

Physiological Response to Sport-Specific Aerobic Interval Training in High School Male Basketball Players

**Nick Stone
BSR (AUT University)**

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Primary Supervisor: Dr Andrew Kilding

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

Signed: _____

Date: ____/____/____

Dedication

This thesis is dedicated in the first instance, to my beautiful fiancé, Miranda Hall, who has supported me from the very beginning. Without a doubt this thesis would not have been possible without her by my side.

I also dedicate this thesis to my mother, Carole Stone. Mum is the strongest, bravest and most loving woman I know and I will forever cherish the relationship we have.

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Glossary

Assist a pass that leads directly to a team mate scoring, if and only if the player scoring the goal responds by demonstrating immediate reaction towards the basket

Blocked shot credited to a player any time he appreciably alters the flight of a field goal attempt and the shot is missed

Defence defending the goal from an opponent's attacking play

Exercise economy the ratio of work done to the energy expended; represented by the energy expenditure and expressed as the sub-maximal VO_2 at a given running speed

Field Goal

Attempt is charged to a player any time he shoots, throws, or taps a live ball at his opponent's basket in an attempt to score a goal, and the goal is missed or is not counted

Made is credited to a player any time a field goal attempt by him results in a goal being scored or being awarded because of illegal interference with the ball by a defensive player

Free Throw

Attempt charged to a player when that player shoots a free throw unless there is a violation by a defensive player and the shot misses

Made credited to a player any time a free throw attempt by that player results in a score of one point being awarded

Lactate mid-point determined by averaging the minimum and maximum values of log-transformed lactate concentrations from a series of lactate threshold tests

Lactate threshold the point at which lactate production begins to exceed lactate removal in the blood

Offence movements of a team directed toward attacking an opponent's goal

Oxygen uptake

Maximal the maximal amount of oxygen the body can utilise during intense whole body exercise while breathing air at sea level

Rebound the controlled recovery of a live ball by a player after a shot has been attempted

Rejection See Blocked Shot

Sport-specific incorporates skills and movements specific to the sport

Steal credited to a defensive player when his positive, aggressive action causes a turnover by an opponent

Traditional aerobic conditioning continuous or interval based straight line running with minimal changes of direction

Turnover a mistake by an offensive player that results in the defensive team gaining possession of the ball without the offensive team having attempted a field goal or free throw, except when period time expires without such an attempt

$\text{VO}_{2\text{peak}}$ See Oxygen uptake, maximal

Abstract

Background: It has been shown that a high level of aerobic fitness is important for athletes participating in intermittent (team) sports. The majority of studies investigating the effects of traditional and sport-specific aerobic interval exercise on physiological measures and performance have involved field-based team sports. In some instances the effectiveness of sport-specific aerobic training has been questioned. To date, no study has investigated the influence of a sport-specific training approach in the sport of basketball. **Purpose:** The aim of the present study was to evaluate the effectiveness of a basketball specific endurance circuit on improving measures of aerobic fitness. **Methods:** Ten male high school basketball players, age 16.4 ± 1.2 years, ranked by fitness level and randomly assigned to a training group ($N = 6$) or control group ($N = 4$) participated in the study. The sport-specific aerobic endurance training replaced the fitness component of regular training and was performed during the competitive season. The sport-specific training consisted of interval training using a basketball specific endurance circuit, four times 4 min at 90-95% HR_{peak} with a 3 min recovery at 60-70% HR_{peak} , twice per week for 6 weeks. During this time the control group performed regular basketball training. **Results:** For both the training and control groups the actual mean training intensity for total training duration were $77.4 \pm 2.9\%$ HR_{peak} and $74.1 \pm 6.7\%$ HR_{peak} , respectively. The actual mean training intensity during the work intervals in the training group was $84.1 \pm 2.3\%$ HR_{peak} . There were no clear differences between effects of the two training approaches for measures of maximal oxygen uptake (3.3%; 90% confidence limits, $\pm 19.3\%$), running economy (-3.3%; 90% confidence limits, $\pm 14.2\%$), repeated sprint ability (0.6%; 90% confidence limits, $\pm 5.7\%$) and anaerobic power maintenance during the repeated sprints (-13.7%; 90% confidence limits, $\pm 49.0\%$). However, a clear non-trivial effect on sub-maximal heart rate was observed (-7.3%; 90% confidence limits, $\pm 2.0\%$) suggesting a beneficial training effect after training. Some evidence for attenuation of speed (-1.8 to -2.8%; 90% confidence limits, ± 3.4 to 5.7%) and power (-1.7%; 90% confidence limits, $\pm 17.1\%$) was apparent. **Conclusion:** Although clear changes in sub-maximal HR responses were observed in the training group, the data in the present study suggests that a basketball specific endurance circuit has little effect on other laboratory and field-based measures of aerobic fitness. In fact, the basketball specific endurance circuit may lead to reduced improvements in jumping and sprinting performances. Further research is required to clarify the effect of aerobic training approaches on basketball-specific fitness and performance.

Key Words: aerobic, interval training, sport-specific, running economy, repeated sprint ability.

Chapter One: Introduction

Basketball is one of today's fastest team sports and is epitomized by grandiose manoeuvres such as the slam-dunk and blocked shot. These showcases of athletic ability clearly demonstrate the nature of the sport in that speed, strength, and power are all major determinants of successful basketball performances. Although such characteristics are commonly associated with modern basketball athletes, it is interesting to consider basketballs evolution from its humble beginnings into one of the most popular and dynamic team sports of modern society.

1.1 The History of Basketball

Basketball was invented in 1891 by a Canadian born physical education instructor, James Naismith. Naismith's original intention was to keep his football team in shape during the off-season with an exciting new game that required both skill and physical ability (Bellis, 2007). With influences from ancient Aztec, Mayan, and Maori handball sports, the object of the game was to throw a soccer ball into a peach basket suspended ten feet above the ground. Originally, every time a point was scored the ball would have to be retrieved, because the bottoms of the peach baskets were intact at first.

Basketballs popularity increased rapidly from the first public game being played in Springfield, MA, USA, on March 11th 1892 to the formation of the first professional league only six years later in 1898, known today as the National Basketball Association (NBA). It was not until 1903, however, that an open-ended net was introduced to put an end to manually retrieving the ball from the basket after each goal scored.

The 1936 Berlin Olympics saw basketball being played for the first time as an official Olympic sport, where the United States defeated Canada 19-8 for the gold medal. It was not until 1943

that the stereotypical basketball athlete began to emerge with Bob Kurland (7 foot) and George Mikan (6 foot 10 inches) being among the first real big men to become a dominant force in the game. Similarly, the first black man, Charles Cooper, was drafted into the NBA in 1950 and many more followed suit to such an extent that black athletes now dominate basketball in size, skill, and physical ability. As the game reached new heights, the skill level of players improved dramatically with Wilt Chamberlain's 1962 showcase - 100 individual points in one game, leading his team to a 167-147 victory (Bellis, 2007). This was a far cry from the first public basketball game in 1892, which had a score of 1-0.

The following years saw the spread of basketball throughout Europe with European countries starting to show their ability to play the game when the Soviet Union defeated the United States for the gold medal during the 1976 Olympics. Today basketball is played by over 450 million participants worldwide who enjoy the game at both competitive and grassroots levels (FIBA, 2007).

1.2 The Game of Basketball

The modern game varies in duration depending on the association governing over the competition. College teams competing in the National College Athletic Association (NCAA) play a 40 minute game divided into two, 20 minute halves while professional teams competing in the NBA play a 48-minute game divided into four, 12 minute quarters. However, the International Basketball Federation (FIBA) endorses a game time of 40 minutes, divided into four, ten minute quarters, which is also adopted by Basketball New Zealand (BBNZ) and its associated competitions. At any stage during game play, an official can stop the game clock when a breach of the rules occurs. Similarly, the coach of either team can call a 'time-out' from game play, which stops the game clock and is generally used to strategize upcoming offensive and/or defensive plays.

A team consists of ten players where only five will be involved in game play while the other five are used as substitutions during the game. There are five playing positions: 1) the point guard (position 1) is responsible for calling the plays and directing the offence. It is the point guard's job to bring the ball up the court and set up the play. Therefore, the point guard is usually the team's best dribbler and passer (Lindsay, 2007); 2) the shooting guard (position 2) has similar duties as the point guard but usually does not bring the ball up the court. The shooting guard is usually one of the team's best scorers as they are counted on to hit from the outside and take more field goal attempts than the point guard (Lindsay, 2007); 3) the power forward or 'big' forward (position 3) are usually bigger and stronger than other players and are known for their size, defence, and rebounding (Lindsay, 2007); 4) the small forward (position 4) is not necessarily physically small. They are known primarily for their scoring and ball handling abilities. Often, the small forward is the most talented player on the team (Lindsay, 2007); 5) the centre (position 5) is important to both offence and defence ball play. The centre is usually the tallest player on the team and is the focal point of the team's offence. Defensively, the centre is responsible for rebounding and blocking (Lindsay, 2007). The main substitute to come off the bench is known as the 'sixth' player and can play a variety of positions or does one specific thing very well. This may include skills such as being a great long-range shooter, playing solid defence, or being able to play a number of positions well (Lindsay, 2007).

A point is scored in basketball when the basketball is thrown through the basket. If a basket is scored outside of the three-point circle, the bucket is worth three points. Whenever a field goal is made from within the three-point circle the bucket is worth two points. Foul shots, or free throw attempts, made from the free throw line are worth one point each (FIBA, 2004).

1.3 The Physical Requirements of Intermittent Exercise

Basketball has evolved from a sport in which skill was the primary prerequisite for successful play into one that not only requires a high degree of skill, but also demands physical prowess. Team sports, including basketball, typically involve periods of high-intensity exercise over short durations (<10 s), interspersed with periods of recovery or lower-intensity exercise, performed over an extended time period ranging from 40 to 90 min (Bishop, Lawrence, & Spencer, 2003; Edge, Bishop, Goodman, & Dawson, 2005). In the scientific literature sports eliciting these characteristics have been termed 'intermittent' (Atkins, 2006; Castagna, Impellizzeri, Chamari, Carlomagno, & Rampinini, 2006; McMillan, Helgerud, Macdonald, & Hoff, 2005; Thomas, Dawson, & Goodman, 2006). It is commonly acknowledged that the greater part of the adenosine triphosphate (ATP) required to fuel a brief period of high-intensity exercise is provided through anaerobic pathways, specifically phosphocreatine (PCr) degradation and glycolysis (Jacobs, Tesch, Bar-Or, Karlsson, & Dotan, 1983). However, the ability to repeatedly perform high-intensity exercise over a prolonged period is in contrast to the ability to produce a single, short duration effort of maximal intensity. Indeed, the contribution of glycolysis to energy supply during repeated sprint exercise has been shown to decline by 45% when a second 30 s sprint is performed (Bogdanis, Nevill, Boobis, & Lakomy, 1996). The decline in the rate of glycolysis is compensated for by an increase in aerobic metabolism of about 18% during the second 30 s sprint, consequently providing a significant (49%) part of the energy required during the sprint (Bogdanis, Nevill, Boobis, & Lakomy, 1996). As sprints are repeated, an approximate 70% contribution to a third 30 s sprint has been previously reported (Trump, Heigenhauser, Putman, & Spriet, 1996) with the level of aerobic ATP provision increasing progressively across ten, six second sprints (Bogdanis, Nevill, Boobis, & Lakomy, 1996; Gaitanos, Williams, Boobis, & Brooks, 1993; Trump, Heigenhauser, Putman, & Spriet, 1996).

During competitive team sport, sprints or high-intensity efforts are often repeated, typically ranging between 100 to 250 brief intense actions during a match, lasting approximately 1 to 5 s, equating to one high-intensity effort every 12 to 30 s depending on the sport (Abdelkrim, El Fazaa, & El Ati, 2007; Bangsbo, 1994a; Bangsbo, Norregaard, & Thorso, 1991; Bishop & Wright, 2006; Boyle, Mahoney, & Wallace, 1994; Coutts, Reaburn, & Abt, 2003; Deutsch, Maw, Jenkins, & Reaburn, 1998; Duthie, Pyne, & Hooper, 2005; McInnes, Carlson, Jones, & McKenna, 1995; McLean, 1992; Mohr, Krstrup, & Bangsbo, 2003; O'Donoghue, Boyd, Lawlor, & Bleakely, 2001; Spencer et al., 2004; Taylor, 2003; Withers, Maricic, Wasilewski, & Kelly, 1982). Frequently, these high-intensity efforts are separated by short rest periods (<30 s), which are inadequate for full recovery and have been shown to negatively affect subsequent sprint performance (Balsom, Seger, Sjodin, & Ekblom, 1992a). Furthermore, it has been shown that an a high level of aerobic fitness is associated with a greater number of sprints, involvements with the ball, and total distance travelled during a soccer match compared to those of lower aerobic fitness (Helgerud et al. 2001). Therefore, to perform at an elite level, a well-developed aerobic capacity is required in order to effectively sustain repeated high-intensity efforts throughout a competitive game lasting 40 to 90 min.

Recently, several researchers have designed and evaluated sport-specific conditioning programmes based upon the recommendations of time-motion analysis studies (Gabbett, 2006b; Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002; Impellizzeri, Rampinini, & Marcora, 2005; Reilly & White, 2004). These training experiments have incorporated movement patterns and work rates typically observed during competitive match play into actual training sessions. One of the first studies to develop and evaluate a sport-specific circuit training approach was Hoff et al. (2002). This particular study involved soccer players dribbling a ball through cones and over hurdles in addition to moving backwards while maintaining control of the ball at an intensity of 90 to 95% peak heart rate (HR_{peak}). Such sport-specific approaches have been demonstrated to induce

sufficient physiological stress (Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002) resulting in an increase in several measures of aerobic fitness, including maximal oxygen uptake (VO_{2peak}), running economy (RE), and lactate threshold (LT; Chamari et al., 2005; McMillan, Helgerud, Macdonald, & Hoff, 2005). Whilst there has been a gradual increase in the use of sport-specific conditioning for team sports, several researchers have questioned its effectiveness when compared to traditional methods of training, i.e., straight line continuous or interval based aerobic training (Gabbett, 2006b; Gamble, 2004; Impellizzeri, Rampinini, & Marcora, 2005; Reilly & White, 2004). To date there has been a minimal number of investigations into the influence of aerobic training on measures of aerobic fitness in basketball players. Furthermore, modern approaches to aerobic conditioning, such as sport-specific movement circuits, have not been investigated in the sport of basketball. These gaps in the literature provide an opportunity to investigate the influence of different aerobic conditioning approaches within the basketball environment.

1.4 Aim of the Study

The aim of this study was to evaluate the effectiveness of a basketball specific endurance circuit on improving aspects of aerobic fitness.

1.5 Significance of the Thesis

The results of this thesis will be significant in that they will assist in the development of physical conditioning programmes for New Zealand's young elite basketball players representing the country at the first under-17-years-of-age international basketball tournament in 2009.

Chapter Two: The Physical Demands of Team Sport Competition - The Importance of Aerobic Endurance

The review of the literature is divided into two parts: 1) a descriptive review outlining the physical demands imposed upon team sport athletes during competition; and 2) a review of aerobic conditioning approaches used within the team sport environment. Due to the limited number of studies specific to basketball, several other sports with similar characteristics have been analysed including rugby, and soccer. Therefore, the purpose of this part of the review is to summarize the physical demands of intermittent (team) sport competition. To accomplish this, aspects that differentiate team sports will be reported and discussed. These include match activity, game intensity, high-intensity periods during team sport competition, energy system contribution to performance, and finally how recovery and fatigue are affected by the demands of competitive team sport. Attention will also be given to positional differences and playing level with respect to the above mentioned themes, outlining the importance of position specific preparation for team sport athletes. Furthermore, throughout this review special reference to the importance of aerobic endurance for successful individual and/or team performance will also be made.

Numerous factors influence the physical stress imposed upon a team sport athlete during training and competition. These factors include, but are not limited to, the rules and structure of the game, skill and tactical ability of players (McLean, 1992), level of playing competition, playing style, positional role, and the environmental conditions (Reilly, 1996). Understanding the physical demands of competitive team sports is essential when designing conditioning programmes, estimating energy requirements, and attempting to reduce the risk of injury (O'Donoghue, Boyd, Lawlor, & Bleakely, 2001). Such requirements have necessitated the development of time-motion analysis.

Time-motion analysis allows for movement patterns, distances covered, average velocities, levels of exertion, and work-to-rest ratios to be established by quantifying the time spent performing different activities during a game (Duthie, Pyne, & Hooper, 2003). Movement pattern and work rate studies of sports such as basketball, field hockey, rugby union, and soccer have revealed much about the time athletes are engaged in low-, medium-, and high-intensity activities (Abdelkrim, El Fazaa, & El Ati, 2007; Bangsbo, Norregaard, & Thorso, 1991; Duthie, Pyne, & Hooper, 2005; McInnes, Carlson, Jones, & McKenna, 1995; Spencer et al., 2004). Accordingly, such studies have differentiated between 1) 'live time', during which the game clock is running and the athlete is on the playing area; and 2) 'total time', which commonly refers to all of the time the athlete is on the playing area, including stoppages in play, but generally excluding breaks between quarters and/or halves (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995). The most sophisticated and contemporary method of time-motion analysis uses six cameras, three of which are placed high on each side of the playing area, permitting synchronized observations of all athletes in the playing area (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Video-based time-motion analysis has been shown to be a reliable and effective tool to assess the overall demands of intermittent sports (Abdelkrim, El Fazaa, & El Ati, 2007; Bishop & Wright, 2006; Duthie, Pyne, & Hooper, 2003; McInnes, Carlson, Jones, & McKenna, 1995). Time-motion analysis, in conjunction with monitoring physiological responses to competition, such as heart rate (HR) and blood lactate concentration (B[Lac]), provides invaluable information concerning team sport 'performance'.

Recently, differential Global Positioning Systems (dGPS) have also been proposed as an effective method to monitor physical activity during sport (Larsson, Burlin, Jakobsson, & Henriksson-Larsen, 2002; Larsson & Henriksson-Larsen, 2001; Schutz & Herren, 2000; Terrier, Ladetto, Merminod, & Schutz, 2001). The use of dGPS in combination with an accelerometer, HR, and/or metabolic gas measurements has been suggested as one method to achieve a more

detailed analysis of sport performance (Larsson & Henriksson-Larsen, 2001). However, the signal from satellites is influenced by the atmosphere and by bouncing off various local obstructions before reaching the receiver. This gives an error in the calculated distance to the satellite, and thus the computed position and speed may be affected (Larsson, 2003). Nonetheless, Larsson et al. (2001) demonstrated that dGPS distance measurements during orienteering (cross-country running) displayed a mean error of 0.1 to 0.8 m (-1.7 to 2.8 m; 95% CI). The major disadvantage of dGPS is that measurements can only be performed in an environment in which access to the satellites is not obstructed; therefore, distance measurements of sports inside a building, such as basketball, are not possible (Schutz & Herren, 2000). When comparing the use of dGPS and computer-based time-motion analysis for measuring player movement patterns during Australian Rules football, it was revealed that overestimations are relatively small for both systems (less than ~7%) and in experienced hands the computer-based system is slightly more accurate than GPS (~1%; Edgecomb & Norton, 2006). Up-to-date time-motion analyses of the physical demands associated with modern team sport competition provide numerous opportunities for future research.

2.1 Match Activity During Team Sport Competition

Several studies have documented the different types of movements performed by team sport athletes during training and competition (Abdelkrim, El Fazaa, & El Ati, 2007; Bangsbo, Norregaard, & Thorso, 1991; Bloomfield, Polman, & O'Donoghue, 2007; Deutsch, Maw, Jenkins, & Reaburn, 1998; Duthie, Pyne, & Hooper, 2005; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mayhew & Wenger, 1985; McInnes, Carlson, Jones, & McKenna, 1995; McLean, 1992; Mohr, Krstrup, & Bangsbo, 2003; Spencer et al., 2004). Differences between the movement classifications of such studies are a major cause of inconsistency within the literature (Dobson & Keogh, 2007), where both qualitative (Deutsch, Kearney, & Rehrer, 2007; Spencer et al., 2005) and quantitative (Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krstrup, & Bangsbo,

2003) classifications have been used. In order to minimize differences and produce consistent results that can be accurately compared to other studies, prospective time-motion analysis investigations should use more objective/quantitative measures to classify movements, such as those outlined by Krstrup et al. (2005) and Mohr et al. (2003).

2.1.1 Movement Frequency

The intermittent nature of team sports is demonstrated by the large number of discrete and frequent movements occurring during play (Table 1) and the many stoppages, due to time-outs, penalties, or injuries. Understanding the type of movements and how frequent these movements are executed by team sport athletes assists in the planning the focus of strength and conditioning programmes. For Example, many studies have documented the number of discrete movements (i.e., standing, walking, running, sprinting, jumping, back pedalling, etc.) occurring during team sport competition, with soccer averaging 1,000 to 1,500 movements (Bangsbo, Norregaard, & Thorso, 1991; Bloomfield, Polman, & O'Donoghue, 2007; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krstrup, & Bangsbo, 2003; Rienzi, Drust, Reilly, Carter, & Martin, 2000), basketball averaging approximately 1,000 movements (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995), and rugby union averaging approximately 200 to 700 movements during a match (Deutsch, Maw, Jenkins, & Reaburn, 1998; Duthie, Pyne, & Hooper, 2005; Menchinelli, Morandini, & De Angelis, 1992; Treadwell, 1988). The differences between sports are likely due to several factors including: 1) the playing area of court-based sports (Figure 1); where a small area may necessarily reduce the durations spent performing one particular movement, such as running at a continuous speed (McInnes, Carlson, Jones, & McKenna, 1995); 2) the number of players on the team; where a smaller team size would essentially increase the number of movements performed by each player; and 3) the use of hands as opposed to feet may influence movement frequency in that accelerating, decelerating,

and changing direction would become easier to perform while using hands, subsequently increasing movement frequency.

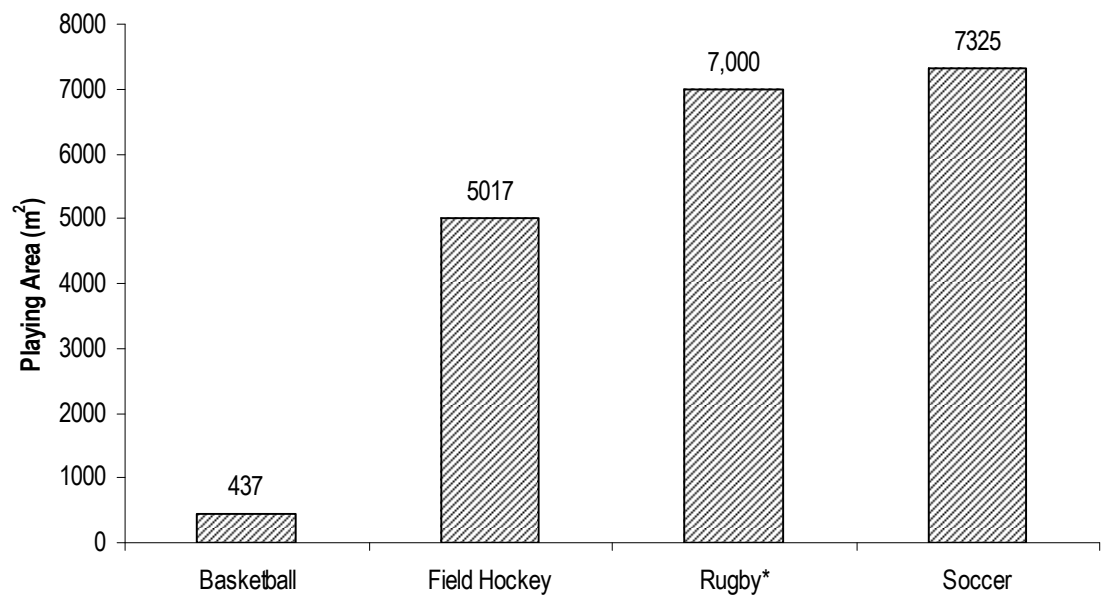


Figure 1. Comparison of playing areas for different team sports. * Excluding in goal areas.

Table 1. Movement frequency in team sports. All values are means \pm SD unless otherwise indicated.

Sport	Reference	N	Movement		Time Spent in Movement Categories (% live time)					
			Frequency	Duration (s)	Standing	Walking	Jogging	Striding	Sprinting	Sport-Specific
Basketball	Abdelkrim et al., 2007	38 M	1050 \pm 51	2.0	15.5 \pm 1.2	14.4 \pm 1.1	11.6 \pm 0.8	10.4 \pm 0.8	5.3 \pm 0.8	42.8
	McInnes et al., 1995	8 M	997 \pm 183	2.0 \pm 0.1						31
	Tessitore et al., 2006	10 M			15	48		17		20
Rugby Union	Deutsch et al., 1998	24 M	618 \pm 64	50.1 \pm 4.5	43.4 \pm 3.1	21.3 \pm 6.9	19.6 \pm 1.2	2.3 \pm 0.5	0.7 \pm 0.5	12.8 \pm 3.9
	Duthie et al., 2005	47 M	711 \pm 47	36.2 \pm 0.8	40.8 \pm 2.6	32.8 \pm 7.8	17.8 \pm 2.2	1.9 \pm 0.4	1.0 \pm 0.6	6.0 \pm 5.3
Soccer	Bangsbo et al., 1991 ^a	14 M	1179	4.5	17.1 \pm 1.5	40.4 \pm 1.6	16.7 \pm 2.3	23.5	0.7 \pm 0.1	1.3 \pm 0.3
	Bloomfield et al., 2007	55 M	1563	13.1 \pm 3.2	4.6 \pm 3.2	14.2 \pm 4.3	28.1 \pm 9.6	11.1 \pm 6.8	4.8 \pm 3.2	37.3
	Capranica et al. 2001	6			4	38		55		
	Mayhew & Wenger, 1985	3 M		6.1	2.3	46.4	38.0	11.3		2.0
	Mohr et al., 2003	18 M	1346 \pm 34	3.5 \pm 0.1	19.5 \pm 0.7	41.8 \pm 0.9	16.7 \pm 0.9	16.8 \pm 0.3	1.4 \pm 0.1	3.7 \pm 0.3
		24 M	1297 \pm 27	3.6 \pm 0.1	18.4 \pm 1.5	43.6 \pm 0.8	19.1 \pm 0.9	15.1 \pm 0.3	0.9 \pm 0.1	2.9 \pm 0.2
	Rienzi et al., 2000	17 M	1431 \pm 206	4.0		32.0	42.0	11.0	4.0	11.0
	Withers et al., 1982	20 M				31.4	47.1			

^a = mean \pm SE; M = Male

Playing position within the team can influence the number of discrete movements performed by an athlete. In rugby union, Treadwell (1988) established that half backs in first class matches had the greatest number of discrete movement patterns ($N=432$) compared with centres ($N=270$), wings/fullback ($N=296$), front five ($N=332$), and back row ($N=320$). However, there were no differences between the number of movement patterns between the backs ($N=333$) and the forwards ($N=326$). In contrast, Duthie et al. (2005) reported significant differences ($P<0.05$) in the frequency and duration of movement patterns between playing positions in rugby union. Rugby forwards performed 122 ± 21 individual work movements per game and 122 ± 21 individual rest movements per game, averaging 6.2 ± 1.8 s and 39.8 ± 7.8 s, respectively. Rugby backs, on the other hand, perform 72 ± 23 work movements and 72 ± 23 rest movements per game with a mean duration of 4.1 ± 0.6 s and 75.8 ± 21.6 s for resting movements, respectively (Duthie, Pyne, & Hooper, 2005). A lot of the differences in rugby union can be attributed to the classification of work and rest activities within the literature. Similarly, professional rugby league players perform different activities during competition depending on playing position, with forwards involved in significantly more physical collisions and tackles than backs (Meir, Newton, Curtis, Fardell, & Butler, 2001). Movement patterns of basketball players do not show significant differences between forwards ($1,022 \pm 45$) and centres ($1,026 \pm 27$) with respect to the number of discrete movements executed (Abdelkrim, El Fazaa, & El Ati, 2007). Basketball guards, however, demonstrated significantly greater movement frequencies ($1,103 \pm 32$, $P<0.01$) than forwards and centres, most probably because guards are usually more involved in ball possession during a game. In soccer, the average number of times during a game that a defender stood still was 266 ± 24 compared to 210 ± 38 for midfielders and 183 ± 21 for forwards (Thatcher & Batterham, 2004). This data is further supported by the recent findings of Bloomfield et al. (2007) where FA Premier League midfielders were found to spend a less amount time standing still and shuffling and spent the most time running and sprinting compared to both defenders and strikers. It appears as though players in positional roles linking defence and

offence, such as midfielders in soccer, guards in basketball, and halfbacks in rugby union, execute more discrete movements than players with primarily attacking or defending roles.

Sport-specific movements, such as jumping in basketball, physical collisions in rugby union, and heading a ball in soccer, also appear to be related to positional roles. For example, the number of tackles and jumps performed during a soccer game has been shown to vary between 1 and 36 depending on the position in the team (Mohr, Krustup, & Bangsbo, 2003). In basketball, the mean number of jumps performed by centres (49 ± 3) appears to be appreciably greater than forwards (41 ± 6) and guards (41 ± 7), most likely due to their major role in both offensive and defensive rebounding (Abdelkrim, El Fazaa, & El Ati, 2007). A greater number of jumps are likely to increase the demands on the muscle during the game if all else is equal and potentially this could result in a greater level of fatigue when playing in this position. While in rugby union, front row forwards and back row forwards average 72 and 78 instances of rucking and mauling, respectively, while the inside and outside backs, on average, engaged in only 12 and 8 rucks or mauls, respectively (Deutsch, Maw, Jenkins, & Reaburn, 1998). The differences in discrete movements within positional roles for a range of sports highlights the importance of position specific conditioning programmes for athletes involved in team sport competition.

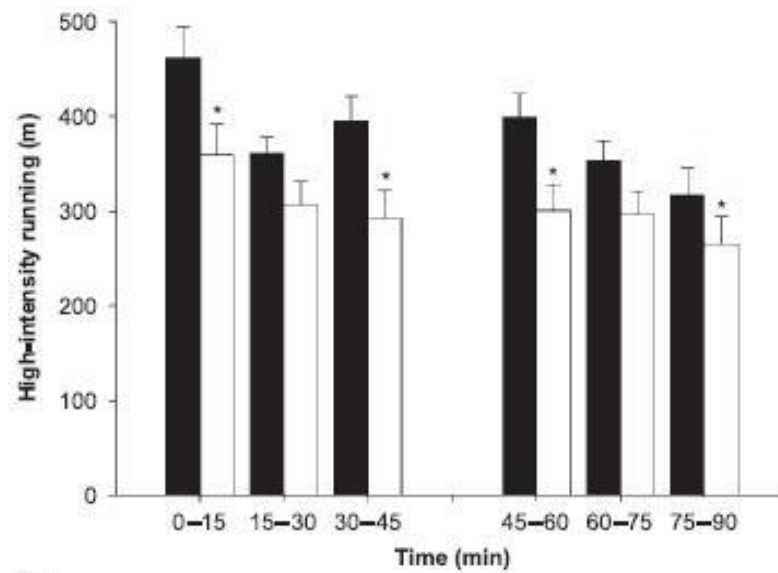
With regards to the rate of recurrence of different movements, the most frequent activities performed in elite soccer games are running (43% Bangsbo, 1994b; 49% Mayhew & Wenger, 1985) and walking (55% Bangsbo, 1994b; 40% Bangsbo, Norregaard, & Thorso, 1991; 46% Mayhew & Wenger, 1985; 32% Rienzi, Drust, Reilly, Carter, & Martin, 2000). Young soccer players however, have been shown to perform more running activity (55% Capranica, Tessitore, Guidetti, & Figura, 2001) and less walking activity (38% Capranica, Tessitore, Guidetti, & Figura, 2001). Approximately 16% of the distance covered by soccer players is moving backwards, sideways, or 'jockeying' for position (Reilly, 1996). In comparison, non-elite senior (>45 years of

age) basketball play has been reported to elicit similar percentages of walking (48% Tessitore et al., 2006) and specific movements (19% Tessitore et al., 2006) during a game, but far less running (17% Tessitore et al., 2006) than that of soccer. In contrast, during elite Tunisian basketball, 41% of live time is spent in specific movements, such as side-shuffling and back pedalling (Abdelkrim, El Fazaa, & El Ati, 2007), which is greater than the 32% reported for Australian professional players (McInnes, Carlson, Jones, & McKenna, 1995), suggesting both a greater emphasis on such movements over the last decade and the differences in playing styles between countries. However, it must be considered that the percentage of time reported by Abdelkrim et al. (2007) includes not only shuffling movements but also back pedalling and basketball specific foot patterns, such as swing steps, therefore making such movements appear to have increased over the last decade. Additionally, during basketball play, combined standing and walking accounts for 30 to 35% of live time (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995). Miller & Bartlett (1994) observed that basketball guards and forwards were solely staying in a static position 27% and 28% of the time, respectively. These data are lower than that reported for walking alone in soccer (Bangsbo, 1994b; Bangsbo, Norregaard, & Thorso, 1991; Mayhew & Wenger, 1985), further emphasizing the impact playing area has on movement frequency in team sport competition. In rugby union, the percentages of time spent jogging ($20 \pm 4\%$ forwards, $16 \pm 4\%$ backs), striding ($1.7 \pm 0.9\%$ forwards, $2.1 \pm 0.8\%$ backs), and sprinting ($0.5 \pm 0.4\%$ forwards, $1.5 \pm 0.5\%$ backs) in super 12 rugby competition (Duthie, Pyne, & Hooper, 2005) are similar to those reported previously for colts (Deutsch, Maw, Jenkins, & Reaburn, 1998), club (Docherty & Sporer, 2000; Treadwell, 1988), and international players (Docherty & Sporer, 2000). The reported percentage of time spent sprinting in rugby union (0.5 to 1.5%) is considerably less than that reported for basketball (5.3% Abdelkrim, El Fazaa, & El Ati, 2007) and soccer (1 to 11% Mohr, Krstrup, & Bangsbo, 2003; van Gool, van Gerven, & Boutmans, 1988; Withers, Maricic, Wasilewski, & Kelly, 1982). This is most probably due to the large amounts of time rugby union players spend engaged in intense static activity (1

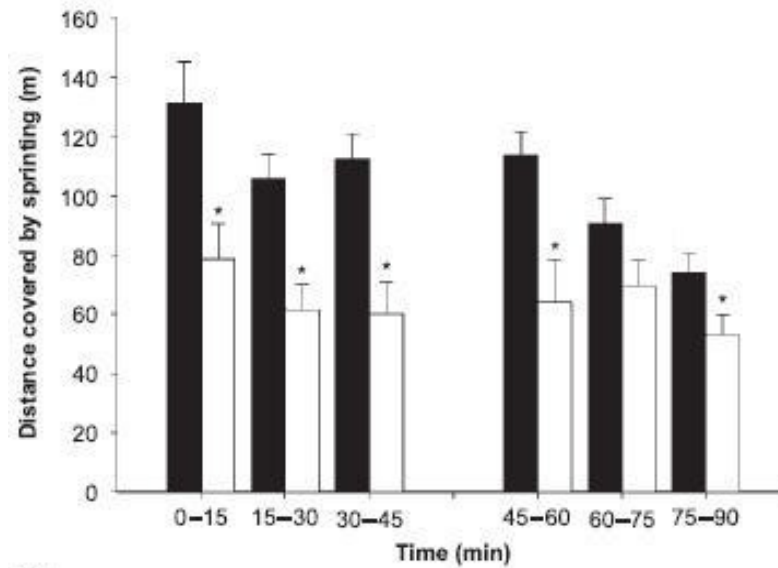
to 16%), such as rucking, mauling, and scrummaging (Deutsch, Maw, Jenkins, & Reaburn, 1998; Docherty & Sporer, 2000), which would essentially limit the opportunities to cover appreciable distance during movements such as sprinting, cruising, or jogging.

