A PROFILE OF HANDBALLERS AND PHYSIOLOGICAL RESPONSES TO EXERCISE RELATED TO THE GAME

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Abstract

Literature concerned with scientific aspects of handball is scant in particular kinanthropometric characteristics of players and the physiological responses to handball match-play. The aims of this thesis were to determine the physical profiles of male and female handball players and to assess the physiological responses to an exercise protocol reproducing physiological responses to handball matches. The influence of environmental temperature on physiological and thermoregulatory responses to the exercise protocol was also examined, with and without carbohydrate (CHO) ingestion. A series of kinanthropometric measures was obtained on 63 male and 60 female players who were recruited during the 12th Asian Games in Hiroshima (1994). For the elite male handballers body height and % body fat were the important variables in discriminating between the successful and unsuccessful teams. Male eastern players were taller with less body mass and lower percentage body fat than the western players. A homogeneous kinanthropometric profile was found among player-positions for male and female Asian handball players. Among the female Asian handball players there were significant differences between teams in kinanthropometric characteristics. The Kuwait male players were also compared to the national English players. Neither aerobic nor anaerobic fitness were significantly different between these groups but the Kuwaiti players were superior in long and vertical jump ($P < 0.05$) to the English players. The HR-VO_2 relation determined in the laboratory during measurement of VO_{2max} for Kuwaiti players was used to estimate the VO_2 and energy expenditure during handball matches and training. The HR during handball matches (143 ± 6 beats.min^{-1}) was higher than training sessions (136 ± 5 beats.min^{-1}). The HR during handball matches provided the basis for designing a generic intermittent exercise protocol reflecting the physiological response of handball match-play. The effects of environmental temperature (34°C and 20°C) on physiological and thermoregulatory responses during the generic intermittent exercise protocol were compared with those exhibited during continuous exercise at the same external work load (same average speed and duration). Rectal and skin temperatures were recorded. Average HR and VO_2 were significantly higher during continuous exercise than was observed during generic intermittent exercise in normal conditions. The perceived exertion was higher ($P < 0.05$) for continuous exercise in hot conditions than for intermittent exercise. Body mass loss was greater after continuous than after intermittent exercise in the normal condition, however body mass loss was significantly greater after intermittent exercise in hot compared to normal. Also the effect of CHO ingestion on the physiological and thermoregulatory responses was examined during a series of experiments using the generic intermittent exercise protocol. Ingesting CHO raised blood glucose concentration at rest and during exercise compared to placebo trial, but this had no additional effects on the physiological and thermoregulatory responses during exercise or into recovery in either hot or in normal conditions. Motion analyses of handball matches indicated that the generic intermittent exercise protocol was representative of handball match-play in terms of frequency of high intensity activity. It is concluded that Asian handball players exhibit homogeneous kinanthropometric characteristics within male and female players. The average intensity of handball match-play was moderate to high. Exercise and environmental temperature, but not carbohydrate ingestion, were the main factors responsible for the physiological alterations observed in response to the laboratory generic intermittent exercise used to induce physiological stress of a handball match. Further field-based studies are needed to examine the effect of these changes on performance during match play.

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INTRODUCTION

1. INTRODUCTION

1.1 HISTORY OF HANDBALL

1.1.1. World-wide

The sport of handball as it is played today certainly has had an eventful history. The fact that man has always used his hands more than his feet lends credibility to the claim made by famous sports historians that playing handball occurred much earlier then, say, football. The games that were precursors of handball can only be said to be distantly related to it in terms of their structure and rules of play. Nonetheless, the game of “Urania” played by the Ancient Greeks (and described in the Odyssey) and “Harpaston” played by Romans (and described by the Roman doctor Claudius Galenus in 130 to 200 A.D) as well as in the “feagballspiel” (German for catch ball game) featured in the songs of the German lyrical poet Walther von der Vogelweide (1170 - 1230), all contained certain features that can be described as ancient forms of handball.

Field handball or modern handball was first played towards the end of the 19th century. For instance, one such game was played in the Danish town of Nyborg in 1897. The real impulse emanated from Denmark, Germany and Sweden. German sports instructors can be considered as the founders of the modern form of field handball (outdoor handball) as a separate sport at the turn of century. In 1928 the International Amateur Handball Federation was founded at the Amsterdam Olympic Games and it was played for the first time at the Berlin Olympic Games in 1936. The first outdoor championship was held in Germany in 1938. The end of the Second

World War marked the beginning of the indoor handball court game and handball returned to the Olympic Games in 1972. Since then the sport has increased in popularity world-wide.

Handball is now played on all five continents. The International Handball Federation (IHF) has 142 member federations represented from the continents as 44 African members, 30 Asian members, 46 European members, 4 Oceanic members and 18 Pan-American members. Women's handball was included in the Montreal Olympic Games programme in 1976 and handball became one of the most popular team sports of the Games. Therefore the International Olympic Committee has increased the number of women's teams in the handball tournament to ten teams for the 2000 Olympic Games in Sydney, and so far eight women's and twelve men's teams have qualified (Hahn et al., 1996)

1.1.2. Kuwait Handball Association history

Handball activities were started in Kuwait through the schools in 1964. In 1966 the Kuwait Handball Association was established and became a member of the International Handball Federation in 1970. Subsequently, in 1975 and 1976 Kuwait became a member of the Arabic Handball Federation and the Asian Handball Federation, respectively. Since then the game of handball has spread to all the schools and the sports clubs in the country to the extent that handball is now considered to be the fourth most popular sport in Kuwait after soccer, basketball and volleyball.

The development of handball was very quick due to endeavours of the clubs and the Kuwait Handball Association. The game of handball is now played by men, juniors, youth and mini-handball teams. Since the Kuwait Handball Association was established, the national team of Kuwait has participated in all the Arab and Asian championships, and won some of these championships. Also the Kuwait handball national team qualified to play in the world championships in 1983 and 1985. In the last few years the Kuwait handball national team has participated in the men's world championships in Iceland 1995 and in the Olympic Games of 1996 in Atlanta. These developments have enabled the game of handball to rival basketball and volleyball in popularity. Unfortunately women have had no opportunity to play handball in Kuwait because of social and cultural factors.

1.1.3. Asian Handball Federation history

The Asian Handball Federation began when H.E. Sheikh Fahid al Ahmed Al Sabah, head of the Kuwait delegation to the Seventh Asian Games which was held in Tehran 1974, presented a proposal to the Executive Committee of the Asian Games Federations requesting approval to accept the sport of handball and the formation of an Asian Handball Federation. Therefore, the Asian Games Federations resolved at its meeting in 26th of August 1974 to recognise the game of handball which was then included in the Asian Games programme. Since then the game of handball has been practised in many Asian countries. In 1976 the handball federations in Asia were invited to attend the constituent meeting in Kuwait. Fourteen Asian countries attended the meeting with the general secretary of the International Handball Federation. The Council and the Executive Committee were elected and Kuwait City was selected for the headquarters. Since the Asian Handball Federation was established, it has developed significantly towards increasing the members to 30 countries and increasing the activities in men's and women's events. The Asian Handball Federation has organised 8 championships for men (the first one was held in Kuwait in 1977) and 5 for women, 6 for junior men, 5 for junior women and all the qualification tournaments of the world championships. Handball was included in the Asian Games for the first time in India in 1982. Subsequently, some of the Asian Handball Federation members have been successful in international tournaments; for example, South Korea won the handball tournament in the Olympic Games in Barcelona 1992 and the women's world championship in 1995. These successes reflect the development of handball in Asia.

1.1.4. British Handball Association history

The British Handball Association was formed in Liverpool in 1968. In 1970 it was accepted as a full member in the International Handball Federation. Unfortunately, there was no representative national team for handball in United Kingdom throughout this time as the federation has not consistently supported a senior international squad. Nevertheless, Liverpool is still the base of national handball and its club players are periodically called upon for representative matches.

1.2. BACKGROUND OF HANDBALL

Handball is one of the most popular sports in the world in terms of participation and spectators. Handball has been played by males and females, old and young for competitive and recreation sports and in these days handball is played on the beach as well as on hard court. Performance in handball is determined by a number of factors. Physiological, psychological, tactical and technical elements are closely linked to performance. During the game, players engage in a wide variety of activities that vary in intensity from light exercise to high intensity. The exercise pattern is intermittent with the change in activity being frequent but irregular in duration. Specific handball match activities such as shooting, throwing, dribbling, jumping and blocking are all required for successful performance at any level. These serve to increase further the physiological stresses placed on players and increase the complexity of evaluating the energy demands imposed on players during participation. The physiological demands of handball can be examined by making relevant observations during game play, obtaining physiological measures (e.g. heart rate, blood lactate, oxygen uptake) during real and simulated games and determining the physiological capacities of elite handball players on performance tests.

