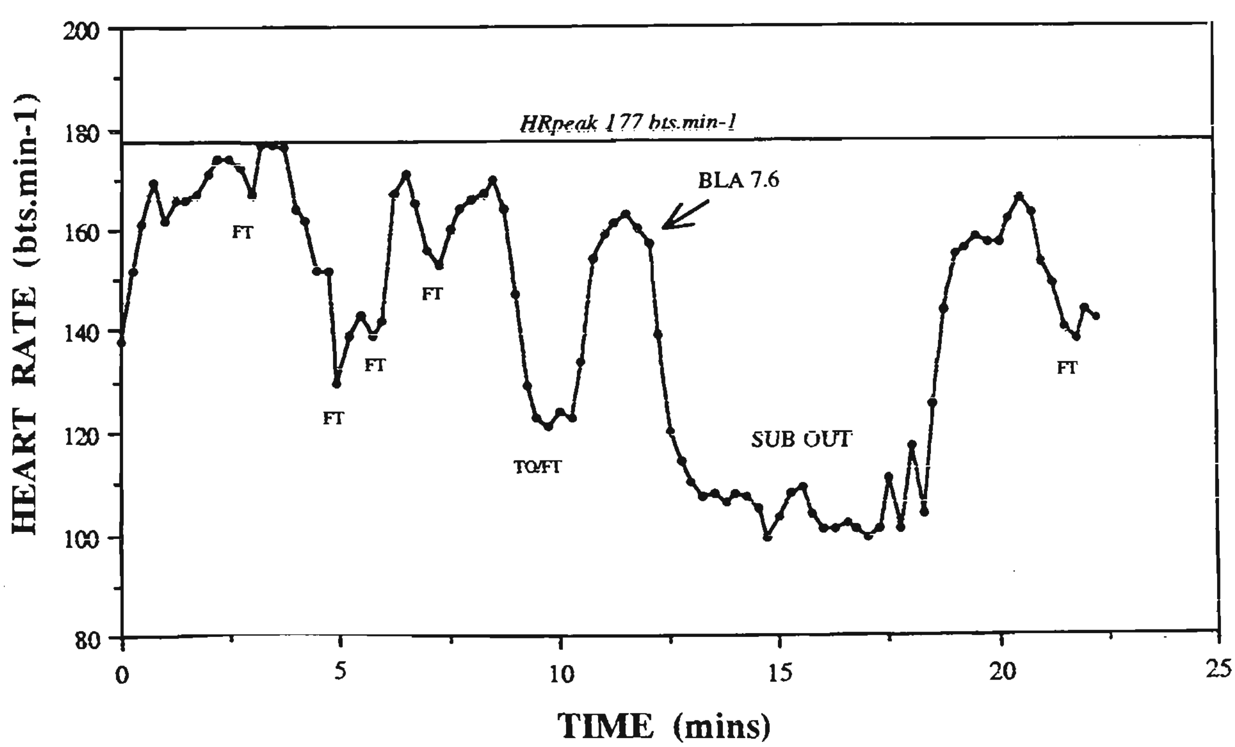


APPENDIX C.8A. Heart Rate responses of subject #8.

1st quarter.

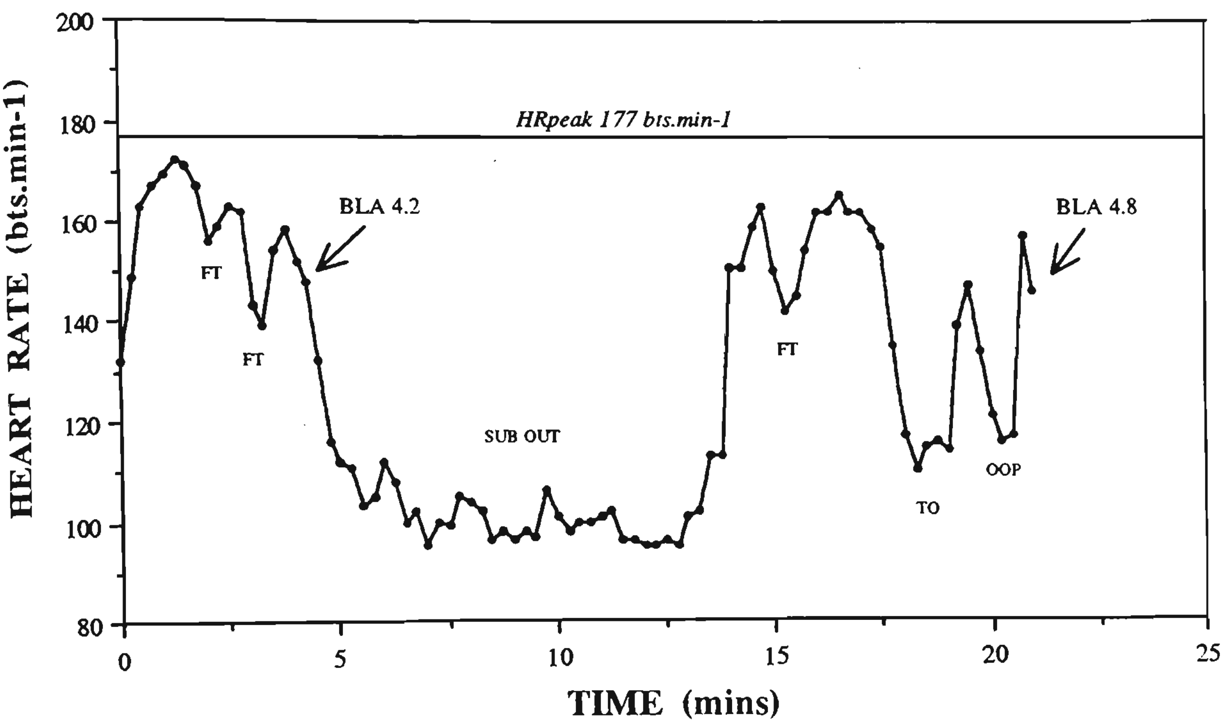


3rd quarter.



APPENDIX C.8A. cont.

4th quarter.



APPENDIX C.8B. Heart Rate responses of subject #8 to the entire game not including the 2nd quarter and the breaks between quarters.