2.1.2 Distance Covered

In soccer, the typical distance covered during a match is 10,000 to 13,000 m (Table 2) (Bangsbo, 1994b; Bangsbo, Norregaard, & Thorso, 1991; Helgerud, Engen, Wisloff, & Hoff, 2001; Krustup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mayhew & Wenger, 1985; Mohr, Krustup, & Bangsbo, 2003; Reilly, 1996; Rienzi, Drust, Reilly, Carter, & Martin, 2000; van Gool, van Gerven, & Boutmans, 1988; Withers, Maricic, Wasilewski, & Kelly, 1982). Interestingly, only about 2% of the total distance covered is in possession of the ball, with the majority of activity spent performing 'off the ball' positional manoeuvres peripheral to 'on the ball' actions (Reilly, 1997; Withers, Maricic, Wasilewski, & Kelly, 1982). Additionally, the total distance covered during a match has been associated with playing level, where the difference between distance covered in the first and second halves of a match have been found to be more pronounced (9%) in lower level players (van Gool, van Gerven, & Boutmans, 1988). Similarly, the total distance covered running at high-intensity and sprinting during a match for top class soccer players was 28% and 58% more ($P<0.05$), respectively, than for moderate level players (Figure 2) (Mohr, Krustup, & Bangsbo, 2003). These data suggest that players performing at a higher level are able to sustain physical work due to specifically enhanced fitness for soccer performance (Edwards, MacFadyen, & Clark, 2003).



(a)



(b)

Figure 2. High-intensity running (a) and sprinting (b) in 15-min intervals for top-class soccer players (■) and moderate soccer players (□) (mean \pm SEM). * Significant difference ($P<0.05$) between top-class and moderate players (Mohr et al., 2003).

Table 2. Total distance travelled during team sport competition and positional differences in total distance travelled. Values are means \pm SD.

Sport	Study	Level/Country	Position	Total Distance (m)
Basketball	Blake, 1941 ^a			2000
	Colli et al., 1987			4500 - 5000
Rugby Union	Deutsch et al., 1998	U-19/Australia	6 Front Row	4400 \pm 398
			6 Back Row	4080 \pm 363
			6 Inside Backs	5530 \pm 337
			6 Outside Backs	5750 \pm 405
	Morton, 1978		Centre	5800
Soccer	Bangsbo et al., 1991	P/Denmark	14 Players	10800
			7 Midfield	11400
			7 Defence	10100
			7 Forward	10500
	Helgerud et al., 2001	E/Norway after training	19 Players	8619 \pm 1237
				10335 \pm 1608
	Mohr et al., 2003	EP/Italy	18 Players	10860 \pm 180
		P/Denmark	24 Players	10330 \pm 260
			13 Midfield	11000 \pm 210
			9 Full Back	10980 \pm 230
			9 Forward	10480 \pm 300
			11 Defence	9740 \pm 220
	Rienzi et al., 2000	E/South America	17 Players	8638 \pm 1158
		P/England	6 Players	10104 \pm 703
			9 Defence	8696 \pm 976
			10 Midfield	9826 \pm 1031
	Withers et al., 1982	P/Australia	4 Forward	7736 \pm 929
			20 Players	11527 \pm 1796
			5 Full Back	11980 \pm 1873
			5 Defence	10169 \pm 1460
			5 Midfield	12194 \pm 2366
			5 Forward	11766 \pm 949

^a defensive play only; U-19 under-19-years-old; P professional; E elite; EP elite professional

Extensive research has been conducted concerning the distances covered within specific positional roles in soccer (Bangsbo, Norregaard, & Thorso, 1991; Ekblom, 1986; Mohr, Krstrup, & Bangsbo, 2003; Rienzi, Drust, Reilly, Carter, & Martin, 2000; Withers, Maricic, Wasilewski, & Kelly, 1982). As a consequence, it has been proposed that the greatest physical demands during a soccer match are imposed upon the midfield players due to the role they play in linking attacking and defensive plays (Rienzi, Drust, Reilly, Carter, & Martin, 2000). In support of this, midfield players have been found to cover 5% (Ekblom, 1986) and 10 to 20% (Rienzi, Drust, Reilly, Carter, & Martin, 2000) more distance than forward and defensive players during a 90 min match. Not surprisingly, midfield soccer players have also been reported to cover significantly more distance jogging (47%, $P<0.05$; Rienzi, Drust, Reilly, Carter, & Martin, 2000) and cruising/sprinting (37%, $P<0.05$; Rienzi, Drust, Reilly, Carter, & Martin, 2000) than both forwards and defenders. Forward player positions, on the other hand, in elite South American soccer, cover a significantly greater ($P<0.05$) distance sprinting than defenders (forwards 557 ± 288 m, defenders 231 ± 142 m; Rienzi, Drust, Reilly, Carter, & Martin, 2000) possibly due to a different style of play.

In rugby union, early estimations on the distance covered during a match indicated that a centre covered 5,800 m, of which 2,200 m was walking, 1,600 m jogging, and 2,000 m sprinting (Fry, Morton, & Keast, 1992). This is supported by more recent findings (Deutsch, Maw, Jenkins, & Reaburn, 1998), showing that rugby union players cover between $4,080 \pm 363$ m and $5,750 \pm 405$ m depending on playing position (Table 2). Similar to soccer forwards, positions involving more offensive opportunities, such as outside backs, cover greater distance at sprinting speed compared with rugby union forwards (253 ± 45 m vs. 94 ± 27 m, respectively; Deutsch, Maw, Jenkins, & Reaburn, 1998). Additionally, rugby backs score the majority of the teams points, while in contrast to soccer forwards, travel the greatest distances during a match (Deutsch, Maw, Jenkins, & Reaburn, 1998).

Accurate measures of the distances covered during basketball are limited, but the literature has reported players to cover total distances similar to that of rugby union, about 4,500 to 5,000 m (Colli, Faina, Gallozzi, Lupo, & Marini, 1987) and 2,000 m during defensive play alone (Table 2) (Blake, 1941). The distances travelled by basketball players during competition is not often measured, as in Abdelkrim et al. (2007) and McInnes et al. (1995) studies, possibly due to the large amount of time spent in shuffling movements, where players would often cover little ground despite a high-intensity of activity. Consequently, calculating the total distance travelled may underestimate the true physiological demands of basketball competition. The use of devices such as accelerometers during basketball competition may provide further information regarding the physical demands of basketball play.

In summary, the distance covered by team sport athletes depends on several factors including the quality of the opponents, tactical considerations, and the importance of the game. However, distance covered reflects only a portion of the physiological demands placed on a player during a match, since in addition to running, players are engaged in many other energy demanding activities, such as jumping, accelerating, and turning (Bangsbo, 1994b). This notion is exemplified in data from rugby union where, despite lower exertions, backs cover greater total distances (5,640 m) than forwards (4,240 m, $P < 0.01$; Deutsch, Maw, Jenkins, & Reaburn, 1998). It could be suggested that team sports eliciting greater total distance coverage during competition require a greater demand from aerobic pathways and hence a high VO_{2peak} in such athletes is more important to successful performance. Indeed, a relationship between the total distance covered during team sport competition and maximal aerobic capacity has been demonstrated suggesting that athletes that cover a greater distance during a match also exhibit the highest VO_{2peak} (Helgerud, Engen, Wisloff, & Hoff, 2001). However, it should be acknowledged that it is relatively unknown whether the greater distance covered by fitter players, or after a conditioning

intervention, is actually associated with enhanced match performance e.g. a greater number or more useful/effective contributions to the game and this warrants further investigation.

2.2 The Competition Intensity of Team Sports

Research evidence to date suggests that the average exercise intensity of team sport competition is close to the anaerobic threshold, approximately 70 to 80% $\text{VO}_{2\text{peak}}$. For example, in several studies the average intensity during top-class competitive soccer match play was equivalent to 80 to 90% HR_{peak} or 70 to 80% $\text{VO}_{2\text{peak}}$ (Bangsbo, 1994a; Bangsbo, Mohr, & Krstrup, 2006; Helgerud, Engen, Wisloff, & Hoff, 2001; Mohr, Krstrup, & Bangsbo, 2003; Reilly, 1990, , 1997; Reilly, Bangsbo, & Franks, 2000; van Gool, van Gerven, & Boutmans, 1988). The average intensity of effort during a semi-professional rugby league match has been estimated to be 80% $\text{VO}_{2\text{peak}}$ (Coutts, Reaburn, & Abt, 2003). The mean VO_2 reported for field hockey match play has been reported to be $48.2 \pm 5.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which equated to $77.9 \pm 7.3 \text{ \%VO}_{2\text{peak}}$ (Boyle, Mahoney, & Wallace, 1994), while game intensity in Gaelic football competition at inter-county level is slightly lower, approximately 70 to 75% $\text{VO}_{2\text{peak}}$ (Florida-James & Reilly, 1995). Overall, these data demonstrate moderately high overall exercise intensity during team sport competition and indicates there are negligible differences in average intensity between team sports.

Despite no real differences in overall match intensity between sports, differences are clearly evident when game intensity is divided into the amount of low-, medium-, and high-intensity activities performed during a game. Low-intensity activities in team sports generally include standing, walking, and jogging in all directions. Low-intensity activity accounts for approximately 80% of total match time in soccer (Rienzi, Drust, Reilly, Carter, & Martin, 2000; Withers, Maricic, Wasilewski, & Kelly, 1982) and 85% of match time in rugby union (Deutsch, Maw, Jenkins, & Reaburn, 1998). Older research (Treadwell, 1988) reported that rugby union players spent a lower amount of time (73% for backs, 64% for forwards) engaged in low-intensity activities

(rucking/mauling, scrummaging, standing, walking, and jogging). Game analysis of elite Australian male field hockey players revealed 59% of live game time is spent in low-intensity activity such as standing (11%) and walking (48%; Spencer et al., 2005).

Basketball has lower percentages of time performing low-intensity activities (Figure 3). Such intensities in elite British and Tunisian basketball game play consume 56% and 26% of game time, respectively (Abdelkrim, El Fazaa, & El Ati, 2007; Bishop & Wright, 2006). The demands of elite Australian basketball are different again. McInnes et al. (1995) reported that 35% of live time was spent in low-intensity activities such as walking. Medium-intensity activity has been reported to account for 41% of total time for British basketball players (Bishop & Wright, 2006) and 28% of live time for Tunisian players (Abdelkrim, El Fazaa, & El Ati, 2007), while Australian basketball play reportedly involves greater than 65% of live time engaged in activities of greater intensity than walking (McInnes, Carlson, Jones, & McKenna, 1995). The study by Abdelkrim et al. (2007) demonstrated that basketball players from various positional groups spent approximately 11% of live time in medium-intensity running, similar to that recorded by other authors (McInnes, Carlson, Jones, & McKenna, 1995). Furthermore, U.S. collegiate basketball players spend approximately 94% of game time exercising at sub-maximal levels (Taylor, 2003).

It is noticeable in some sports, especially basketball, that there has been great variation in the amount of time reportedly spent in low-intensity activities. The notable differences within and between team sports could be explained by several reasons: 1) the method used to classify different exercise intensities; 2) the number of games analyzed could lead to an over-estimation or under-estimation of the durations working at different intensities; and 3) the importance of the game and the level of the opposition could both increase or decrease the percentage of high-intensity activities performed. Nevertheless, research to date suggests that the majority of game time in team sports is performed at sub-maximal levels, emphasising the importance of aerobic

fitness in team sport competition. Although research suggests that team sport players spend the majority of their time in low-intensity activities, success depends on the less frequent but higher-intensity activities that involve combinations of sprinting, jumping, and tackling which place extreme demands on the anaerobic energy systems during competition, but rely on an effective aerobic system for rapid recovery. The high-intensity activities during team sports will be discussed in a later section (Section 2.3 High-Intensity Periods During Team Sport Competition).

A deeper understanding of game intensity can be gained when exercise ratios are considered. In professional soccer, the high-intensity to low-intensity activity ratio has been reported to be approximately 1:7 to 1:12 (Bangsbo, 1994a; Mayhew & Wenger, 1985; O'Donoghue, Boyd, Lawlor, & Bleakely, 2001), meaning that for every four seconds spent running at very high-intensities, approximately 28 s is spent in activities more aerobic in nature. Similar exercise ratios in rugby league have been reported where it is recognized that the ratio of high-intensity activity to low-intensity activity is higher for forwards (1:7 to 1:10) compared to backs (1:12 to 1:28; Meir, Newton, Curtis, Fardell, & Butler, 2001). Meir et al. (2001) suggested that in professional rugby league, every four seconds of high-intensity activity is followed by approx 30 to 80 s of low-intensity activity, with no single high-intensity effort exceeding ten seconds. The results of Bishop and Wright (2006) indicate that if all high-intensity activity in basketball is considered as exercise and all other activities are defined as rest, the work:recovery ratio would be 1:9, which is similar to soccer activity ratios of 1:7, 1:8 and 1:12 (Bangsbo, 1994a; Mayhew & Wenger, 1985; O'Donoghue, Boyd, Lawlor, & Bleakely, 2001).

More specifically, the ratio of rest:low:high-intensity exercise during elite South American soccer competition has been reported to be 3:16:1 (Rienzi, Drust, Reilly, Carter, & Martin, 2000). In contrast, an activity ratio between low:medium:high-intensity of 5:4:1 exists in British basketball play (Bishop & Wright, 2006). Conversely, the mean work to rest ratio for under-19 colts (rugby

union) has been reported as 1:1.4 for forwards and 1:2.7 for backs (Deutsch, Maw, Jenkins, & Reaburn, 1998). This is similar to previously reported data of McLean (1992) who reported most work to rest ratios during international match play were in the range of 1:1 or 1:1.9. The difference between rugby union and other team sports could be as a result of the definition of work and rest periods. In Deutsch et al. (1998) and McLean (1992) work periods were defined as those when a player was cruising, sprinting, rucking, mauling or scrummaging, with the remaining activities defined as rest, whereas other studies have not needed to consider the impact of static efforts physically opposing an opponent on game intensity.

Collectively, these studies reveal a large proportion of game time in team sport competition is devoted to low-to-moderate intensity effort, suggesting a great dependence upon aerobic energy transfer. Additionally, these studies demonstrate that only a small proportion of game time is spent engaged in high-intensity activities, yet it is these high-intensity periods that are of vital importance to successful performance in team sport events. Therefore, possessing the ability to recover adequately during the lower-intensity periods could be considered of paramount importance.

2.2.1 Heart Rate

With the advent of portable and downloadable HR monitors, team sport players are now able to wear monitors during training and competition. Such information can then be used to determine a close measure of the physiological stress and energy expenditure associated with match play (McInnes, Carlson, Jones, & McKenna, 1995; Rodriguez-Alonso, Fernandez-Garcia, Perez-Landaluce, & Terrados, 2003). Heart rate has been determined during several team sport situations including basketball (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995; Rodriguez-Alonso, Fernandez-Garcia, Perez-Landaluce, & Terrados, 2003), field hockey (Boyle, Mahoney, & Wallace, 1994), rugby union (Coutts, Reaburn, & Abt, 2003;

Deutsch, Maw, Jenkins, & Reaburn, 1998; McLean, 1992), as well as soccer training and competition (Ali & Farrally, 1991; Bangsbo, 1994a; Bangsbo, Norregaard, & Thorso, 1991; Capranica, Tessitore, Guidetti, & Figura, 2001; Reilly, 1997; van Gool, van Gerven, & Boutmans, 1988). The most widely used strategy has been to measure HR during match play and juxtapose the observations on HR-VO₂ regression lines determined during incremental running on a treadmill (Reilly, 1997), as it is well established that during sub-maximal exercise there is a linear relationship between oxygen uptake and HR (Karvonen & Vuorimaa, 1988; McArdle, Katch, & Katch, 1996; Saltin & Astrand, 1967). Furthermore, by subdividing HR records, expressing them as a percentage of HR_{peak}, one can determine the time spent below, at or above LT during match play (Wilkins, Petersen, & Quinney, 1991; Woolford & Angove, 1992). While direct measurements of VO₂ using portable metabolic systems are more accurate in quantifying energy expenditure during competitive matches, the equipment used may restrict vision and movement (Boyle, Mahoney, & Wallace, 1994), therefore, the use of HR is probably the most viable method for collecting information surrounding energy expenditure (Boyle, Mahoney, & Wallace, 1994).

Team sport athletes typically display high HR values during training and even more so during competition. Heart rates during soccer competition average 150 to 180 b·min⁻¹ (Ali & Farrally, 1991; Bangsbo, 1994a; Bangsbo, Norregaard, & Thorso, 1991; Capranica, Tessitore, Guidetti, & Figura, 2001; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krstrup, Nybo, Nielsen, & Bangsbo, 2004; Reilly, 1997; Stroyer, Hansen, & Klausen, 2004; van Gool, van Gerven, & Boutmans, 1988), and are rarely below 65% of HR_{peak}, suggesting that blood flow to the exercising leg muscle is continuously higher than at rest, meaning oxygen delivery is high (Bangsbo, Mohr, & Krstrup, 2006). Similar game HR values have been recorded during basketball with 171 ± 4 b·min⁻¹ and 168 ± 9 b·min⁻¹ being reported for live time (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995), equating to 91 ± 2% HR_{peak} and 89 ± 2% HR_{peak}, respectively. In addition, 50% of live time in basketball is spent with HR

responses greater than 90% HR_{peak} (Figure 4) (McInnes, Carlson, Jones, & McKenna, 1995). This is surprising given the small amount of time spent performing high-intensity exercise (15 to 16.1%, Figure 3) during basketball competition (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995). The high HR responses during soccer and basketball appear to conflict with observations that the majority of live time is spent performing activities of low- or sub-maximal intensity.

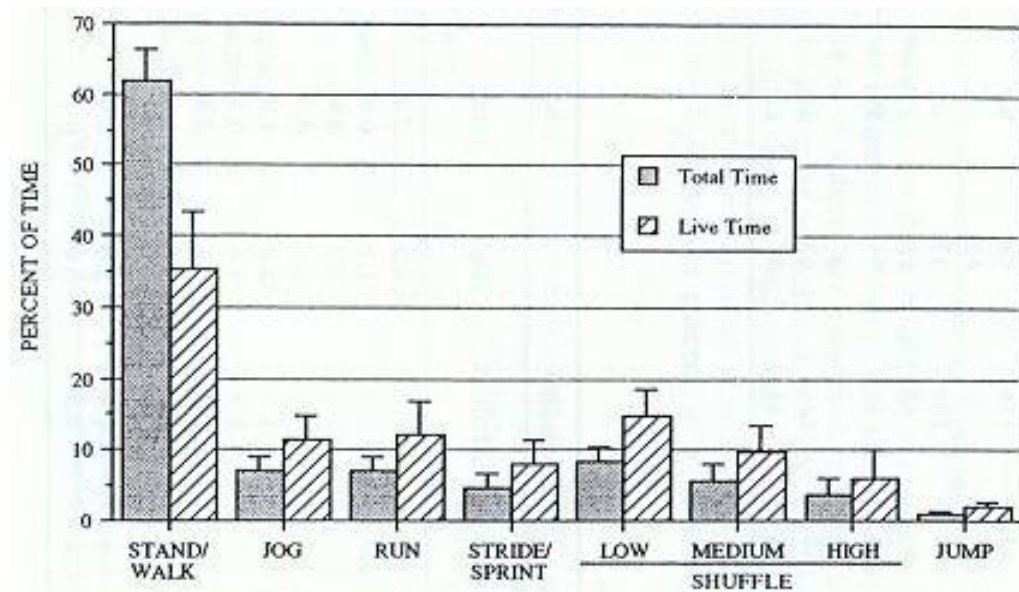


Figure 3. Percent of total time and live time spent in the categories of movement during basketball competition. Values are means \pm SD (McInnes et al., 1995).

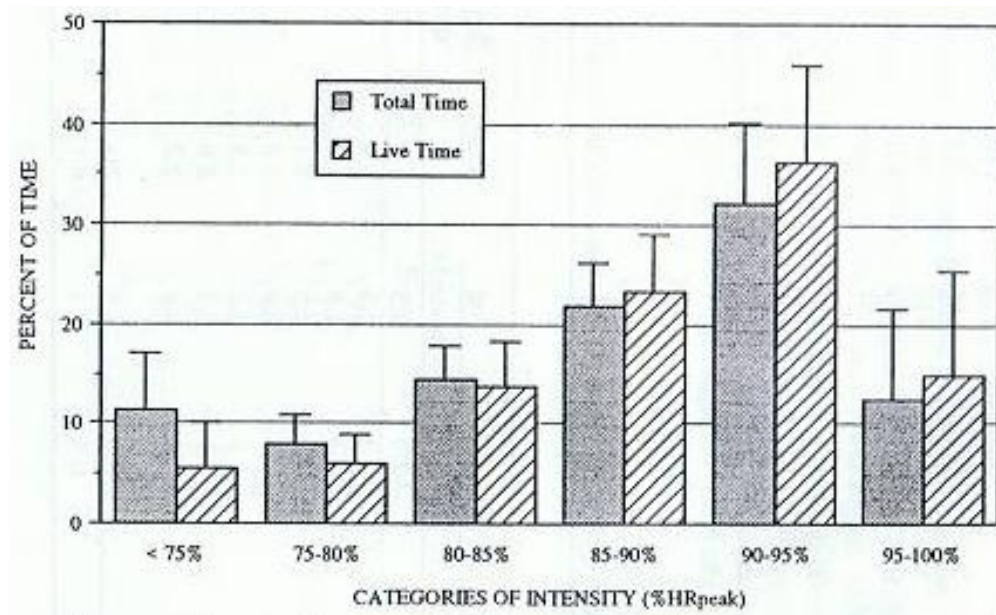


Figure 4. Percent of total time and live time spent in different heart rate categories during basketball competition. Values are means \pm SD (McInnes et al., 1995).

Further evidence to support the concept that high HR values are present despite a large majority of game time spent performing low- or sub-maximal intensity activities can be found amongst rugby studies. Although there are limited HR data on rugby league and rugby union players due to logistical problems in taking measurements during highly vigorous contact sports, Morton (1992) reported that a rugby union back's HR throughout a game averaged $161 \text{ b} \cdot \text{min}^{-1}$ when approximately 85% of game time is spent performing low-intensity activities (Deutsch, Maw, Jenkins, & Reaburn, 1998), while the mean HR in semi-professional rugby league players during competition has been reported as $166 \text{ b} \cdot \text{min}^{-1}$ (Coutts, Reaburn, & Abt, 2003). Furthermore, the results of Deutsch et al. (1998) suggest that front row forwards and back row forwards in rugby union may spend up to 20% of match time above 95% HR_{peak}, with all forwards spending 72% of the match with HR responses greater than 85% HR_{peak}, while backs spent the majority of time in moderate- (37% of total time) and low-intensity (18% of total time) activities (Figure 5). Likewise, the mean HR observed during field hockey match play has been reported to be $159 \pm 8 \text{ b} \cdot \text{min}^{-1}$ (Boyle, Mahoney, & Wallace, 1994). The relatively high average HR observed during team sport

match play suggest high levels of aerobic loading and reinforce the importance of aerobic fitness in team sport performance.

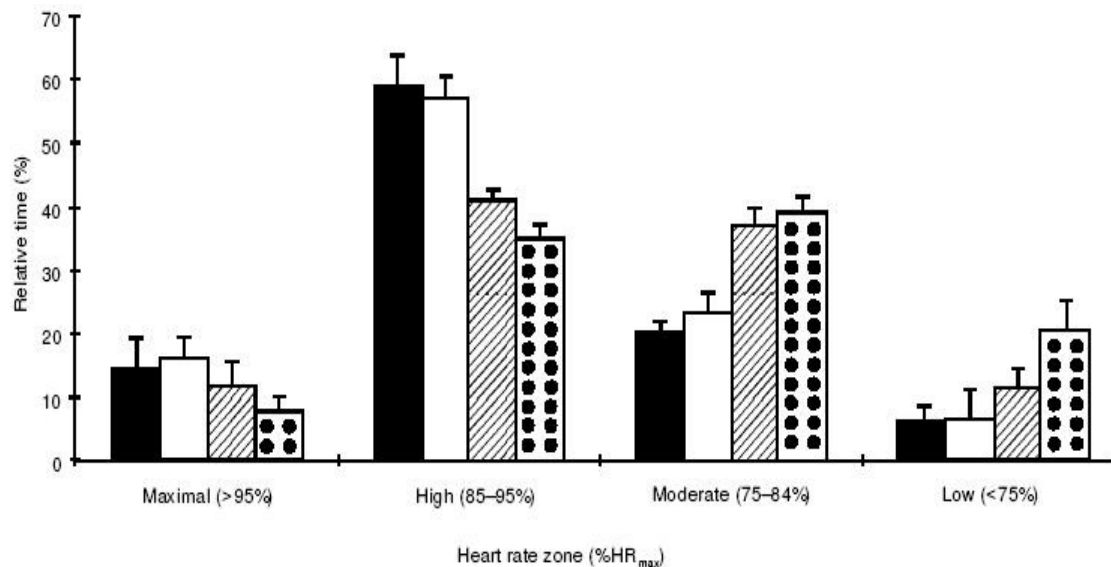


Figure 5. Mean (\pm SEM) percent time spent in four heart rate zones (%HR_{peak}) for the four positional groups ($N = 6$ for each group) during rugby union match play. (■) front row forwards; (□) back row forwards; (▨) inside backs; (▤) outside backs (Deutsch et al., 1998).

It has been observed that HR declines during the latter stages of team sport competition, which may be due to a greater number of time-outs, especially in sports such as basketball, where HR responses have been reported to decrease to approximately 60% HR_{peak} (McInnes, Carlson, Jones, & McKenna, 1995). In soccer, mean HR has been reported during the first half of a match as 169 b·min⁻¹ while for the second half the mean value was 165 b·min⁻¹, corresponding to 87% and 84% HR_{peak}, respectively (van Gool, van Gerven, & Boutmans, 1988). Similarly, the average HR during elite youth soccer matches average 177 to 178 b·min⁻¹ for the first half and 173 to 174 b·min⁻¹ for the second half (Stroyer, Hansen, & Klausen, 2004). These data, although limited, suggested that exercise intensity, as indicated by HR, decreases during the latter stages of soccer match play most likely as a result of fatigue and a drop in game intensity. As previously discussed (Section 2.1.2 Distance Covered), the decreases in mean HR between halves and/or

quarters would essentially be influenced by similar factors as that which affect game intensity and the total distance travelled during competitive team sport.

Although measures of competition HR prove useful in estimating energy expenditure during team sport games and matches, there are certain factors that may influence the accuracy of such data. It is well known that HR is not only influenced by exercise intensity and duration, but it is also affected by factors such as psychological arousal and anxiety (Tumilty, 1993). This is supported by the HR response to free-throws in basketball, a low-intensity activity, averaging 70 to 75% HR_{peak} (McInnes, Carlson, Jones, & McKenna, 1995). However, as far as the emotional influence on HR is concerned it has been suggested that psychological factors have more influence on HR at rest or during low-intensity work, but at higher intensities the emotional influence on HR is somewhat neutralized by the higher workload (Saltin & Astrand, 1967). Another factor influencing the HR- VO_2 relationship is bouts of static work in which athletes are maintaining position against physical resistance from a competitor (i.e., scrummaging during rugby), which may also contribute to high HR responses in certain positions within team sports. During such activities, nearly all the muscles are involved in isometric and dynamic work, which has a noteworthy effect on HR values reached (Patterson & Pearson, 1985). Moreover, factors such as temperature, dehydration, hyperthermia, and mental stress elevate HR without affecting oxygen uptake (Bangsbo, Mohr, & Krstrup, 2006; Brooks, Hittelman, Faulkner, & Beyer, 1971; McArdle, Katch, & Katch, 1996; Vokac, Bell, Bautz-Holter, & Rodahl, 1975). Overall, the data discussed reveal an elevated mean HR during team sport competition, suggesting a high aerobic loading. It appears that mean HR is equivalent to values just below LT, indicating the highest possible intensity is maintained during team sport competition. Then again, HR collected during a competitive situation must be interpreted with caution and only represents an estimation of energy expenditure.

2.2.2 Blood Lactate

Blood lactate concentration measures are frequently used to estimate intensities during team sport competition and can provide information regarding the aerobic and anaerobic contributions to energy expenditure (Smekal et al., 2003), supplementing HR data. The high-intensity of team sports is made evident with peak B[Lac] values above 12 mmol⁻¹ being measured during basketball (McInnes, Carlson, Jones, & McKenna, 1995) and soccer competition (Bangsbo, 1994a; Ekblom, 1986; Krstrup, Mohr, Steensberg et al., 2006). Mean B[Lac] values collected during basketball, field hockey, rugby league, rugby union, and soccer competition are in the ranges of 4 to 10 mmol⁻¹ (Table 3) (Abdelkrim, El Fazaa, & El Ati, 2007; Bangsbo, 1994a; Coutts, Reaburn, & Abt, 2003; Deutsch, Maw, Jenkins, & Reaburn, 1998; Ekblom, 1986; Krstrup, Mohr, Steensberg et al., 2006; McInnes, Carlson, Jones, & McKenna, 1995; McLean, 1992; Sunderland & Nevill, 2005; Tessitore et al., 2006; Thatcher & Batterham, 2004). Consistent with HR measures, the mean B[Lac] values appear to be lower at the end of the second half when compared with those taken after the first half of team sport matches. This is especially apparent in elite basketball, where B[Lac] values have been reported to drop from approximately 7.3 mmol⁻¹ at half time to approximately 5.4 mmol⁻¹ at full time (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995). Equally as noticeable, B[Lac] values for soccer competition have been reported to decline from 4.9 mmol⁻¹ after the first half to 3.7 mmol⁻¹ at full time in elite Danish players (Bangsbo, Norregaard, & Thorso, 1991). The lower B[Lac] levels reported towards the end of match play is not surprising given the declines in game intensity, demonstrated through the total distance travelled and HR during the second halves of games or matches. This indicates that B[Lac] concentration is not a major determining factor of fatigue in team sports. To support this, a B[Lac] concentration of up to 10 mmol⁻¹ was not associated with a significant performance decline in repeated sprint bouts separated by 120 s of recovery, but, while at the same 10 mmol⁻¹ B[Lac], sprint performance deteriorated when recovery was only 30 s (Seiler & Hetlelid, 2005). Thus, high B[Lac] levels along with decreased muscle glycogen are

usually connected with impaired neuromuscular performances. The negative impact of high levels of B[Lac] on coordinative function have been demonstrated by Ekblom (1986), where soccer players were able to juggle the ball on average 64 times consecutively before a hard training bout, compared with three times immediately after the training bout (B[Lac] level approximately 15 mmol⁻¹). Furthermore, because of its relationship with intramuscular acidosis (Loftin, Anderson, Lytton, Pittman, & Warren, 1996), B[Lac] has been linked to fatigue (Deutsch, Kearney, & Rehrer, 1998). However a greater muscle buffer capacity may allow high levels of B[Lac] to accumulate without a simultaneous increase in H⁺ concentration, which is associated with fatigue (Allen & Westerblad, 2001). Therefore, the role of B[Lac] in the fatigue process remains relatively unclear.

Positional differences in B[Lac] concentration have also been found in the research. According to playing position, the mean plasma lactate for basketball guards is significantly higher ($P < 0.05$) than that for centres (6.36 ± 1.24 mmol⁻¹ vs. 4.92 ± 1.18 mmol⁻¹, respectively), possibly due to the greater percentage of live time spent in high-intensity activities by the guards (Abdelkrim, El Fazaa, & El Ati, 2007). In rugby league and rugby union, the higher exertion of forward players is in part reflected by their respective B[Lac]. Forwards tend to sustain higher mean B[Lac] than backs (6.6 to 8.5 mmol⁻¹ vs. 5.1 to 6.5 mmol⁻¹, respectively; Coutts, Reaburn, & Abt, 2003; Deutsch, Kearney, & Rehrer, 1998) during match play and it has been demonstrated that during Scottish first division matches, rugby union centres and props achieve 56% and 85% of their peak B[Lac] values, obtained during an incremental treadmill test to exhaustion (McLean, 1992). No doubt the differences in B[Lac] reached during competition between forwards and backs in rugby union is due to the greater amount of time spent performing high-intensity activity, such as scrummaging, by forwards, and the limited recovery time that follows such work periods (Deutsch, Kearney, & Rehrer, 2007; Duthie, Pyne, & Hooper, 2005).

As previously mentioned, blood or plasma lactate concentration during team sport competition is often used as an indicator of anaerobic lactic acid energy production. However, this has been shown to be a poor representation of muscle lactate (Krustrup, Mohr, Steensberg et al., 2006). The rate of lactate removal is significantly higher in skeletal muscle than in blood (Krustrup, Mohr, Steensberg et al., 2006) and, therefore, during intermittent exercise the B[Lac] can be high even though the muscle lactate concentration is relatively low (Gaitanos, Williams, Boobis, & Brooks, 1993; Nevill, Boobis, Brooks, & Williams, 1989). This could influence the interpretation of true metabolic demand during intermittent sports. Furthermore, the substantially high B[Lac] seen in soccer (Bangsbo, 1994a; Krustrup, Mohr, Steensberg et al., 2006; McInnes, Carlson, Jones, & McKenna, 1995) may not represent a high lactate production in a single action, but rather an accumulated/balanced response to a number of repeated high-intensity activities (Bangsbo, Mohr, & Krustrup, 2006). This is demonstrated by the significant correlation between B[Lac] and the percentage of time spent in high-intensity activity five minutes before sampling (Abdelkrim, El Fazaa, & El Ati, 2007; Bangsbo, 1994a). Overall, B[Lac] values provide valuable information concerning the metabolic demands of team sport competition and follow a similar pattern to that of HR by declining towards the end of matches. This in itself suggests that high B[Lac] is not a major contributor to the fatigue associated with the latter stages of team sport competition. Also, B[Lac] more accurately represents an accumulated response to repeated high-intensity efforts and it has been shown to be a poor indication of muscle lactate concentration.

Table 3. Peak blood lactate concentrations (B[Lac]) measured during team sport competition. Values are means \pm SD.

Sport	Reference	Level/Country	N/Position	Peak B[Lac] (mmol ⁻¹)
Basketball	Abdelkrim et al., 2007	E/Tunisia	38 Players	5.49 \pm 1.2
			8 Guards	6.36 \pm 1.2
			12 Centres	4.92 \pm 1.2
	McInnes et al., 1995	E/Australia	8 Players	8.50 \pm 3.1
Rugby League	Atkins, 2006	P/England	23 Players	10.8 \pm 1.1
	Coutts et al., 2003	SP/England	27 Players	9.10 \pm 1.1
		SP/Australia	17 Players	7.20 \pm 2.5
Rugby Union	Deutsch et al., 1998	U-19/Australia	12 Forwards	8.5
	McLean, 1992	E/Scotland	12 Backs	6.5
			3 Props	5.10 \pm 0.7
			3 No. 8's	6.60 \pm 0.5
			3 Stand-off	5.90 \pm 1.4
			3 Props	5.60 \pm 0.3
			3 No. 8's	6.70 \pm 2.0
			3 Centres	5.80 \pm 0.6
Soccer	Al-Hazzaa et al., 2001	E/Saudi Arabia	154 Players	9.80 \pm 1.1
			64 Full Back	10.5 \pm 1.0
			67 Centre Back	9.30 \pm 1.1
			23 Midfield	9.90 \pm 0.6
	Bangsbo et al., 1991	P/Denmark	9 Players	4.9
	Chamari et al., 2005	E/Norway	18 Players	10.4 \pm 1.6
	Helgerud et al., 2001	E/Norway	9 Players	8.10 \pm 1.5
		after training period		8.50 \pm 1.9
		E/Norway	10 Players	7.80 \pm 1.4
		after training period		7.90 \pm 1.5
	Krustrup et al., 2006	4D/Denmark	31 Players	6.70 \pm 0.9
	Labsy et al., 2004	N/France	14 Players	11.4 \pm 1.0
	Lemmink et al., 2003	A/Netherlands	15 Players	7.60 \pm 1.6
	Metaxas et al., 2005	E/Greece	35 Players	10.3 \pm 2.0
	Psotta et al., 2005	E/Czech Republic	29 Players	9.90 \pm 1.6
	Williford et al., 1999	Y/United States	13 Players	6.10 \pm 1.4

4D = 4th division; A = amateur; E = elite; N = national; P = professional; SP = semi-professional; U-19 = under-19-years-old; Y = youth

2.3 High-Intensity Periods During Team Sport Competition

In team sports an athlete's ability to repeatedly perform maximal or near-maximal sprints of short duration (1 to 7 s), perform quick changes in direction, and repeatedly jump is fundamental to success (Bishop & Spencer, 2004; Denadai, Gomide, & Greco, 2005). In basketball, field hockey, rugby union, and soccer, decisive actions are often preceded by sprints. In these sports, players have to sprint to receive the ball before their opponents and then to kick, throw, or hit the ball before the opponent reaches it. Therefore, an important fitness component of intermittent sports is what has been termed repeated sprint ability (RSA) or, more broadly, anaerobic endurance.