1.3. INTRODUCTION TO RESEARCH STUDIES

Insight into the demands of handball could be attained by the use of field-based and laboratory-based investigations. A generic intermittent exercise model was taken as a starting point for the laboratory-based work. Field-based research provides crucial information about the demands of the sport and hence the relative importance of different aspects of fitness to intermittent exercise performance. Therefore, it is pertinent to investigate the physiological demands of handball match-play as this provides information regarding the physiological consequences of the game in general. Some methodological problems restrict the information that can be collected in competitive match situations so the emphasis has to be placed on laboratory representations or part simulations for specific investigations. Laboratory representations of the activity patterns associated with handball match-play may then supplement physiological information. In many instances the laboratory worker may have to rely on generic exercise models in view of the difficulties posed in designing good laboratory simulations. Nevertheless, the information so obtained about the responses to intermittent exercise is a useful addition to field-based research as it permits accurate physiological and respiratory measurement techniques to be used in, for example, the assessment of exercise intensity.

Handball is a sport in which movement is characterised as intermittent and continuously adapted to different offensive and defensive phases of play. In competitive handball, players are expected to perform at the limit of their physical capabilities. Handball is an intense game with specificity of activities both in attack and in defence. During the game, which lasts for 60 min, the players perform numerous dynamic actions which are characterised by maximum efforts over very short periods of time.

It is assumed that playing competitive handball requires a high level of fitness, although the emphasis on different aspects of fitness varies with ability and the level of competition. The various components of fitness for handball include strength in the arms and legs, an ability to jump high for blocking and scoring, flexibility, agility and speed for moving around the court. Since handball matches require 60 min of play over two halves (with 10 min rest intervening), muscular and cardiorespiratory endurance are likely to be important for the handball player to achieve success in the game. Prolonged intermittent exercise associated with the game requires an amalgam of fast reactions, speed, agility, muscle strength, anaerobic and aerobic power. Handball belongs to the group of sport disciplines which rely heavily on sustained repetitive efforts and so the physiological demands of handball may be regarded as dominated by severe exertion of mixed anaerobic and aerobic characteristics. Consequently the demands of the game may dictate the physical and physiological characteristics that players need to possess in order to compete successfully.

In some countries team sports such as soccer, handball and hockey are played in very high environmental temperatures. Reilly (1996a) reported that when exercise is performed in hot conditions, core temperature is elevated and the players' performance may be compromised. The mechanisms responsible for these observations have been extensively investigated during steady state continuous exercise and relate to reduction in plasma volume. By comparison, the thermal response to intermittent exercise has received little attention. In addition, few researchers have endeavoured to implement a game-specific laboratory protocol in an attempt to replicate the actual exercise patterns usually performed during the sport. The laboratory situation gives the researcher the opportunity to use research apparatus, giving depth and accuracy of data provided by the controlled conditions associated with experimental work. The present study will attempt to provide a greater insight into the physiological, thermoregulatory and metabolic responses to an intermittent exercise protocol broadly compatible with a team game such as handball. Metabolic substrate utilisation during such exercise protocol may be influenced by environmental conditions and by pre-exercise nutrition. The extent to which global models of intermittent exercise correspond to the patterns observed during match-play in team sports (and to handball in particular) will also be considered.

1.4. AIMS OF THE STUDY

1.4.1. Overall aims

The broad aims of the research within this thesis were as follows:

1. To describe the kinanthropometric characteristics of elite handball players.
2. To establish the relationship between a laboratory based generic protocol for intermittent exercise and physiological demands of handball play.
3. To examine the influence of heat exposure and carbohydrate ingestion on selected physiological responses to this generic protocol.
4. To relate handball match-play work rate characteristics to the laboratory intermittent exercise model.

The aims will be achieved by means of the following objectives.

1.4.2. Objectives of the study

1. To determine the relationship between kinanthropometric measurements and success in game performance in elite male and female national handball teams.
2. To establish and compare fitness profiles of top Kuwaiti and English handball players .

3. To establish the heart rate responses of handball players during match-play in order to develop a laboratory based generic intermittent exercise protocol suitable for experimental investigations.
4. To determine the effect of heat stress on selected physiological and thermoregulatory responses to laboratory-based intermittent exercise protocol performed at heart rate response equivalent to handball match-play.
5. To examine the effect of carbohydrate supplementation on selected physiological responses to the same intermittent exercise protocol in normal and hot environmental conditions.
6. To establish the work-rate characteristics of handball play.
7. To relate the work-rates of specific games to the generic intermittent exercise protocol.

1.5. OVERVIEW

There is a shortage of literature concerned with scientific aspects of handball both in the field and in the laboratory. In particular there is little information on physiological responses during training and matches. The few studies that have been reported dealt mostly with injuries and techniques. In the main, these studies were published in French, German and Polish, while little or no attention has been paid to kinanthropometric or fitness profiles or physical performance of handball players. This lack of information about physiological responses in handball has stimulated the investigations conducted as part of this thesis. These entail acquiring descriptive data about international level handball players in terms of kinanthropometric and physiological characteristics. Physiological responses to incremental exercise tests provide a basis for interpreting observations made in training and competitive contexts. The traditional laboratory-based models of intermittent exercise fall short of the patterns of exercise induced by competitive games. Nevertheless, generic models of intermittent exercise may be the appropriate means of representing the global factors of the intermittent activities of games in general. Insights may then be obtained also from laboratory investigations to highlight physiological characteristics of games including handball. Information about physiological stress during competitive matches can be gained from investigations of how performance in such laboratory situations can be affected by subjecting players to heat stress or providing them with extra energy. The overall appropriateness of the generic intermittent exercise protocols can be gauged by comparing activity profiles with motion analysis of real matches.

CHAPTER 2

REVIEW OF THE LITERATURE

2. REVIEW OF LITERATURE

2.1. PLAYERS' CHARACTERISTICS AND RESPONSES TO HANDBALL

2.1.1. Kinanthropometry related to team sports

Since the 1920s several studies have focused on physical and physiological factors that might contribute to success for elite athletes in different sports. Performance in team sports at the highest level is not only the result of good physical conditioning, of excellent technical and tactical knowledge and above average intellectual abilities, but also requires constitutional pre-requisites varying according to the type of sport and the discipline. It seems that characteristics of physique are decisive or jointly decisive for performance (e.g. as a prerequisite of physical abilities or as physical superiority over the opponent as the decisive determinant in a match) (Hlatky and Holdhaus, 1993). Kinanthropometry is defined as the quantitative interface between human structure and function (Ross and Ward 1984). This interface is examined through the measurement and analysis of age, body size, shape, proportion, composition and maturation as they relate to gross body function. Consequently, the discipline incorporates the measures long used by classical anthropometrists. Results of kinanthropometric research have suggested that high level performance in many sporting events is associated with certain somatotype characteristics (Carter, 1984).

Several cross-sectional studies have examined the relationship between kinanthropometric profiles of male and female athletes and their sports activity. Toriola et al. (1987) evaluated the differences between basketball and volleyball players with respect to height, weight and compared these physical traits with those of a nonathletic group. The results showed that the basketball players were significantly taller and heavier than the volleyball players and nonathletes. Similar results were reported earlier by Morrow et al. (1980) when kinanthropometric measurements were made on women basketball, volleyball players and non-athletes. These results could be attributed to the tendency for tall persons to select participation in basketball preferentially because height is advantageous in performing basketball skills (Toriola et al., 1987). The relatively low body weight found in the volleyball groups in these studies is not surprising since weight is a limiting factor in executing strength-related skills (Ross and Ward, 1984), such as spiking in volleyball. In this respect, Carter (1984) compared the mean heights and weights of Montreal Olympic track and field athletes, and noted that the differences in absolute height and weight were related to the biomechanical or physiological demands of the events. Similarly, Musaiger et al. (1994) revealed that basketballers and volleyballers were the tallest athletes, while handballers were the heaviest ones.

It appears that the kinanthropometric characteristics have a major role to play in the success of the athlete at all levels of competition (Sodhi, 1980). In fact, performance in certain athletic activities is determined mainly by morphological factors in addition to the training and motivation of players. For example, Laska-Mierzewska (1978) compared the physical characteristics of women handball players of three different performance levels with those in the normal population. The results showed that the first level players were taller and heavier than the second and third level counterparts and inactive women in the normal population. The greatest differences were found in adiposity which was significantly lower for the first level players than for lower level players (Laska-Mierzewska, 1978). In contrast, Hlatky and Holdhaus (1993) found that the differences in the mean values for body weight and body height were negligible when 38 women handball players from the best handball teams in Austria, Norway and Lithuania were examined for performance diagnosis. However, in comparison with the Olympic Games in Montreal in 1976, top-class women handball players in Hlatky and Holdhaus's study (1993) were on average 3.4 cm taller and 2.7 kg heavier. These results confirm the earlier study by Hirata (1979) and Khosla (1983) who demonstrated that the players in the medal-winning teams were taller than the others, thus suggesting how important body height and weight are to play handball successfully.

In accordance with the findings in handballers, Sodhi (1980) reported that the Indian basketball player were considerably lighter in weight and shorter in stature when compared with their Olympic counterparts. The results suggest that body height plays an important role in the success of basketball players and shortness seems to be highly disadvantageous. On the contrary, success in soccer seems to depend on other factors such as technical and tactical components. This explanation seems to be compatible with the evidence that indicated no significant differences in kinanthropometric variables between three different groups of soccer players (Tiryaki et al., 1995).