High-intensity periods generally include sprinting in all directions, but can also consist of near-maximal running or striding, repetitive jumping, rucks/mauls, and scrums in rugby league or rugby union. Soccer players tend to perform the greatest number of brief intense actions, reportedly 125 to 250 during a game (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krustrup, & Bangsbo, 2003). This equates to approximately one sprint every 90 s or a high-intensity effort (striding plus sprinting) once every 30 s (Bangsbo, Norregaard, & Thorso, 1991; Mayhew & Wenger, 1985; Mohr, Krustrup, & Bangsbo, 2003; Withers, Maricic, Wasilewski, & Kelly, 1982). Very similar to soccer is basketball, with players observed to perform 105 to 242 brief intense actions during a game (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995; Taylor, 2003). It appears though, that the intensity of basketball has increased over the last decade with McInnes et al. (1995) reporting 105 ± 52 high-intensity efforts per game, Taylor (2003) 135 ± 32 , and Abdelkrim et al. (2007) 193 ± 24 high-intensity activities per game. These figures equate to approximately one high-intensity effort every 12 to 23 s. This is not surprising, due to the fact that basketball players only have 24 s after a turnover to move the ball into their offensive half, create a play, and score a basket. This demonstrates the influence of rules on activity frequency and intensity. The high-intensity of basketball is further demonstrated by Tessitore et al. (2006), where during a senior basketball match, high-intensity activity was

predominant with only 3% of the match spent with a HR response $<70\%$ HR_{peak} . Using a different method of analysis, in field hockey, players perform an average of 17 repeated sprinting bouts throughout a game, with each bout consisting of 4 ± 1 sprints (Spencer et al., 2004). Specific to rugby union, the mean number of scrums per game ranges between 32 and 38 (Deutsch, Kearney, & Rehrer, 2007; McLean, 1992), while other high-intensity periods, such as line-outs and rucks/mauls, average 41 and 67 to 73, respectively (Deutsch, Kearney, & Rehrer, 2007; McLean, 1992). These figures indicate that roughly one scrum/ruck/maul is carried out every 33 s. It should be noted that older research classified rucks/mauls and scrums as low-intensity activity (Treadwell, 1988), demonstrating how the opinion regarding the intensity of these activities over the last two decades has changed. It is clear from this data that team sports involve repeated high-intensity efforts, interspersed with inadequate recovery time.

The ability to sprint repeatedly depends on several factors, including sprint duration (Balsom, Seger, Sjodin, & Ekblom, 1992b). Sprinting efforts in team sports are typically of short duration with means of 1 to 4 s in basketball (Abdelkrim, El Fazaa, & El Ati, 2007; Bishop & Wright, 2006; McInnes, Carlson, Jones, & McKenna, 1995), 1 to 5 s in field hockey (Spencer et al., 2004; Spencer et al., 2005), 2 to 3 s in rugby union (Deutsch, Kearney, & Rehrer, 2007), and 2 to 4 s in soccer (Bangsbo, 1994a; Bangsbo, Norregaard, & Thorso, 1991; Mayhew & Wenger, 1985; Mohr, Krstrup, & Bangsbo, 2003; Thatcher & Batterham, 2004; Withers, Maricic, Wasilewski, & Kelly, 1982). The rules and structure of team sport games, including player numbers and playing area, would necessarily reduce the duration of maximal sprints, placing a large emphasis on acceleration, deceleration, and changing direction (Abdelkrim, El Fazaa, & El Ati, 2007).

Regarding total match time, the frequency and duration of high-intensity activity for most team sports ranges approximately between 15 and 19% of the total distance covered (Bangsbo & Lindquist, 1992; Rienzi, Drust, Reilly, Carter, & Martin, 2000; Withers, Maricic, Wasilewski, &

Kelly, 1982) or 10 to 15% of game time (Abdelkrim, El Fazaa, & El Ati, 2007; Docherty & Sporer, 2000; McInnes, Carlson, Jones, & McKenna, 1995). Exceptions to these generalizations have been observed in British basketball play where 6.1% of game time was spent in high-intensity movements (Bishop & Wright, 2006). These exceptions could be explained by the different approaches used during time-motion analyses to categorize high-intensity movements. Interestingly, it has been reported that the total distance covered during a soccer match is moderately related to the total distance covered at high-intensities ($r=0.61$, $N=20$, $P<0.05$; Bangsbo & Lindquist, 1992). In line with this, the distance covered at high-intensity in soccer is closely related to the aerobic fitness of players ($r=0.81$, $P<0.001$; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005), while in basketball the amount of live time spent in high-intensity activity is significantly correlated with VO_{2peak} ($r=0.55$, $P<0.05$; Abdelkrim, El Fazaa, & El Ati, 2007).

Continuing with this theme, the quality of soccer performance is supposedly associated with the amount of high-intensity running during a match (Bangsbo, Norregaard, & Thorso, 1991) and tends to differentiate top class players from those of a lower skill level (Bangsbo, Norregaard, & Thorso, 1991; Ekblom, 1986; Mohr, Krstrup, & Bangsbo, 2003). However, convincing data is limited and therefore this topic warrants further research. According to the literature, it seems that the higher the level of soccer, the more frequent and lengthy the periods of high-intensity physical exercise and this is exemplified with international soccer players performing 28% more high-intensity running (2,430 m vs. 1,900 m; $P<0.05$) and 58% more sprinting (650 m vs. 410 m) than professional soccer players of a lower standard (Mohr, Krstrup, & Bangsbo, 2003).

The amount of high-intensity activities also exhibits trends within playing positions. For example, rugby union backs have superior sprinting ability in relation to forwards, performing nearly double the amount of sprints (13 ± 6 vs. 24 ± 7 , respectively; Duthie, Pyne, Marsh, & Hooper, 2006) per game and achieving faster maximal speeds over 40m (9%) and 30 m (10%) compared to

forwards (Quarrie, Handcock, Toomey, & Waller, 1996). The ability to accelerate appears to be the most critical factor in performance for rugby forwards given that the mean duration of sprints is less than three seconds and the maximal sprint duration is less than five seconds, most probably precluding the attainment of maximal velocity (Duthie, Pyne, & Hooper, 2005). Conversely, backs have sprint durations of six seconds, which permits the attainment of maximal speed. However, when all high-intensity efforts are compared, rugby union forwards spend 14% of game time in such activities while backs only spend 6% (Duthie, Pyne, & Hooper, 2005). This difference is likely due to a greater amount of time spent engaged in maximal isometric contractions during scrums (Duthie, Pyne, & Hooper, 2005). A recent time-motion analysis of rugby union competition (Deutsch, Kearney, & Rehrer, 2007) provides a different perspective on the differences between positions, with forwards and backs reportedly spending 12 to 13% and only 4.5% of total match time performing high-intensity work, respectively. This difference is likely due to the greater number of tackles, rucks/mauls and intense static work (scrums) inherent in forward playing positions. Analysis by playing position in basketball shows that guards averaged more sprints and spent greater live time in this activity than forwards and especially centres (Abdelkrim, El Fazaa, & El Ati, 2007). This may be because guards are usually the first players who assure the fast transitions from defence to offence and vice versa. In elite field hockey, positional differences in the frequency of sprints performed is greater with strikers and inside forwards, performing approximately twice as many sprints compared with fullback players (Spencer et al., 2004). While in soccer, the percentage of match time spent performing high or very high-intensity activity was $6.6 \pm 2.0\%$ for the strikers, $5.2 \pm 2.4\%$ for the midfielders and $4.9 \pm 1.7\%$ for the defenders (Bloomfield, Polman, & O'Donoghue, 2007). It appears from these data that playing positions associated with goal scoring (i.e., backs in rugby union and strikers in field hockey) perform more high-intensity sprints, except in basketball, where guards perform the highest number of sprints and are commonly acknowledged as the playmakers.

A profound decrease in the time involved in high-intensity activities has been observed in the last quarter of each half in basketball play (Abdelkrim, El Fazaa, & El Ati, 2007). Similar findings have been reported for soccer, where the distance and number of sprints is lower in the second half of the match (Bangsbo, Norregaard, & Thorso, 1991; Mohr, Krstrup, & Bangsbo, 2003). This is consistent with physiological data. A decline in high-intensity effort during the last stages of a game is likely to increase ball possession, and, consequently, the proportion of straight play and fast breaks may decrease, causing the entire game pace to slow down (Abdelkrim, El Fazaa, & El Ati, 2007). Moreover, tactical emphasis, especially towards the latter stages of team sport games, is generally placed on retaining possession and producing quick decisive passing movements when an opportunity is presented or created (Rienzi, Drust, Reilly, Carter, & Martin, 2000). Such tactical restraints reduce the need for players to perform a lot of activity in trying to regain possession of the ball and thus reducing the total distance covered and level of intensity (Rienzi, Drust, Reilly, Carter, & Martin, 2000).

The ability of team sport athletes to keep producing high-intensity efforts may be dependent upon how effectively the PCr system is replenished, which, to a certain extent, is heavily reliant upon factors related to aerobic fitness (Bishop, Edge, & Goodman, 2004; Hamilton, Nevill, Brooks, & Williams, 1991; McMahon & Wenger, 1998) as well as the ability to buffer hydrogen ions (H^+ ; Bell, Petersen, Quinney, & Wenger, 1988; Bishop, Edge, & Goodman, 2004; Nevill, Boobis, Brooks, & Williams, 1989). To support this, Dupont et al. (2005) suggested that individuals with a higher VO_{2peak} , and consequently faster VO_2 kinetics during constant load exercise, might also have a faster adjustment of VO_2 during repeated high-intensity exercise, leading to a lower relative decrease in performance, confirming that the contribution of oxidative phosphorylation might be one of the determinants for repeated high-intensity performance. Indeed, Phillips et al. (1995) found that a faster VO_2 kinetics was associated with a reduction in the fall of muscle PCr concentration, allowing improved power maintenance across multiple sprints. However, in well

trained subjects, factors other than $\text{VO}_{2\text{peak}}$ may be more important to repeated high-intensity activity, including a likely contribution from differences in muscle buffer capacity and/or ion regulation. In support, the results of Bishop et al. (2003) demonstrate that RSA is not significantly correlated with $\text{VO}_{2\text{peak}}$ in elite team sport athletes. This suggests that RSA may not be dependent on $\text{VO}_{2\text{peak}}$ *per se* but the oxidative potential of the muscle in elite team sport athletes, which can be determined by measuring VO_2 kinetics during high-intensity exercise. Furthermore, those who have reported improvements in muscle buffer capacity following training have also reported greater single and repeated sprint performance, as well as improvements in short endurance performance (Bell, Petersen, Quinney, & Wenger, 1988; Edge, Bishop, Dawson, & Goodman, 2002; Weston et al., 1997). A greater muscle buffer capacity may improve high-intensity exercise performance by allowing anaerobic glycolysis to continue, resulting in a larger lactate production without a concomitant increase in H^+ accumulation, which has been linked with fatigue (Allen & Westerblad, 2001).

Overall, the research indicates that team sport athletes perform numerous bouts of high-intensity efforts during a typical game. These high-intensity efforts appear to be related to playing position and the level of performance. Also, high-intensity activity has been shown to decrease in the latter stages of a game, which may be explained by several factors including fatigue and the tactical approach used. Maximal oxygen uptake and muscle buffer capacity in several studies are closely related to the ability to repeatedly perform high-intensity efforts through faster VO_2 kinetics and an increased clearance of H^+ from the muscle, which has an association with fatigue. These data collectively reinforce that a high aerobic capacity is beneficial for team sport athletes in helping them repetitively execute (and recover from) explosive high-intensity efforts.

2.4 Energy System Contribution to Team Sport Performance

Based on the mean distances covered during a match, game intensities, HR, B[Lac], and the repeated high-intensity efforts, it is clear that team sport competition requires energy supplied predominantly from aerobic sources. In fact, it is not uncommon in the literature to recognize that aerobic metabolism is the predominant energy source during team sport competition, and this has been documented for basketball (Abdelkrim, El Fazaa, & El Ati, 2007; Bishop & Wright, 2006; Hoffman, Epstein, Einbinder, & Weinstein, 1999; McInnes, Carlson, Jones, & McKenna, 1995), rugby union (Docherty & Sporer, 2000; Duthie, Pyne, & Hooper, 2005; Treadwell, 1988), and soccer (Ali & Farrally, 1991; Bangsbo, 1994a; Bangsbo, Norregaard, & Thorso, 1991; Ekblom, 1986; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Krstrup, Mohr, Steensberg et al., 2006; Reilly, 1997). The importance of aerobic energy contribution to team sport performance has been demonstrated in soccer, where it has been shown that an improved level of aerobic fitness dramatically increases the distance travelled, the number of sprints performed, and the number of involvements with the ball during a match (Helgerud, Engen, Wisloff, & Hoff, 2001). This is also confirmed through approximately 88% of a soccer match typically being spent performing activities that are primarily aerobic in nature (Bangsbo, 1994a) and the remaining 12% of match time spent in activities that would primarily stress the anaerobic energy supply systems (Mayhew & Wenger, 1985).

Early literature has classified basketball as deriving 85% of its energy expenditure from the phosphagen stores (ATP & PCr) and 15% of its energy from anaerobic glycolysis (Fox, 1984). However, a closer analysis of basketball competition (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995; Taylor, 2003) reveals that anaerobic energy supply is indeed only a minor contributor to the overall energy requirements of basketball. Additionally, in elite rugby union players it appears that they require aerobic conditioning to facilitate the recovery between high-intensity bouts, where energy is derived from predominantly anaerobic sources

(Duthie, Pyne, & Hooper, 2005). As suggested by Tomlin & Wenger (2001), a higher oxygen uptake during sprinting results in less reliance on anaerobic glycolysis and thus superior power maintenance. The normal duration of team sport games (40 to 90 min) provides further reinforcement that aerobic energy metabolism is predominant. Based on the research, a vast majority of the energy required during a team sport game is provided through aerobic metabolism, but during the most decisive and influential situations, anaerobic metabolism is most likely predominant.

Modes of motion, such as running backwards and sideways, accelerating, decelerating, and changing direction accentuate the metabolic loading during competition (Reilly, 1997) causing anaerobic metabolism to become increasingly taxed during a game. In the past rugby union has been described as primarily anaerobic in nature (McLean, 1992). To a certain extent this is supported by the findings of Deutsch et al. (2007), especially for backs, where work-to-rest ratios (mean work ~5 s, mean rest ~80 to 110 s) indicate that the PCr system plays an important role (Balsom, Seger, Sjodin, & Ekblom, 1992b). Although the mean work period for forwards is also ~5 s, the mean rest duration of approximately 30 to 40 s would in most cases only result in partial replenishment of the PCr stores (Gaitanos, Williams, Boobis, & Brooks, 1993) and place more emphasis on the anaerobic glycolytic pathway (Deutsch, Kearney, & Rehrer, 2007). However, it is now well known that most of the time during match play is spent in low-intensity activities and it is the high-intensity activities, such as sprinting and physical collisions, that place considerable demands on the anaerobic energy systems (Deutsch, Maw, Jenkins, & Reaburn, 1998).

In other sports, HR responses to basketball competition indicate an important degree of effort from guards in particular, with B[Lac] values showing a large contribution from the anaerobic energy systems towards the end of the first half (Abdelkrim, El Fazaa, & El Ati, 2007). Also, the observation that elite soccer players perform 150 to 250 brief, intense actions during a game

(Mohr, Krstrup, & Bangsbo, 2003) and have B[Lac] values of 2 to 14 mmol⁻¹ (Bangsbo, Norregaard, & Thorso, 1991; Ekblom, 1986; Reilly, 1997) indicates that the rate of anaerobic energy turnover is transiently high during periods of a game. While B[Lac] underestimate muscle lactate production, it is likely that the overall anaerobic energy yield during a team sport game is small. This is because the total duration of high-intensity exercise during team sport competition accounts for only a small proportion of game time. Hence, PCr and to a lesser extent intramuscular ATP, provide a considerable amount of the energy for the short individual bouts of high-intensity exercise (Williams, 1996). Consequently, lactate and inorganic phosphate accumulates, pH and PCr decrease, glycolytic rate limiting enzymes are inhibited, while ATP turnover is attenuated and, subsequently, power output is reduced (Bangsbo, Norregaard, & Thorso, 1991). However, as previously discussed, as the duration of the high-intensity efforts increases, a greater demand from oxidative metabolism is experienced (Bogdanis, Nevill, Boobis, & Lakomy, 1996; Gaitanos, Williams, Boobis, & Brooks, 1993) as it is well known that intramuscular ATP and PCr storage are only able to sustain muscular activity for up to ~10 s (Bishop, Lawrence, & Spencer, 2003). Therefore, in a typical team sport game situation, lasting 40 to 90 min, the role of oxidative metabolism in supplying energy for performance may be increased, no doubt increasing the importance of aerobic capacity during exercise recovery (Duthie, Pyne, & Hooper, 2005; Hoffman, Epstein, Einbinder, & Weinstein, 1999).

2.5 Recovery and Fatigue Associated with Team Sport Performance

2.5.1 Recovery

Recovery in team sport competition is generally low-intensity activity such as standing, walking and sub-maximal jogging/running. Recovery is marked by a rapidly declining VO₂ and HR. It is during this period that tissue stores of oxygen are quickly replenished (Gaesser & Brooks, 1984) and most of the ATP and PCr depleted in the muscle are restored, with 70% of the phosphagens restored within 30 s and 100% restored within 3 to 5 min (Hultman, GBergstrom, & McLennan-

Anderson, 1967). Enhanced oxygen delivery to muscles post-exercise potentially accelerates the rate of PCr resynthesis, an oxygen-dependent process (Colliander, Dudley, & Tsech, 1988).

Recent game analysis of team sport competition has revealed that some of the sprints performed are separated by short rest periods (<30 s; Bloomfield, Polman, & O'Donoghue, 2007; Duthie, Pyne, & Hooper, 2005; McInnes, Carlson, Jones, & McKenna, 1995; Spencer et al., 2004), which are inadequate for complete recovery and have been shown to negatively affect subsequent sprint performance (Balsom, Seger, Sjodin, & Ekblom, 1992a). Therefore, this data provides further evidence towards the fitness requirements of team sport athletes, where the ability to perform short duration sprints (<10 s) with often short recovery time (<30 s) is of paramount importance. In a study of elite male soccer players, fifteen 40 m sprints were alternated with periods of 25 s of active recovery (50% of maximal aerobic speed) and it was found that from the third sprint, the times were significantly longer than those of the first sprint (Dupont, Millet, Guinhouya, & Berthoin, 2005). This result suggests that the 25 s active recovery period was not long enough to recover entirely, or perhaps the recovery was of too greater intensity to allow adequate recovery. In basketball, one high-intensity sprint is on average performed every 21 s, with each effort lasting a mean 1.7 s, leaving only approximately 19.3 s mean recovery time between maximal efforts (McInnes, Carlson, Jones, & McKenna, 1995). Also, Abdelkrim et al. (2007) reported that 30% of live time was spent in 'recovery' movements such as standing still and walking. Although nearly one third of live time was spent in recovery movements they had a mean duration of only 2.3 ± 0.2 s, providing evidence of the need for a highly developed aerobic system for basketball. Field hockey and rugby union show similar trends with the average recovery time between repeated sprinting bouts for field hockey ranging between 12 and 16 s (Spencer et al., 2005) and the mean rest duration in rugby union being 33 s (Menchinelli, Morandini, & De Angelis, 1992) and less than 20 s in recent publications (Duthie, Pyne, & Hooper, 2005). Saltin & Essen (1971) have reported that rest periods of less than 20 s are not

sufficient to allow significant replenishment of PCr stores following maximal intensity work bouts of 10 s. However, there are occasions when extended recovery time is evident, as during free throws and time outs in basketball where HR responses have been shown to drop to 70 to 75% and 60% HR_{peak}, respectively (McInnes, Carlson, Jones, & McKenna, 1995). Stoppages in play for injuries, penalty kicks and conversions are responsible for the prolonged rest periods in rugby union (McLean, 1992) and these stoppages result in an average rest duration for all playing positions of 35 to 95 s.

When the type of recovery is considered, it is revealed that rugby union forwards spend significantly more time standing still (45%) than backs (39%; Deutsch, Kearney, & Rehrer, 2007; 39%; Deutsch, Maw, Jenkins, & Reaburn, 1998; Docherty & Sporer, 2000; Treadwell, 1988). This suggests that much of the recovery in rugby union is of a passive rather than an active nature. However, the greater mean distances walked by backs (1760 m) compared with forwards (995 m) may suggest active recovery, as opposed to passive, is more important for the backs. Active recovery has been reported by some to promote greater exercise capacity (Dorado, Sanchis-Moysi, & Calbet, 2004), while others have not confirmed these results (Bangsbo, Graham, Johansen, & Saltin, 1994; Dupont, Blondel, & Berthoin, 2003; Dupont, Moalla, Guinhouya, Ahmaidi, & Berthoin, 2004). Supposedly, active recovery enhances work capacity during high-intensity intermittent exercise by increasing the aerobic energy yield without significant changes in the estimated anaerobic contribution to total energy turnover (Dorado, Sanchis-Moysi, & Calbet, 2004). Thus, the higher aerobic energy contribution is due to faster VO₂ kinetics combined with a longer working time. Also, for intermittent exercise, active recovery is generally recommended in order to lower B[Lac] concentrations (Bonen & Belcastro, 1976; Gupta, Goswami, Sadhukhan, & Mathur, 1996; Taoutaou et al., 1996) and to increase blood flow, therefore increasing oxygen delivery to the muscles (Billat, 2001a, , 2001b).

In summary, high-intensity bouts of exercise in team sports are often followed by what appears to be inadequate recovery durations (<30 s) for optimal ATP and PCr restoration. Such short recovery periods have been shown to have a negative effect on power development across repeated sprints further emphasizing the need for maximizing the use of the recovery time that is available to team sport athletes. In order to maximize these recovery periods both active and passive recovery has been suggested depending on positional requirements. Additionally, an elevated level of aerobic metabolism is suggested to elevate the rate of PCr resynthesis, an oxygen dependent process.

2.5.2 Fatigue

Fatigue does not refer to the termination of a particular form of exercise, but rather that in the course of a match, such as soccer or field hockey, distances run and exercise intensity are reduced, compared with early levels, but not terminated (Sunderland & Nevill, 2005). Previous sub-sections in this review have revealed that the amount of sprinting, high-intensity activity, and the total distance covered during team sport competition declines during the second half of a match when compared to the first, and the distance covered has been reported to be approximately 5 to 6% lower during the second half in a soccer match (Bangsbo, 1994a; Bangsbo, Norregaard, & Thorso, 1991; Mohr, Krstrup, & Bangsbo, 2003; Rienzi, Drust, Reilly, Carter, & Martin, 2000; van Gool, van Gerven, & Boutmans, 1988). In addition, jumping, sprinting, and intermittent exercise performance is often lower after vs. before a soccer match (Mohr, Krstrup, & Bangsbo, 2005; Mohr, Krstrup, Nybo, Nielsen, & Bangsbo, 2004). The decline in the total distance covered seems greater in top class soccer players (5.5 ± 0.1 vs. 5.4 ± 0.1 km) than that observed for moderate level players (5.2 ± 0.14 vs. 5.13 ± 0.12 km; Mohr, Krstrup, & Bangsbo, 2003). However, this could be influenced by the tactical approach to the match and the skill of the players. Similar trends have been observed during basketball play where a profound decrease in the time involved in intense activities was observed in the last quarter of each half

during a basketball game (Abdelkrim, El Fazaa, & El Ati, 2007) and this was noticeable across all playing positions. In contrast, there have been reports in basketball (McInnes, Carlson, Jones, & McKenna, 1995) and rugby union (Duthie, Pyne, & Hooper, 2005) where there have been no significant differences observed between the four quarters of play and the two halves, respectively, suggesting that fatigue although likely present did not elicit a marked decrease in overall activity levels.

Several studies suggest that fatigue in soccer is not casually linked to high muscle lactate, high muscle acidosis, low muscle PCr, or low muscle ATP (Hellsten, Richter, Kiens, & Bangsbo, 1999; Krstrup et al., 2003; Krstrup, Mohr, Steensberg et al., 2006). The extent that fatigue is experienced by team sport athletes has been shown to be linked to a reduction in muscle glycogen (Gollnick et al., 1973), a low aerobic power (Reilly & Seaton, 1990), poor nutritional status (low carbohydrate intake) (Gollnick et al., 1973), and physiological factors, i.e., the failure of excitation-contraction coupling as a consequence of accumulating levels of potassium (Bangsbo, Graham, Johansen, & Saltin, 1994). The most striking consequence of low glycogen stores was in running speed, since players with initially low glycogen stores covered 50% of the total distance walking and 15% at top speed, in contrast to 27% walking and 27% sprinting for players who started the match with high muscle glycogen concentrations (Gollnick et al., 1973). As found previously by several authors (Aziz, Chia, & Teh, 2000; Dawson, Fitzsimons, & Ward, 1993; McMahon & Wenger, 1998), the findings of Dupont et al. (2005) confirm that VO_{2peak} is significantly correlated with fatigue percentage. Furthermore, a greater VO_{2peak} and LT has been associated with a greater ability to rapidly resynthesize PCr after exercise (McMahon & Jenkins, 2002). Other factors such as dehydration and hyperthermia have also been suggested as agents responsible for the development of fatigue in the later stages of team sport competition (Reilly, 1997).

It is acknowledged that any decrease in the amount of distance travelled, or the number of high-intensity efforts performed over the course of a team sport game may be viewed as the onset of fatigue, but there are many other factors that could explain the observed decreases in the literature. Tactical strategies can also explain the decline in high-intensity activity during the final stages of team sport competition since during the last minutes of a game teams that are winning are likely to attempt to keep possession of the ball (Abdelkrim, El Fazaa, & El Ati, 2007). Consequently, the proportion of straight play and fast breaks decreases, causing the pace of the game to slow down (Abdelkrim, El Fazaa, & El Ati, 2007). Alternatively, when a team is winning by a large amount, the players may be less driven to score further goals and thus reduce their contributions to the game. Conversely, when a team is losing by a large margin, the players may be less interested because they think that they cannot win (Ali & Farrally, 1991). Overall, fatigue, or decline in output is a factor that requires further research as it is not clear to what extent declines in performance are attributed to physiological imbalances, environmental conditions, tactical/team strategy, or player motivation.

2.6 Summary

The acyclic, intermittent nature of team sport competition is made evident with the movement frequencies observed during match play being in excess of 1,000 discrete movements, regardless of sport. The total distance travelled suggests a high level of aerobic fitness is required, especially with respect to outdoor field-based team sports such as field hockey, rugby union, and soccer. The average game intensity appears relatively constant across all sports, equating to just below lactate threshold, 80 to 90% HR_{peak} , or 70 to 80% VO_{2peak} . However, when defining characteristics of team sport performances are broken down into low-, medium-, and high-intensity activities, clear differences between sports arise. Players in rugby union and soccer appear to spend the greatest amount of times performing low-intensity movements (80 to 85% of game time), whereas field hockey and basketball spend a considerably lower amount of time at

low-intensity (~50% of game time) and more at medium-intensity (~40%). The amount of high-intensity exercise carried out is consistent across most sports, being about 10 to 15% of game time. Heart rate and blood lactate concentration data reinforce these observations with a moderately high level of lactate found during team sport competition and this is significantly correlated to the amount of high-intensity activity performed during the five minutes before sampling. The energy system contribution to team sport performance tends to reflect game intensity in that the majority of the ATP required to perform is supplied via aerobic pathways based on the large amounts of game time spent engaged in low-intensity activity.

Improving the ability to repeatedly perform high-intensity activities is of paramount importance during the physical preparation of team sport athletes, and aerobic conditioning should play a significant part in this respect. It should be noted that due to recovery time being typically of short duration (<30 s) during team sport competition, a higher $\text{VO}_{2\text{peak}}$ and faster VO_2 kinetics will assist with the replenishment of PCr stores thus helping maintain power output across multiple high-intensity efforts. Although endurance capacity *per se* is likely to have a small affect on performance in multiple sprints, the related functional adaptations may prove influential in offsetting fatigue, due to improved rates of phosphocreatine rephosphorylation during recovery periods present within the sprints (Hamilton, Nevill, Brooks, & Williams, 1991). An increase in the capacity of the oxygen transport system leads to a higher aerobic contribution to the energy expended, taxing the anaerobic energy system less and, consequently, reducing fatigue through sparing glycogen and preventing the decrease of muscle pH. Ultimately, players who are aerobically well trained are better able to maintain their work rates/power output towards the end of a game or match situation than those of poorer aerobic fitness.

Chapter Three: Aerobic Conditioning for Team Sport Athletes - A Review

Based on the physical demands and characteristics of team sport competition (outlined previously, Chapter 2.0, pp 7), it is clear that a significant portion of the conditioning programmes of team sport players should focus on improving their ability to repeatedly perform high-intensity exercise and to recover. To a large extent, as will be discussed below, these abilities can both be improved by performing aerobic conditioning.

3.1 Physiological Adaptations to Aerobic Conditioning

Several studies have shown that aerobic conditioning is associated with adaptations in the pulmonary (Acevedo & Goldfarb, 1989; Casaburi, Storer, Ben-Dov, & Wasserman, 1987; Hill, Jacoby, & Farber, 1991; Tzankoff, Robinson, Pyke, & Brawn, 1972), cardiovascular (Andrew, Guzman, & Becklake, 1966; Coyle, Hemmert, & Coggan, 1986; Green, Sutton, Coates, Ali, & Jones, 1991; Wilmore et al., 2001a, , 2001b), neuromuscular (Desaulniers, Lavoie, & Gardiner, 1998; Lucia, Hoyos, Pardo, & Chicharro, 2000) and metabolic systems (Green, Jones, Ball-Burnett, Farrance, & Ranney, 1995; Green et al., 1991; Holloszy & Coyle, 1984; LeBlanc, Peters, Tunstall, Cameron-Smith, & Heigenhauser, 2004; Lucia, Hoyos, Pardo, & Chicharro, 2000; Wibom et al., 1992). However, it is clearly apparent from the literature that the physiological adaptations to training depend upon several factors including the exercise intensity (Burke & Franks, 1975; Faria, 1970; Gaesser & Rich, 1984; Wenger & MacNab, 1975) and frequency (Fox et al., 1975; Hickson, Overland, & Dougherty, 1984; Pollock, Miller, Linnerud, & Cooper, 1975; Raven, Gettman, Pollock, & Cooper, 1976), the duration of training (Holloszy & Coyle, 1984; Terjung, 1976), the total length of time of the training programme (Cunningham, McCrimmon, & Vlach, 1979; Fox et al., 1975; Hickson & Rosenkoetter, 1981) as well as the initial fitness level of the individual (McArdle, Katch, & Katch, 1996; Wenger & MacNab, 1975). Each of these factors interact to determine the overall magnitude of the training response.

Depending on the intensity of the aerobic conditioning, physiological adaptation may primarily occur centrally or peripherally (Saltin et al., 1976). At intensities slightly below LT (~70 to 80% $\text{VO}_{2\text{peak}}$), physiological adaptations occur primarily in the central component (Cunningham, McCrimmon, & Vlach, 1979; Sale & MacDougall, 1981). Central adaptations include an improvement in the heart's capacity to pump blood, primarily through increased stroke volume, which occurs because of an increase in end-diastolic volume and an increase in left ventricular mass (Astrand & Rodahl, 1987). Subsequently, these adaptations result in an increased cardiac output, which, according to the Fick equation, will increase maximal oxygen uptake ($\text{VO}_{2\text{peak}}$; Laffite, Mille-Hamard, Koralsztein, & Billat, 2003). As the training intensity increases above the lactate threshold (>80% $\text{VO}_{2\text{peak}}$), significant peripheral adaptation occurs, with substantial changes in muscle capillarisation (Gute, Fraga, Laughlin, & Amann, 1996), oxidative enzyme activity (Gollnick et al., 1973), mitochondrial volume and density (Harms & Hickson, 1983), myoglobin (Hickson & Rosenkoetter, 1981), and the preferential use of free fatty acids as an energy substrate (Holloszy & Coyle, 1984). As a consequence of the above central and peripheral adaptations, performance-related measures such as whole-body $\text{VO}_{2\text{peak}}$ (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999), exercise/work economy (Jones, 1998), lactate threshold (LT; Davis, Frank, Whipp, & Wasserman, 1979), and oxygen uptake kinetics (Carter et al., 2000) are all improved (Jones & Carter, 2000).

The potential benefits of the above training-induced peripheral and central adaptations for team sport performance are numerous. For example, athletes with a greater muscle oxidative capacity have been reported to boast greater PCr resynthesis and an ability to remove lactate and hydrogen (H^+) ions from skeletal muscle (McCully, Kakihiira, & Vandenborne, 1991; McMahon & Jenkins, 2002; Neya et al., 2002; Takahashi, Inaki, & Fujimoto, 1995). Similarly, improvements in oxygen uptake kinetics as a result of endurance training, is suggested to increase the efficiency during recovery, which assists in delaying the onset of fatigue (Tomlin & Wenger, 2001). In further

support of the use of aerobic conditioning in team sports, a high VO_{2peak} appears to be moderately related with repeated sprint ability (RSA; $r=0.62$, $r=0.68$, $P<0.05$) in field hockey, rugby union, soccer, endurance trained and untrained populations (Bishop, Edge, & Goodman, 2004; Bishop & Spencer, 2004; McMahon & Wenger, 1998), suggesting that the body's ability to deliver and use oxygen both during and between high-intensity sprints is important (Bogdanis, Nevill, Boobis, & Lakomy, 1996). Overall, a high VO_{2peak} will likely serve to reduce the metabolic disturbances resulting from anaerobic metabolism.

Despite the potential benefits of aerobic conditioning, the optimal approach to induce central and peripheral adaptations in team sport players is relatively unclear. Several different approaches can be used to develop the aerobic condition of team sport players. These include a range of traditional, classical and sport-specific (movement-specific) conditioning approaches. Each will be defined and discussed in the following sections.