The physical characteristics of game players have an important part in their choice of players to implement the game plan. This is more clearly evident in basketball and soccer than in handball. Kinanthropometric measurements were examined in relation to the playing position of the female basketball players in the England under-17 basketball squad (Bale, 1991). The results showed that the centres generally were tallest in stature and heaviest in weight than the forwards, and the shortest and lightest were the guards. The results are similar to a study by Spurgeon et al. (1980) when national Canadian, Czechoslovakian, Polish, Soviet and American female basketball players were studied. Data on height and body mass of soccer teams suggest that players vary widely in body size; being tall is an advantage for the goalkeeper, for centre-backs and for a forward player used as a 'target' for winning possession of the ball with the head. In contrast the players deployed in midfield, in full-back and on the wings tend to be smaller in size then those in other positional roles (Puga et al., 1993).

More specific in providing information about an athlete's physique is the assessment of body composition i.e. the relative adiposity or body fat percent. Hlatky and Holdhaus (1993) reported that the lowest value of percent fat was found for the most internationally successful handball teams when compared to the other teams when skinfold technique was used. Correspondingly they also had the highest proportion of lean body weight. Similarly, Brewer and Davis (1991) found distinct differences in percent fat between different level of soccer players with percentage fat of 11% for professional and 15% for semi-professional players. These data would suggest that a lower proportion of body fat and a higher value of lean body weight constitute a feature of the physique susceptible to influence the play in both handball and soccer.

In summary, the requirements of physique and body composition may vary in different types of game sports, and the performance of athletes in game sports is not only the result of excellent technical-tactical knowledge but also is partially dependent on their physique and body composition. The lack of information on the relationship between kinanthropometry and handball players' performance and playing position would be interesting to explore in the present study.

2.1.2. Physical fitness requirements for team sports and specific to handball

2.1.2.1. Requirements of handball

Handball is the perfect illustration of a sport in which the fundamental principles of play are to run, jump and throw. It is thought that the level of physical performance required for handball play has increased considerably in the last few years. This is due to the development of the game's rules which have greatly influenced playing techniques and tactics. Additionally, progress in the understanding of the demands of the game has led to the design and utilisation of training programmes more specific to the game. Delamarche et al. (1987) highlighted the physiological effects of the frequent changes in game rhythm, which is closely related to varying reliance on the aerobic and anaerobic capabilities. Physical training influences several factors which contribute to physical capability and physical fitness. It may cause changes not only in muscle strength and oxygen transport, but also structural and functional changes in a number of organs and physiological systems.

Competitive handball games represent intermittent exercise that combines short bouts of physical effort with brief pauses or low intensity activity. For this reason handball players may not require the same level of physical endurance or aerobic power as athletes engaged in continuous, long lasting effort of near maximal intensity (Astrand and Rodahl, 1986). Nevertheless participants in sport events, such as handball, that entail high performance intensity achieve better results in anaerobic tests than do endurance athletes (Jaskolska et al 1990).

The duration of handball would suggest that aerobic mechanisms may still play a major role in metabolic processes during match-play. For this reason aerobic measures of fitness are discussed in the next section prior to a description of the physiological responses (heart rate, energy expenditure, body temperature) during handball play.

The contribution of the aerobic and anaerobic energy systems to energy expenditure during a handball match can be manifested in the handball players' performance on exercise tests that attempt to measure the aerobic and anaerobic capabilities of the players. The physiological responses reflect the intensity of exercise during play and thereby provide an indication of the demands of the game. Behaviour in the competitive match context is the best way to measure the players' performance. However, it is very difficult to assess the physical activities related to handball match-play within the game itself. The most important physical fitness measure which can be evaluated outside of the game, using either field or laboratory tests, has conventionally been deemed to be the maximal oxygen uptake or $VO_{2\ max}$.

2.1.2.2. Maximal oxygen uptake

Maximal oxygen uptake (VO_{2max}) has been considered to be synonymous with aerobic power. Maximal aerobic power is the maximal energy output that can be produced by aerobic processes within the functional capacity of the circulation system (Astrand and Rodahl 1986). The VO_{2max} is the highest oxygen uptake the individual can attain during physical exercise while breathing air at sea level. The VO_{2max} represents a good approximation of an individual's capacity for the aerobic resynthesis of adenosine tri-phosphate [ATP] (McArdle et al., 1994).

Oxygen uptake increases during the first minute of exercise to reach a steady state after about 5 min when the oxygen uptake corresponds to the demands of the tissues (Saltin and Astrand, 1967). Oxygen consumption increases linearly with exercise intensity until a maximum value is attained. Maximum oxygen uptake is determined during an incremental exercise test to volitional exhaustion. The following criteria showing that this maximum has been reached: i) A plateau in the oxygen uptake/exercise intensity relationship. This has been defined as an increase oxygen uptake of less than 2 $ml.kg^{-1}.min^{-1}$ or 3% with an increase in exercise intensity ii) the final respiratory exchange ratio of 1.1 or above iii) A final heart rate within 10 $beats.min^{-1}$ of the age -related maximum iv) A post-exercise (4-5 min) the blood lactate concentration of 8 $mmol.l^{-1}$ or greater v) Subjective fatigue and volitional exhaustion. There is no one test protocol ideal for all situations. It is recommended that one adapts the initial rate of exercise and the increment in work-rate to an estimated maximal aerobic power of the subject to be tested (Lange-Anderson et al 1971).

In laboratory experiments, three methods of producing a standard work-test have been applied. These are running on the treadmill, exercising on a cycle ergometer and using a step-test. The exercise test should involve large muscle groups and the measurement of VO_{2max} should be initiated when the exercise has lasted a few minutes to promote the oxygen uptake to reach its maximum. The treadmill method mentioned by Fox and Mathews (1981) requires that the subject walks for 10 min at 4.8 km. h^{-1} on a 1.0 % grade; this light exercise (warm-up) is to allow the subject to become familiar with the equipment. Following a 10 min rest period, the subject begins running at 9.7 km.h^{-1} at a 0 % grade for 2.5 min. The expired gas is collected for purposes of analysis from min 1.5 to 2.5 of the run. Following the first bout a 10 min rest period is allowed. For the next run the speed remains constant, but the grade is elevated to 2.5 %. The procedure is repeated until a maximal value is obtained. Authors stated that the techniques is valid for the assessment of $VO_{2max.}$

In Saltin and Astrand's method (Saltin and Astrand, 1967), the subject first exercises for 5 min at a submaximal intensity on a cycle ergometer while heart rate is recorded during the last minute. These data are used to predict the subject's $VO_{2\ max}$. This is done by use of a nomogram; the predicted VO_{2max} is then used to determine the appropriate initial speed and inclination of the treadmill, so that the all-out run will last between 3 and 7 min. If the subject's predicted VO_{2max} was 45 ml.kg^{-1}.min^{-1} the starting speed and the inclination of the treadmill would be 12.5 km.h^{-1} and 5.2 per cent grade, respectively.

Direct measurements of maximal oxygen consumption are time consuming and often difficult or to obtain. Although, indirect assessment of VO_{2max} is not vary accurate, it is usually used to provide an estimation of maximal oxygen consumption. The most popular test to estimate the VO_{2max} is the progressive 20 m shuttle run designed by Leger and Lambert (1982). During the 20 m shuttle run test subjects are required to run back and forth on a 20 m course and must touch the 20 m line at the same time that a sound signal is emitted from a pre-recorded tape. The frequency of the sound signal increases in such a way that running speed is increased by 0.5 $km.h^{-1}$ each minute from a starting speed of 8.5 $km.h^{-1}$. The test is stopped when the subject is no longer able to follow the set pace. The last announced stage number or the equivalent maximal speed is then used to calculate the VO_{2max}.

This test has not been used to estimate the $VO_{2\ max}$ of handball players, but it has been used in different sports team, especially for soccer players. Brewer and Davis (1992) reported that the estimated $VO_{2\ max}$ was 58 to 60 $ml.kg^{-1}.min^{-1}$ for soccer professional and semi-professional English players. However, Dunbar and Power (1995) examined senior and junior soccer player from a variety of playing standards using a battery of field test. They found that the estimated VO_{2max} values for this population were comparable to laboratory measurements seen previously in players of similar standard. There are no available data for handballers based on this test.

In the United Kingdom the protocol for exercise testing to measure VO_{2max} directly was first outlined on behalf of the British Association of Sport and Exercise Sciences by Hale et al. (1988). The original document has been revised with experience of testing national squads and a 3rd edition is published.

The protocol entails 16 min of continuous running on a level treadmill during which running speed is increased every 4 min. Respiratory variable are recorded and lactate concentration is measured in blood samples obtained at the end of each 4 min stage for the subsequent determination of running speed equivalent to a reference concentration of 4 $mmol.l^{-1}$.

2.1.2.3. Maximal oxygen uptake of handball players

Delamarche et al. (1987) found that the maximal oxygen uptake was approximately 5.0 $l.min^{-1}$ for handball players in the national second division of France. As the average body mass of the players was 77.3 kg, this figure corresponded to 58.3±5.3 $ml.kg.min^{-1}$. This value was lower than that observed in international standard handball players by Danish workers in 1976 (Delamarche et al., 1987) and less than those reported by Svedenhag and Sjodin (1984) in long distance runners due to the handball players' greater body weight. Nevertheless, whether VO_2 was considered as an absolute value or expressed per kilogram body weight, it had little to do with the players' performance. They found that the players with the greatest VO_2 were not necessarily the most active players during the game.

Polimac (1994) tried to estimate VO_2 for three groups of sport teams (soccer, handball and basketball) by monitoring heart rate during the match. The author reported that the VO_2 values for the three groups were 48.2 ± 8.2, 42.3 ± 8.8 and 35.3± 0.6 $ml.kg^{-1}.min^{-1}$ for soccer, basketball and handball respectively. However, in view of the modest values for the first two sports when compared with values in the literature (Reilly et al., 1990), the values for the handballers may also be underestimated.

Chatterjee et al. (1991) reported that no significant difference was observed between handball and basketball players for VO_{2max}. This is possibly due to certain similarities in physiological demands of the two sports, particularly a demand for vigorous energy expenditure in repeated short bursts throughout the game. They also reported that there was correspondence between the level of VO_{2max} and the size of the pitch used in team sports. However, young female handball players (age 16.1 ± 1.0 years) obtained the lowest value for VO_{2max} (36.2 $ml.kg^{-1}.\ min^{-1}$) compared with long-distance runners, sprinters, jumpers and javelin throwers, but were higher than the basketball (34.9 $ml.kg^{-1}.min^{-1}$) and badminton (34.4 $ml.kg^{-1}.min^{-1}$) players.

Jousselline et al. (1984) reported that for athletes involving in team sports, the level of VO_{2max} ($ml.kg^{-1}.min^{-1}$) corresponding with the distance covered by the players during the game. They found that male volleyball players had the lowest $VO_{2\ max}$ (52.3 ± 4.3 $ml.kg^{-1}.min^{-1}$) while soccer players had the highest value of VO_{2max} (63.9 ± 5.5 $ml.kg^{-1}.min^{-1}$). However, handball players had intermediate results (57.2 ± 5 $ml.kg^{-1}.min^{-1}$). Similar observations of a link between VO_{2max} and distance covered have been made for soccer, with a high correlation being reported between VO_{2max} and work-rate in the game (Reilly, 1997)

2.1.3. Energy expenditure during match-play in team sports

2.1.3.1. Aerobic energy expenditure

Handball is an Olympic sport. It is an indoor and outdoor sport played by two teams of 12 players. The game consists of two halves, each of 30 min duration and separated by break of 10 min. The physiological fitness levels should enable players to cope with the work-rate demands of the game. These demands increase as the standard of competition improves. Little scientific information is available on the fitness characteristics of elite handball players or on the demand of the game.

Handball involves intermittent exercise of varying intensities from walking to jogging, running and sprinting. Therefore, the review of literature for this section will focus on the available studies of team sports which are intermittent in nature such as handball, soccer, basketball, Gaelic football, Australian rules football, field hockey.

The physiological responses to match-play during team sports indicate the variety of stresses that are placed on the players during a game. In handball, soccer and basketball, for example, the players perform different activities; the intensity may alternate at any time from standing to running or to sprinting. For example, Thomas and Reilly (1976) found that English First Division soccer players had about 1000 changes in playing activities during a match with each activity lasting for a mean duration of 5-6 s. There have been different attempts to determine the aerobic contribution to energy expenditure during team sports by measuring oxygen uptake (VO_2) during match-play especially in soccer (Bangsbo 1994a). Since the gas collection procedure interferes with normal play and only minor parts of a match are analysed, the values which are obtained may be not representative of VO_2 during match-play.

The second way to estimate the energy expenditure during team games is by measuring heart rate continuously during a match and estimating energy expenditure from the HR-VO_2 relationship determined in the laboratory. Heart rate (HR) has been used in investigations of soccer play (Reilly, 1990), and for handball play (Polimac, 1994; Jousselline et al., 1984; Roattino and Poty, 1983), and the mean heart rate used as an index of physiological strain. When laboratory-based regression equations are available for HR-VO_2, estimates of energy expenditure may be based on heart rate during matches or in friendly games. The VO_2 value is used to estimate energy expenditure by using the respiratory exchange ratio (RER) observed at the appropriate HR in the laboratory-based test, or assuming an RER value from the literature. No studies have been located where energy expenditure (or VO_2) has been estimated during a handball game. Energy expenditure estimation has been done for soccer (Reilly, 1996a), Gaelic football (Florida-James and Reilly, 1995), volleyball (MacLaren, 1990) and other games such as Rugby League and Rugby Union football (Reilly et al., 1990). Whilst this approach may be criticised on the grounds that temperature, mode of exercise and emotions can influence heart rate but not VO_2, the error involved in the procedure has been reported to be apparently small (Bangsbo, 1994). Heart rate measurements can be used without any restriction on the players, and give a good picture of the contribution of the aerobic system in team games. Mean values of HR during a soccer match, for example, have been recorded between 157 and 175 beats.min^{-1} (Reilly, 1986; Van Gool et al., 1988; Bangsbo, 1994a). Based on individual relationships between heart rate and VO_2 assessed during exercise in the laboratory, the HR determination for each player during match-play can be converted to oxygen uptake (Reilly and Thomas, 1979; Ekblom, 1986). Bangsbo (1994a) emphasised that HR determinations provide an indirect measure of the aerobic energy expenditure. Thus problems related to conversion of HR to VO_2 have to be considered because of the large inter-individual differences in the aerobic energy production during matches caused by the various factors influencing the exercise intensity.

Soares (1988) concentrated on the study of handball goalkeepers. He measured the heart rate of five Portuguese handball goalkeepers during official competition and training sessions, and in attack and defence situations. He reported that the handball goalkeeper's HR during attack phases was significantly lower than in defence situations during training, being 135 ± 13 beats.min^{-1} with a range of 102 to 170 beats.min^{-1}, 146 ± 12 beats.min^{-1} with a range 122 to 178 beats.min^{-1}, respectively. As far as the official competition was concerned, the average HR was 143 ± 11 beats.min^{-1} with a range from 122 to 178 beats.min^{-1} during attack while during defence situations the HR mean value was 155 ± 14 beats.min^{-1} with a range from 129 to 182 beats.min^{-1}. It was concluded that HR did not appear to be significantly changed during official competition but there was a significant difference between attack and defence situations. Delamarche et al. (1987) showed that during a handball match, variations in heart rate remained constant within about a 20 beats.min^{-1} range for each of the players. Individual values varied from 160 to 180 beats.min^{-1}.

Ekblom (1986) estimated that the average oxygen uptake during a soccer game could be up to 80% of the player's maximum. The maximum aerobic power of soccer players in a national team was approximately 65-67 ml.kg^{-1}.min^{-1} with some individual values exceeding 70 $ml.kg^{-1}.min^{-1}$. For other games with high intensity non-continuous intermittent exercise, such as handball, basketball, volleyball and hockey, a high maximal aerobic power can lower the demand on anaerobic energy yield.

Roattino and Poty (1983) examined six handball players from the 30 best France junior national teams. The VO_{2max} and blood lactate were measured during running on a treadmill and heart rate was recorded by telemetry during a handball match and during traditional and interval training sessions. They found that during a handball match, the HR was above 80% of maximal HR and sometimes reached the maximal HR, while the HR was often below the 80% of maximal HR during traditional training.

Polimac (1994) compared three different team sports-soccer, basketball and handball during match-play. He observed higher HR values during soccer matches (159 $beats.min^{-1}$), followed by basketball (152 $beats.min^{-1}$) and handball (146 $beats.min^{-1}$). The intensity would still place handball in an intensity zone which indicates a training stimulus is provided for the circulation system.

In conclusion, in handball match-play the players perform many different activities, the intensities of which may change at any time from aerobic to anaerobic exercise. There have been different attempts to determine the aerobic contribution to energy expenditure during team sports by measuring oxygen uptake or by measuring heart rate continuously and estimating energy expenditure from the HR-VO_2 relation. Heart rate gives a very good picture of the contribution of the aerobic system in handball.

However, Delamarche et al. (1987) and other have confirmed that handball requires an excellent aerobic capacity. In team sports there is usually a correspondence between the level of VO_{2max} and the distance covered by the players and also between the VO_{2max} and the size of the ground used in team sports.