3.2 Traditional Aerobic Conditioning for Team Sports

Traditional aerobic conditioning, defined here as continuous or interval based straight line running with minimal changes of direction, is used by many athletes and fitness enthusiasts to increase aerobic fitness. Since it has been suggested that VO_{2peak} improvements generally occur when a high percentage of VO_{2peak} is elicited during exercise (Wenger & Bell, 1986), the general goal of interval conditioning is to accumulate a greater training stimulus at high-intensities compared to what can be tolerated in a single bout of continuous exercise. The prescription of interval training is based on five variables: work interval intensity and duration, recovery interval intensity and duration, and total work duration (work interval number x work duration). These variables can be manipulated to generate a large range of interval training prescriptions designed to primarily stress aerobic and/or anaerobic energy metabolism. Sufficient physiological data are now

available to classify different types of aerobic interval training, ranging in intensity from 85% to 130% of the power or velocity associated with $\text{VO}_{2\text{peak}}$ (Billat, 2001a, , 2001b).

Despite the inclusion of traditional aerobic conditioning in the training programmes of many team sports, surprisingly few studies have documented the true effectiveness of traditional aerobic conditioning approaches on physiological measures and their subsequent influence on team sport performance (Table 4). However, in the few studies reporting its effect on individual fitness, individual performance, and team sport performance, traditional interval conditioning has resulted in favourable changes in aerobic fitness and performance suggesting it is an effective approach (Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003; Dupont, Akakpo, & Berthoin, 2004; Helgerud, Engen, Wisloff, & Hoff, 2001). In this regard, it is important to understand that when increases in individual fitness and/or individual performance are observed, team performance may not necessarily improve. Therefore, when considering these factors, any improvements in individual performance reported in the following sections, although an excellent result, do not imply an improvement in team performance *per se*.

In a unique longitudinal training study, Helgerud et al. (2001) were amongst the first researchers to clearly show that high-intensity 'traditional' aerobic interval training significantly influenced a soccer player's aerobic fitness and perhaps more importantly, their performance during a soccer match. In this study, traditional interval endurance training was performed twice per week, over an eight week period at the beginning of the competitive soccer season, where players performed four, four minute running intervals at 90 to 95% HR_{peak} , interspersed with three minutes of active recovery, jogging at 50 to 60% HR_{peak} . Consequently, $\text{VO}_{2\text{peak}}$ increased by 0.67% each training session or 10.8% over the duration of the study. The LT and RE improved by 16.0%, and 6.7%, respectively ($P<0.05$), suggesting a marked effect on measures of aerobic function. However, two regular training sessions involving game play, tactical, technical, strength, and sprint training

activities along with one competitive game per week were performed concurrently with the endurance training. The intensity of these additional training sessions were not reported by Helgerud et al. (2001) and, therefore, based on the control groups post-training increases in $\text{VO}_{2\text{peak}}$ (2%) and in the number of sprints performed during a match (8%), it is possible that they may have contributed towards the improvements in aerobic fitness in the experimental group. Nevertheless, most important was how this improved level of aerobic fitness influenced subsequent soccer performance. Firstly, traditional aerobic conditioning resulted in significantly higher exercise intensities (3.5%, $P<0.05$), when expressed in relation to HR_{peak} , during a soccer match following the training period. This is presumably related to the improved exercise economy and LT as result of the endurance training. It was also clearly shown that the number of sprints and involvements with the ball increased significantly ($P<0.05$) from 6.2 to 12.4 (100%) and 47.4 to 58.8 (24%), respectively. Furthermore, a significant increase in the total distance covered (8619 m to 10,335 m, 20%; $P<0.01$) during a match was observed. Collectively these results are very encouraging; however, it must be acknowledged that the soccer performance was determined during a single soccer match following the training period. Given the tactical/technical nature of soccer, this single match could have biased the conditions, opposition, and/or importance of the game. Clearly, analysis of several soccer matches would have greatly assisted and strengthened the observations of Helgerud et al. (2001).

More recently, Helgerud et al. (2003) used the same successful aerobic interval training approach with a European champions league team, who showed a similar improvement in $\text{VO}_{2\text{peak}}$ (8.1%, $P<0.001$). This pre-season improvement was observed despite concurrently training for both maximal strength and aerobic endurance. Furthermore, this increase was exhibited in soccer players of a higher standard compared with Helgerud et al. (2001). Running economy also improved by 3.7% ($P<0.05$) from pre- to post-training. It is likely that this improvement was augmented through the maximal strength training that was performed, as resistance training has

been demonstrated to benefit exercise economy (Millet, Jaouen, Borrani, & Candau, 2002; Paton & Hopkins, 2004). However, it seems as though the concurrent training approach may have slightly hindered the improvement in RE when compared to the younger soccer players involved in a previous aerobic training study by Helgerud et al. (2001).

Using a different approach to Helgerud et al. (2001), a later study by Dupont et al. (2004) investigated the effect of traditional aerobic conditioning on aerobic fitness without any subsequent decrease in match performance during the in-season in professional soccer players. This study demonstrated that one weekly session of short intermittent exercises (12 to 15 x 15 s at 120% of maximal aerobic speed) and one weekly session of repeated sprinting exercise (40 m sprints repeated every 30 s) over ten weeks induced substantial improvements in aerobic fitness (Dupont, Akakpo, & Berthoin, 2004). The maximal aerobic speed improved by $8.1 \pm 3.1\%$ ($P < 0.001$). Similar to other research (Helgerud, Engen, Wisloff, & Hoff, 2001), the athletes involved in this study also performed an additional two team training sessions per week, reportedly involving light exercises. Unfortunately, post-training VO_{2peak} was not reported for this study, making comparisons with other related research difficult (e.g., Helgerud, Engen, Wisloff, & Hoff, 2001; Helgerud, Kemi, & Hoff, 2003). However, given the type of training performed, the improvements in maximal aerobic speed could be a consequence of a greater amount of time spent at VO_{2peak} (Billat et al., 2000). The more time spent at a high percentage of VO_{2peak} during training necessarily induces a positive change in measures of aerobic fitness (Wenger & Bell, 1986). With respect to the affects of the conditioning regime on match performance, the team won 33% of its matches during the ten week control period (no high-intensity training) and 78% of its matches during the ten week high-intensity training period. However, this 136% increase must be interpreted with caution as many factors could have influenced the outcomes of the matches during both the control and the training periods, including, but not limited to, the quality of the opposition and the environmental conditions in which the matches were played. Overall, the

findings of Dupont et al. (2004), Helgerud et al. (2001) and Helgerud et al. (2003) all suggest that improvements in VO_{2peak} can be achieved during the pre- and/or early in-season without any decrease in match performance.

Parallel to the research on traditional aerobic conditioning and soccer performance, traditional aerobic interval conditioning has also been shown to increase VO_{2peak} in collegiate basketball players while simultaneously training for both muscular strength and aerobic adaptations (Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003). Balabinis et al. (2003) examined the effects of endurance, strength, and concurrent strength and endurance conditioning on several physiological parameters over a seven week duration (training phase of the season was not stated). Endurance conditioning involved performing between 2 and 10 repeats of 30 to 1000 m running intervals every 30 to 60 s. Endurance conditioning alone improved VO_{2peak} by approximately 7% which was slightly less than that reported by Helgerud et al. (2001). Interestingly, however, greater changes in VO_{2peak} (13%) were observed when concurrent strength and endurance conditioning were performed (Table 4), despite all experimental groups being relatively equally matched for aerobic fitness (Figure 6) at the start of the study. Given that participants from both Helgerud et al. (2001) and Balabinis et al. (2003) displayed similar pre-training VO_{2peak} values ($58 \text{ ml}\cdot\text{kg}^{-1}\text{min}^{-1}$ and 54 to $55 \text{ ml}\cdot\text{kg}^{-1}\text{min}^{-1}$, respectively) the greater increase in aerobic function for the strength and endurance trained group reported by Balabinis et al. (2003) may have been augmented through the periodised strength training programme that the group performed. The strength training undertaken was divided into three phases: 1) maximum strength, 1 to 4 sets x 3 to 6 repetitions at 75 to 95% one repetition maximum (1RM); 2) explosive power, 4 to 5 sets x 5 to 6 repetitions at 70% 1RM; and 3) muscular endurance, 3 sets x 30 to 40 repetitions at 40% 1RM. It is very possible that the latter muscular endurance phase promoted additional peripheral oxidative adaptations, which has been previously observed in other studies (Hickson, Rosenkoetter, & Brown, 1980; Hoff, Gran, & Helgerud, 2002; McCall,

Byrnes, Dickinson, Pattany, & Fleck, 1996; Osteras, Helgerud, & Hoff, 2002; Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999). Though Balabinis et al. (2003) did not measure any subsequent influence on game performance following the training period these results suggest that combining strength and endurance training maybe a worthwhile approach in basketball.

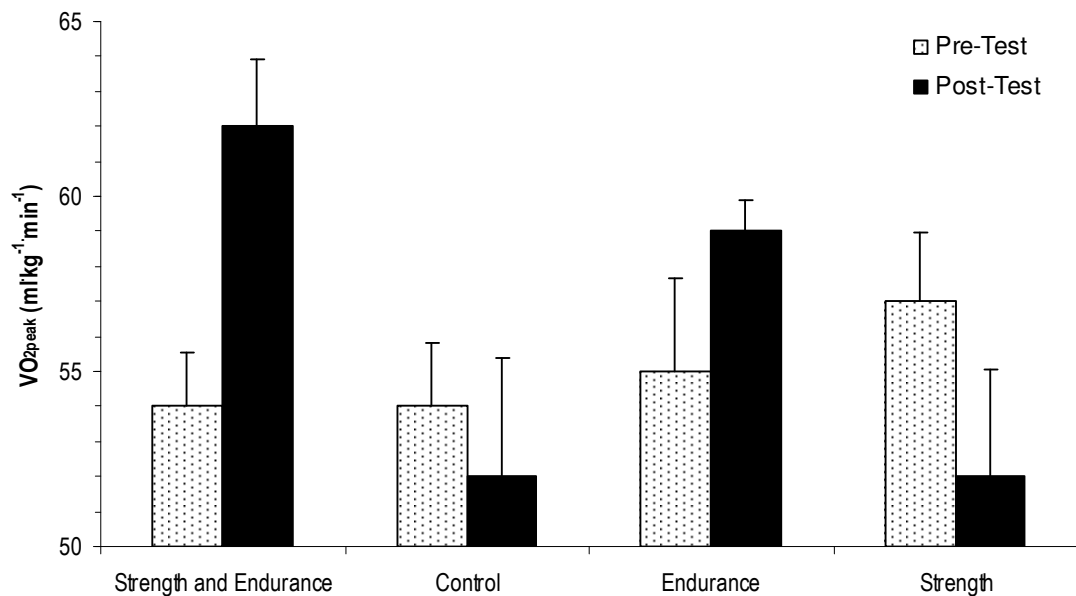


Figure 6. Mean (\pm SD) VO_{2peak} for concurrent strength and endurance, control, endurance only, and strength only training groups' pre and post 7-week training intervention (Balabinis et al., 2003).

In summary, it is clear that traditional aerobic conditioning involving repeated running intervals at intensities ranging between 85 and 95% HR_{peak} and lasting up to four minutes, separated by a maximum of three minutes active recovery at about 60% HR_{peak} appear to promote beneficial changes in aerobic function. Some limited evidence exists to suggest that this improvement in fitness is transferable to the actual game situation and subsequently enhances team sport performance. Furthermore, periodised concurrent strength and endurance training in team sport athletes may elevate VO_{2peak} to a greater extent than endurance training alone. The results of both Dupont et al. (2004) and Helgerud et al. (2001; , 2003) demonstrate that aerobic fitness of soccer players can be improved during the competitive season without a decrease in match

performance. However, traditional aerobic conditioning methods and their subsequent influence on sport performance is an area requiring further research.

Table 4. Traditional aerobic endurance conditioning used in team sports and the subsequent influence on aerobic fitness and individual/team performance.

Sport	Reference	N	Age	Season	Training Intervention	Findings
Basketball	Balabinis et al., 2003	7 M	22.6 ± 0.8	Unknown	7 weeks SE training, 4 x per week running intervals 100-500 m @ 85-90% HR _{peak} on 30-60 s	VO _{2peak} ↑13%*
		7 M	22.4 ± 0.5	Unknown	7 weeks E training, 4 x per week running intervals 100-500 m @ 85-90% HR _{peak} on 30-60 s	VO _{2peak} ↑7%*
Soccer	Dupont et al., 2004	22 M	20.2 ± 0.7	In	10 weeks, 1 x per week 12-15 x 40 m sprints on 30 s; 1 x per week (15 s @ 120% MAS; 15 s rest) x 12-15	MAS ↑8%*** Win Percentage ↑136%
	Helgerud et al., 2001	19 M	18.1 ± 0.8	In	8 weeks, 2 x per week running intervals (4 min @ 90-95% HR _{peak} ; 3 min @ 50-60% HR _{peak}) x 4	VO _{2peak} ↑11%* LT ↑16%* RE ↓7%* No. of sprints ↑100%** No. of involvements with ball ↑24%* Distance covered ↑20%**
	Helgerud et al., 2003	21 M	25.0 ± 2.9	Pre	8 weeks, 2 x per week treadmill running intervals (4 min @ 90-95% HR _{peak} ; 3 min @ 50-60% HR _{peak}) x 4	VO _{2peak} ↑8%*** RE ↓4%*

* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; HR_{peak} = heart rate peak; M = male; ↓ = decrease; ↑ = increase; LT = lactate threshold; RE = running economy; SE = strength and endurance; E = endurance; MAS = maximal aerobic speed

3.3 Classic Team Sport Conditioning

“Classic” team sport conditioning usually integrates strength, power, speed, and aerobic conditioning components directed towards improving the athlete’s overall functional and physical capacities specific to their sport within a coaching framework (Hoffman, Tenenbaum, Maresh, & Kraemer, 1996). Under such conditions some research, but not all (Gillam, 1985; Krstrup et al., 2003; Tavino, Bowers, & Archer, 1995), suggests that aerobic power can be maintained and even increased simply from participation in classic team sport training and competition (Table 5) (Gabbett, 2004, , 2005a, , 2006a; Hoffman, Fry, Howard, Maresh, & Kraemer, 1991; Hunter, Hilyer, & Forster, 1993). For example, in basketball, it has been demonstrated that the intensity and duration of running during team practice and competition created sufficient stimulus for the maintenance of aerobic power over single (Hoffman, Fry, Howard, Maresh, & Kraemer, 1991; Maresh, Wang, & Goetz, 1985) and consecutive (four) seasons (Hunter, Hilyer, & Forster, 1993). However, Hunter et al. (1993) reported the training objective for most players was to maintain, not increase their VO_{2peak} ($50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) over the four seasons, based on similar VO_{2peak} values reported for other college players (Bolonchuk, Lukaski, & Siders, 1991). Subsequently, no improvements in VO_{2peak} were observed. Conversely, another study has shown that a conditioning programme for professional basketball players involving speed exercises, technical drills, match situations, and endurance training resulted in a marginal increase in VO_{2peak} (6%) from pre-season through to the competitive season (Laplaud, Hug, & Menier, 2004).

Observing an increase in VO_{2peak} during the competitive season is not unique to basketball since in amateur rugby league Gabbett (2005a; , 2005b) found that players undertaking a progressively overloaded training program, involving specific skill, speed, muscular power, agility, and endurance training exercises twice per week, showed a 18 to 19% increase in predicted VO_{2peak} during the course of a rugby league season. The findings of Gabbett (2006a) also demonstrate that junior and senior rugby league players increased aerobic fitness between 5.1 and 8.6% over

a 14-week preseason training period. Despite having lower training loads, junior rugby league players exhibited greater adaptations in predicted relative $\text{VO}_{2\text{peak}}$ than senior rugby league players (8.6% vs. 5.1%, respectively). This suggests that junior (17 years old) and senior (26 years old) rugby league players adapt differently to an absolute training stimulus and that training programmes should be modified to accommodate differences in training age (Gabbett, 2006a). Furthermore, across three consecutive pre-season periods, $\text{VO}_{2\text{peak}}$ values in rugby league players have been shown to progressively improve (2001, 7.7%; 2002, 11.8%; 2003, 15.6%; Figure 7), with each pre-season period inducing a significant increase ($P>0.05$) in $\text{VO}_{2\text{peak}}$ (Gabbett, 2004). This improvement was a result of a periodised conditioning programme consisting of two game specific training sessions per week of approximately 60 to 100 min duration. Interestingly, following the initial season (2001), training loads were decreased through reductions in training duration (2002) and training intensity (2003) while improvements in $\text{VO}_{2\text{peak}}$ were still observed. However, it should be noted that the greater changes in relative $\text{VO}_{2\text{peak}}$ over the three pre-season periods could possibly be a result of the slightly lower pre-training $\text{VO}_{2\text{peak}}$ of players in the 2002 and 2003 pre-season periods (Gabbett, 2004).

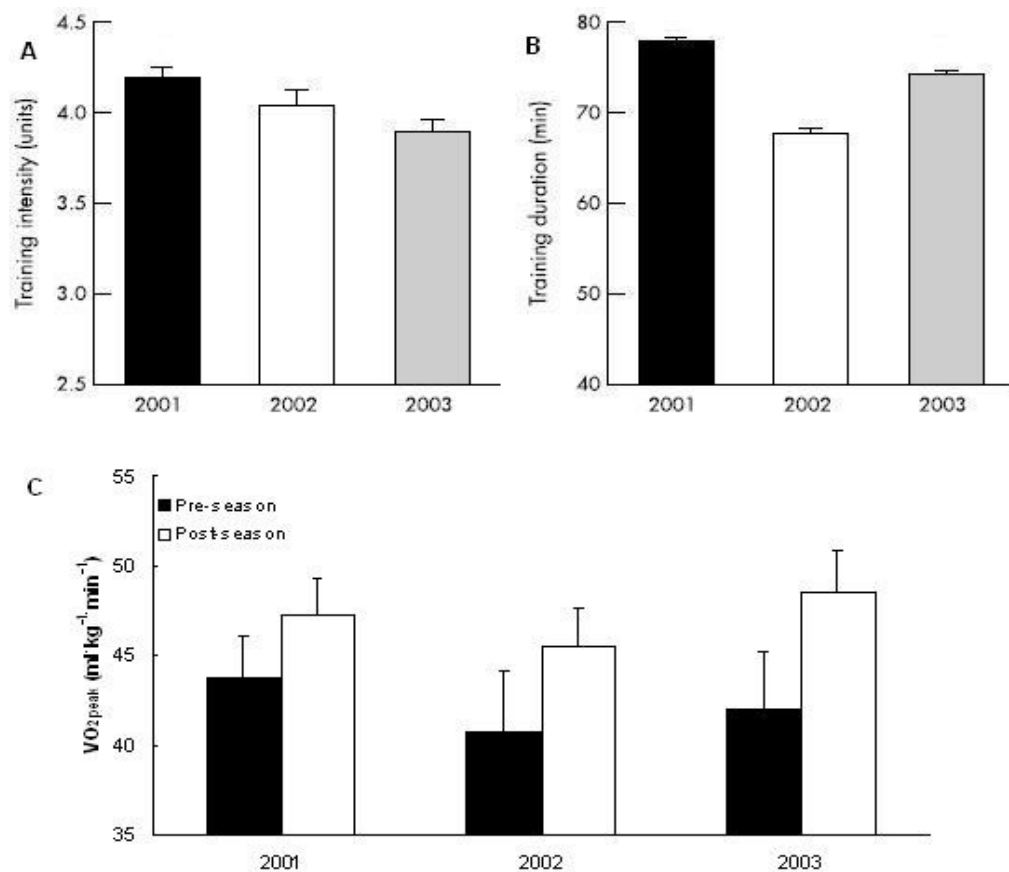


Figure 7. Overall training intensity (A), duration (B) and VO_{2peak} (C) of sub-elite rugby league players over three consecutive pre-season preparation periods. Values are means \pm 95% CI (Gabbett, 2004).

Despite these positive changes in fitness, especially VO_{2peak} , findings from a number of studies refute the notion that classic team sport training can result in substantial changes in aerobic fitness. For example, presuming a classic conditioning approach was used (as it is not stated in the paper), seasonal changes in aerobic fitness of elite soccer players appears to increase through to the start of the competitive season (25%), and decline by 5% when measured at the end of the season, as illustrated in Figure 8 (Krustrup et al., 2003). A similar trend has been observed in a recent analysis of the aerobic fitness of soccer players over the course of a soccer season (Krustrup, Mohr, Nybo et al., 2006). Additionally, college basketball training and competition has been reported to have little effect on aerobic capacity during a season (Gillam, 1985; Tavino, Bowers, & Archer, 1995). During the pre-season, the training administered by Tavino et al. (1995) consisted of anaerobic conditioning (5 x week), weight training (3 x week),

scrimmages (2 to 4 x week), and aerobic conditioning (5 x week). This resulted in a 4.7% increase in VO_{2peak} . However, during the competitive season only scrimmages (intra-team games) and anaerobic conditioning were continued in conjunction with approximately two basketball games per week. Consequently, a 5.3% decrease in aerobic fitness over the course of the competitive season was observed. When the conditioning focus of the training programme does not include aerobic conditioning it would be expected that minimal changes in VO_{2peak} would be observed which could be detrimental to individual and team performance. However, it could be argued that the exclusion of aerobic conditioning from in-season professional basketball practice was warranted given that Gillam (1985) found a negative relationship between points scored per minute of play and the cardiovascular endurance of players ($r = -0.66$). This is supported indirectly by the more recent findings of Hoffman et al. (1996), who reported a low correlation ($r = 0.10$) between the total amount of playing time per player and aerobic endurance in basketball athletes, suggesting that those with the highest levels of aerobic fitness had the least amount of playing time. The major determinant of playing time in this study was the coach's evaluation of the player's ability.

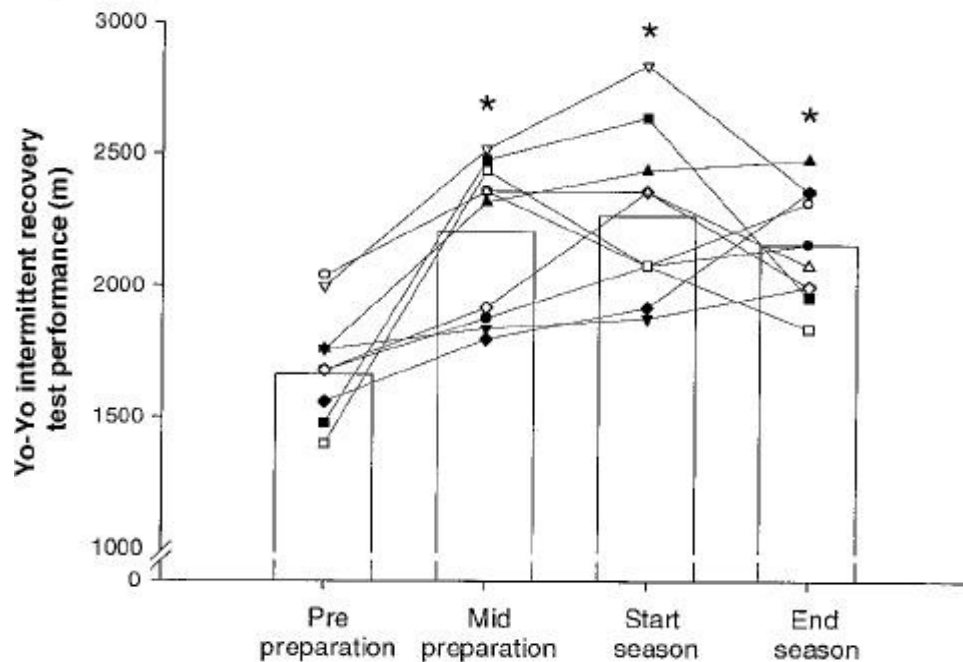


Figure 8. Seasonal changes in Yo-Yo intermittent recovery test performance for elite soccer players. Values are means \pm SEM as well as individual values. * Denotes significant difference ($P < 0.05$) from pre-preparation period (Krustrup et al., 2003).

Overall, the aerobic capacity of team sport players (basketball, rugby league, and soccer) has been shown to increase throughout the pre-season and decrease during the competitive season when using a classic team sport conditioning approach (Krustrup et al., 2003; Tavino, Bowers, & Archer, 1995). The reduced consideration to aerobic conditioning during the competitive season in some sports suggests that little importance is placed upon aerobic endurance. In some instances this may be warranted if other aspects (technical or physical) are shown to be more important. Accordingly, it appears that coaches along with strength and conditioning professionals prioritise training regimes focused on improving anaerobic fitness during the competitive season, most probably because high-intensity activities are associated with important game winning situations, such as scoring points in basketball or a try in rugby union. However, it should be emphasised that a lack of focus on aerobic conditioning is also very likely to influence the ability to repeatedly perform, and recover from, high-intensity activity (sprints) and so the absence of aerobic conditioning during the competitive season, regardless of sport may not represent best practice in terms of optimising athlete condition. Further research is needed to determine the

impact of classic team sport conditioning regimes on aerobic fitness and possibly game performance so that the strengths and weaknesses of such approaches can be identified for different team sports. Future training studies can then be developed to further develop strengths and improve on weaknesses.

Table 5. Influence of a 'classic' approach to team sport conditioning on measures of aerobic fitness.

Sport	Reference	N	Age	Season	Training	Findings
Basketball	Hoffman et al., 1991	9 M	18.8 ± 0.7	Pre & In	25 weeks	1.5 mile run time ↑5%
	Hunter et al., 1993	24 M		Unknown	4 x competitive seasons, 2 x per week 1.5-3 mile run 3 x per week 6-20 x 100-440 yard runs	VO _{2peak} ↑↓
	Laplaud et al., 2004	8 M	24 ± 4	Pre & In	4.7 ± 0.7 months, 19 ± 2 hrs per week speed, technical, match situations, & endurance training	VO _{2peak} ↑6% HR _{rest} ↓18%**
	Tavino	9 M	18-22	Pre & In	6 months, 0-5 x per week weights, aerobic, & anaerobic training	VO _{2peak} ↓5%
Rugby League	Gabbett, 2006	36 M	16.9	Pre	14 weeks, 2 x 60-100 min per week skill, speed, muscular power, agility, & endurance training	VO _{2peakP} ↑9%*
		41 M	25.5	Pre	14 weeks, 2 x 60-100 min per week skill, speed, muscular power, agility, & endurance training	VO _{2peakP} ↑5%*
	Gabbett, 2005	36 M	17.9	Off, Pre, & In	9 months, 2 x 60-100 min per week skill, speed, muscular power, agility, & endurance training	VO _{2peakP} ↑19%
	Gabbett, 2005	52 M	>18	Off, Pre, & In	9 months, 2 x 60-100 min per week skill, speed, muscular power, agility, & endurance training	VO _{2peakP} ↑18%

Gabbett, 2004	79 M	22.9	2001	10 months, 2 x 60-100 min per week periodised game specific training programme	VO _{2peak} ^P ↑8%*
	65 M	19.6	2002	10 months, 2 x 60-100 min per week periodised game specific training programme	VO _{2peak} ^P ↑12%*
	76M	21.5	2003	10 months, 2 x 60-100 min per week periodised game specific training programme	VO _{2peak} ^P ↑16%*

* = $P < 0.05$; ** = $P < 0.01$; ↑↓ = no change; ↑ = increase; ↓ = decrease; M = male; ^P = predicted; HR_{rest} = resting heart rate

3.4 Sport-Specific Aerobic Conditioning for Team Sports

Sport-specific aerobic conditioning that incorporates skills and movements specific to the sport, at intensities sufficient to promote aerobic adaptations, are being increasingly implemented in professional team sport environments (Table 6) (Lawson, 2001; Meir, Newton, Curtis, Fardell, & Butler, 2001). The perceived benefit of performing sport-specific exercise is that the training will transfer better into the athletes' competitive environment and that the greatest training benefits occur when the training stimulus simulates the specific movement patterns and physiological demands of the sport (McArdle, Katch, & Katch, 1996).

In view of the specific skill requirements that are superimposed on the physiological strain of playing a game, there is an increased emphasis on training with the ball where possible (Chamari et al., 2005; Gabbett, 2006a; Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002; McMillan, Helgerud, Macdonald, & Hoff, 2005). In any sport, the advantage of skill-based conditioning games over traditional interval training is that the skill-based conditioning games also provide the opportunity to develop decision-making and problem solving skills whilst under stressful physical loads (Gabbett, 2001). Moreover, it is possible that team sport players may respond better, both psychologically and physiologically, to sport-specific physical conditioning rather than traditional continuous or interval-based conditioning. In consideration of these factors, researchers have designed and investigated the efficacy of sport-specific methods to develop aerobic endurance (Gabbett, 2006b; Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002).

Sport-specific aerobic conditioning can take many forms. An example of such is a dribbling circuit that incorporates changes of direction, acceleration and deceleration and skills specific to the sport. Such circuits have been utilised to improve aerobic fitness, especially in soccer (Chamari et al., 2005; Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002; McMillan, Helgerud, Macdonald, & Hoff, 2005). One of the first studies to investigate this was Hoff et al. (2002) who designed a soccer-

specific dribbling track (Figure 9), where accelerations, changes of direction and using a ball, in addition to small group playing sessions were used for specific interval training. In Norwegian first division players, Hoff et al. (2002) reported that interval training using a dribbling track resulted in physical loads equivalent to 94% HR_{peak} and 92% VO_{2peak} which are optimal intensities for developing aerobic fitness (Wenger & Bell, 1986). Similarly, it was demonstrated that the accompanying interval training sessions using small-sided games (5 vs. 5) induced steady-state exercise intensities of 91% of HR_{peak} , corresponding to about 85% of VO_{2peak} . Together, both training modes provided an optimal training intensity. Interestingly, however, it was observed that players with the highest VO_{2peak} elicited the lowest percentage of VO_{2peak} during small group play suggesting that the playing situation designed for this experiment had a ceiling effect for the achievable intensity and consequently the development of aerobic endurance. That is, the technical/tactical constraints of the game prevented maximal intensities from being reached. Therefore, for athletes with an already high aerobic capacity, and with good skill, the aerobic energy system would not be fully stimulated under these training conditions. It may be preferential to prescribe traditional, interval-based, aerobic conditioning where high workloads can be achieved for sustained periods. Alternatively, it is possible that with some modification, e.g. reducing the number of players or increasing pitch size, such small-sided games may elicit a more intense/strenuous scenario, which could be physiologically beneficial for athletes with a relatively high initial aerobic fitness. In support, it has been shown that three-a-side small-sided games result in more high-intensity activity, more overall distance, less jogging and less walking, higher HR, more tackling, dribbling, goal attempts and passes than five-a-side soccer games (Platt, Maxwell, Horn, Williams, & Reilly, 2001). Likewise, when player numbers are kept constant, a larger playing area increases the intensity while a smaller playing area has the opposite effect (Rampinini et al., 2007). Additionally, a similar effect could be seen depending on the skill level of the player, independent of player numbers and pitch size. For example, it has been reported that junior players with less skill are not be able to maintain the skill/drill/technique

at a fast enough pace or with sufficient consistency to achieve and maintain the required metabolic stress and training may be counterproductive (Castagna, Belardinelli, & Abt, 2005). Potentially, therefore, such athletes will not achieve the optimal physiological adaptation during sport-specific aerobic conditioning, which might negatively influence future playing performance. Clearly the conditioning of younger/less skilled players using modern-day training techniques requires further thought and research.

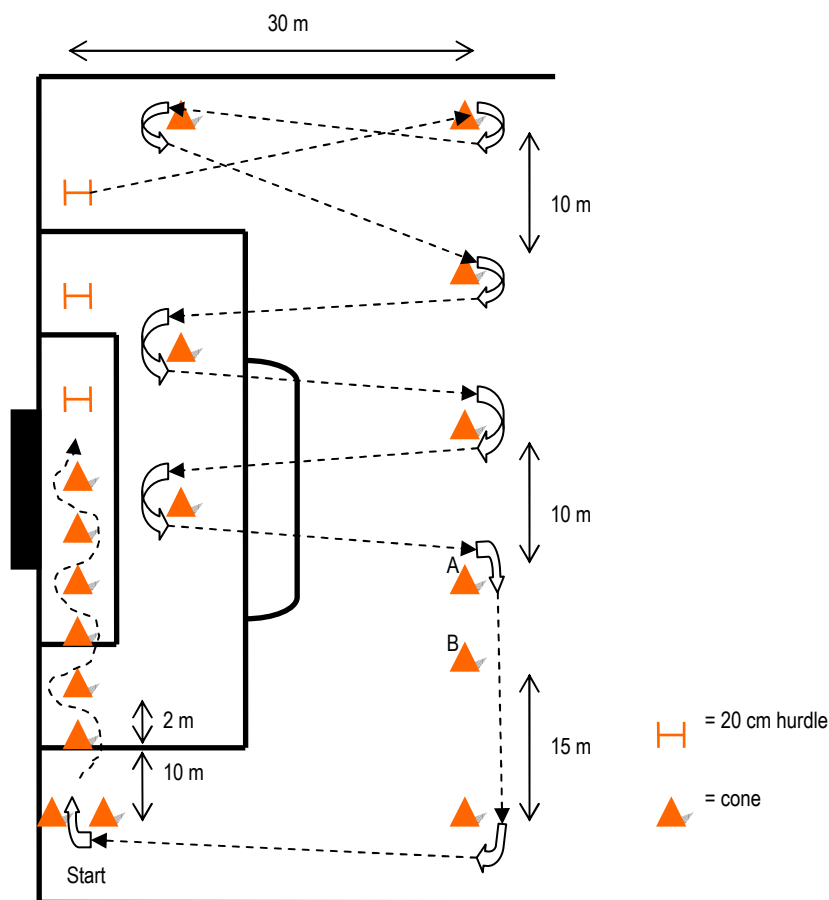


Figure 9. Soccer-specific dribbling track - 'The Hoff Track' (Hoff et al., 2002).

As aforementioned, the modifiable characteristics/parameters of small-sided games may be influential in determining physical loads. In a comprehensive study, Rampinini et al. (2007) recently examined the effects of player numbers, field dimensions, and coach encouragement on the exercise intensity of small-sided soccer games designed specifically for aerobic conditioning.

Twice per week over eight months, using 20 amateur soccer players, a total of 67 three-, four-, five-, or six-a-side games were performed as interval training, on three different sized pitches (small – 12 to 24 x 20 to 32 m, medium – 15 to 30 x 25 to 40 m, and large – 18 to 36 x 30 to 48 m), with and without coach encouragement. Each small-sided game consisted of three bouts of four minutes duration with three minutes active recovery separating bouts. A specific training intensity was not prescribed for the work intervals nor was the type of activity defined for the recovery periods. Although not the primary aim of the study, performance measures following the training period increased, with the group mean in the Yo-Yo intermittent recovery test up by 7.4% ($P<0.01$) and by an extraordinary 44.3% ($P<0.001$) in the Yo-Yo endurance test. These increases provide evidence regarding the benefits of performing sport-specific aerobic conditioning in soccer players. An improvement in Yo-Yo performance suggests a potential increase in soccer performance given that the amount of high-intensity running performed during a soccer match has been closely associated with the distance covered during the Yo-Yo test (Krustrup et al., 2003). The factor that had the greatest affect on the physiological response to small-sided games was encouragement, followed by player numbers and field dimensions (Rampinini et al., 2007). Three-a-side was more intense than four-, five-, and six-a-side games, irrespective of field dimensions and coach encouragement. The higher exercise intensity for three-a-side might be due to the players having more possession of the ball (Balsom, 1999; Reilly, Robinson, & Minors, 1984). In the same way, a larger pitch size was more intense than a smaller one (1%, $P<0.017$), independent of player numbers and coach encouragement, albeit by a small amount. Not surprisingly, in all situations, small-sided games with coach encouragement produced higher HR (2.5%) and blood lactate (30%) responses than without. By manipulating such variables it would be possible to impose a sufficient physiological stress on players already possessing a high level of aerobic fitness. A factor that was not considered by Rampinini et al. (2007) was the impact of rules on the physiological responses to small-sided games.