2.1.3.2. Anaerobic energy expenditure

Activities in handball include walking, jogging, running, sprinting and jumping; some of these activities add to the anaerobic energy cost. The energy for such activities during game play is provided by adenosine triphosphate (ATP) and creatine phosphate (CP) stored in the muscle because these activities are very short in duration. As a result of the intermittent nature of the game, the CP concentration may change continuously. Although the net utilisation of CP is quantitatively little during a sport like soccer, CP has a very important function for the resynthesis of ATP through the creatine kinase reaction during rapid elevation in the exercise intensity (Bangsbo, 1994a). The next most immediate source of energy for anaerobic metabolism is glycogen stored within the muscle. When this metabolism is engaged, lactate is produced and soon diffuses into the blood. The intensity of exercise in team sports involving intermittent exercise can be gauged from measurements of blood lactate concentration which provides an indication of lactate production and removal rate that the anaerobic lactate system is making a contribution to metabolism (Ekblom, 1986). Polimac (1994) reported that anaerobic metabolism as indicated by the blood lactate level is much higher in basketball and soccer, compared to in handball players (4.59 ± 0.9, 4.36 ± 0.4 and 3.1 ± 1.5 $mmol.l^{-1}$, respectively). However, the exact contribution of the lactate system to anaerobic metabolism may be underestimated as lactate produced in the muscle may be cleared without an appreciable rise in blood lactate.

Delamarche et al. (1987) found that the maximal lactate level ranged from 4 - 9 $mmol.l^{-1}$ for handball players during match-play and the peak occurred between the 10th and 25th minute of the play and at the end of the first half. The authors noted that the most active players reached blood lactate levels similar to those observed after maximal exertion on the cycle ergometer. Moreover, these players ran at least 20 to 30 min with a blood lactate level higher than 4 $mmol.l^{-1}$. These values had returned to baseline following a 10 min rest period at the end of the first-half. They reported that lactate levels observed in the laboratory did not necessarily have the same significance as compared to lactate levels produced in the field.

Ohkuwa et al. (1988) examined the responses of 23 subjects including untrained male students, female handball players, female sprinters and female long-distance runners on different variables including lactate, glycerol, adrenaline and noradrenaline in venous blood measured following 400 m and 3000 m runs. They found that peak blood lactate for the 400 m sprints did not differ significantly between untrained males subjects (13.40 ± 3.24 $mmol.l^{-1}$) and female handball players (12.27 ± 2.37 $mmol.l^{-1}$). Peak blood lactate values for the 3000 m run in female sprinters, long-distance runners, handball players and untrained males were 8.42 ± 2.17 $mmol.l^{-1}$, 8.76 ± 1.25 $mmol.l^{-1}$, 10.76 ± 2.64 $mmol.l^{-1}$ and 11.76 ± 3.66 $mmol.l^{-1}$, respectively. Peak blood lactate following the 3000 m run was not significantly different between any the groups. Authors concluded that the relationship between running velocity and peek blood glycerol concentration after 3000 m run was about the same in untrained males and female handball players.

Exercise intensity falls off as a result of fatigue towards the end of the game there is an increased reliance and this is associated with an increase the relative in fat rather than carbohydrate (CHO) as a source of energy for active muscles. Blood lactate levels fluctuate during games which entails intermittent activity (Bangsbo et al., 1991a). They may also vary with the tactics used, for example man-to-man making. Additionally, as players fatigue the lowered activity is associated with decreased blood lactate levels.

Mougios et al. (1993) found that in their study of national junior handball players blood lactate rose from a resting value of 1.8 ± 0.1 $mmol.l^{-1}$ to 3.8 ± 0.4 $mmol.l^{-1}$ at half-time and then decreased to 2.5 ± 0.3 $mmol.l^{-1}$ at the end of the handball match. This confirmed that muscle metabolism had been predominantly aerobic during the match.

In summary, this review so far has been concerned with kinanthropometric and fitness profile of handball players and the physiological responses to match-play. Kinanthropometric profiles of various elite sports participants have been derived by accumulating data from different sources. Characteristics are apparently specific in a number of sports (Eston and Reilly, 1996). Sports such as handball entail a mixture of physical requirements and the kinanthropometric description of competitors has not been completed. This research is aimed at providing this description.

The requirements of handball play have not been investigated on a systematic basis. The limited number of studies on the game implicate both aerobic and anaerobic mechanisms. This has consequences for determining fitness measures of handballers and investigating the physiological stresses in both competition and training.

Sports that entail high levels of energy expenditure lead to elevations in body temperature. Thermoregulatory responses have not been studied in handballers. Decreases in thermal stress can be achieved by rehydration and by inducing adaptation to exercise in the heat. There is also a need to consider energy provision requirements of handball players. These areas have been studied in sports in general but not in handball in particular, the sport on which this thesis is focused.

In subsequent sections of this review, the physiological responses to intermittent and continuous exercise are addressed in more detail. In addition, the thermoregulatory, nutritional and hydration consequences for intermittent exercise are reviewed.

2.2. PHYSIOLOGICAL RESPONSES TO INTERMITTENT AND CONTINUOUS EXERCISE

The interest in intermittent exercise has been heightened in recent years because this kind of physical activity bears resemblance to multiple-sprint sports such as handball, soccer and basketball. These sports are characterised by a mixture of low and high intensity exercise bouts. Different exercise test protocols have been designed to evaluate the physiological responses to this type of exercise pattern. For example, Wootton and Williams (1983) assessed the physiological responses to repeated bouts of 6 s exercise on a cycle ergometer, while Holmyard et al. (1988) and Brooks et al. (1990) evaluated the physiological responses using a non-motorised treadmill. The physiological responses to an intermittent exercise protocol that simulates a game such as handball have not been evaluated and therefore the literature review is focused on generic models of intermittent exercise with varying periods of alternating activity and recovery.

Balsom et al. (1992) examined the physiological responses to maximal intermittent exercise using physical education students. The exercise consisted of repeated sprints of varying distances with the total distance covered during each session being 600 m. The blood lactate results showed the post-exercise concentrations to be significantly higher than the pre-test concentrations. The authors aimed to highlight any differences that there may have been as a result of the various sprint distances used, 30 s rest periods separating each sprint. It was evident from the sprint times that the rest period was insufficient for recovery due to the fact that the sprint times increased after only three 40 m sprints. The physiological demands of the 30 m and 40 m sprints were also indicated by the high plasma concentrations of hypoxanthine and uric acid post-exercise. The 15 m sprints did not produce the same increases in plasma concentrations of hypoxanthine post-exercise. This was attributed to the fact that the CP system was buffering the energy demands during the sprints and the recovery periods enabled the system to resynthesise CP. It was concluded from this study that in “multiple sprint sports” where 15 m sprints are repeatedly required, the athlete would not show a significant decrease in performance providing adequate recovery periods of approximately 30 s are taken. This was not so for 30 or 40 m sprints where the muscle was unable to recover adequately during the 30 s rest periods and prepare for the greater energy demands of the exercise.

Essen (1978) examined the physiological responses to intermittent exercise using 15 s exercise and 15 s rest for 60 min and continuous exercise for 60 min; the exercise was performed on a cycle ergometer with the overall work done being equal between conditions. The average heart rate and oxygen uptake during the intermittent exercise gave similar results to the continuous exercise at the moderate workload corresponding to 50-60% $VO_{2\ max.}$ Also the author noted a similar metabolic response between intense intermittent exercise (100% VO_{2max} with 25 s exercise and rest periods) and the continuous exercise performed for 60 min periods on a cycle ergometer. The blood lactate concentrations rose initially for the moderate continuous exercise but the lactate levels then fell throughout the rest of the exercise period. During the intermittent exercise blood lactate also rose initially but remained at the same level for the remainder of the exercise. During continuous exercise the greater energy demands are met by the breakdown of glycogen (Astrand and Saltin, 1961). When performing intense exercise there was a greater overall utilisation of glycogen during the continuous exercise than for the intermittent exercise. It may be that the metabolic responses to intermittent and continuous exercise are regulated by factors which determine the utilisation of lipids and carbohydrates and the intermittent exercise may also have called more on phosphagen stores.

Fardy and Hellerstein (1978) compared continuous and intermittent multistage exercise testing using the treadmill. The tests consisted of ten 3-min stages of increasing speed and gradient. The intermittent test required the subjects to rest for 3 min between stages. Both tests were preceded by 5 min of standing at rest. The results showed no significant differences in oxygen consumption between the two tests. However, the intermittent protocol was perceived by the subjects as being less intensive and also produced lower average heart rates, minute ventilation and respiratory exchange ratio. The measurements were made during the third minute of each exercise stage and the heart rate results indicated that the subjects had reached steady state during the first four stages. After this, the subjects were taking longer to reach steady state. The authors suggested that future tests should reduce the exercise time at the lower work loads.

The test protocol used by Astrand et al. (1960) to compare intermittent and continuous exercise was designed with the subject cycling for up to one hour and so may have some relevance for handball. The continuous protocol required the subjects to cycle at 60 $rev.min^{-1}$ with a load of 3 kg (equating to 176.6 W). The intermittent exercise was again at 60 $rev.min^{-1}$ but with a 6 kg load (353.2 W). The intermittent protocol exercise-rest periods started at 30 s each and in subsequent tests increased to 1 min, 2 and 3 min. The subjects perceived the intermittent 30 s exercise-rest protocol to be relatively easy and felt no fatigue after the hour. The 2- and 3- min protocols required much more effort and motivation to complete the hour. Rectal temperature increased for all of the tests but the greatest increase was for the intermittent 3-min protocol where there was an increase of 2 °C from the start to the completion of the test, the final temperature being 38.9°C (compared to 38.0°C in the other tests). Lactate concentrations increased as the exercise-rest periods increased (2.0, 4.5, 9.5 and 12.0 $mmol.l^{-1}$) and were all greater than in the continuous protocol (1.2 $mmol.l^{-1}$).