In a similar study to that reported by Hoff et al. (2002), Chamari et al. (2005) reported on a eight week (twice per week) training study involving 18 young male soccer players. Once per week players performed four, four minute bouts on the Hoff track at 90 to 95% HR_{peak} , separated by three minutes active recovery at 60 to 70% HR_{peak} . During the second session on the following day, players participated in small-sided games (4 vs. 4) on a 20 m square pitch at the same intensity as session one. The three minutes active recovery involved two players passing and juggling with the ball. When expressed in $ml\cdot kg^{-1}\cdot min^{-1}$, this training regime resulted in a 7.5% increase in VO_{2peak} and a 14% improvement in RE while running at 7 $km\cdot h^{-1}$. Heart rate whilst running at 7 $km\cdot h^{-1}$ also decreased by 9 $b\cdot min^{-1}$ indicating improved stroke volume. Likewise, with 16 young male soccer players, McMillan et al. (2005) demonstrated that ten weeks of aerobic endurance training, performing a similar training intervention to Chamari et al. (2005) using the Hoff track, was equally effective in elevating VO_{2peak} (6.4 $ml\cdot kg^{-1}\cdot min^{-1}$ or 9%). Given these reported improvements in VO_{2peak} , and considering the findings of previous research (Helgerud, Engen, Wisloff, & Hoff, 2001), it is reasonable to suggest that a concomitant increase in the total distance travelled and the average exercise intensity would be observed during a competitive match following each training period. Unfortunately, a weakness of both Chamari et al. (2005) and McMillan et al. (2005) studies was that no match performance measures were reported following the training intervention periods. Despite this limitation, both studies demonstrate that a specifically designed dribbling track and small-sided conditioning games allow a high percentage (>85%) of HR_{peak} and VO_{2peak} to be reached by young soccer players, resulting in improvements in VO_{2peak} of 7.5% to 9% over an eight to ten week period.

Most previous sport-specific training studies have considered soccer. However, studies in other sports such as rugby league (Gabbett, 2003; Gabbett, 2006b) and rugby union (Gamble, 2004) do exist. Gamble (2004) demonstrated that skill-based conditioning games with elements derived from gridiron, netball, and soccer were successful at improving markers of aerobic endurance

during the pre-season in professional rugby union players. Specifically, it was found that during a standardised interval work bout, consisting of four, two-minute stages interspersed with one-minute passive rest, a significant reduction ($P<0.01$) in the group mean percentage HR_{peak} during the final stage decreased over the nine-week training period. This trend for improvement was also observed within positional roles and, collectively, indicates a lower overall exercise intensity at an absolute power output from pre- to post-training. Recovery HR (i.e. decline in HR from the end of the final stage to the end of the final minute of rest also improved significantly ($P<0.01$) following the training period. Although the focus of the study by Gamble (2004) was to evaluate changes in endurance fitness of elite rugby union players following a metabolic conditioning programme, it is surprising that no data surrounding VO_{2peak} were reported. Unfortunately, the magnitude of the changes were not reported along with training intensity, training volume, and any influence on match performance, making conclusions regarding the benefits of skill-based conditioning games for rugby union players difficult to ascertain.

Skill-based conditioning games for rugby league have also been designed to develop specific aspects of the game including scrambling defence and support play, the ability to play the ball at speed, increase defence line speed, ball control and patience. During such conditioning activities Gabbett (2003) found similar HR ($152 \text{ b}\cdot\text{min}^{-1}$ vs. $155 \text{ b}\cdot\text{min}^{-1}$) and $B[\text{Lac}]$ ($5.2 \text{ mmol}\cdot\text{l}^{-1}$ vs. $5.2 \text{ mmol}\cdot\text{l}^{-1}$) during competition and training which suggests that skill-based conditioning games have the capacity to replicate the intensity of rugby league competition. However, simply replicating game intensity is not enough to induce reasonable improvements in aerobic function, which, as outlined previously, depends on factors such as exercise intensity and duration (Wenger & Bell, 1986). A more detailed discussion of the effectiveness of skill-based conditioning games when compared to traditional aerobic conditioning methods for rugby league players can be found in section 3.5. Besides, blood lactate measures have been reported to be a poor indicator of muscle lactate (Krustrup, Mohr, Steensberg et al., 2006) and are directly influenced by the amount of

high-intensity activity performed within five minutes of the blood sample being taken (Abdelkrim, El Fazaa, & El Ati, 2007). Therefore, such observations must be interpreted with caution. Likewise, the primary objectives of skill-based conditioning games in rugby league and rugby union tend to be largely technique focussed compared to physical development (although this will happen to some extent at the same time) and this may influence the extent of improvements in specific aerobic parameters such as VO_{2peak} and exercise economy.

In summary, there is no doubt that sport-specific aerobic conditioning has the ability to induce positive changes in aerobic fitness (and technique under physical load) and this is clearly demonstrated by the collective results of the aforementioned studies. However, athletes with high fitness levels and young players with limited skill may not benefit from small-sided games if the specifics of the game (number of players involved and pitch size) are not considered. Regardless, in most studies, the impact of sport-specific aerobic conditioning on subsequent game performance is lacking though the inherent difficulties and challenges in collecting worthwhile match performance data are acknowledged.

Table 6. Sport-specific aerobic conditioning in team sports and the subsequent influence on aerobic fitness.

Sport	Reference	N	Age	Season	Training Intervention	Findings
Rugby Union	Gamble, 2004 [†]	35 M	27.6 ± 4.2	Pre	9 weeks, skill-based conditioning games	HR _{peak} ↓** %HR recovery ↑**
Soccer	Chamari et al, 2005	18 M	14.0 ± 0.4	In	8 weeks, 2 x per week Hoff track & SSG (4 vs. 4) (4 min @ 90-95% HR _{peak} ; 3 min @ 60-70% HR _{peak}) x 4	VO _{2peak} ↑8% RE ↓14%**
	Hoff et al, 2002 [‡]	6 M	22.2 ± 3.3	Unknown	Hoff track & SSG (5 vs. 5) (4 min @ 90-95% HR _{peak} ; 3 min @ 70% HR _{peak}) x 2	Hoff track 94% HR _{peak} , 92% VO _{2peak} SSG 91% HR _{peak} , 85% VO _{2peak}
	McMillan et al, 2005	11 M	16.9 ± 0.4	Pre & In	10 weeks, 2 x week Hoff track (4 min @ 90-95% HR _{peak} ; 3 min @ 70% HR _{peak}) x 4	VO _{2peak} ↑11%*** HR @ 9km·h ⁻¹ ↓5%*
	Rampinini et al, 2007	20 M	24.5 ± 4.1	Pre & In	8 months, 2 x per week SSG (3 vs. 3 up to 6 vs. 6) (4 min @ >83% HR _{peak} ; 3 min active recovery) x 3	Yo-Yo IRT ↑7%** Yo-Yo ET ↑44%***

* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; HR = heart rate; HR_{peak} = heart rate peak; M = male; ↓ = decrease; ↑ = increase; RE = running economy; SSG = small-sided games;

HI = high-intensity; IRT= intermittent recovery test; ET = endurance test

† = findings demonstrate the responses to a specifically designed aerobic fitness test post training

‡ = findings demonstrate the intensities achieved during one bout of each training mode

3.5 Traditional Vs. Sport-Specific Aerobic Conditioning for Team Sports

Whilst there has been an increase in the use of sport-specific conditioning approaches for team sports, several researchers have questioned its effectiveness when compared to traditional methods of conditioning (Table 7) (Gabbett, 2006b; Impellizzeri, Rampinini, & Marcora, 2005; Reilly & White, 2004; Sassi, Reilly, & Impellizzeri, 2004). Since aerobic fitness has been shown to decline throughout the competitive season (Krustrup et al., 2003; Krustrup, Mohr, Nybo et al., 2006; Tavino, Bowers, & Archer, 1995), a priority of team sport athletes during the competitive season must at least focus on maintaining aerobic fitness while at the same time keeping up the practice of game skills (Reilly & White, 2004). Sport-specific aerobic conditioning methods may prove useful in achieving such priorities, especially when the time between competitive engagements is short. However, coaches and trainers alike need reassurance that sport-specific methods are as effective as traditional approaches to develop aerobic fitness. It has yet to be clearly identified whether a combined training stimulus of skill-based conditioning games, traditional conditioning activities, and strength training would improve physiological capacities to a greater extent than either skill-based conditioning games or traditional conditioning activities alone. Nevertheless, many authors have proposed sport-specific exercises, such as small-sided games, as an alternative mode of aerobic conditioning for team sport athletes (Gabbett, 2006b; Impellizzeri, Rampinini, & Marcora, 2005; Reilly & White, 2004; Sassi, Reilly, & Impellizzeri, 2004).

Several studies have compared the effectiveness of traditional aerobic interval conditioning with skill-based conditioning games in soccer players (Impellizzeri, Rampinini, & Marcora, 2005; Reilly & White, 2004; Sassi, Reilly, & Impellizzeri, 2004). Reilly and White (2004) trained 18 professional, premier league soccer players twice per week over six weeks. Sport-specific conditioning involved small-sided games (5 vs. 5) over six, four minute bouts, interspersed with three minutes active recovery, jogging at 50 to 60% HR_{peak}. No intensity for the work intervals

during the small-sided games was reported. Aerobic interval conditioning involved performing six, four minute periods of running at 85 to 90% HR_{peak} , interspersed with three minutes active recovery, jogging at 50 to 60% HR_{peak} . After the training intervention VO_{2peak} increased only by 0.2% (57.7 ± 3.0 to 57.8 ± 3.0 $ml \cdot kg^{-1} \cdot min^{-1}$) for the sport-specific group and by 0.3% (57.8 ± 3.2 to 58.0 ± 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$) for the aerobic interval group. This negligible improvement in VO_{2peak} is somewhat surprising given that the prescribed intensity of intervals were similar to those previously employed (Chamari et al., 2005; Helgerud, Engen, Wisloff, & Hoff, 2001; McMillan, Helgerud, Macdonald, & Hoff, 2005), which, despite higher pre-training VO_{2peak} values than Reilly and White (2004), reported large (7.5 to 9%) increases in VO_{2peak} . The lack of improvement in aerobic fitness may be related to the number of players involved in the small-sided games (Platt, Maxwell, Horn, Williams, & Reilly, 2001), the rules of the game, and/or the playing area in which the conditioning games were conducted (Bangsbo, 2003). Nevertheless, it was concluded by the authors that skill-based conditioning games were acceptable substitutes for aerobic interval training to maintain fitness during the competitive season. Similarly, Sassi et al. (2004) compared the responses of repetitive interval running with small-sided games (4 vs. 4 and 8 vs. 8) and drills for technical/tactical training in top European league soccer players. Repetitive running consisted of 4 x 1000 m runs, separated by 150 s of recovery. The authors concluded that small-sided games with the ball could present physiological training stimuli comparable with and sometimes exceeding interval training without the ball. This was demonstrated by the higher intensity observed, expressed as HR, during small-sided games (178 ± 7 $b \cdot min^{-1}$), than repetitive running (167 ± 4 $b \cdot min^{-1}$). Strengthening this finding further, Reilly and Ball (1984) had previously shown a higher energetic cost of dribbling with a ball compared to normal running. The authors found, irrespective of speed, an added cost of 5.2 $kJ \cdot min^{-1}$, which was supported by an increase in blood lactate (Figure 10). Collectively, therefore, these findings suggest that small-sided games are adequate alternatives to traditional repetitive running bouts.

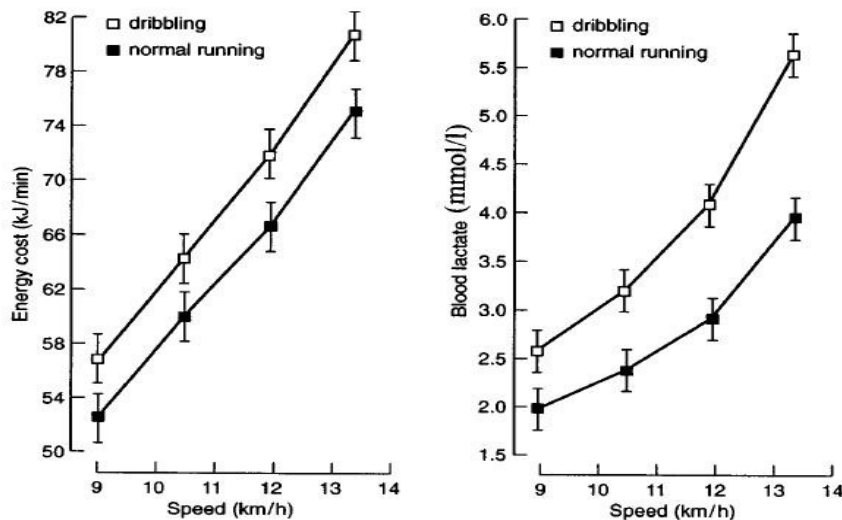


Figure 10. The added energy cost and elevation in blood lactate with dribbling a soccer ball at different speeds (Reilly & Ball, 1984).

In a similar study but of longer duration (14 weeks), involving 29 soccer players trained twice a week with part of the training session devoted to aerobic interval training (Impellizzeri, Rampinini, & Marcora, 2005). Both the sport-specific and generic training groups completed four bouts of exercise lasting four minutes, separated with three minutes active recovery (60 to 70% HR_{peak}) as suggested by Helgerud et al. (2001). The mode of exercise for the generic training group was running around the regular soccer pitch at an intensity corresponding to 90 to 95% HR_{peak} . The sport-specific training group played different small-sided games (3 vs. 3 with goal keeper, 2 to 3 ball touches, 25 x 35 m field dimensions; 4 vs. 4 with goal keeper, 2 ball touches, 40 x 50 m field dimensions; 4 vs. 4 and 5 vs. 5). The average exercise intensity expressed as a percentage of HR_{peak} during the generic training sessions was not different from that reached during the small-sided games training sessions ($90.7 \pm 1.2\%$ and $91.3 \pm 2.2\%$ respectively; Impellizzeri, Rampinini, & Marcora, 2005) suggesting that both approaches result in sufficient exercise intensities to promote aerobic adaptation. However, after training, greater increases in VO_{2peak} (7%), LT (10%), and exercise economy at LT (2%) were observed in the generic training group. Despite similar training intensity and pre-training VO_{2peak} values (56 to 58 $ml \cdot kg^{-1} \cdot min^{-1}$, Impellizzeri, Rampinini, & Marcora, 2005; 58 $ml \cdot kg^{-1} \cdot min^{-1}$, Reilly & White, 2004), these are

substantially greater than those previously reported by Reilly and White (2004). The differences observed are most probably due to the greater duration of the training intervention (14 weeks vs. 6 weeks). Nevertheless, it should be noted that the improvements reported by Impellizzeri et al. (2005) are lower than the corresponding 10%, 16%, and 7% increases in $\text{VO}_{2\text{peak}}$, LT, and exercise economy reported by Helgerud et al. (2001) after only eight weeks of interval training. This could be explained by different initial fitness levels and possibly the training programme employed by Helgerud et al. (2001) prior to the training intervention.

In addition to the observed increases in aerobic fitness, Impellizzeri et al. (2005) found, perhaps more importantly, substantial changes in several measures of match performance albeit derived from one (post-training) match analysis, for both training groups. Perhaps most relevant to soccer performance was the 22.8% and 25.5% increases in the time spent performing high-intensity activities for the generic and sport-specific training groups, respectively. The amount of high-intensity activity performed is generally accepted to differentiate top-level professional players from those of a lower standard and therefore it is an important parameter to consider (Mohr, Krstrup, & Bangsbo, 2003). Additionally, high-intensity activities are generally associated with critical moments in a soccer match, such as scoring a goal. The total distance covered during match play also increased (6.4 and 4.2% for the generic and sport-specific training groups, respectively). However, the corresponding 594 m and 399 m increases were lower than the remarkable 1716 m previously reported by Helgerud et al. (2001). Although the total distance travelled during a soccer match is a poor indicator of soccer performance (van Gool, van Gerven, & Boutmans, 1988), the differences in the improvements in total distance travelled in these studies could have been influenced by several factors including: 1) the importance of the match; 2) the skill level of the opposition; and 3) the tactical approach used. Other match performance characteristics identified included the time spent performing low-intensity activities which increased by 18.2% for the generic training group and by 7% for the sport-specific training group.

This difference is difficult to explain given that both groups performed active recovery, jogging at 60 to 70% HR_{peak} . Active recovery during training would essentially induce improvements in exercise economy at the intensities associated with recovery, therefore, allowing greater ground to be covered during a match situation at lower-intensities. Finally, walking time was decreased in both groups by similar amounts (9.3% and 8.2% for the generic and sport-specific training groups, respectively). The observed reduced walking time may suggest that players were more 'engaged' in the game. In summary, the findings of Impellizzeri et al. (2005) demonstrate that sport-specific aerobic conditioning has minimal advantage over traditional interval-based aerobic conditioning, with respect to both increases in aerobic fitness and most importantly match performance characteristics. Perhaps the marginally larger improvements observed in the sport-specific group can be attributed to an increased level of motivation and enjoyment from the players during training. It should be noted that these findings refer only to soccer.

In other football codes, interval training using distances and activities specifically related to competition, such as moving up and back over ten metres for periods of 30 to 90 s, repeat tackling efforts on a bag for 5 to 10 repetitions, and sprint efforts over distances ranging from 5 to 60 m with varying exercise to rest ratios, have been recommended for rugby league players (Meir, Newton, Curtis, Fardell, & Butler, 2001). Recently, similar skill-based conditioning games have been compared with traditional conditioning activities in rugby league (Gabbett, 2006b). Skill-based conditioning in this study consisted of games designed to develop passing, catching, and ball carrying technique, tackling technique, scrambling defence and supportive play, play the ball speed, defensive line speed and shape, and ball control. Traditional conditioning sessions were not strictly aerobic in nature and consisted of speed, muscular power, agility, and aerobic endurance training common to rugby league. Both groups performed two weekly training sessions of approximately 60 to 100 min duration over the nine-week in-season training period. Training intensity was estimated using a modified rating of perceived exertion scale (Foster et al.,

2001) and no significant differences were detected between conditioning groups. Gabbett (2006b) found similar changes in $\text{VO}_{2\text{peak}}$, predicted from the multi-stage shuttle run test, in athletes participating in both groups post-training, with skill-based conditioning games and traditional conditioning bringing about a 4.7% and 5.2% increase in predicted $\text{VO}_{2\text{peak}}$, respectively. In terms of performance, both groups won 75% of their games during the training period, however, the skill-based conditioning games approach resulted in significantly more points scored per game (61%, $P<0.05$) and fewer points conceded per game compared to traditional training methods. As previously mentioned for studies involving match performance outcomes in soccer (Dupont, Akakpo, & Berthoin, 2004; Helgerud, Engen, Wisloff, & Hoff, 2001), these differences could be influenced by several factors including, but not limited to, ground and environmental conditions, injuries, and the quality of the opposition (Gabbett, 2006b). Still, skill-based conditioning games have been campaigned for team sport athletes as a method of developing skills under pressure and fatigue (Gabbett, 2002; Mallo Sainz & Navarro, 2004). Therefore, it is feasible that the sport-specific training regime employed by Gabbett (2006b) transferred better into the competitive rugby league environment, allowing better decision making while under pressure from opposition, ultimately resulting in greater points scored and fewer points conceded. Future research into the points scored and points conceded following traditional and sport-specific aerobic conditioning methods requires further investigation. Such information would prove extremely useful, especially in competitions where bonus points are awarded for reaching a threshold in points scored during a match situation, as in the elite southern hemisphere super 14 rugby union competition.

It appears that sport-specific or traditional aerobic conditioning approaches are equivocal in soccer and rugby league in terms of developing aerobic fitness and match performance. As expected, the magnitude of response in most instances is dependent upon the intensity, frequency and duration of training as well as the total duration of the training programme, and the initial fitness level of the athletes involved. Sport-specific conditioning games seem slightly more

physically strenuous than traditional training approaches, as demonstrated by the elevated HR responses, which may potentially evoke greater improvements in cardiovascular function and subsequently aerobic fitness. These higher responses can be attributed to the additional physical demands imposed upon players during small-sided games (Reilly, Robinson, & Minors, 1984) and possibly the motivation and enthusiasm of players where they may enjoy completing sport-specific conditioning games/drills rather than traditional interval training activities.

Table 7. Effect of traditional vs. sport-specific aerobic conditioning on team sport performance and aerobic fitness.

Sport	Study	N	Age	Season	Group	Training Intervention	Findings
Rugby League	Gabbett, 2006	37 M	22.1 ± 0.9	In	Spec	9 weeks, 2 x per week skill-based conditioning games, 60-100 min	VO _{2peak} ^P ↑5%* 75% win-loss ratio
		32 M	22.3 ± 0.8	In	Trad	9 weeks, 2 x per week speed, power, agility, & endurance training, 60-100 min	VO _{2peak} ^P ↑5%* 75% win-loss ratio
Soccer	Impellizzeri et al., 2005	14	Unknown	Pre & In	Spec	12 weeks, 2 x per week SSG (4 min; 3 min @ 60-70% HR _{peak}) x 4	VO _{2peak} ↑7% %VO _{2peak} @ LT ↑4% RE @ LT ↓3% Distance covered ↑4% HI activity ↑26%
		15	Unknown	Pre & In	Trad	12 weeks, 2 x per week running intervals (4 min @ 90-95% HR _{peak} ; 3 min @ 60-70% HR _{peak}) x 4	VO _{2peak} ↑8% %VO _{2peak} @ LT ↑4% RE @ LT ↓3% Distance covered ↑6% HI activity ↑23%
	Reilly & White, 2004	9	18.2 ± 1.4		Spec	6 weeks, 2 x per week SSG (5 vs. 5) (4 min; 3 min @ 50-60% HR _{peak}) x 6	VO _{2peak} ↑↓ La _{peak} ↑↓
		9	18.2 ± 1.4		Trad	6 weeks, 2 x per week running intervals (4 min @ 85-90% HR _{peak} ; 3 min @ 50-60% HR _{peak}) x 6	VO _{2peak} ↑↓ La _{peak} ↑↓
	Sassi et al., 2004 [†]	9	Unknown		Spec	SSG (4 vs. 4, 8 vs. 8)	91% HR _{peak}

Trad running intervals
(1000 m; 150 s rest) x 4

85% HR_{peak}

* = $P < 0.05$; ** = $P < 0.01$; Spec = sport-specific training group; Trad = traditional training group; M = male; ↓ = decrease; ↑ = increase; ↑↓ = no change; ^p = predicted;
 HR_{peak} = heart rate peak; La_{peak} = lactate peak; SSG = small-sided games; LT = lactate threshold; RE = running economy; HI = high-intensity
 † = findings demonstrate the intensities achieved during one bout of each training mode

3.6 Relevance of the Literature to the Current Study

Traditional aerobic training, or straight line running with minimal changes in direction and no skill component, has been shown to increase VO_{2peak} in collegiate basketball players by 7% and when performed concurrently with resistance training this increases to 13% (Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003). Similarly, traditional aerobic training has been demonstrated to improve the VO_{2peak} of professional soccer players by 8 to 11% (Helgerud, Engen, Wisloff, & Hoff, 2001; Helgerud, Kemi, & Hoff, 2003). Recently, sport-specific aerobic training has also been demonstrated to elicit 7 to 9% improvements in the VO_{2peak} of youth soccer players (Chamari et al., 2005; McMillan, Helgerud, Macdonald, & Hoff, 2005). Currently there is no published research surrounding sport-specific aerobic conditioning in basketball athletes. Therefore, by gathering an understanding of the different sport-specific approaches used by other intermittent team sports, such as soccer, one can design an evidence based physical training regime.

3.7 Summary

It has been well established (especially in basketball, rugby union and soccer) that team sport athletes require a high level of aerobic fitness in order to maintain repeated high-intensity efforts and to recover adequately between such activities throughout the full duration of a typical game (40 to 90 min). Research to date suggests that these adaptations can be achieved by regularly performing aerobic conditioning. Traditional aerobic conditioning, with minimal changes of direction and no skill component, has been demonstrated to effectively increase aerobic function within an eight to ten week period in team sport players. More importantly, traditional aerobic conditioning methods have been shown to substantially increase sport performance with increases in total distance covered and the number of sprints performed during a match. Despite these benefits many professional team sports require the upkeep of both aerobic fitness and

sport-specific skills during the competitive season. With classic team sport trainings being shown to evoke marginal increases/decreases in aerobic fitness, sport-specific aerobic conditioning methods have been designed to allow adequate intensities to be maintained to induce improvements in VO_{2peak} . Such activities have incorporated movement-specific and skill-specific tasks, such as small-sided games and dribbling circuits. Sport-specific methods have been demonstrated to promote increases in VO_{2peak} , however, research to date has revealed little about any subsequent effect on game performance. The implementation of sport-specific conditioning may be influenced by the skill level of the athlete, where those with lower skill levels may not be able to maintain the skill or drill at a suitable intensity to promote the desired aerobic adaptations; or current fitness, where players with already high levels of fitness who can easily achieve the desired physical load during small-sided games. However, these factors can be somewhat overcome when conditions such as player numbers, field dimensions, and coach encouragement during small-sided games are manipulated. Smaller numbers, larger playing areas and coach encouragement tend to increase the metabolic loading of small-sided games. When traditional and sport-specific conditioning approaches are compared with each other, results are equivocal. Both approaches promote similar increases in aerobic fitness and sport performance when training intensity and volume are constant. Perhaps the only benefit of performing sport-specific conditioning is that it allows for both aerobic fitness and game skills to be developed simultaneously and that players may enjoy trainings more.

Chapter Four: Methodology

4.1 Methods

4.1.1 Subjects

Fourteen male high school aged basketball players volunteered to participate in this study. However, during the course of the training study four players withdrew. The mean (\pm SD) age, height, and body mass were 16.4 ± 1.2 years, 1.79 ± 0.1 m, 73.4 ± 15.1 kg, respectively. On average, the players had 2.9 ± 2.1 years of playing experience with the senior/premier high school basketball team and were regularly participating in two school training sessions per week prior to the commencement of this study. All participants were informed of the procedures, risks, and benefits of the study, and completed parental informed voluntary consent and personal assent documents prior to the research commencing (Appendix 1; Appendix 2; Appendix 3). The AUT University Ethics Committee (AUTEC) granted ethical consent before participants were recruited for involvement in this study (Appendix 4).

4.1.2 Experimental Design

The duration of the training study was six weeks and was carried out during the competitive phase of the high school basketball season. Two 'baseline' physical testing periods (laboratory and field) preceded the six week training intervention, which was followed by a post-intervention physical testing period. The two pre-intervention testing periods were used to determine the reliability of the testing methods. Pre- and post-intervention physical testing occurred over approximately seven days and involved three different physical testing sessions, with each testing day separated by 24 to 48 hours of recovery time.

4.1.3 Testing Protocols

The initial testing session involved performing a battery of physical tasks to assess maximal running speed, maximal vertical jump height, agility, and repeated sprint ability. The battery of physical tests took place on a wooden, inner sprung, indoor court of Olympic standard. A standardized ten minute basketball specific warm-up was conducted prior to each battery of physical tasks. This included jogging, running, sprinting, side shuffling, and jumping. The warm-up activity was followed by a five minute period of dynamic and static stretching. Physical testing was conducted in a specific sequence to allow adequate recovery of energy systems and to avoid fatiguing energy systems that may impact upon the performance of subsequent tests. The order was: 1) maximal running speed; 2) maximal vertical jump; 3) agility; and 4) repeated sprint ability. Three trials of each assessment, except the repeated sprint ability test, were performed and the mean of the best two trials were determined and used for analysis. To improve reliability, one practice trial prior to each test was permitted.

4.1.3.1 Running Speed

Maximal running speed was measured over 20 m with split times recorded at five and ten metres using double laser beam electronic timing equipment (Swift Performance Equipment, Lismore, NSW, Australia). Electronic timing equipment has been shown to produce an accurate measure of running speed, reporting speeds to the nearest 0.1 m·s⁻¹ (Yeadon, Kato, & Kerwin, 1999). Timing gates were set at 0.75 m above ground level, two metres apart facing each other at the start line, 5, 10, and 20 m marks. Participants started 0.50 m behind the first timing gate with both feet in line with each other. Participants were instructed to lean forward into the sprint and that the first step must be forward of the body. All participants practiced this starting technique during the warm-up period and during the practice sprint immediately prior to performing the three trials. Any 'back steps', rocking while in the start position, or rolling starts during the 20 m sprints were not permitted. Participants were instructed to run as fast as possible and not to slow down until they

had passed the last timing gate. Times were recorded to the nearest 0.01 s and were later converted into standardized units for velocity (m·s⁻¹). The mean of the best two times for each testing occasion is reported in this study. Throughout the sprint, participants were given consistent verbal motivation from the test administrators. Between trials each participant received adequate recovery time (approximately 3 to 5 min).

4.1.3.2 Vertical Jump

Maximum vertical jump height was measured using a double-leg counter-movement jump, accompanied by an arm swing, for maximum height using a contact mat system (Swift Performance Equipment, Lismore, NSW, Australia). The system measures jump height, flight time, and ground contact time. The contact mat system has been shown to demonstrate very high reliability (flight time $r=0.95$; contact time $r=0.99$) when compared to a force platform (Cronin & McLaren, 1999). As the contact mat system is not a solid object, such as a wall, any inhibition due to fear of injury was minimized, allowing for maximum effort during the jump (Young, Macdonald, Heggen, & Fitzpatrick, 1997). Participants positioned their feet approximately shoulder width apart on the contact mat before attempting the jump. Steps or run-ups into the jumping action were not permitted and the landing had to occur on the contact mat. Jump height was determined to the nearest cm using the following formula which was based on simple Newtonian principals using acceleration due to gravity and flight time:

$$\text{Jump Height (m)} = 0.5 * g (\frac{t}{2})^2$$

$$\text{E.g., Jump Height (m)}$$

$$= 0.5 * 9.81 * (\frac{0.64}{2})^2$$

$$= 4.905 * 0.32^2$$

$$= 0.50 \text{ m}$$

Equation 1. Calculation for jump height.

where g represents acceleration due to gravity ($9.81 \text{ m}\cdot\text{s}^{-2}$); and t represents the flight time of the jump in seconds. Participants performed three jump trials in succession with approximately 15 to 30 s recovery between jumps. One practice jump was permitted. The mean of the best two jumps for each testing date was recorded. Jumps were considered void if the participant 1) went into extreme (>45 degrees) hip flexion during the flight time of the jump; 2) flexed the knees to the extent that the heel nearly touched the gluteal muscles; and 3) did not land on the contact mat.

4.1.3.3 Agility

Agility was determined using the Triangle Agility, also known as the Arrow Agility test, as illustrated in Figure 11 (Bailey, Burke, & Shanks, 2006). This test is basketball specific as it evaluates the participant's ability to change direction quickly and without the loss of speed in a confined area. Currently administered by Basketball New Zealand during high-performance athlete testing, the protocol integrates forward and backward running as well as both left and right shuffling. An 'X' was marked on the floor in front of each cone (B, C, and D). Participants started 0.50 m behind the start line and the same starting protocol was used as that described for the maximum running speed assessment. At their own discretion, participants sprinted forward seven metres to point B, placing their left foot on the 'X'. They then shuffled three metres diagonally to the right to point C, placing their right foot on the 'X', which was followed immediately by shuffling six metres to the left to point D, placing their left foot on the 'X'. Then they ran forward to point B placing their right foot on the 'X'. To finish, participants then ran backwards, passing through the finishing line at point A. Timing gates (Swift Performance Equipment, Lismore, NSW, Australia) were mounted 0.75 m above the ground and positioned facing each other, two metres apart on either side of the starting line (A). Times were recorded to the nearest 0.01 s and the mean of the best two times for each testing date was recorded. The test was repeated when the athletes failed to place their foot on an 'X' at the base of each cone, crossed their feet while shuffling, and/or did not face forward at all times.

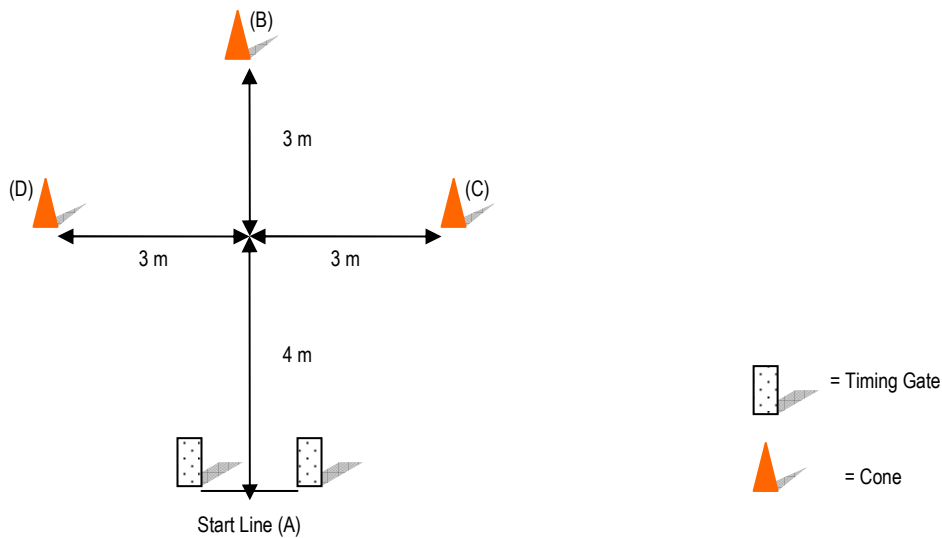


Figure 11. Layout of the Triangle Agility or Arrow Agility Test.

4.1.3.4 Repeated Sprint Ability

Repeated sprint ability (RSA) was measured using the Repeated High-Intensity Endurance Test (RHIET; Bailey, Burke, & Shanks, 2006). The RHIET is used across numerous sports in New Zealand to assess an athlete's anaerobic ability. The RHIET covers a total distance of 60 m per run. Participants started 0.50 m behind the baseline (A), adopting the same starting protocol as outlined for the maximal running speed test. Participants were required to sprint towards the five metre mark (B), placing one foot on or over the mark, then return towards the baseline (A), placing one foot on or over the mark. Immediately, they sprint towards the ten metre mark (C), placing one foot on or over the mark, and returning to the baseline (A). Finally, they sprint to the 15 m mark (D), placing one foot on or over the mark, and returning towards the start by sprinting over the baseline (A). This pattern constituted one repeat and each participant completed six repeats on 30 s intervals at 0:00, 0:30, 1:00, 1:30, 2:00, and 2:30 min. If a participant completed all the mini shuttles before the 30 s interval expired, the remaining time was given as rest. For example, if the participant were to run all three mini shuttles in 14 s they would receive 16 s as rest before they attempted the next run. Three participants ran simultaneously with separate timekeepers assigned to each lane. Each running lane was two metres in width. Stopwatches

were used to record the time that each participant took to complete a repeat and was recorded to the nearest 0.01 s. The total time of all six repeats was calculated and recorded along with the mean shuttle time and the fatigue percentage. Percent fatigue was calculated via the following formula:

$$\text{Fatigue (\%)} = (T_{\max} - T_{\min}) / T_{\min} \times 100.$$

Equation 2. Calculation for fatigue index (%) during the RHIET.

where T_{\max} represents the slowest shuttle time and T_{\min} represents the fastest shuttle time in s. Timing began the instant the participant moved forwards over the baseline and terminated the instant they crossed the baseline upon completion of the mini shuttles. The layout of one lane of the RHIET is illustrated in Figure 12.