These concentrations had all reached a constant level after 15-20 min. The authors attributed the low lactate concentrations during the short exercise periods to one of two causes. One was that lactate is formed at the same rate irrespective of the duration of exercise, but during the short rest periods the lactate was removed at the same rate at which it was produced. Their second explanation was that the production of lactate during the shorter exercise periods was minimised due to the O_2 uptake buffering action of myoglobin in the muscle where it is re-charged during rest in readiness for its reduction during the next exercise period (Astrand et al., 1960).

A similar protocol to that used by Astrand et al. (1960) was employed by Edwards and co-workers (1973). The intermittent protocol comprised either 10 or 30 s bouts of exercise, both having 30 s rest periods. One of the main findings from this study was that, for the same amount of work, the intermittent exercise resulted in a greater O_2 consumption. Heart rate, ventilation, VO_2, respiratory exchange ratio and blood lactate responses were all greater in the intermittent exercise. These findings contradict those previously discussed where the continuous exercise produced the higher physiological responses.

The conclusion from this study was that intermittent exercise would be more advantageous if the aim is to target the individual's adaptive mechanisms. If the requirements of the exercise are to reduce the physiological costs then continuous exercise is recommended at a low power output. These recommendations were upheld by Tabata et al. (1996) who found greater physiological costs with intermittent compared to continuous exercise.

Intermittent and continuous treadmill runs were used by Zauner and Benson (1981) where the intermittent test consisted of 3-min exercise periods with 2 min rest. After each bout of exercise the treadmill gradient was increased by 2.5% with the test continuing until exhaustion or when the subject's heart rate reached 200 beats.min^{-1}, whichever occurred first. The subjects' VO_2 was greater for the intermittent exercise and the subjects felt that the continuous exercise was hard with their heart rate averaging 183 beats.min^{-1}. The intermittent exercise, however, resulted in heart rates of at least 200 beats.min^{-1} at which point the test was discontinued. There was a significant difference ($P < 0.01$) between the heart rates after 1 min recovery, with the continuous exercise heart rate being 115 beats.min^{-1} and the intermittent exercise 136 beats.min^{-1}. This supports the observation that there was a greater physiological load as indicated by the VO_2 during the intermittent exercise. The authors concluded that in order to obtain maximum effort, an intermittent exercise protocol would be advisable.

Lockhart and Ruffin (1994) examined cardiovascular responses to continuous and intermittent exercise using a cycle ergometer. The continuous and intermittent exercise tests were undertaken at the same workload, with the intermittent exercise periods varying between 30 s and 2.5 min. The rest periods were 30 s to 3 min long depending on the recovery of the heart rate to within 10 beats.min^{-1} of the resting rate. The continuous exercise time and work output were calculated so that the protocol resulted in a work output which was the same as for the intermittent exercise. The results showed no significant differences for the O_2 consumption between the intermittent and the continuous exercise. The authors concluded from this study that intermittent exercise can produce cardiovascular responses corresponding to moderate continuous exercise.

McCartney et al. (1986) investigated muscle glycogen and lactate levels during intermittent exercise on a cycle ergometer. The exercise protocol consisted of 4 bouts of 30 s exercise and 4 min rest. The greatest increase in lactate was observed during the first period of exercise where also the greatest power output and greatest decrease in muscle glycogen were found. The subsequent exercise periods did not produce any further changes in these variables due to the fact that the glycogen levels did not fall any further nor did the lactate concentration increase. It was surmised that the process of glycogenolysis was limited. These results were supported by Karlsson and Saltin (1971) who found an increase in blood lactate concentrations mainly during the first period of exercise. They explained this by the fact that the lactate was distributed and oxidised in various tissues of the body such as inactive muscles and the liver.

Essen (1978) reported that lactate concentration and muscle glycogen levels during continuous exercise were greater than during intermittent exercise but the rate of fat oxidation was lower during intermittent exercise. This implies that there is an increased reliance on muscle glycogen as an energy source when the exercise is intermittent. Nevill et al. (1994) found that heart rate, oxygen uptake, blood lactate, and oral and rectal temperatures were significantly increased during intermittent exercise when compared to continuous exercise with a further significant difference observed in hot conditions compared to normal. The same finding was observed by Garrett and Boyd (1995) that intermittent exercise induced higher rectal temperature, oxygen uptake, blood lactate, heart rate and rating of perceived exertion compared to 45 min continuous cycle exercise at the same average intensity.

Bangsbo (1994) observed that there was a difference between continuous and intermittent exercise in terms of high energy phosphate use, but there were small changes in ATP-PC concentrations during continuous exercise with large fluctuations during the intermittent exercise. It is known that the ATP-PC system is utilised at the initial stages of exercise and the glycolytic system is utilised during maximal continuous exercise. The component of the anaerobic system used mainly is the ATP-PC system (Margaria et al., 1969; Essen et al., 1977; Reilly, 1991). It has also been shown that the muscles react faster after low intensity exercise is performed and it may thus be advantageous for the player to remain active instead of standing still after the high intensity exercise periods during a soccer match (Bangsbo, 1994). Handball players too have to perform short duration maximal and moderate exercise with intermissions between the exercise bouts; therefore the handball game makes demands on both the aerobic and anaerobic energy delivery systems and offers the potential for active recovery within the game.

Falk (1995) discussed the physiological effects of intermittent and continuous exercise. He cited the recommendations of the American College of Sports Medicine (1991) for cardiovascular fitness as requiring “at least 20 min of continuous exercise three times per week with a heart rate of 60-80% maximum. It was also noted that an individual’s energy expenditure is related to his/ her total work output and not the actual intensity of the exercise as the energy expenditure was the same for walking 1 km and jogging 1 km. In a similar manner, walking and running 1 km intermittently requires the same energy expenditure as walking or running 1 km continuously. Thus, for individuals wanting to increase energy expenditure and promote body mass reduction, training programmes involving continuous exercise or intermittent exercise are equally appropriate.

Drust (1997) found no significant difference between the oxygen uptake for intermittent and steady state exercise (90 min) with the same overall work output, but oxygen uptake was significantly greater in the second period of both protocols. Energy expenditure was similar between intermittent and continuous exercise, and heart rate was not significantly different between intermittent (168 ± 10 beats.min^{-1}) and steady state (162 ± 1 beats.min^{-1}). He reported that heart rate was significantly higher in the second 45-min period for both intermittent and continuous exercise. This increase in heart rate was a function of the duration of exercise. The intermittent exercise showed a significantly greater mean minute ventilation (VE) than continuous exercise, and VE was also higher during the second period of both protocols. Rectal temperature was significantly higher in the second period for intermittent and steady state exercise (39.7 ± 0.7 °C, 38.7 ± 0.4 °C, respectively). He reported that a soccer-specific intermittent exercise protocol elicited a significantly greater rise in core temperature than did compensable steady state exercise. Sweat production showed no significant difference between the two protocols. Rating of perceived exertion was significantly higher during intermittent exercise than continuous exercise.

2.3. THERMOREGULATION

The following sections of the review of the literature provide the brief mechanism of thermoregulation, heat loss during exercise and thermoregulation in heat stress. The majority of the literature available regarding the thermoregulatory responses to exercise under hot conditions refers to sub-maximal continuous exercise. An appreciation of the body's responses to such protocols will be presented before the effects of intermittent exercise can be discussed.

2.3.1. Thermoregulatory responses to exercise

Body temperature, or more specifically the temperature of the deeper tissues (core), is in dynamic equilibrium between factors that produce and eliminate body heat. This balance is maintained by the integration of mechanisms that alter heat transfer to the periphery (shell) and regulate heat production. The processes of conduction, convection and radiation allow for either heat loss or heat gain (depending on environmental conditions) with evaporation being a major avenue of heat loss when body temperature is rising (Reilly and Cable, 1996). Heat is produced during the metabolic process and the level of heat production can be increased dramatically by physical exercise. One consequence is a requirement for an increase in skin blood flow (SkBF) to promote heat dissipation to the environment during exercise in order to maintain body core temperature. Skin blood flow is initially reduced through vasoconstriction to provide additional blood flow for the exercising muscle (Kellogg et al., 1991b). However, as exercise continues, with its attendant metabolic heat production, internal temperature rises. If exercise is performed long enough, internal temperature reaches a threshold at which thermoregulatory reflexes for heat dissipation are evoked (Johnson and Park, 1982). Above this threshold, thermoregulatory demands begin to exert control over SkBF and lead to net cutaneous vasodilation to facilitate heat loss (Rowell, 1983). Accompanying the increase in SkBF with body heating is an increase in the peripheral venous volume because cutaneous vasodilation enhances the rate at which the capacitance vessels fill (Rowell, 1977). During heavy exercise, maintenance of adequate flow to the muscles at the expense of the skin limits the ability to transfer heat to the site of dissipation, resulting in progressive hyperthermia and ultimately to cessation of exercise (Nadel et al., 1979). Conversely, the increase in cardiac output is limited by the translocation of blood volume into dependent veins (Rowell, 1983) as a result of the increased SkBF. If such increases are uncompensated, a progressive reduction in central blood volume would lead to progressive reductions in cardiac filling pressure, resulting in tachycardia and ultimately, circulatory collapse (Nadel et al., 1979).