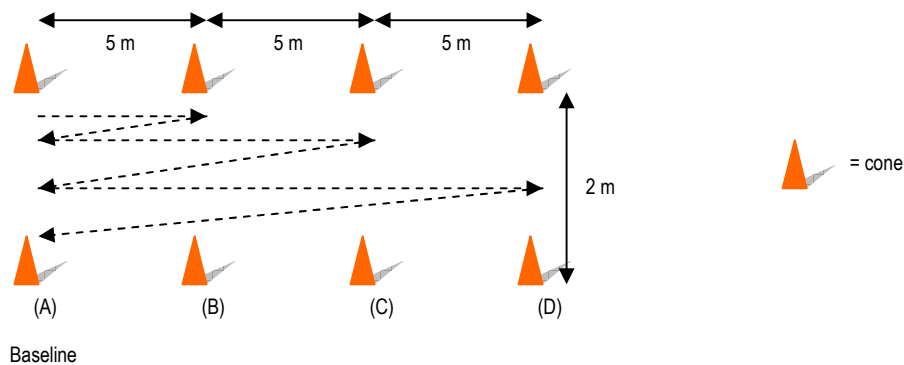


Figure 12. Layout of the Repeated High-Intensity Endurance Test (RHIET).

4.1.3.5 Yo-Yo Intermittent Recovery Test

During the second testing session, sport specific aerobic fitness was assessed using the Yo-Yo Intermittent Recovery Test, Level 1 (Krustrup et al., 2003). The Yo-Yo intermittent recovery test consists of repeated 2 x 20 m runs back and forth between the starting, turning, and finishing line at a progressively increased speed controlled by audio bleeps from a tape recorder (Krustrup et al., 2003). Between each running bout, participants are permitted a ten second active rest period,

consisting of 2 x 5 m of jogging. When a participant failed to reach the finishing line in time on two consecutive occasions, the test ended and the total distance covered recorded. The Yo-Yo intermittent recovery test, level 1, consists of four running bouts at 10 to 13 km·h⁻¹ (0 to 160 m) and another seven runs at 13.5 to 14 km·h⁻¹ (160 to 440 m), where after it continues with 0.5 km·h⁻¹ speed increments after every eight running bouts (i.e., after 760, 1080, 1400, 1720 m, etc.) until exhaustion (Krustrup et al., 2003). The test was performed as a group on an indoor court with the 20 m running distance marked out with cones. Another row of cones was placed five metres behind the finishing line and marked the jogging distance during the active recovery period (Figure 13). Finger prick blood samples were analyzed immediately post-test for B[Lac]. Before the test, participants carried out a warm-up period consisting of the first four speed levels in the test, which was followed by five minutes of passive recovery and dynamic stretching. Before starting the test, the speed of the tape recorder was manually calibrated by timing the interval between two audio bleeps set 60 s apart with a stopwatch. If the measured time was between 59 to 61 s the test could begin. If the measured time was outside of the 59 to 61 s time bracket, the tape was tightened and/or the speed of the tape recorder was adjusted and the speed calibration was repeated. The Yo-Yo intermittent recovery test took place on a wooden, inner sprung, indoor court of Olympic standard.

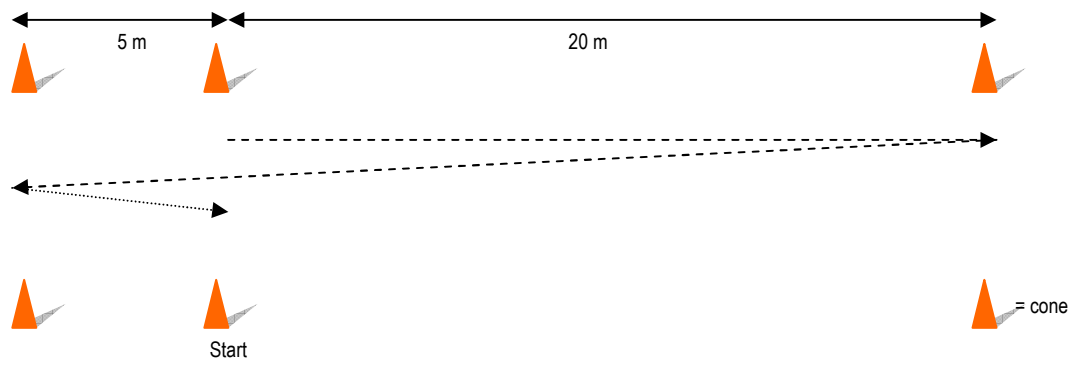


Figure 13. Layout of the Yo-Yo Intermittent Recovery Test. Dashed arrows indicate the direction of an individual shuttle run.

If participants terminated their participation in the Yo-Yo test between stages, the following equation was used to determine peak running speed (V_{\max}):

$$V_{\max} (\text{km}\cdot\text{h}^{-1}) = V + V_{\text{step}} \times (R_{\text{com}} - R_{\text{total}}/2)/R_{\text{total}}$$

Equation 3. Calculation for peak running speed during the Yo-Yo IRT.

where V represents the speed of the stage in $\text{km}\cdot\text{h}^{-1}$; V_{step} represents the increase in speed between each stage in $\text{km}\cdot\text{h}^{-1}$; R_{com} represents the number of shuttle runs the participant completed during the stage; and R_{total} is the number of shuttle runs corresponding to the stage.

Blood lactate analysis was performed immediately after the Yo-Yo intermittent recovery test using a portable blood lactate test meter (Lactate Pro, Arkray Inc., Kyoto, Japan). The portable blood lactate analyser used in this study has been reported to be reliable and valid (Pyne, Boston, Martin, & Logan, 2000). Approximately five μL of whole blood was drawn into the strips reaction space with measurement starting automatically. When the blood sample drawn from the tip of the test strip reached the reaction layer, lactate concentration in the sample was determined based on an amperometric method using an enzymatic reaction. The measuring range, according to the manufacturer, of the lactate pro was 0.8 to 23.3 $\text{mmol}\cdot\text{L}^{-1}$ and blood lactate values were measured to the nearest 0.1 $\text{mmol}\cdot\text{L}^{-1}$. Prior to collecting blood samples, each lactate pro was calibrated using

a calibration strip designed exclusively for use with the lactate pro. Heart rate was monitored, throughout the entire duration of the Yo-Yo intermittent recovery test using a team HR monitoring system (Team Polar, Polar Electro Oy, Kempele, Finland).

4.1.3.6 Traditional Aerobic Capacity

The final testing session was administered in an environmentally controlled exercise laboratory where the participants individually completed an incremental running test to voluntary exhaustion to determine several measures of aerobic function including: VO_{2peak} , LT and RE. Prior to the commencement of the test, participant's height, body mass, seated resting HR, and seated resting blood lactate were measured and recorded. Initial treadmill (Powerjog, Birmingham, UK) running speed was between seven and nine $km \cdot h^{-1}$ (depending on fitness level) and at a constant gradient of 1.5%. Participants ran at the start pace for three minutes. This was followed by a one minute rest period where the participant straddled the treadmill so that a blood sample could be taken from the fingertip for blood lactate determination. Speed increased thereafter with stepwise one $km \cdot h^{-1}$ per stage increments after every three minutes. When the participant self-terminated the test, a final blood sample was taken from the fingertip. To ensure that VO_{2peak} had been reached during the treadmill step test, each participant was required to have met at least three of the following criteria: 1) a peaking and levelling of VO_2 despite an increase in running speed; 2) a respiratory exchange ratio >1.1 ; 3) attainment of $>95\%$ age-predicted HR_{peak} ; and 4) a $B[Lac] >8$ $mmol \cdot l^{-1}$ (Williford, Scharff-Olson, Duey, Pugh, & Barksdale, 1999). Peak running speed was also recorded. Individual HR_{peak} and VO_{2peak} were determined as the peak values reached in a five s and 30 s period, respectively. Pulmonary oxygen uptake was measured every ten s throughout the test via a mixing-chamber gas analysis system (Metalyzer II, Cortex, Leipzig, Germany). Oxygen uptake data was collected and stored to a computer using specifically designed software (Metasoft 3B, Cortex, Leipzig, Germany). Before each test a two-point gas calibration using

gases of known O_2 and CO_2 concentrations was performed. The volume sensor was also calibrated using a three-litre syringe (Series 5530, Hans Rudolph, Inc., Kansas City, U.S.A.).

Blood samples during the treadmill test were collected via capillary tube (YSI 1505, approximately 25 μ L) and immediately analyzed for lactate using an YSI 1500 Sport, blood lactate analyzer (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio, U.S.A.). The YSI sport uses immobilized enzyme electrode technology where a thin film of lactate enzyme is immobilized within a membrane. Hydrogen peroxide is produced when the lactate in the blood sample injected diffuses through the membrane. The hydrogen peroxide, measured at a platinum anode, is proportional to the lactate in the sample. According to the manufacturers, the YSI has a measurement range of 0 to 30 $mmol^{-1}$ with a precision of $\pm 2\%$ of the reading or 0.1 $mmol^{-1}$, whichever is larger. Blood lactate values for the treadmill test were measured to the nearest 0.01 $mmol^{-1}$. Prior to each incremental treadmill test, the blood lactate analyzer was calibrated with a lactate standard (5 $mmol^{-1}$) supplied by the manufacturer (YSI 2327). This followed the manufacturers recommended calibration point of 5 $mmol^{-1}$. Upon completion of the test, the lactate analyzer was checked for system linearity with the 5 $mmol^{-1}$ lactate standard. Heart rate was monitored, throughout the entire duration of the incremental treadmill step test protocols, using a team HR monitoring system (Team Polar, Polar Electro Oy, Kempele, Finland).

4.1.3.7 Running Economy

Running economy was calculated as the oxygen cost (VO_2) of running during the last 30 s of three sub-maximal running velocities at 9, 11, and 13 $km \cdot h^{-1}$ during the incremental step test. All VO_2 values were determined in both absolute ($L \cdot min^{-1}$) and relative ($ml \cdot kg^{-1} \cdot min^{-1}$) values but also using an allometric scale. Oxygen uptake is a measure of power and, in order to be independent of absolute body mass, should be expressed in ml per kg lean body mass raised to a power of

0.75 (Bergh, Sjodin, Forsberg, & Svedenhag, 1991). Therefore, all VO_2 values were also calculated in $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$.

4.1.3.8 Lactate Mid-Point

A measure representing the individual LT speed was derived from the treadmill tests by assuming a log-log relationship between lactate concentration and running speed (Beaver, Wasserman, & Whipp, 1985). The Trend function in Microsoft Excel was used to fit straight lines to the pre-training and post-training lactate plots, then predicted running speed corresponding to a 'mid-point' of the lactate concentration in the treadmill step test was calculated (Bonetti, Hopkins, & Kilding, 2006). The 'mid-point' was determined by averaging the minimum and maximum values of the log-transformed lactate concentrations from all three tests.

4.1.4 Basketball Specific Endurance Training Intervention

Basketball participants were ranked based on their performance in the two pre-intervention aerobic assessments and randomly assigned into two groups, either the sport specific training group (E_{spec}) or the control group (CON), using a matched pairs design. Endurance based interval training using a dribbling circuit (Figure 14) replaced the regular physical fitness activity for E_{spec} at the start of each of the two training sessions per week. This was carried out on an indoor court. The dribbling circuit was based on a previous design (Smith, 2004) and adapted to mimic as closely as possible the movement patterns of basketball match play as reported by McInnes et al. (1995). Briefly, participants ran the circuit in four, four minute intervals at 90 to 95% HR_{peak} with three minute jogging at $\sim 70\%$ HR_{peak} separating each four minute work period. Participant specific HR_{peak} was determined from the aerobic tests. This training protocol was adapted from Helgerud et al. (2001). The average running time of one circuit was 33 s and the total distance covered during one lap was approximately 108 m, with 72% of the movements forward sprinting, 20% side shuffling, and 8% back-peddalling. The proportion of the circuit considered 'offence'

activity where a basketball was dribbled, was 42%, while 58% was considered 'defensive' activity without the ball. One field goal attempt, one rebound, three vertical jumps, one pivot, and 14 changes of direction were completed during one repeat of the circuit. Participants in CON performed their typical basketball training drills during the E_{spec} training time, which was overseen by the coach. Basketball training drills included dribbling, passing, footwork, offensive skill, and defensive skill activities. Heart rate was monitored during the six week endurance training regime with the team system. Basketball participants from both E_{spec} and CON wore HR transmitter belts and HR monitors (Team Polar, Polar Electro Oy, Kempele, Finland), which were continuously observable throughout the duration of the training session by the participant. After each team training, participant HR was uploaded and analyzed using Polar Performance software (Polar Electro Oy, Kempele, Finland). All HR were recorded at five s intervals (Ali & Farrally, 1991).

4.1.5 Statistical Analysis

A pre-configured Microsoft Excel spreadsheet was used for the analysis of reliability of both the pre-training tests and for the comparison of the pre- and post-training tests (Hopkins, 2002). Means and standard deviations were calculated for each of the descriptive and dependent variables. The usual analysis of the raw values of the dependent variable was based on the unequal-variances unpaired t statistic. The effects are the differences in the two pairwise changes between the trials (pre2-pre1 and post1-pre2). An analysis of logarithmic transformed values of the dependent variable were also determined to deal with any systematic effect of an individual's pre-test value on the change due to the training. The magnitudes of log-transformed effects are expressed in percentages and Cohen units: the difference in the changes in the mean as a fraction or multiple of the pre-test between-subject standard deviation. The magnitude of the Cohen effect sizes was determined using the following scale: <0.2 is trivial, 0.2-0.5 is small, 0.6 to 1.1 is moderate, 1.2 to 1.9 is large, and 2.0 or more is very large (Hopkins, 2000). Cohen effect sizes were used for effects derived from physiological variables and for some measures of

performance that had no direct association with competitive performance scores. Reliability was expressed as the typical error of measurement and change in the mean. The typical error was calculated as the standard deviation of the change score in CON divided by $\sqrt{2}$. Estimates of uncertainty were expressed as 90% confidence limits for all effects. The value of the effect that was considered the smallest worthwhile response to the training was a Cohen's effect statistic of 0.2 or a 1% difference in performance. An effect was deemed unclear if its confidence interval overlapped the thresholds for significance; that is, if the effect could be substantially positive and negative, or beneficial and detrimental (Batterham & Hopkins, 2006).

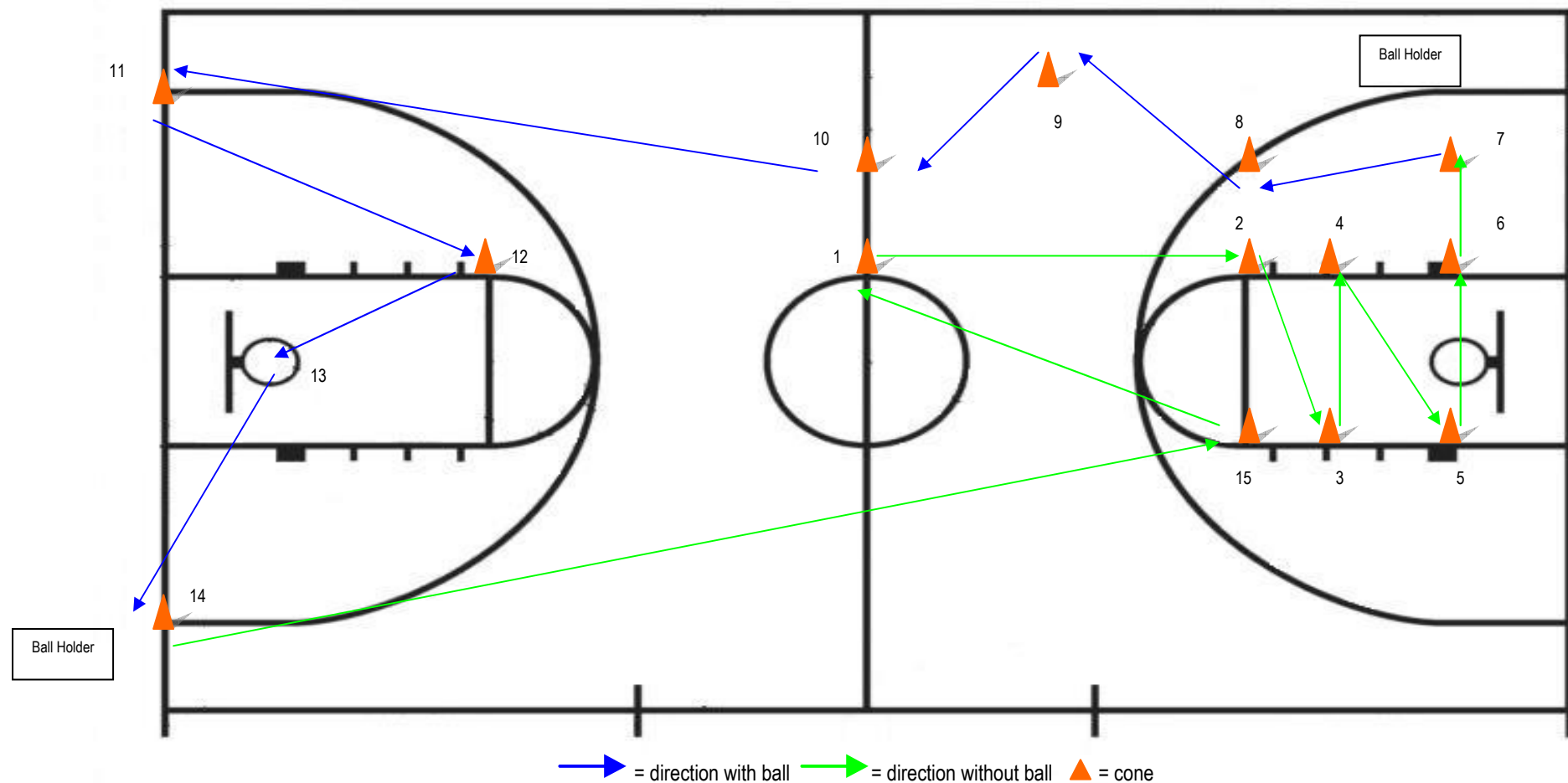


Figure 14. Basketball movement specific training circuit. 1-2 forward sprint; 2 pivot left; 2-3 shuffle left; 3-4 shuffle right; 4-5 shuffle left; 5-6 shuffle right; 6-7 run into vertical jump (collect ball upon landing); 7-10 speed dribble ball around cones; 10-11 speed dribble; 11-12 speed dribble; 12-13 lay-up attempt; 13 lay-up rebound; 13-14 speed dribble (drop ball at 14); 14-15 forward sprint; 15-1 back pedal.

Chapter Five: Results

Results are presented below in two parts: 1) pre-intervention reliability study ($N = 14$); and 2) experimental training study ($N = 10$). Pre-training baseline values for ten participants involved in the experimental training study are presented in Table 10. All data are presented as means [\pm 90% confidence limits (CL)] unless otherwise stated.

5.1 Reliability

5.1.1 Field Test Measures

Reliability calculations for all variables associated with the battery of field tests are presented in Table 8. The percent (%) change in means (90% CL) between the two testing occasions ranged from -0.6% (-1.7, 0.6) for 20 m speed to 4.9% (2.6, 7.3) for time to complete the agility test. Intraclass correlation coefficients (ICC) for the variables assessed during the battery of field tests were very large according to the criteria outlined by Hopkins (2000). Twenty metre speed had the highest ICC with $r = 0.89$ (0.73, 0.96) whereas agility time produced the lowest ICC of $r = 0.73$ (0.41, 0.89). Typical error was calculated in both absolute and percentage terms for each variable. The % typical error for the vertical jump was 6.5% (4.9, 9.8) and the absolute or raw typical error was 2.6 cm (2.0, 3.8) and the change in mean was 0.7% (-3.5, 5.0).

The change in mean for the total distance covered during the Yo-Yo intermittent recovery test was 8.2% (-5.0, 23.3). All variables produced medium to strong ICC values: distance covered $r = 0.73$ (0.41, 0.89), peak speed achieved $r = 0.73$ (0.40, 0.89), and HR_{peak} $r = 0.76$ (0.43, 0.91). The large % change in mean for distance covered resulted in an absolute typical error of 217 m (166, 323) and a % typical error of 21.4% (15.9, 33.4). Peak speed and HR_{peak} had smaller typical error values. Reliability data for the Yo-Yo test are presented in Table 8.

Table 8. Test-retest reliability data for field test measures prior to the experimental training study (N = 14)

	Pre-test 1 mean \pm SD	Pre-test 2 mean \pm SD	Change in Mean (%) (90% CL)	ICC (<i>r</i>) (90% CL)	Typical Error (90% CL)	% Typical Error† (90% CL)
Battery of Field Tests						
5 m Speed (m s ⁻¹)	4.18 \pm 0.23	4.18 \pm 0.22	-0.2 (-1.8, 1.4)	0.80 (0.55, 0.92)	0.10 (0.08, 0.15)	2.5 (1.9, 3.7)
10 m Speed (m s ⁻¹)	5.05 \pm 0.26	5.03 \pm 0.25	-0.3 (-1.6, 0.9)	0.87 (0.68, 0.95)	0.09 (0.07, 0.14)	1.9 (1.4, 2.8)
20 m Speed (m s ⁻¹)	5.93 \pm 0.30	5.89 \pm 0.29	-0.6 (-1.7, 0.6)	0.89 (0.73, 0.96)	0.10 (0.07, 0.15)	1.7 (1.3, 2.6)
Vertical Jump (cm)	42.0 \pm 7.9	42.1 \pm 7.0	0.7 (-3.5, 5.0)	0.87 (0.68, 0.95)	2.6 (2.0, 3.8)	6.5 (4.9, 9.8)
Agility (s)	7.97 \pm 0.56	8.35 \pm 0.48	4.9 (2.6, 7.3)	0.73 (0.41, 0.89)	0.27 (0.20, 0.40)	3.4 (2.6, 5.0)
RHIET Total Time (s)	97.17 \pm 5.70	96.98 \pm 6.42	-0.2 (-2.2, 1.8)	0.77 (0.48, 0.91)	3.01 (2.29, 4.47)	3.1 (2.3, 4.6)
Yo-Yo Intermittent Recovery Test, Level 1						
Distance Covered (m)	1026 \pm 351	1129 \pm 470	8.2 (-5.0, 23.2)	0.73 (0.41, 0.89)	217 (166, 323)	21.4 (15.9, 33.4)
Peak Running Speed (km h ⁻¹)	15.2 \pm 0.5	15.3 \pm 0.7	1.0 (-0.5, 2.5)	0.73 (0.40, 0.89)	0.3 (0.3, 0.5)	2.2 (1.7, 3.3)
HR _{peak} (b min ⁻¹)	203.6 \pm 9.1	197.0 \pm 9.1	-3.4 (-5.0, -1.9)	0.76 (0.43, 0.91)	4.4 (3.3, 6.7)	2.2 (1.7, 3.5)

† = typical error as a coefficient of variation (%)

5.1.2 Physiological Measures

5.1.2.1 Maximal Oxygen Uptake

Table 9 presents the reliability data for all physiological variables determined during the laboratory based incremental step test. The $\text{VO}_{2\text{peak}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) presented a change in mean of -0.9% (-4.8, 3.1) and represented the largest change in mean. HR_{peak} produced a change in mean of -0.1% (-1.5, 1.3) and represented the smallest change score. ICC's ranged from 0.69 to 0.93 for relative $\text{VO}_{2\text{peak}}$, allometrically scaled $\text{VO}_{2\text{peak}}$, HR_{peak} , and peak treadmill speed. The highest typical error as a % was 6.1% (4.6, 9.2) for relative $\text{VO}_{2\text{peak}}$, which represented an absolute error of 2.7 (2.1, 4.1) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. HR_{peak} presented the lowest typical error as a % with 2.1% (1.6, 3.2) or 4.0 (3.1, 6.1) $\text{b}\cdot\text{min}^{-1}$.

5.1.2.2 Running Economy

The change in mean scores for the RE variables ranged from -2.6% (-6.5, 1.5) to -0.4% (-3.3, 2.5). The highest ICC was B[Lac] [$r = 0.88$ (0.70, 0.95)]. The lowest ICC was observed for VO_2 expressed in $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$ [$r = 0.49$ (0.01, 0.78)]. Blood lactate concentration at 11 $\text{km}\cdot\text{h}^{-1}$ also produced a high percent typical error [18.4% (13.8, 28.6)] while RER was associated with a low [3.7% (2.7, 5.6)] absolute error.

5.1.2.3 Lactate Mid-Point

The greatest observed change in mean was for VO_2 in $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$ at the lactate mid-point, which presented a change of -4.0% (-8.1, 0.4). The smallest change in mean was associated with the running speed ($\text{km}\cdot\text{h}^{-1}$) at the lactate mid-point [0.8% (-3.7, 5.6)]. Intraclass correlations ranged from $r = 0.22$ (-0.27, 0.62), for $\%\text{VO}_{2\text{peak}}$ at the lactate mid-point, to $r = 0.79$ (0.52, 0.92),

Table 9. Test-retest reliability data for the laboratory based incremental step test prior to the experimental training study (N = 14).

	Pre-test 1 mean \pm SD	Pre-test 2 mean \pm SD	Change in Mean (%) (90% CL)	ICC (<i>r</i>) (90% CL)	Typical Error (90% CL)	% Typical Error† (90% CL)
VO_{2peak}						
ml.kg.min ⁻¹	49.0 \pm 6.4	48.6 \pm 6.4	-0.9 (-4.8, 3.1)	0.83 (0.59, 0.93)	2.7 (2.1, 4.1)	6.1 (4.6, 9.2)
ml.kg ^{-0.75} .min ⁻¹	142.1 \pm 18.1	141.4 \pm 17.7	-0.5 (-4.3, 3.5)	0.78 (0.53, 0.92)	7.9 (6.1, 11.8)	6.0 (4.5, 9.1)
HR _{peak} (b.min ⁻¹)	198.6 \pm 7.4	198.8 \pm 7.5	-0.1 (-1.5, 1.3)	0.69 (0.32, 0.88)	4.0 (3.0, 6.1)	2.1 (1.6, 3.2)
Peak Treadmill Speed (km.h ⁻¹)	13.9 \pm 2.0	14.0 \pm 1.8	0.7 (-1.8, 3.3)	0.93 (0.83, 0.97)	0.5 (0.4, 0.8)	3.9 (2.9, 5.8)
RE @ 11 km.h⁻¹						
ml.kg.min ⁻¹	40.2 \pm 3.8	39.1 \pm 3.0	-2.6 (-6.5, 1.5)	0.52 (0.06, 0.80)	2.4 (1.8, 3.6)	6.0 (4.5, 9.3)
ml.kg ^{-0.75} .min ⁻¹	116.1 \pm 11.2	112.7 \pm 8.1	-2.8 (-6.8, 1.4)	0.49 (0.01, 0.78)	7.0 (5.3, 10.5)	6.2 (4.7, 9.6)
%VO _{2peak}	81.2 \pm 10.1	78.9 \pm 6.8	-2.4 (-6.0, 1.3)	0.76 (0.44, 0.91)	4.4 (3.3, 6.6)	5.5 (4.1, 8.4)
HR (b.min ⁻¹)	177.3 \pm 12.5	176.7 \pm 13.9	-0.4 (-3.3, 2.5)	0.71 (0.34, 0.89)	7.2 (5.5, 10.9)	4.2 (3.2, 6.5)
RER	1.00 \pm 0.05	0.99 \pm 0.06	-1.7 (-4.1, 0.8)	0.53 (0.07, 0.80)	0.03 (0.03, 0.05)	3.7 (2.7, 5.6)
Lactate (mmol.l ⁻¹)	3.07 \pm 1.76	2.90 \pm 1.39	-2.2 (-12.6, 9.6)	0.88 (0.70, 0.95)	0.64 (0.49, 0.95)	18.4 (13.8, 28.6)
Lactate Mid-Point						
km.h ⁻¹	12.0 \pm 1.7	12.0 \pm 1.5	0.8 (-3.7, 5.6)	0.76 (0.46, 0.90)	0.8 (0.6, 1.1)	7.1 (5.4, 10.8)
ml.kg.min ⁻¹	42.7 \pm 6.8	40.9 \pm 5.1	-4.0 (-8.1, 0.4)	0.79 (0.52, 0.92)	2.8 (2.1, 4.2)	6.8 (5.2, 10.3)
ml.kg ^{-0.75} .min ⁻¹	124.4 \pm 19.8	118.9 \pm 14.0	-3.9 (-8.1, 0.5)	0.77 (0.47, 0.91)	8.4 (6.4, 12.5)	6.9 (5.2, 10.4)
%VO _{2peak}	87.1 \pm 6.7	84.8 \pm 9.7	-3.0 (-8.6, 2.8)	0.22 (-0.27, 0.62)	7.2 (5.5, 10.7)	9.1 (6.9, 13.9)

† = typical error as a coefficient of variation (%)

for scaled VO_2 at the lactate mid-point. Typical error had a peak value of 9.1% (6.9, 13.9) for $\%\text{VO}_{2\text{peak}}$ at the mid-point and a lowest value of 6.8% (5.2, 10.3) for scaled VO_2 .

Table 10. Baseline measures of the participants who completed the study (values taken from pre-test 2).*

	All Participants (N = 10)	E _{spec} (N = 6)	CON (N = 4)
Battery of Field Tests			
5 m Speed (m s^{-1})	4.18 \pm 0.23	4.13 \pm 0.24	4.25 \pm 0.22
10 m Speed (m s^{-1})	5.03 \pm 0.24	5.00 \pm 0.25	5.09 \pm 0.26
20 m Speed (m s^{-1})	5.90 \pm 0.26	5.88 \pm 0.29	5.93 \pm 0.27
Vertical Jump (cm)	42.5 \pm 7.3	42.9 \pm 9.1	41.8 \pm 4.3
Agility (s)	8.24 \pm 0.48	8.27 \pm 0.58	8.20 \pm 0.35
RHIET Total Time (s)	95.51 \pm 6.89	96.54 \pm 8.86	93.96 \pm 2.54
Yo-Yo Intermittent Recovery Test, Level 1			
Distance Covered (m)	1260 \pm 493	1227 \pm 572	1310 \pm 420
Peak Running Speed (km h^{-1})	15.5 \pm 0.8	15.5 \pm 0.9	15.6 \pm 0.7
HR _{peak} (b min^{-1})	196.9 \pm 7.9	194.8 \pm 3.0	199.0 \pm 11.2
Peak Lactate (mmol l^{-1})	10.3 \pm 1.3	9.8 \pm 1.4	11.0 \pm 0.6
Incremental Step Test			
VO_{2peak}			
ml kg ⁻¹ min ⁻¹	50.0 \pm 4.1	50.0 \pm 5.2	50.0 \pm 2.2
ml kg ^{-0.75} min ⁻¹	145.3 \pm 15.0	145.8 \pm 19.9	144.4 \pm 3.3
HR _{peak} (b min^{-1})	198.1 \pm 7.8	196.6 \pm 5.2	200.0 \pm 10.7
Peak Treadmill Speed (km h^{-1})	14.4 \pm 1.5	14.5 \pm 1.9	14.3 \pm 1.0
RE @ 11 km h⁻¹			
ml kg ⁻¹ min ⁻¹	38.8 \pm 2.9	39.0 \pm 3.0	38.5 \pm 3.1
ml kg ^{-0.75} min ⁻¹	112.4 \pm 8.8	113.9 \pm 10.3	110.3 \pm 6.5
$\%\text{VO}_{2\text{peak}}$	77.9 \pm 6.7	78.6 \pm 8.4	77.0 \pm 4.2
HR (b min^{-1})	173.4 \pm 13.2	170.8 \pm 16.2	177.3 \pm 7.5
RER	0.97 \pm 0.05	0.95 \pm 0.06	1.01 \pm 0.01
Lactate (mmol l^{-1})	2.46 \pm 1.07	2.57 \pm 1.41	2.31 \pm 0.31
Lactate Mid-Point			
mmol l ⁻¹	3.51 \pm 0.67	3.26 \pm 0.59	3.88 \pm 0.68
km h ⁻¹	12.2 \pm 1.5	11.9 \pm 1.7	12.6 \pm 1.0
ml kg ⁻¹ min ⁻¹	40.7 \pm 4.0	40.2 \pm 4.8	41.5 \pm 3.0
ml kg ^{-0.75} min ⁻¹	118.2 \pm 14.0	117.2 \pm 16.2	119.8 \pm 11.9
$\%\text{VO}_{2\text{peak}}$	81.8 \pm 9.3	80.9 \pm 11.3	83.1 \pm 6.6

* All values are mean \pm SD

RHIET repeated high intensity endurance test; RE running economy; E_{spec} training group; CON control group; RER respiratory exchange ratio; HR heart rate; HR_{peak} heart rate peak; VO_{2peak} maximal oxygen uptake

5.2 Basketball Specific Endurance Training

Due to dropout, only 10 (E_{spec} , $N = 6$; CON, $N = 4$) participants completed the second aspect of the study. In total, subjects attended 10.5 ± 2.0 training sessions (out of a total of 12 training sessions) over the six week training period. The mean total time of each training session was 43 ± 5 min. Total time refers to the full amount of time spent at the training session (i.e. 43 min) and included the basketball specific endurance training regime (28 min). Mean HR for total training time, i.e. including the typical basketball training (dribbling, passing, footwork, offensive skill, and defensive skill activities), for both E_{spec} and CON, was $154.5 \pm 9.6 \text{ b} \cdot \text{min}^{-1}$ ($76.3 \pm 4.4 \% \text{HR}_{\text{peak}}$). When mean training HR is considered separately for E_{spec} ($77.4 \pm 2.9\% \text{HR}_{\text{peak}}$) and CON ($74.1 \pm 6.7\% \text{HR}_{\text{peak}}$) it was apparent that they were relatively evenly matched for intensity (Appendix 7). HR_{peak} reached during total training time for both E_{spec} and CON was on average $189.1 \pm 8.4 \text{ b} \cdot \text{min}^{-1}$ ($93.3 \pm 3.9 \% \text{HR}_{\text{peak}}$). E_{spec} had a mean training HR during the work intervals of the basketball dribbling circuit (4 min) of $172.2 \pm 4.5 \text{ b} \cdot \text{min}^{-1}$ which equated to $84.1 \pm 2.3 \% \text{HR}_{\text{peak}}$. The mean total time to complete one circuit was $33.9 \pm 3.6 \text{ s}$ and ranged from 29.4 s to 41.3 s.

5.3 Training Effects on Performance

5.3.1 Field Test Measures

The smallest beneficial or harmful change in performance was based on a 1% improvement in performance or a Cohen's effect statistic (ES) of greater than or equal 0.20. Table 11 shows the mean changes in performance during the field performance measures relative to CON and statistics for the difference in the changes. E_{spec} demonstrated substantial improvements in fatigue index during the RHIT test ($25.0\% \pm 39.6\%$, $\pm \text{SD}$), but this result was unclear. The effect on repeated sprint ability and total sprint time in the RHIT was a $4.1 \pm 6.1\%$ decrease in total time for E_{spec} and a $4.7 \pm 1.9\%$ decrease for CON (Figure 15) basketball specific endurance training programme seemed to have had less of an effect on E_{spec} relative to control for 5, 10, and

20 m sprinting speed. However, the difference in sprinting speed was considered trivial to non-trivial between the groups. No changes were observed for vertical jump or agility. The total distance covered and the peak running speed achieved during the Yo-Yo test were unchanged (Figure 16; Table 11). The changes in measures for E_{spec} relative to CON ranged from $-13.7\% \pm 49.0\%$ (total distance covered) to $2.9\% \pm 8.2\%$ (agility). Cohen's effect sizes ($\pm 90\%$ CL) ranged from -0.57 ± 0.68 to 0.46 ± 1.27 for all performance measures.

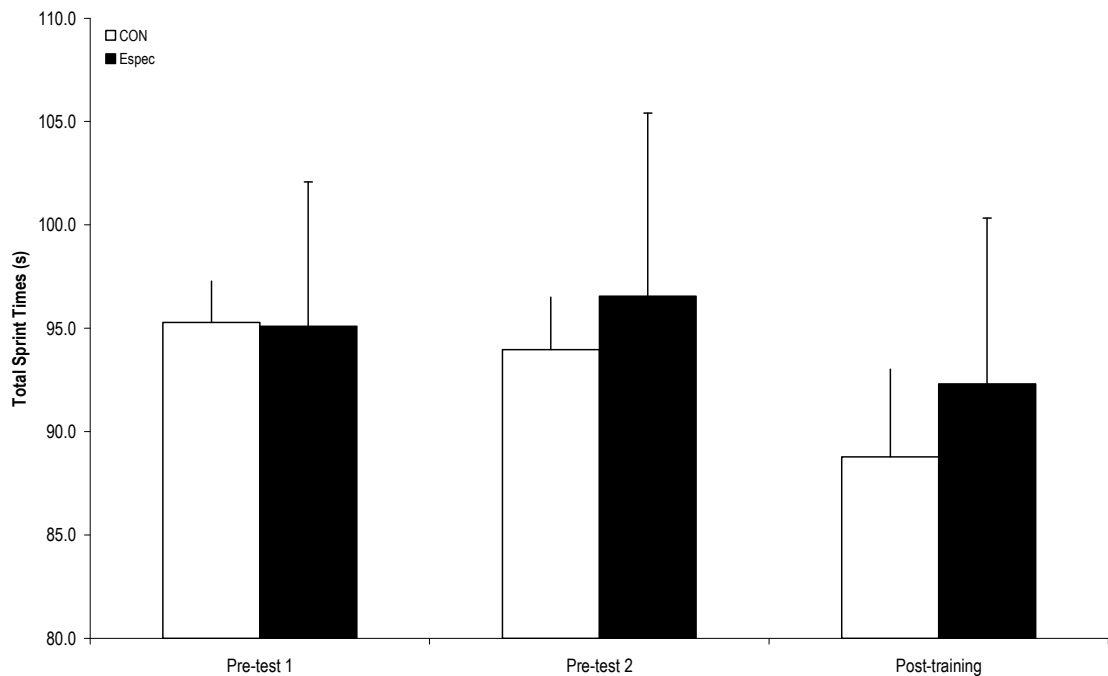


Figure 15. Effect of basketball specific endurance training and control on RHIET total time (mean \pm SD, $N = 10$).

Table 11. Mean changes in performance immediately post-training and control for field test measures, and chances that the true difference in the changes is substantial.

	Change in Measure†			Cohen's ES ±90% CL	Practical Inference‡
	E _{spec} mean ± SD	CON mean ± SD	Difference; ±90% CL		
Battery of Field Tests					
5 m Speed (m s ⁻¹)	2.8 ± 2.6	4.7 ± 3.8	-1.8; ± 5.7	-0.29; ± 0.92	unclear
10 m Speed (m s ⁻¹)	2.2 ± 2.4	4.8 ± 2.4	-2.4; ± 3.4	-0.46; ± 0.63	trivial-nontrivial negative
20 m Speed (m s ⁻¹)	1.8 ± 3.0	4.8 ± 2.3	-2.8; ± 3.4	-0.57; ± 0.68	trivial-nontrivial negative
Vertical Jump (cm)	8.2 ± 11.8	10.1 ± 12.2	-1.7; ± 17.1	-0.10; ± 0.89	unclear
Agility (s)	-1.0 ± 5.9	-3.8 ± 5.7	2.9; ± 8.2	0.46; ± 1.27	unclear
RHIET Total Time (s)	-4.1 ± 6.1	-4.7 ± 1.9	0.6; ± 5.7	0.08; ± 0.72	unclear
RHIET Fatigue Index (%)	-25.0 ± 39.6	-13.1 ± 32.4	-13.7; ± 49.0	-0.32; ± 0.87	unclear
Yo-Yo Intermittent Recovery Test, Level 1					
Distance Covered (m)	25.6 ± 9.2	36.6 ± 13.0	-8.0; ± 18.8	-0.20; ± 0.41	unclear
Peak Running Speed (km h ⁻¹)	2.9 ± 1.4	3.9 ± 2.1	-1.0; ± 2.9	-0.19; ± 0.53	unclear

† = percent change (%)

‡ = based on the smallest beneficial or harmful change in performance of 1%.

±90%CL = add and subtract this number to the difference to obtain the 90% confidence limits for the true difference.

E_{spec} training group; CON control; ES effect statistic; RHIET repeated high-intensity endurance test

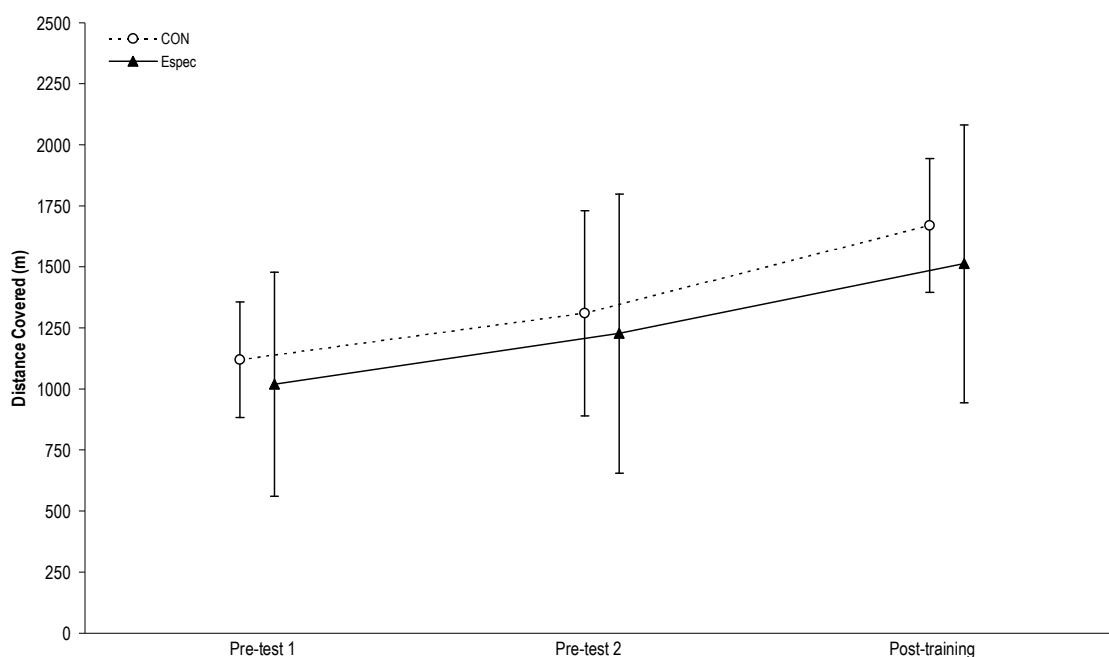


Figure 16. Effect of basketball specific endurance training and control on the total distance covered during the Yo-Yo intermittent recovery test (mean \pm SD, $N = 10$).

5.3.2 Physiological Measures

5.3.2.1 Maximal Oxygen Uptake

The VO_{2peak} , regardless of expression, did not substantially differ relative to CON. However, despite no change in body mass, the endurance training did induce increases in VO_{2peak} of 12.4% and 8.8% in E_{spec} and CON (Figure 17), respectively, with E_{spec} also showing a trend for a greater scaled VO_{2peak} post-training (Table 12). HR_{peak} during the incremental test was observed to be lower in E_{spec} post-training while CON showed increased HR_{peak} values. Peak treadmill speed changed $2.9\% \pm 3.5\%$ ($\pm 90\%$ CL) and presented a Cohen's effect statistic of 0.25 ± 0.30 in relation to control. However, the positive improvement was considered trivial to nontrivial.

5.3.2.2 Running Economy

No substantial changes were observed in relative VO_2 , scaled VO_2 , $\%VO_{2peak}$, and RER for RE at $11 \text{ km}\cdot\text{h}^{-1}$. However, E_{spec} elicited an improved RE (expressed as $\%VO_{2peak}$) at $11 \text{ km}\cdot\text{h}^{-1}$ in relation to CON (Figure 18). Changes in RE, relative to CON, at $11 \text{ km}\cdot\text{h}^{-1}$ ranged from $-7.3\% \pm 2.0\%$ for

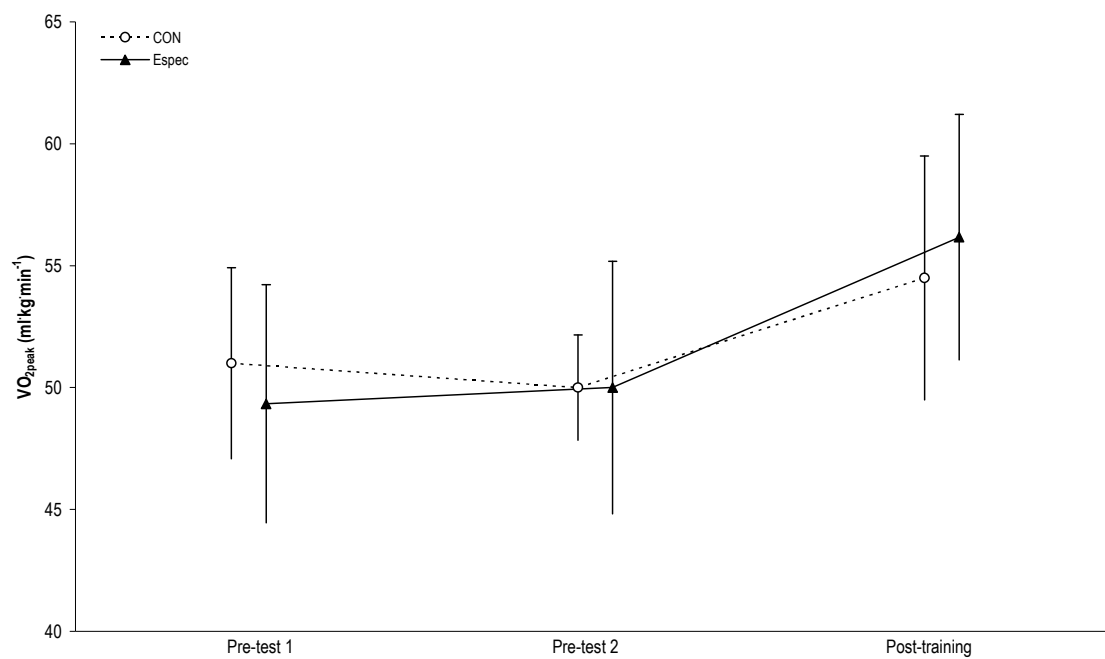


Figure 17. Effect of basketball specific endurance training and control on VO_{2peak} (mean \pm SD, $N = 10$).

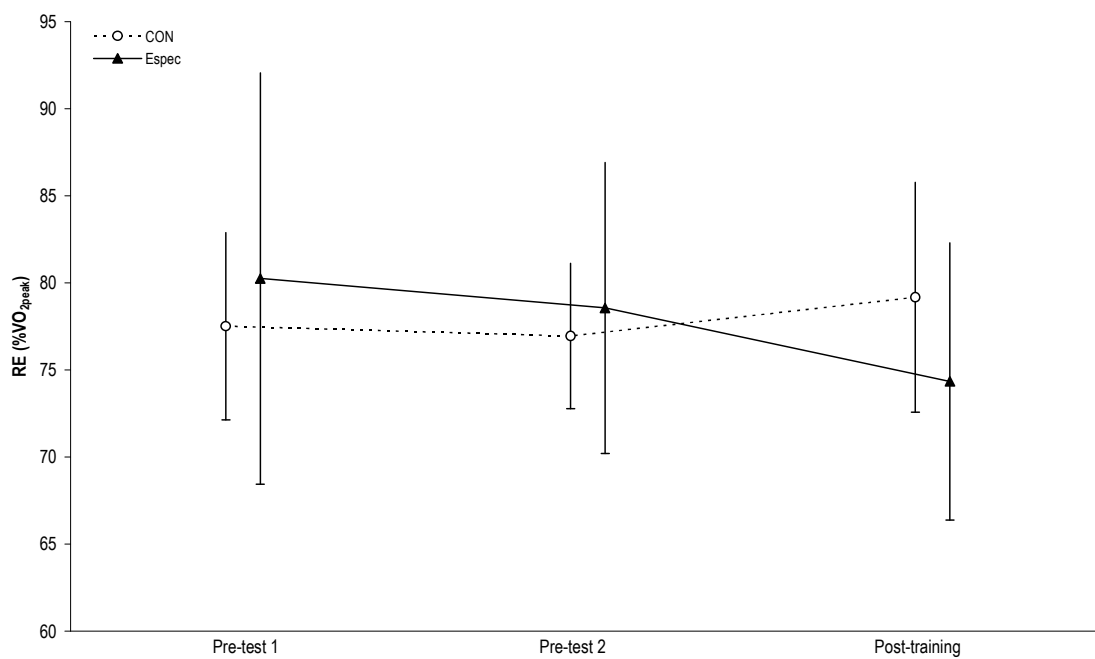


Figure 18. Effect of basketball specific endurance training and control on RE at 11 km·h⁻¹ (mean \pm SD, $N = 10$).

HR to $7.1\% \pm 12.4\%$ for the respiratory exchange ratio (RER). Heart rate at $11 \text{ km}\cdot\text{h}^{-1}$ demonstrated a statistically significant negative nontrivial percent change with a Cohen's effect statistic of -0.87 ± 0.23 , indicating a lower HR response to the speed level for E_{spec} .

5.3.2.3 Lactate Mid-Point

Changes in running speed and relative VO_2 at the lactate mid-point were not substantial, compared to CON ($-7.3\% \pm 5.8\%$ for $\% \text{VO}_2$; $-3.7\% \pm 9.9\%$ for speed). Cohen's effect statistics ranged from -0.27 ± 0.68 to -0.60 ± 0.73 for the lactate variables. A significant negative change in $\% \text{VO}_{2\text{peak}}$ at lactate mid-point was observed from pre- to post-tests for E_{spec} (Cohen's ES: -0.59 ± 0.44 ; Figure 19). This represented a lower $\% \text{VO}_{2\text{peak}}$ at the lactate mid-point post-training relative to CON. Relative VO_2 at the lactate mid-point produced substantial change scores and represented a negative trivial to nontrivial difference from the pre-tests to the post-test (Table 12). This finding represented an increased relative VO_2 at the lactate mid-point.

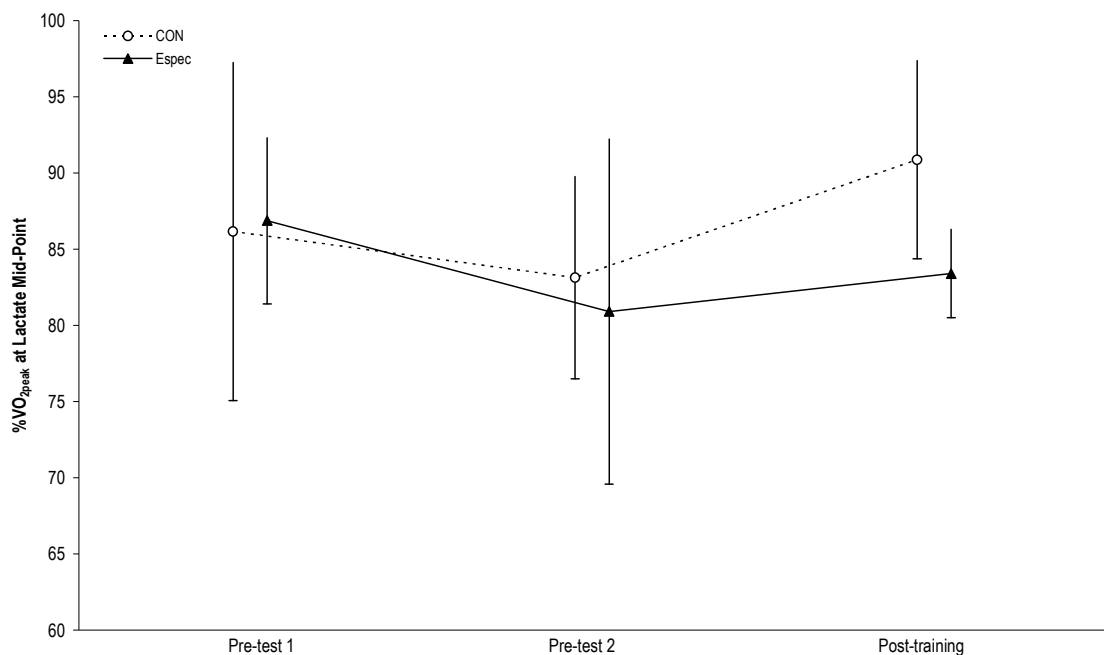


Figure 19. Effect of basketball specific endurance training and control on $\% \text{VO}_{2\text{peak}}$ at lactate mid-point (mean \pm SD, $N = 10$).

Table 12. Mean changes in performance immediately post-training and control for physiological measures, and chances that the true difference in the changes is substantial.

		Change in Measure†				
		E _{spec}	CON	Difference;	Cohen's ES	Practical Inference‡
		mean ± SD	mean ± SD	±90% CL	±90% CL	
VO _{2peak}						
	ml·kg·min ⁻¹	12.4 ± 6.7	8.8 ± 11.5	3.3; ± 19.3	0.36; ± 1.95	unclear
	ml·kg ^{-0.75} ·min ⁻¹	13.0 ± 6.0	7.7 ± 7.5	5.0; ± 10.9	0.42; ± 0.91	unclear
	HR _{peak} (b·min ⁻¹)	-1.3 ± 2.7	2.2 ± 4.7	-3.4; ± 6.6	-0.81; ± 1.48	unclear
	Peak Treadmill Speed (km·h ⁻¹)	10.1 ± 4.0	7.0 ± 0.0	2.9; ± 3.5	0.25; ± 0.30	trivial-nontrivial positive
RE @ 11 km·h ⁻¹						
	ml·kg·min ⁻¹	7.0 ± 7.6	10.7 ± 9.9	-3.3; ± 14.2	-0.42; ± 1.64	unclear
	ml·kg ^{-0.75} ·min ⁻¹	7.1 ± 6.9	12.8 ± 16.1	-5.1; ± 29.2	-0.64; ± 3.14	unclear
	%VO _{2peak}	-5.3 ± 4.8	0.5 ± 6.4	-5.7; ± 9.2	-0.60; ± 0.90	unclear
	HR (b·min ⁻¹)	-4.4 ± 2.1	3.1 ± 0.4	-7.3; ± 2.0	-0.87; ± 0.23	nontrivial negative
	RER	3.1 ± 5.3	-3.8 ± 1.0	7.1; ± 12.4	1.17; ± 1.99	unclear
Lactate Mid-Point						
	km·h ⁻¹	-2.6 ± 8.0	1.1 ± 6.7	-3.7; ± 9.9	-0.27; ± 0.68	unclear
	ml·kg·min ⁻¹	11.3 ± 9.5	19.2 ± 3.6	-6.6; ± 8.7	-0.60; ± 0.73	trivial-nontrivial negative
	ml·kg ^{-0.75} ·min ⁻¹	11.7 ± 11.5	18.9 ± 1.1	-6.0; ± 10.0	-0.47; ± 0.72	unclear
	%VO _{2peak}	-0.6 ± 3.0	7.2 ± 4.1	-7.3; ± 5.8	-0.59; ± 0.44	trivial-nontrivial negative

† = percent change (%)

‡ = based on the smallest beneficial or harmful change in performance of 1%

±90%CL = add and subtract this number to the difference to obtain the 90% confidence limits for the true difference

E_{spec} training group; CON control; ES effect statistic; VO_{2peak} maximal oxygen uptake; HR heart rate; HR_{peak} heart rate peak; RE running economy; RER respiratory exchange ratio

Chapter Six: Discussion

The aim of this study was to determine the effectiveness of a basketball specific endurance circuit at improving aerobic fitness in basketball players during the competitive season. There were, however, few clear differences in measures of aerobic fitness (field or laboratory). It was observed that high-intensity aerobic interval training using the basketball specific endurance circuit resulted in a drop in sub-maximal HR which is suggestive of improved aerobic fitness compared to a control group who continued with their normal (classic) team training. Although there was a trend for improvement, there was no clear difference in anaerobic power maintenance, as represented by the fatigue index, during the repeated high-intensity endurance test (RHIT). However, the magnitude of improvement associated with power-related performances (speed and explosive leg power) was reduced for E_{spec} in relation to CON indicating a possible harmful effect on these performance measures.

6.1 Field Test Measures

6.1.1 Sport-specific Aerobic Power

In the present study, the Yo-Yo intermittent recovery test (IRT) was used as a measure of sport-specific aerobic power. The baseline Yo-Yo IRT scores for E_{spec} and CON were $1,227 \pm 572$ m and $1,310 \pm 420$ m, respectively (Table 10). In comparison to other team sports the present values were similar to that of older elite female soccer players (1379 m; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005). Complementing this, both E_{spec} and CON produced greater Yo-Yo IRT scores than Australian state-level cricket players ($1,049 \pm 285$ m) and female field hockey players (840 ± 280 m) of a similar age (Thomas, Dawson, & Goodman, 2006). On the other hand, the Yo-Yo IRT scores of the present study are lower than the distances covered by older moderate level and top-class soccer players (1,800 to 2,300 m; Krstrup et al., 2003; Mohr, Krstrup, & Bangsbo, 2003) as well as older semi-professional and elite rugby league players

(1,564 \pm 415 m and 1,656 \pm 403 m, respectively; Atkins, 2006). Such differences are likely due to the training age of the athletes involved in the present study and perhaps the physical demands of different team sports.

Despite the differences with other sports, after six-weeks of in-season, high-intensity, aerobic interval training using the basketball specific endurance circuit, the mean distance covered during the Yo-Yo IRT increased by approximately 287 m (26%) for E_{spec} and by 360 m (37%) for CON (Cohen's ES -0.20 \pm 0.41; \pm 90%CL; Table 11). This is a positive result since it has been previously reported that aerobic fitness actually depreciates by approximately 5% over the course of the competitive season when sport-specific fitness was measured using the Yo-Yo IRT in elite soccer players (Krustrup et al., 2003; Krustrup et al., 2006) and the multi-stage shuttle run test in amateur rugby league players (Gabbett, 2005a, 2005b). The results of the present study suggest that the basketball specific endurance circuit not only maintained aerobic fitness but further increased fitness. However, this finding did not reach substantiveness and was deemed unclear because the effect's confidence interval overlapped the threshold for substantiveness (Batterham & Hopkins, 2006). This was possibly due to the larger increase in the distance covered during the Yo-Yo IRT recorded for CON.

CON performed their normal 'classic' in-season basketball training alone and somewhat surprisingly exhibited a large improvement in the Yo-Yo IRT. A classic basketball training approach, especially during the in-season, generally has a primary focus of increasing anaerobic performance (Section 3.3 Classic Team Sport Conditioning) (Tavino, Bowers, & Archer, 1995). Whilst the Yo-Yo IRT has been advocated as an aerobic-based test (Castagna, Impellizzeri, Rampinini, D'Ottavio, & Manzi, 2007), a strong relationship ($r=0.83$; Appendix 5) between the total distance covered during the Yo-Yo IRT and the total time to complete the RHIET (anaerobic test) in elite semi-professional New Zealand basketball players suggests an anaerobic component to

the test probably exists. Therefore, it appears as though successful performance in both the Yo-Yo IRT and the RHET depends upon one's ability to recovery between high-intensity bouts of exercise, which is associated with oxidative metabolism (Colliander, Dudley, & Tsech, 1988). Since previous research has demonstrated that the volume of high-intensity running during a soccer match is closely related to the distance travelled during the Yo-Yo IRT ($r=0.71$; Krustup et al., 2003), it is appropriate to consider that an increase in Yo-Yo IRT score after training in the present study would similarly result in a greater amount of high-intensity activity performed during a basketball game. Regrettably, we do not have any data from basketball games to support this possibility.

The magnitude of change (26%) in the Yo-Yo IRT score in the present study is much greater than that reported by Rampinini et al. (2007) who observed a 7.4% increase after approximately eight months (67 training sessions) of high-intensity soccer-specific aerobic interval training. This difference could be credited to the lower pre-training mean Yo-Yo IRT scores in the present study ($1,227 \pm 572$ m vs. $1,986 \pm 334$ m; Rampinini et al., 2007). Differences could also be due to the lower initial VO_{2peak} (50 ± 2 ml \cdot kg $^{-1}\cdot$ min $^{-1}$ vs. 56 ± 5 ml \cdot kg $^{-1}\cdot$ min $^{-1}$) and age (16.4 ± 1.2 years vs. 24.5 ± 4.1 years) of the basketball players compared to those of Rampinini et al. (2007). This is supported by previous research where it was established that initial fitness level has a substantial effect on the improvements observed following aerobic training interventions (Gabbett, 2006; Wenger & Bell, 1986).

A reduction in B[Lac] taken immediately after the Yo-Yo IRT also suggests that aerobic fitness in E_{spec} and CON were improved following the training intervention. Immediately post Yo-Yo IRT mean B[Lac] values decreased from 11.0 ± 1.1 mmol $^{-1}$ to 9.4 ± 2.4 mmol $^{-1}$ from pre- to post-training. The measured decreases in B[Lac] during the Yo-Yo IRT equated to an approximate 15% reduction in the mean group value for E_{spec} and a 14% reduction for CON. These values are

similar to that of older elite female soccer players where a mean of 8 mmol^{-1} with a range of 5.8 to 10.3 mmol^{-1} has been established directly after performing the Yo-Yo IRT (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005). The B[Lac] data of the present study also confirm the findings of Krustrup et al. (2003) where the Yo-Yo IRT appeared to heavily stimulate both the aerobic and anaerobic energy systems in elite team sport (soccer) athletes, of which the latter was made evident by the high post-test B[Lac] values ($10.1 \pm 0.6 \text{ mmol}^{-1}$). HR_{peak} obtained during the Yo-Yo IRT was similar to that observed during the laboratory-based assessment of $\text{VO}_{2\text{peak}}$ (Appendix 6) and suggests that the Yo-Yo IRT was indeed performed maximally.

Collectively, for both groups, the increase in the total distance covered during the Yo-Yo IRT and the decrease in B[Lac] from pre- to post-training suggests that aerobic energy contribution to the performance was increased. The lower post-test B[Lac] in both E_{spec} and CON is likely due to improved central and peripheral factors that improve oxygen delivery and utilisation which combine to either reduce the production of lactate or increase the rate of removal. After interval training, this is typically achieved through increases in cardiac output (Ekblom & Hermansen, 1968; Laffite, Mille-Hamard, Koralsztejn, & Billat, 2003), oxidative enzyme activity (Gollnick et al., 1973), mitochondrial volume and density (Harms & Hickson, 1983), muscle capillarisation (Gute, Fraga, Laughlin, & Amann, 1996), an improved ability to vasodilate (Sinoway, Musch, Minotti, & Zelis, 1986), and an increase in haemoglobin (Kjellberg, Rudhe, & Sjostrand, 1949) and myoglobin (Hickson, Hagberg, Ehsani, & Holloszy, 1981; Tomlin & Wenger, 2001). Together, these enhancements result in an increased ability to supply energy through aerobic pathways during high-intensity exercise, thus decreasing the reliance on anaerobic glycolysis and thereby resulting in less B[Lac] and H^+ accumulation (Cerretelli, Pendergast, Paganelli, & Rennie, 1979).

In general, regardless of training group, an increase in the distance covered during the Yo-Yo IRT inevitably suggests an improvement in recovery dynamics with effective recovery from high-

intensity exercise having been shown to be somewhat reliant upon aerobic fitness (Colliander, Dudley, & Tsech, 1988). The data of the present study show that the basketball specific endurance training promoted an increase in aerobic fitness for E_{spec} during the in-season that is relevant to basketball performance as measured by the Yo-Yo IRT. However, these improvements were not greater than improvements made by normal 'classic' training (as performed by CON) suggesting that the endurance training had no additional benefit compared to CON.

6.1.2 Anaerobic Endurance and Power Related Measures

To quantify 'anaerobic' ability or repeated sprint ability (RSA) in the present study, the RHIET was used (Figure 12). This is a commonly used test, especially in New Zealand, to determine a players ability to perform repeated maximal intensity bouts of exercise interspersed with short recovery durations (Bailey, Burke, & Shanks, 2006). The RHIET is very relevant to basketball performance as it involves performing several high-intensity efforts within a similar time frame as that of the shot clock (30 s vs. 24 s, respectively). There are two measures of interest that can be obtained from the RHIET: 1) the total time to complete the six maximal effort shuttle runs; and 2) the associated degree of fatigue between the fastest and slowest individual sprints, which is termed the fatigue index (Section 4.1.3.4 Repeated Sprint Ability).

In line with previous research (Hamilton, Nevill, Brooks, & Williams, 1991; Psotta, Blahus, Cochrane, & Martin, 2005), the first two sprints of the RHIET were much faster than the remaining four in all subjects across all testing occasions suggesting that fatigue occurred and maximal efforts were indeed given by subjects. Furthermore, the first two sprints of the RHIET were approximately 5% faster in both groups post-training suggesting that general speed had improved. The improvement in sprints one and two contributed to the reduced total time taken to complete the RHIET from pre- to post-training in both groups (E_{spec} : $-4.1 \pm 6.1\%$; CON: $-4.7 \pm$

1.9%; Cohen's ES 0.08 ± 0.72 ; $\pm 90\%CL$). Although this result was deemed unclear, overall it indicates improved RSA. The positive change in RHIET total time for E_{spec} is similar to previous research where five-weeks of high-intensity aerobic interval training resulted in substantially greater improvements in RSA than moderate-intensity training (13 vs. 8.5%, respectively, $P < 0.05$; Edge, Bishop, Goodman, & Dawson, 2005).

In the present study, E_{spec} and CON were matched for anaerobic ability (RHIET total time, Table 10) prior to the training intervention. However, in E_{spec} the rate of fatigue associated with the RHIET was 12% less than that observed for CON (13% vs 25%, respectively; Cohen's ES -0.32 ± 0.87 ; $\pm 90\%CL$; Table 11). During repeated sprints depletion of PCr stores and a decrease in intracellular pH may contribute to the decline in power output or the rate of fatigue (Bishop, Edge, & Goodman, 2004). As PCr resynthesis primarily occurs by oxidative processes (McCully, Fielding, Evans, Leigh Jr, & Posner, 1993) and intracellular acidosis potentially interferes with muscle contractile processes (Favero, Zable, Bowman, Thompson, & Abramson, 1995) thereby inhibiting force production, the lower rate of fatigue observed in E_{spec} may be attributed to either an improved aerobic power (Bishop, Edge, & Goodman, 2004; Dawson, Fitzsimons, & Ward, 1993) or an increased capacity of muscle to buffer hydrogen ions (H^+ ; Bishop, Edge, & Goodman, 2004; Edge, Bishop, & Goodman, 2006). Given the nature of the training prescribed it is likely aerobic adaptations were the primary causes. Several aerobic-related mechanistic adaptations, centrally and peripherally, could be responsible for such improvements. For example, an enhanced capillary supply (Gute, Fraga, Laughlin, & Amann, 1996), greater oxidative enzyme capacity (Gollnick et al., 1973) and mitochondrial content (Harms & Hickson, 1983) in muscle are all typically observed after endurance training. Similarly, an increase in stroke volume, as a result of increased left ventricular mass and end-diastolic volume (Astrand & Rodahl, 1987), leading to an increased cardiac output (Laffite, Mille-Hamard, Koralsztejn, & Billat, 2003) is also observed. Therefore, most likely due to the increase in aerobic fitness, the fatigue index for E_{spec} during the

RHIET showed similar trends to that of endurance trained athletes (Bishop & Spencer, 2004). To support this, Bogdanis et al. (1996) found a high correlation between $\text{VO}_{2\text{peak}}$ and the percentage of energy contributed by aerobic metabolism during two all-out cycle sprints (sprint one $r=0.79$ and sprint two $r=0.87$). Thus, $\text{VO}_{2\text{peak}}$ appeared to determine the magnitude of the aerobic response to repeated sprints, albeit in untrained individuals. The moderate relationships between $\text{VO}_{2\text{peak}}$ and RHIET total time ($r= -0.60$) and the total distance covered during the Yo-Yo IRT and RHIET total time ($r= -0.63$) in the present study involving trained athletes helps strengthen this in that those with a higher aerobic power ($\text{VO}_{2\text{peak}}$ or Yo-Yo IRT) tended to perform better in the RHIET (i.e., lower total time). Associated with this, Dupont et al. (2005) suggested that individuals with a higher $\text{VO}_{2\text{peak}}$, and consequently faster VO_2 kinetics, might also have a faster adjustment of VO_2 during repeated high-intensity exercise, leading to a lower relative decrease in performance, confirming that the contribution of oxidative phosphorylation might be one of the determinants for repeated high-intensity performance. Indeed, Phillips et al. (1995) found that a faster VO_2 kinetics was associated with a reduction in the fall of muscle PCr concentration, allowing improved power maintenance across multiple sprints.

Along with aerobic related physiological changes following endurance training contributing to an improved RSA performance, a substantial correlation between the rate of fatigue during repeated sprint exercise and change in blood pH has been reported ($r=0.75$; Bishop, Lawrence, & Spencer, 2003). Therefore, athletes who are better able to buffer H^+ and to resist changes in blood pH may have greater RSA (Bishop, Edge, & Goodman, 2004). Coincidentally, the 13% improvement observed in CON may be a result of the intermittent, high-intensity activity during training and match play, which is suggested to be linked to the high muscle buffer capacity observed in team sport athletes (Edge, Bishop, Hill-Haas, Dawson, & Goodman, 2006).

The data of the present study confirm the findings of Bishop and Spencer (2004) and Hamilton et al. (1991) where 'classically' trained team sport athletes are able to perform more work but are less able to maintain power output during a RSA test than endurance trained players, despite being matched for VO_{2peak} . Although CON did not show as great of an improvement in fatigue index during the repeated sprints, it should be considered that better sprinters utilise more of their available PCr stores than sprinters of lesser ability (Hirvonen, Rehunen, & Rusko, 1987). This is supported by athletes with the greatest glycolytic rate during an initial sprint having the greatest rate of fatigue over ten, six second sprints (Gaitanos, Williams, Boobis, & Brooks, 1993). Furthermore, the greater the PCr depletion, the greater the time that is required for full replenishment (Dawson, Goodman, & Lawrence, 1997). Therefore, it is likely that better sprinters (fastest over the first two sprints in the RHIET) will exhibit a greater fatigue index during repeated sprints as a result, in part, of greater PCr depletion and less subsequent PCr replenishment (Bishop, Lawrence, & Spencer, 2003). Thus, coaches and athletes should appreciate that greater levels of fatigue are likely after high levels of power output in RSA performances, as greater fatigue has been associated with more powerful efforts (Hamilton, Nevill, Brooks, & Williams, 1991).

It is possible that the basketball specific endurance training weakened the gains in anaerobic performance for E_{spec} . Indeed, some research suggests that aerobic endurance training can interfere with the development of strength (Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003; Bell, Syrotuik, Socha, Maclean, & Quinney, 1997; Dolezal & Pottenger, 1998; Hickson, 1980; Lee, Craig, Lucas, Pohlman, & Stelling, 1990; McCarthy, Agre, Graf, Pozniak, & Vailas, 1995) and this could potentially limit improvements in speed and explosive power (Bentley, Zhou, & Davie, 1998; Dudley & Djamil, 1985; Glowacki et al., 2004; Hennessy & Watson, 1994; Leveritt, Abernethy, Barry, & Logan, 2003; McCarthy, Agre, Graf, Pozniak, & Vailas, 1995; Millet, Jaouen, Borrani, & Candau, 2002). In the present study, however, six-weeks of basketball specific

endurance conditioning did not reduce power related performances, such as sprinting (5, 10, and 20m speed) and jumping ability (jump height; Table 11). This observation of no interference effect parallels the results of similar aerobic endurance training studies involving team sport (soccer) players (Helgerud, Engen, Wisloff, & Hoff, 2001; McMillan, Helgerud, Macdonald, & Hoff, 2005). However, whilst maintaining physical measures may be acceptable in some sports, simply maintaining speed and vertical jump height during the competitive season in basketball may not be desirable since a strong relationship between playing time and speed ($r=0.62$, $P=0.05$) and vertical jump height ($r=0.68$, $P=0.05$) has been reported (Hoffman, Tenenbaum, Maresh, & Kraemer, 1996).