During exercise in the heat, the increase in environmental temperature causes a reduction in heat loss and hyperthermia develops. The major mechanism for the dissipation of heat is the evaporation of sweat. The increase sweat production onto the surface of the skin results in the loss of body water and electrolytes in sweat. Sweat losses have the potential to impair cardiovascular function and cause dehydration, which will further compromise the ability to dissipate heat and accelerate the rise in core temperature (Kellogg et al., 1991a).

A sustained relative reduction in SkBF is, however, observed in a hot environment under exercise condition compared to rest (Johnson, 1987), thus affecting the body's ability to lose heat. Johnson et al. (1974) reported that such reductions in SkBF during exercise in the heat (compared to rest) are a product of cutaneous vessels being under the competing drives of the vasodilatory response to increased internal temperature and the vasoconstrictor responses to exercise per se. The SkBF response during exercise is also attenuated by changes in the active vasodilation mechanism. Kellogg et al. (1991b) have shown that although rising core temperature is accompanied by significant cutaneous vasodilation, the elevation in SkBF is delayed until a higher core temperature is reached during exercise than during rest. The increase in internal temperature for cutaneous vasodilation is believed to be a direct consequence of an exercise-induced delay in the vasodilation system as opposed to removal of vasoconstrictor tone (Kellogg et al., 1991b). The vasodilation continues in parallel to the rise in core temperature (Nadel et al., 1979) and necessitates an increase in cardiac output (Q) (an additional 2-3 $l.min^{-1}$ during sub-maximal exercise under hot conditions) (Rowell, 1983; Rowell et al., 1986). The increase in total percentage of cardiac output directed to the skin is met also by a redistribution of blood from other regions of the body. Both the renal and splanchnic circulation possess high blood flows that can be restricted without compromising the tissue's oxygen supply. The splanchnic and renal circulation are therefore placed under a greater than normal vasoconstictory stimulus during exercise in the heat (Rowell, 1993).

Rowell et al. (1966) investigated the effect of exercise in the heat on such volume reservoirs response to a heat stimulus of 43 °C. Subjects walked on a treadmill at 5.6 $km.h^{-1}$ for 15 min at 4 different inclinations (7.5, 10, 12.5 and 15 %). Central blood volume and stroke volume (SV) decreased while mean arterial pressure, total peripheral resistance and cardiac output were maintained. Cardiac output was maintained as a result of tachycardia. This phenomenon is known as cardiovascular drift and is a consequence of a progressive increase in the percentage of cardiac output directed to the skin as core temperature increases (Rowell, 1993).

The loss of central blood volume results in a further alteration of the thermoregulatory response during exercise compared with rest. A plateau in SkBF is observed when the internal temperature reaches 38 °C (Kenney and Johnson, 1992) mediated by the baroreflex response (Nadel, 1983). This limit on SkBF is mediated by a reduction in active vasodilation tone which triggers visceral and cutaneous vasoconstriction as a result of increased sensitivity to a decrease in central venous pressure (Rowell, 1983). This relative vasoconstriction contributes to the maintenance of an adequate stroke volume thus preventing a fall in cardiac output during exercise. The limit of SkBF will ultimately result in a increase core temperature if exercise is continued. This suggests that blood pressure regulation and metabolic demands have precedence over thermoregulatory concerns (Rowell, 1983).

Nadel et al. (1979) demonstrated the precedence of circulatory regulation over temperature regulation using an intermittent experimental protocol. Cardiac output was maintained at similar levels during a 20 min exercise period performed at 70 %

VO_{2max} at room temperatures of 20, 26 and 36 °C. Cardiac output was maintained as a results of increased of heart rate and relative cutaneous vasoconstriction. This ensures an adequate central circulating blood volume, thus preventing a fall in stroke volume. The attenuation of SkBF leads to a vast reduction in the rate of heat loss from the body thereby necessitating an increase in the evaporative heat loss to the environment.

Evaporative heat loss only becomes important following the reduction in vasodilation, though sweating is initiated soon after the onset of exercise. With prolonged exercise a progressive decrease in sweat rate is observed despite elevated core and skin temperatures. The decline in sweat rate is brought about by a need to conserve body water as fluid balance is critical for optimal cardiovascular and thermoregulatory function. A large proportion of the water lost in sweat comes from the blood with decreases being observed in plasma volume during exercise (Brandenberger et al., 1989). Decreases in plasma volume will adversely affect the circulatory capacity, leading to decreases in blood pressure. Decreases in blood pressure will subsequently reduce the blood flow to skin and muscle as the body attempts to maintain central blood volume and stroke volume. Such cardiovascular adjustments will have further consequences for the heat dissipation mechanisms and core temperature.

Continuous submaximal exercise in hot conditions results in increases in SkBF as a result of the need for heat dissipation. This causes competition between the active muscles and the skin for blood flow. Cardiac output is therefore increased, by increases in heart rate and reductions in blood flow in the splanchnic and renal areas.

The cutaneous vasodilation leads to shifts in blood volume to the skin and lower central blood volume. Decreased cardiac output as a result of this redistribution reduce stroke volume. The loss of central blood volume leads to a sub-maximal plateau in SkBF, thus reducing heat loss and increasing the need for evaporative losses to be made. The circulatory adjustments to sub-maximal exercise are likely to be further exaggerated under intermittent exercise as the physiological demands will be increased above those associated with low intensity sub-maximal exercise. This may have consequences for the performance of handball players during match-play in relation to the energy requirement and substrate utilisation to support the activity.

2.3.2. Intermittent exercise in hot conditions

The heat strain of continuous exercise in a hot environment has been well documented, but little information exists on the effects of thermal stress on the intermittent exercise such as soccer and handball. It has been widely acknowledged for some time that the stress associated with training and competition is often exacerbated by the environmental conditions and that heat stress during prolonged activity can accelerate the onset of fatigue (Edwards et al., 1972; MacDougall et al., 1974). During extreme climatic conditions there is competition for cardiac output, with the need for an increased skin circulation and heat dissipation in addition to the metabolic requirements of the exercising muscle. Heat loss is dependent upon the temperature gradient between the skin and the external environment, with the heat dissipation mechanisms and the external thermal conditions determining the extent to which heat transfer takes place from the body's core to the environment. However, the thermal response to exercise is influenced by the intensity and type of exercise

(Smolander et al., 1991). Core temperature is regulated at a higher level during exercise than at rest with the adjustment being dependent on work-rate and independent of environmental temperature and duration of the exercise (Nielsen 1938).

Smolander et al. (1991) demonstrated that the linear relation between core temperature and work-load only holds true up to an exercise intensity of 75% $VO_{2max.}$ When exercise is performed above this level, the relationship between core temperature and VO_2 becomes curvilinear with large increases in core temperature being observed when exercise intensity approaches maximum. Such increases are believed to be the result of an altered vasoconstrictor response at such high work-rates (Fortney and Vroman, 1985), though changes in cutaneous vasodilation have also been noted with high intensity exercise (Kenney and Johnson, 1992)

High intensity exercise seems to alter the thermoregulatory response to exercise by enhancing cutaneous vasoconstriction in a graded manner in relation to intensity, thus raising the core temperature response to exercise intensity. The rate of vasodilation is also affected in a graded manner resulting in a decreased or attenuated SkBF-core temperature relationship and an increased internal temperature threshold for vasodilation (Kenney and Johnson, 1992).

Ekblom et al. (1971) examined three subjects exercising for 1 h at a work-rate of 60% VO_{2max} on a cycle ergometer. The continuous exercise was compared to intermittent exercise consisting of repeated 30 s exercise by 30 s recovery period. Rectal temperature was higher during intermittent exercise than was observed during the continuous exercise. Skin temperature was also greater in intermittent exercise. The authors suggested that the decrease in blood flow is a consequence of the increased vasoconstriction needed to return blood centrally to maintain cardiac output due to blood pooling in the leg during the recovery.

Also Cable and Bullock (1996) investigated responses to exercise when the total work done was identical between continuous (30 min at 60 % VO_{2max}) and intermittent exercise (20 x 1 min work bouts separated by 2 min rest periods at 90 % VO_{2max}) on a cycle ergometer. Rectal temperature observed in the intermittent exercise was significantly higher along with significantly lower mean skin temperature compared to the continuous exercise. Sweat production rate was significantly attenuated during intermittent exercise. The variables mentioned before were also recorded during a 30 min supine recovery period. No significant difference was observed in mean skin temperature between the two conditions during recovery though rectal temperature was altered in terms of the magnitude and pattern of response during recovery. The adaptations in both exercise periods and recovery were thought to be a consequence of increase in cutaneous vasoconstriction in an attempt to maintain blood volume and blood pressure during periods of thermoregulatory and metabolic competition.