In the present study, CON did exhibit a clear improvement in sprinting speed at 10 and 20 m in relation to E_{spec} . However, changes in sprinting speed at 5 m, vertical jump height, agility, and the total time to complete the RHIET were unclear compared to E_{spec} (Table 11). The marginally greater improvement in CON for 10 and 20 m sprinting speed is perhaps not surprising given that a classic basketball conditioning approach has been shown to focus more on improving anaerobic abilities rather than aerobic abilities (Tavino, Bowers, & Archer, 1995). The fact that E_{spec} showed smaller increases in power related performances suggests that the endurance conditioning circuit may have reduced the extent of the improvements, compared to CON. There is a possibility, however, that due to the basketball specific endurance circuit containing some turning/jumping elements (14 changes of direction and three vertical jumps) it may have 'assisted' in minimizing a potential interference effect. The mechanisms underlying an interference in strength and power gains include mechanical stress and the potential for eccentric muscle damage being high with run training (Kraemer et al., 1995), such as what was administered during the present study. Higher levels of mechanical stress and eccentric muscle damage would induce a higher catabolic state as a result of elevated cortisol concentrations, in turn reducing any gains in skeletal muscle cross-sectional area, which has been associated with depressed gains in

muscular strength (Bell, Syrotuik, Socha, Maclean, & Quinney, 1997; Kraemer et al., 1995). Despite this, 12-weeks of aerobic endurance training consisting of continuous and interval cycling exercise resulted in an unaltered cross sectional area in type I and type IIA fibres (Putman, Xu, Gillies, MacLean, & Bell, 2004) and consequently no appreciable change in knee extensor strength (Bell, Syrotuik, Martin, Burnham, & Quinney, 2000). Suggesting that in the present study, given that strength/speed development was not a primary focus of the training intervention and therefore was not specifically trained, the observed minimal change in power related measures (speed and vertical jump) for E_{spec} is acceptable.

In summary, it appears that the basketball specific endurance circuit provided no additional benefit over a classic training approach when based on the Yo-Yo IRT, RHIET, speed and vertical jump measures. In fact, some evidence exists to suggest an impairment of 10 and 20 m sprinting speed in E_{spec} compared to CON. This was possibly linked to the focus of the training regime employed in the present study being aerobically orientated whereas CON had a greater focus on anaerobic fitness.

6.2 Physiological Measures

6.2.1 Maximal Oxygen Uptake

For many years aerobic endurance was considered of little importance to basketball performance (Gillam, 1985; Hoffman, Tenenbaum, Maresh, & Kraemer, 1996). However, recent time-motion analysis investigations have revealed that aerobic endurance is required for successful basketball performance (Abdelkrim, El Fazaa, & El Ati, 2007; Bishop & Wright, 2006; McInnes, Carlson, Jones, & McKenna, 1995). In support, the amount of live time spent in high-intensity activity is significantly correlated with $VO_{2\text{peak}}$ in basketball performances ($r= 0.55$, $P<0.05$; Abdelkrim, El Fazaa, & El Ati, 2007), thus reinforcing the importance of a high level of aerobic fitness in

basketball players. In this study, pre-intervention $\text{VO}_{2\text{peak}}$ values were $50 \pm 5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $50 \pm 2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for E_{spec} and CON, respectively. These values are comparable with those reported for U.S. collegiate players ($50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; Bolonchuk, Lukaski, & Siders, 1991; Hunter, Hilyer, & Forster, 1993) and elite under-19-year-old Tunisian players ($52.8 \pm 2.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; Abdelkrim, El Fazaa, & El Ati, 2007) but expectedly lower than those observed in older (24 ± 3 years) elite Australian basketball players ($60.7 \pm 8.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; McInnes, Carlson, Jones, & McKenna, 1995).

The basketball specific endurance circuit used specifically to develop aerobic endurance in the present study manifested a 12.4% increase in relative $\text{VO}_{2\text{peak}}$ for E_{spec} during the competitive season (Cohen's ES 0.36 ± 1.95 ; $\pm 90\%$ CL; Table 12; Figure 17). Statistically however, despite similar $\text{VO}_{2\text{peak}}$ values prior to the training intervention, the observed substantial improvement in E_{spec} was somewhat offset by an 8.8% increase in relative $\text{VO}_{2\text{peak}}$ for CON and therefore was considered unclear. The unclear result was likely due to the large error of measurement (6.1%) associated with $\text{VO}_{2\text{peak}}$ (Table 9). The observed increase in $\text{VO}_{2\text{peak}}$ for CON is similar in magnitude to that previously reported by Laplaud et al. (2004) where a 6% improvement in $\text{VO}_{2\text{peak}}$ was measured following a 'classic' training approach during a regular basketball season. That the CON group continued their typical team sport training in the present study corroborates this observation. Therefore, the 3.6% greater improvement in $\text{VO}_{2\text{peak}}$ in E_{spec} relative to CON can reasonably be attributed to the prescribed aerobic interval training regime. This increase is larger than that observed in professional soccer players (0.2 to 0.3%) after a six-week training intervention with a similar exercise intensity (85 to 90% HR_{peak} ; Reilly & White, 2004), likely due to the initial fitness level of the players. However, the change observed in the present study is lower than the 7% and 11% increases in $\text{VO}_{2\text{peak}}$ reported previously in basketball (Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003) and soccer players (Helgerud, Engen, Wisloff, & Hoff, 2001), respectively, after a traditional aerobic endurance training period compared to control

groups. It is also lower than the 7.5 to 9% increases in VO_{2peak} observed in soccer players following eight to ten-weeks of performing a similar sport-specific aerobic endurance training circuit compared to a control group (Chamari et al., 2005; McMillan, Helgerud, Macdonald, & Hoff, 2005).

There are several possible reasons why a smaller change was observed compared to previous works. Firstly, differences observed could be due to the fact that the training was carried out during the competitive season in the present study compared to the pre-season in other studies (Chamari et al., 2005; Helgerud, Engen, Wisloff, & Hoff, 2001; Helgerud, Kemi, & Hoff, 2003; McMillan, Helgerud, Macdonald, & Hoff, 2005). Greater training adaptations are more likely to occur due to a potentially de-trained state pre-season (lower pre-test scores). Secondly, the differences could also be due to the shorter duration training programme in the present study compared to others (Chamari et al., 2005; McMillan, Helgerud, Macdonald, & Hoff, 2005), yet it is still clear that greater aerobic adaptation occurred in E_{spec} compared to CON. Thirdly, and perhaps most influential was the actual intensity of training completed by E_{spec} . In the present study, based on the previous work of Helgerud et al. (2001) McMillan et al. (2005), an intensity of 90 to 95 % HR_{peak} was targeted for each training session. However, during post-intervention analysis, the actual average HR during the work intervals was lower (84.1% HR_{peak} , approximately 78.6% VO_{2peak}). Although this intensity is adequate to induce positive aerobic adaptations (Wenger & Bell, 1986), it was much lower than the intended/targeted intensity for this study and lower than previous investigations (Chamari et al., 2005; Helgerud, Engen, Wisloff, & Hoff, 2001; McMillan, Helgerud, Macdonald, & Hoff, 2005). Therefore, it is conceivable that had the athletes involved in the present study trained at the prescribed % HR_{peak} (90 to 95% HR_{peak}), greater improvements in VO_{2peak} could have been observed post-training. Possible reasons as to why the training intensity was not achieved in the present study include low levels of sport specific skill, initial fitness level, and the design of the circuit, all of which are discussed in section

6.3. Despite this, the basketball specific endurance circuit induced greater improvements in $\text{VO}_{2\text{peak}}$ relative to CON, suggesting it was somewhat effective in improving aerobic fitness during the competitive season.

6.2.2 Running/Movement Economy

In addition to $\text{VO}_{2\text{peak}}$, other important aerobic parameters, including LT and RE, were measured pre- and post-training. The training intervention administered had a positive effect on RE when expressed as the $\%\text{VO}_{2\text{peak}}$ at a defined speed ($11 \text{ km}\cdot\text{h}^{-1}$). This was made apparent through a $5.3 \pm 4.8\%$ improvement in RE for E_{spec} while classic basketball training resulted in a $0.5 \pm 6.4\%$ decrease for CON (Cohen's ES -0.60 ± 0.90 ; $\pm 90\%\text{CL}$). Unfortunately, however, the confidence limits of the effect overlapped the threshold for substantiveness resulting in an unclear practical inference for RE (Batterham & Hopkins, 2006). The lack of change in RE however, is similar to previously published data for soccer players where RE ($\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{m}^{-1}$) did not substantially improve after a ten-week sport-specific aerobic endurance training intervention (McMillan, Helgerud, Macdonald, & Hoff, 2005). Potential limiting factors leading to the lack of substantiveness for RE could be the small sample size of the present study ($N=10$), the speed at which RE was measured, and the 5.5% ($4.1, 8.4$; $90\%\text{CL}$) typical intra-individual variation associated with RE (Table 9). It has been suggested that workloads below LT permit more stable measures of RE to be obtained in trained runners (Pereira & Freedson, 1997) and, therefore, it is possible that the running speed used in the present study was too high for meaningful changes to be observed (Table 10). The 5.5% typical intra-individual variation is similar to that observed for elite 800 m runners (4.7% ; Brisswalter & Legros, 1994) and could have been influenced by treadmill running experience, footwear, time of day testing, prior training activity, and nutritional status (Saunders, Pyne, Telford, & Hawley, 2004). However, every effort was made to minimize the possible effect of such factors in the present study.

Improvements in RE after aerobic endurance training can potentially be attributed to biomechanical adaptations (Saunders, Pyne, Telford, & Hawley, 2004). These adaptations include an improved ability of muscle to store and release elastic energy by increasing muscle stiffness (Aura & Komi, 1986) and more efficient running mechanics (Williams & Cavanagh, 1987). In some (Chamari et al., 2005; Helgerud, Engen, Wisloff, & Hoff, 2001; Helgerud, Kemi, & Hoff, 2003), but not all (McMillan, Helgerud, Macdonald, & Hoff, 2005) previous endurance training studies involving junior (Helgerud, Engen, Wisloff, & Hoff, 2001) and elite professional soccer players (Helgerud, Kemi, & Hoff, 2003), improvements in RE have been observed. However, in the majority of these studies it was noted that the training method was traditional (straight line) interval running. We and others (McMillan, Helgerud, Macdonald, & Hoff, 2005) observed no change for multi-directional, circuit-based aerobic interval training which might suggest that the actual mode of interval training in team sport players is influential in determining RE improvements. Since refining mechanical elements such as stride length and frequency by repeatedly running at a particular speed (Williams & Cavanagh, 1987) or the integration and timing of muscle activity to utilise the storage and release of elastic energy more effectively (Aura & Komi, 1986) have been linked to better RE (Loftin, Anderson, Lytton, Pittman, & Warren, 1996), the constant change in pace and direction associated with the circuit design in the present study may have hindered the development of such qualities. That RE was assessed only during straight line treadmill running in the present could be considered a limitation. If movement economy/efficiency could be reliably measured then it is possible that improvements in efficiency (lower O₂ cost for multi-directional movements) would be observed.

It has been shown that the O₂ cost of dribbling a soccer ball during running is 5.2 kJ·min⁻¹ greater than running without the ball (Reilly & Ball, 1984). Though it is currently unknown whether there is a similar degree of added energy cost when dribbling a basketball during running compared to normal running. Based on the findings of Reilly and Ball (1984), it was anticipated that the O₂ cost

of dribbling the basketball during the training circuit would be greater compared to running the basketball circuit without dribbling the ball and that this would have contributed to a higher energy demand, greater work intensity and a resulting high HR during training sessions. However, it is possible that this did not occur. In fact, the effect of having to dribble the ball during the circuit could have even constrained the subjects' ability to work at a high intensity thus having the opposite energetic effect. That is, the skill required to dribble at very high speeds prevents a players' ability to work physically hard for longer durations.

Although RE was relatively unchanged after the intervention period, mean HR at $11\text{km}\cdot\text{h}^{-1}$ experienced a nontrivial negative change, substantially decreasing by $4.4 \pm 2.1\%$ in E_{spec} , while CON experienced a $3.1 \pm 0.4\%$ increase in HR (Cohen's ES -0.87 ± 0.23 ; $\pm 90\%\text{CL}$). Essentially, the lower error of measurement (4.2%) associated with HR at $11\text{ km}\cdot\text{h}^{-1}$ contributed to the variable reaching substantivness (Table 9). The decrease in sub-maximal HR is similar to youth soccer players after soccer-specific endurance training (McMillan, Helgerud, Macdonald, & Hoff, 2005) where a $9\text{ b}\cdot\text{min}^{-1}$ reduction while running at $7\text{ km}\cdot\text{h}^{-1}$ was observed. Enhanced RE is typically associated with a lower HR (Morgan & Craib, 1992) and the lower sub-maximal exercise HR observed in the present study is similar to previous research (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; Chamari et al., 2005). A reduced HR for a given sub-maximal speed would have been compensated for by an increase in stroke volume (Bailey & Pate, 1991; Jones & Carter, 2000).

In summary, the importance of good exercise economy in team sports is relatively unknown. However, exercise or movement economy takes considerable importance during longer-duration cyclical exercise, where success largely depends on the aerobic capability of the individual. All else being equal, any adjustment in training that improves the economy of effort translates directly into improved performance for endurance-based events (McArdle, Katch, & Katch, 1996).

During a basketball game RE may prove useful in reducing the rate of fatigue by allowing any given sub-maximal speed or movement to be maintained without a high rate of energy turnover, thus resulting in less metabolic stress and conserving energy for more important all-out efforts, such as driving to the basket for a lay-up. More specifically, due to the fact that approximately one third of basketball play is spent performing specific movements (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995), such as side shuffling, an improvement in the execution economy of such movements would no doubt benefit individual basketball performance.

6.2.3 Lactate Mid-Point

The lactate mid-point was used as a measure of aerobic fitness. This previously used method (Bonetti, Hopkins, & Kilding, 2006) was applied because using a fixed lactate value as the threshold, although increasing objectivity, denies individuality since the onset of blood lactate accumulation (OBLA) does not always occur at 4 mmol^{-1} (Kilding & Jones, 2005). In the present study the running speed at the lactate mid-point decreased by $2.6 \pm 8.0\%$ for E_{spec} and increased by $1.1 \pm 6.7\%$ for CON (Cohen's ES -0.27 ± 0.68 ; $\pm 90\% \text{CL}$). The decrease in running speed at the lactate mid-point for E_{spec} , although not substantial, contradicts earlier research (Helgerud, Engen, Wisloff, & Hoff, 2001; McMillan, Helgerud, Macdonald, & Hoff, 2005) in that the velocity associated with the lactate mid-point did not follow the observed improvement in $\text{VO}_{2\text{peak}}$ or improved economy. This is surprising since a higher velocity at the lactate mid-point would have been expected in E_{spec} after six-weeks of training. However, in E_{spec} , a change (decreased) VO_2 at the lactate mid-point did correspond with the increase in $\text{VO}_{2\text{peak}}$ (11.3% vs. 12.4%, respectively). Consequently, the $\%\text{VO}_{2\text{peak}}$ at the lactate mid-point substantially decreased in E_{spec} ($0.6 \pm 3.0\%$) from pre- to post-training, while CON displayed a $7.2 \pm 4.1\%$ increase (Cohen's ES -0.59 ± 0.44 ; $\pm 90\% \text{CL}$). This finding opposes previous research (Helgerud, Engen, Wisloff, & Hoff, 2001; Helgerud et al., 2007; McMillan, Helgerud, Macdonald, & Hoff, 2005) where no change in LT

when expressed as $\%VO_{2peak}$ was observed. Specifically, Chamari et al. (2005) found that high-intensity aerobic interval training did not alter the anaerobic threshold (expressed as $\%VO_{2peak}$) of youth soccer players after an eight-week training period. However, despite these findings it should be acknowledged that the $\%VO_{2peak}$ at the lactate mid-point could be deemed unreliable in the present study due to the low ICC ($r=0.22$) and relatively large percent typical error (9.1%, Table 9).

A training intensity corresponding to 84% HR_{peak} , as in the present study, should induce a positive change in LT (Helgerud et al., 2007). Furthermore, training at speeds associated with LT result in several physiological adaptations including an increase in muscle capillarisation (Gute, Fraga, Laughlin, & Amann, 1996) oxidative enzyme activity (Gollnick et al., 1973), and mitochondrial volume and density (Harms & Hickson, 1983), which result in an increased ability to clear lactate from the muscle leading to an increase in running speed at LT (Helgerud et al., 2007). Therefore, the marginal, seemingly harmful changes in running speed at the lactate mid-point in the present study are most probably due to the typical error associated with the measure. Additionally, the training intervention was designed to promote increases in VO_{2peak} , in conjunction with previous studies (Chamari et al., 2005; McMillan, Helgerud, Macdonald, & Hoff, 2005), and therefore improvements were mostly observed in specific components of aerobic function. Also, the lactate mid-point was assessed using a traditional, laboratory-based protocol involving straight line running only, while the endurance training involved multi-directional movements.

6.3 Training Intensity

In the present study both E_{spec} and CON were matched for training volume as demonstrated by the mean durations, mean HR, and peak HR during the training sessions (Appendix 7; Table 14). The duration and intensity of intervals in the present study (4 min @ 90 to 95% HR_{peak} ; 3 min @ 60 to 70% HR_{peak}) was based on the work of McMillan et al. (2005). However, as previously

mentioned (pp. 118), the actual training intensity measured was lower ($\sim 84.1\% \text{HR}_{\text{peak}}$ equating to $78.6\% \text{VO}_{2\text{peak}}$). It is noted, however, that similar actual training intensities ($>83\% \text{HR}_{\text{peak}}$) have been reported previously in amateur soccer players (Rampinini et al., 2007). Possible reasons for the lower than prescribed training HR include: 1) low levels of sport-specific skill; where those with a low skill level may have found it difficult to maintain a sufficient pace when dribbling to induce the required intensity; 2) initial fitness level; the prescribed training intensity may have been too high for the subjects involved in the present study and due to unfamiliarity with such high-intensity training loads they may have been difficult to maintain; and 3) the design of the circuit; although a similar circuit-based aerobic training approach with soccer players has been shown to elicit a high $\% \text{HR}_{\text{peak}}$ (Section 3.4 Sport-Specific Aerobic Conditioning for Team Sports) it may not be transferable to basketball. Perhaps a larger circuit area with less turning and more cyclical movements would induce a greater intensity. Additionally, reducing the amount of time spent dribbling a basketball could be reduced may help increase intensity. However, it was often observed that faster players frequently caught up to slower players while running the circuit and therefore had to slow down before being able to pass them at an appropriate time. This would have temporarily lowered the HR of fitter players. In retrospect, by measuring the B[Lac] response to the training further information regarding the metabolic demand of the training could have been determined.

The uniqueness of this study was that it was completed during the competition phase of training when improvements in fitness are likely to be much smaller compared to pre-season intervention studies. However, it is possible that fatigue from competitive games may have influenced the ability to attain the required intensity during the training. The findings of Krstrup et al. (2003; , 2006) support a fatigue/detraining effect in that performance in the Yo-Yo IRT in elite soccer players was found to decrease over the course of the competitive season, potentially due to the physical demands of competition having a negative impact. Furthermore, it cannot be discounted

that player motivation to achieve and maintain the desired training intensity may have been decreased due to the study taking place during the competitive season and players wanting to reserve their energy for competition. Of note is that the team involved did not make the 'playoffs' later in the season and thus a lack of focus could have affected their effort during training later in the intervention. However, the investigator is confident that all subjects gave full effort in all testing sessions.

6.4 Future Research

To the best of the authors' knowledge, this is the first training study to investigate the effect of sport-specific aerobic interval training on both laboratory and field measures of aerobic fitness, anaerobic endurance, speed, muscular power, and agility in young basketball players. The best future research to allow a clearer insight into the effect(s) of aerobic training on basketball specific fitness would be to test another cohort. Using a similar research design but with enhanced monitoring of training sessions and use of testing protocols with a lower error of measurement may elucidate the true effects of this mode of training. To further develop the current findings it would also be useful to identify how the intensity of the basketball specific endurance circuit could be increased in order to potentially further clarify the present study's findings. Possibilities could include increasing the length of the circuit, running the circuit for a longer time, or running the circuit without the ball, all of which could lead to a heightened physical response to the circuit.

In soccer, player fitness has been shown to decline over the course of the competitive season (Krustrup et al., 2003; Krustrup et al., 2006). To date, there is limited knowledge as to whether fitness declines during a basketball season (Tavino, Bowers, & Archer, 1995). To justify the development of future in-season aerobic training investigations within a basketball context, it would be useful to quantify the magnitude of intra-season changes in aerobic fitness levels in basketball players. Once this has been identified it would be worthwhile investigating whether an

increase in aerobic fitness actually makes a difference in individual/team performance in basketball as measured via time-motion analysis. Additionally, determining the effects of a more intense circuit design on promoting improvements in aerobic fitness and subsequent individual/team performance would be worthwhile.

6.5 Practical Application

The current study has several practical applications relevant to coaches and strength and conditioning professionals in basketball. This study has determined that aerobic fitness can be increased during the competitive season, with increases in VO_{2peak} , RE, and anaerobic power maintenance being reported, using a basketball specific endurance circuit involving changes of direction and pace along with ball control and field goal attempts. However, it must be acknowledged that the training approach administered in the current study did result in reduced improvements in power related measures such as speed and vertical jumping ability compared to regular basketball training.

At present there is raised importance of maintaining and/or increasing aerobic fitness levels during the competitive season within the team sport environment. This has come about, in part, firstly due to aerobic fitness levels being reported to decrease from the pre-season to the end of the competitive season in soccer teams (Krustrup et al., 2003; Krustrup et al., 2006), secondly due to the demanding fixtures/schedules of elite team sport athletes, and finally due to the limited recovery time between competitive engagements and training sessions. Furthermore, during the competitive season, while the upkeep of sport-specific skills is important, the ability to recover adequately from repeated high-intensity efforts both within and between games is perhaps just as much of a priority. Therefore, by utilising a basketball specific endurance circuit during regular training sessions, especially for those with lower skill levels, both sport-specific skill and aerobic fitness can be developed or increased. In future applications, however, it would be prudent to

modify the circuit to suit the skill level and fitness level of the players involved. This could be achieved by periodising/modifying the circuit throughout the pre-season and competitive phases of the annual plan.

Chapter Seven: Conclusion

In conclusion, the data in the present study suggests that a basketball specific endurance circuit has little effect on traditional (laboratory) and sport-specific measures of aerobic fitness in high school basketball players during the competitive phase of the season. In fact, the basketball specific endurance circuit may lead to reduced improvements in power related performances such as jumping and sprinting compared to typical basketball training. Effects were likely by affected by low subject numbers and large measurement error for some measures. However, compared to the control group, who maintained their normal in-season training, differences in E_{spec} were observed in sub-maximal HR responses suggesting that the endurance training promoted some beneficial physiological changes which in turn could contribute to an improved individual and/or team performance during actual competition. Further research is required to clarify the effect of aerobic training approaches for basketball-specific fitness and performance.

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Appendices

Appendix 1. Participant Information Sheet

Participant Information Sheet

Project Title: **Physiological response to sport-specific and traditional aerobic interval exercise in male basketball players.**

Project Supervisor: **Dr. Andrew Kilding**

Researcher: **Nick Stone**

I would like to invite you to participate in a study investigating the effects of 'traditional' and 'sport-specific' aerobic interval training protocols on basketball athletes. This study is being undertaken as part of a Masters of Health Science qualification. Participation is completely voluntary and you may withdraw at any stage.

What is the purpose of the study?

The purpose of the study is to determine the most effective form of aerobic training for basketball players. Identification of the optimal training approach for physiological development will improve future coaching and conditioning practice, thus optimising players' physical preparation for competition.

Can I join the study?

Yes, if they are male, have basketball playing experience (preferably premier/senior players), no injuries, no major medical conditions, and do not plan to have substantial time away during the study's duration.

Are there any costs of participating?

You will not incur any costs while participating in this study. The only requirement is participation in six maximal aerobic assessments (45 min each), three batteries of fitness tests (1 hour each), as well as two aerobic interval training sessions per week for six weeks (30 min duration each).

What happens in the study?

The study is nine weeks in duration. During weeks one and two, your team will undergo a series of fitness tests that are specific to basketball. These tests include two different maximal effort aerobic assessments, which are performed on separate days. Immediately after the aerobic assessments a small finger prick will be used to collect a blood sample to determine if true maximum effort was achieved. Following this is a six week training intervention that will involve performing two 30 min aerobic interval training sessions per week. Week nine will involve performing the same fitness tests as week one, to make results comparable.

What are the benefits?

These results will improve our understanding of the effects of 'traditional' and 'sport-specific' aerobic training for basketball. This in turn will ensure that research supported modes of aerobic

training are provided to players. You will also gain information relating to your current fitness levels (e.g. VO_{2max}).

What are the discomforts and risks?

The risks involved in this study are minimal. You may experience mild muscular discomfort from the fitness testing protocols, and mild discomfort from the finger-prick blood sampling procedures. If an injury occurs due to unforeseen circumstances, you will receive immediate attention from the qualified sport science practitioners who all hold current first aid certificates.

What compensation is available for injury or negligence?

The researcher, AUT or the principal supervisor will not be responsible for any monetary loss incurred in the unlikely event of injury. The ACC system, with its limitations, will provide standard cover if participants are injured.

How is my privacy protected?

All records will be kept in a locked limited access cabinet. Data will be treated as confidential and will be used only for the purpose of this study.

Results

The results of this project will be published in a scientific journal and presented at a national or international conference. You and your school will receive a copy of the results.

Time To Consider Invitation

Please reply to this invitation within 14 days, if you have any further questions or concerns about the research please do not hesitate to contact me, the principal investigator.

Participant Concerns

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEK, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Project Supervisor

Dr. Andrew Kilding
Senior Lecturer, Exercise Science
Division of Sport and Recreation
Auckland University of Technology
Phone 921 9999 ext 7056

Principal Investigator

Mr Nick Stone
Division of Sport and Recreation
Auckland University of Technology
Phone 921 9999 ext 7251
nstone@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on: 27 September 2005

AUTEK Reference number: 05/172

Appendix 2. Parent/Guardian Consent for Child/Children Participation in Research

Parent/Guardian Consent for Child/Children Participation in Research

Title of Project: **Physiological response to sport-specific and traditional aerobic interval exercise in male basketball players.**

Project Supervisor: **Dr. Andrew Kilding**

Researcher: **Nick Stone**

- I have read and understood the information provided about this research project.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw my child/children and/or myself or any information we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If my child/children and/or I withdraw, I understand that all relevant data will be destroyed.
- I agree to my child/children taking part in this research.
- I wish to receive a copy of the report from the research. ☐ Yes ☐ No
- My child/children do not have any current injuries, major medical conditions, or plans to have substantial time away during the study duration that would exclude them from participation.

Child/children's Names:

Parent/Guardian's Name:

Parent/Guardian's Signature:

Parent/Guardian's Contact Details (if appropriate):

.....
.....
.....

Date:

Approved by the Auckland University of Technology Ethics Committee on: 27 September 2005

AUTEC Reference number: 05/172

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

Appendix 3. Assent to Participate in Research

Assent to Participate in Research

Title of Project: **Physiological response to sport-specific and traditional aerobic interval exercise in male basketball players.**

Project Supervisor: **Dr. Andrew Kilding**

Researcher: **Nick Stone**

- I have read and understood the information sheet telling me about what will happen in this study and why it is important.
- I have been able to ask questions and to have them answered.
- I understand that the tests and trainings that I am part of are going to be measured and recorded.
- I understand that while information is being collected, I can stop being part of this study whenever I want without being punished for doing so.
- If I stop being a part of this study, I understand that all information about me will be destroyed.
- I agree to take part in this research.

Participants Name:

Participants Signature:

Participants Contact Details (if appropriate):

.....
.....
.....

Date:

Approved by the Auckland University of Technology Ethics Committee on: 27 September 2005

AUTEC Reference number: 05/172

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

Appendix 4. Ethical Approval

M E M O R A N D U M

Academic Services

To: Andrew Kilding
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 19 September 2005
Subject: Ethics Application Number 05/172 **Physiological response to sport-specific and traditional aerobic interval exercise in trained male basketball players.**

Dear Andrew

I am pleased to advise that the Auckland University of Technology Ethics Committee (AUTEC) approved your ethics application at their meeting on 12 September 2005, subject to the following conditions:

1. Provision of a reconsidered response to section B.8 of the application. You are referred to the material available through the Frequently Asked Questions section of the Ethics Knowledge Base which may be accessed online through <http://www.aut.ac.nz/research/ethics>.

I request that you provide the Ethics Coordinator with written evidence that you have satisfied the points raised in these conditions at your earliest opportunity. Once this evidence has been received and confirmed as satisfying the Committee's points, you will be notified of the full approval of your ethics application.

You may not of course commence research until full approval has been confirmed. You need to be aware that when approval has been given subject to conditions, full approval is not effective until *all* the concerns expressed in the conditions have been met to the satisfaction of the Committee.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

Yours sincerely



Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Nick Stone nstone@aut.ac.nz

MEMORANDUM

To: Andrew Kilding
From: **Madeline Banda** Executive Secretary, AUTECH
Date: 23 June 2006
Subject: Ethics Application Number 05/172 **Physiological response to sport-specific and traditional aerobic interval exercise in male basketball players.**

Dear Andrew

I am pleased to advise that as the Executive Secretary of the Auckland University of Technology Ethics Committee (AUTECH) I have approved an amendment to your ethics application extending the age range of the sample population to include 14 to 16 year old students. This delegated approval is made in accordance with section 5.3.2 of AUTECH's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTECH's meeting on 10 July 2006. Your ethics application is approved for a period of three years until 27 September 2008.

I remind you that as part of the ethics approval process, you are required to submit to AUTECH the following:

- A brief annual progress report indicating compliance with the ethical approval given using form EA2, which is available online through <http://www.aut.ac.nz/research/ethics> including a request for extension of the approval if the project will not be completed by the above expiry date;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/ethics>. This report is to be submitted either when the approval expires on 27 September 2008 or on completion of the project, whichever comes sooner;

You are also reminded that, as applicant, you are responsible for ensuring that any research undertaken under this approval is carried out within the parameters approved for your application. Any change to the research outside the parameters of this approval must be submitted to AUTECH for approval before that change is implemented.

Please note that AUTECH grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the Committee and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely



Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Nick Stone nstone@aut.ac.nz

Appendix 5. Relationship between the total time to run the repeated high-intensity endurance test and the total distance covered during the Yo-Yo intermittent recovery test

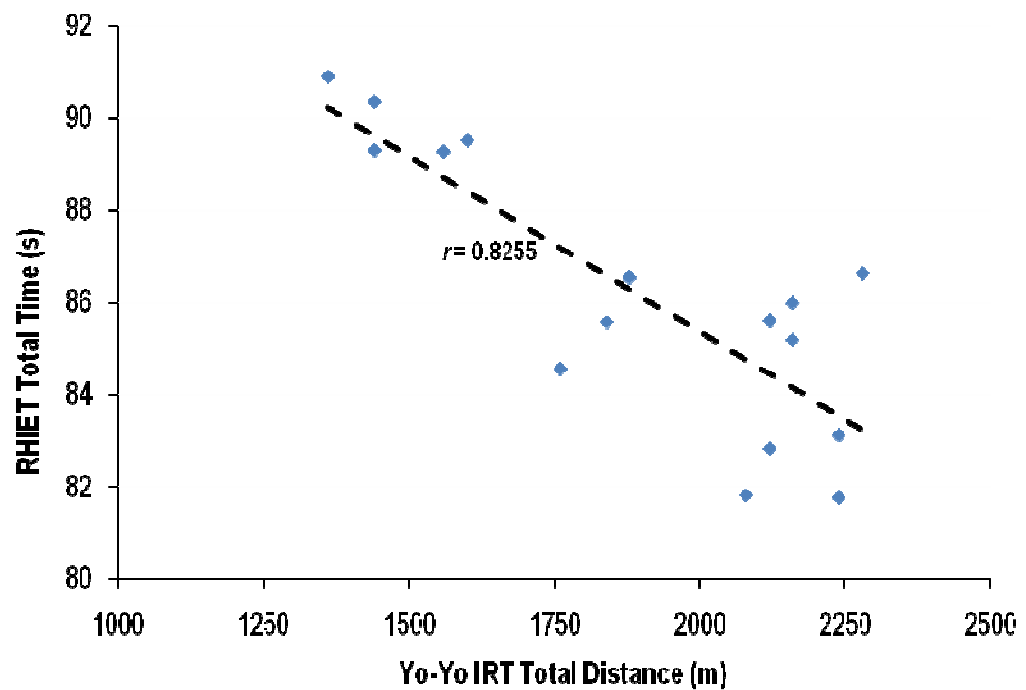


Figure 20. Relationship between the total time (s) to complete the repeated high-intensity endurance test (RHIET) and the total distance covered during the Yo-Yo intermittent recovery test (m) in elite semi-professional basketball players ($N = 17$) (Stone & Kilding, unpublished).

Appendix 6. Peak heart rates recorded during the Yo-Yo IRT and treadmill step tests.

Table 13. Peak heart rates ($\text{b}\cdot\text{min}^{-1}$) recorded during the Yo-Yo IRT and treadmill step tests ($N = 10$).

Subject	Yo-Yo IRT			Incremental Step-Test		
	Pre1	Pre 2	Post	Pre1	Pre 2	Post
1	201	195	198	203	202	205
2	204	199	195	199	201	196
3	204	197	197	197	198	192
4	208	189	196	197	187	204
5	192	194	192	194	189	190
7	199	-	193	194	-	189
10	192	192	189	199	195	199
12	219	215	219	215	213	213
13	203	-	193	187	196	201
14	206	194	196	208	202	192
Mean	202.8	196.9	196.8	199.3	198.1	198.1
S.D.	7.8	7.9	8.2	7.8	7.8	7.8

IRT intermittent recovery test

Appendix 7. Training duration and heart rate values for both experimental groups.

Table 14. Mean training duration and mean and peak training heart rates for both CON and E_{spec} for 12 training sessions over 6 weeks (N = 10).

Subject	Mean Duration	Peak Training HR (b·min ⁻¹)		Mean Training HR (b·min ⁻¹)	
	(hh:mm:ss)	Mean	%HR _{peak}	Mean	%HR _{peak}
CON					
1	00:45:29	188.9	94.0	152.2	75.7
3 ^a	-	-	-	-	-
4	00:32:16	178.5	85.8	138.8	66.7
12	00:42:20	208.1	95.0	174.9	79.9
Mean	00:40:02	191.8	91.6	155.3	74.1
S.D.	00:06:54	15.0	5.0	18.3	6.7
E_{spec}					
2	00:50:49	193.1	94.7	155.7	76.3
5	00:45:46	186.9	97.3	156.6	81.6
7	00:44:52	181.9	91.4	147.1	73.9
10	00:45:31	190.1	99.0	153.8	80.1
13	00:43:31	185.8	91.5	154.5	76.1
14	00:41:45	188.2	91.4	157.0	76.2
Mean	00:45:22	187.7	94.2	154.1	77.4
S.D.	00:03:03	3.8	3.4	3.6	2.9

CON = control group; E_{spec} = sport-specific training group

^a faulty heart rate monitoring equipment