The difference found in core temperature during intermittent and continuous exercise at the same average intensity may not be solely the result of changes in skin temperature and sweat production rate. The 33% greater rise in rectal temperature observed by Kraning and Gonzalez, (1991) after 30 min intermittent exercise, (walking, jogging and seated rest) implies an increase in the rate of deep body heat storage. Such changes can be brought about by differences in heat production or heat dissipation.

Nielsen (1986) compared intermittent exercise with continuous exercise at the same overall work intensity. The intermittent exercise protocol used consisted was 30 min bouts of cycling exercise separated by 30 s periods of rest. Metabolic rate was equal for both exercises protocol. It was concluded that the increases in rectal temperature were in proportion to the actual oxidative activity and independent of the relative strain on the muscle group involved

The intensity and duration of both the work and recovery periods of exercise affect the metabolic and physiological response to intermittent exercise (Christensen et al., 1960) and these factors could also have implication for thermoregulatory response. Recovery during intermittent exercise is not restricted to static periods and can involve exercise at a reduced intensity. Such patterns are observed in the so-called multiple sprint sports e.g. soccer, hockey and handball. Some investigators have examined the effect of such procedures on thermoregulatory and physiological variables (Nevill et al., 1994; Garret and Boyd, 1995)

Nevill et al. (1994) investigated intermittent and continuous exercise at the same average intensity on a cycle ergometer at environmental temperature of 10 and 35 °C.

The intermittent protocol consisted of 90 s exercise at 40% VO_{2max}, a 6 s sprint and a 24 s passive rest. Continuous exercise consisted of cycling at 60 r.p.m at the same average exercise intensity as that achieved during the intermittent test. Intermittent exercise induced significantly greater increases in rectal temperature, heart rate, blood lactate, and ammonia production, and oxygen consumption when compared to the continuous exercise, but with further significant differences being observed in hot compared to cold conditions, thereby indicating a greater thermal and physiological strain during intermittent exercise. The same finding was observed by Garrett and Boyd (1995) that higher rectal temperature, oxygen consumption, blood lactate, heart rate and perceived exertion were found during a 45 min cycle performed intermittently compared to a continuous protocol at the same average intensity.

Drinkwater et al. (1976) examined seven unacclimatised females in three different conditions 28 °C, (45% rh), 35 °C, (65% rh) and 48 °C, (10% rh). Each session consisted of an initial 5 min rest period following by three alternating work (6 min) and recovery periods (20 min). There were no significant differences in cardiovascular responses to the intermittent exercise in the three environments nor during the subsequent recovery periods. In spite of varied environmental conditions the oxygen uptake (VO_2) values averaged 29.5 $ml.kg^{-1}.min^{-1}$ during the exercise and 4.3 $ml.kg^{-1}.min^{-1}$ during the last 5 min of recovery. Ventilation remained constant at all temperatures, averaging 53.3 $l.min^{-1}$ during the exercise. The respiratory exchange ratio was significantly decreased with time but was not affected by ambient temperature. Heart rate was constant for all three environment conditions ranging from 174 ± 3 - 179 ± 4 $beats.min^{-1}$. Skin temperature (T_{sk}) was significantly higher in 48 °C than in 35 °C and 28 °C and significantly higher in 35 °C than 28 °C during intermittent exercise; also T_{sk} was higher during exercise than into the recovery periods but T_{sk} was higher during recovery periods than during the initial rest in the three temperatures. The increase in rectal temperature (ΔT_{rec}) during exercise and recovery was the same for all the three environmental conditions and ranged from 37.0 ± 0.1 °C to 37.7 ± 0.1 °C.

Kraning and Gonzalez (1991) reported that during 30 min intermittent exercise performed under compensable (in which thermoregulation is effective and a normal person can achieve a thermal steady state) and uncompensable (in which thermoregulation is thwarted and can not be achieved a thermal steady state) conditions, that the thermal steady state was achieved when performed in compensable, but it was not achieved during uncompensable conditions. The rectal temperature was the same for both intermittent which consisted of repeated 10-min episodes: 4 min of walking (489 W. m^{-2}), and 4 min of seated rest (average H = 67 W. m^{-2}) and heat production during continuous exercise at the same time-weighted average rate of the above (average H = 204 W. m^{-2}). Other researchers have not succeeded in finding significant differences in thermoregulatory responses to intermittent and continuous exercise.

In summary, heat is produced by metabolism and can be increased dramatically by physical exercise. During exercise in the heat, an increase in environmental temperature causes a reduction in heat loss and hyperthermia develops. Intermittent exercise tends to result in changes in cutaneous circulation and skin evaporation that hint at a decreased efficiency in temperature regulation resulting in an increased core temperature. Some investigators have reported that intermittent exercise induced greater thermal tress than continuous exercise. Thermoregulatory and metabolic responses are dissociated by the activity profile, such as the intermittent pattern observed in handball. The important dimensions in evaluating the core temperature response to intermittent exercise are the duration and the intensity of exercise. Also the large number of activity changes during the game, when played in a high ambient temperature, may have implications for the thermoregulatory response to intermittent exercise.

Ekblom (1986) reported that the distance covered in high-intensity running during soccer match-play at an ambient temperature of 30°C was 500 m compared to 900 m when the temperature was 20 °C. In addition to this, the mean rectal temperature for Swedish First Division players was 39.5°C at ambient temperatures of 20-25 °C. The corresponding average for players of lower divisions was 39.1°C. Delamarche et al. (1987) examined seven handball players during practice games held between 20:00 hours and 22:00 hours in a gymnasium with an ambient temperature of 18 - 20 °C. They found that the rectal temperature during a handball match ranged from 39.1°C-39.8 °C.

2.4. FLUID BALANCE DURING TEAM SPORTS

Mustafa and Mahmoud (1979), Kirkendall (1985) and Ekblom (1986) found that soccer players may lose between 1-5% of their body weight by sweating during a match. Saltin (1964) noted the decrease in plasma volume is associated with significant impairments in endurance performance. Reilly (1996a) claimed that soccer players may lose 3 litres or more of fluid during 90 min play in the heat; this is an average value which varies with climatic conditions and also between individuals. Hawley et al. (1994) and Maughan and Leiper (1994) reported sweat losses of 0.85, 0.5 $l.h^{-1}$ for a soccer team with the players having a fluid intake of 0.1-1.4 l throughout a 90 min game. These fluid losses indicated that moderate to severe dehydration may occur in soccer, depending on the environmental conditions. This is of concern since in many countries such as Kuwait and Saudi Arabia, soccer and handball matches are sometime played in hot and humid conditions.

Woolford and Angove (1991;1992) reported a number of reasons why team sports differed from endurance athletes with regards to fluid loss and fluid intake. Team sports encompass intermittent exercise with higher intensity efforts being interrupted by periods of maximal activity. The authors found that 45-55% of a netball game was played at between 85 and 95% maximum heart rate, and top level soccer players spent over two thirds of the entire match at 85% of their maximum heart rate. This is due to the frequency of sprinting and accelerations. Broad et al. (1996) reported the mode of the game being a potential barrier to team sports players achieving adequate fluid intakes. There are limited opportunities to take fluids, such as in soccer, where the game consists of two 45 min halves and fluids are not permitted ad libitum on the field. In contrast, handball, basketball and volleyball players have frequent opportunities to drink during the time-outs and also when players are substituted or suspended.

Pohl et al. (1981) and Pyke and Hahn (1980) examined the sweat rates of Australian rules football players during a 105 min game. They found their sweat loss decreased (3.63 l, 3.19 l and 1.57 l) with a corresponding decrease in ambient temperature (38°C-27°C). Fluid intakes decreased disproportionately to the reduction in sweat losses (1.5 l, 0.74 l and 0.19 l) whereas there was an increase in the players' rectal temperatures (39.9°C, 39.3°C and 39.6°C). Broad et al. (1996) found that the fluid intake and sweat rate of male soccer players were similar to those reported by Hawley et al. (1994) and Maughan et al. (1994).

2.5. CARBOHYDRATE AND EXERCISE

During prolonged exercise, blood glucose and intramuscular glycogen are the two major sources of carbohydrate (CHO) utilisation by the working muscle (El-Sayed 1997). Studies have shown that fatigue occurred when blood glucose (Coggan and Coyle, 1989) and muscle glycogen (Bosch et al., 1993) were depleted. The role of CHO ingestion has been studied extensively and data have shown that the intake of CHO during physical exercise improves exercise performance (Coggan and Coyle, 1989). In addition, prevention of dehydration and hyperthermia are the main aims of fluid replacement during prolonged and highly intense exercise. The next part of the review of literature will be focused on the effect of CHO ingestion on fluid balance and thermoregulation during exercise; the influence of CHO ingestion on some physiological indices during intermittent exercise in the heat will also be stressed.

2.5.1. Nature and sources of carbohydrate

Carbohydrates, as the name implies, are molecules containing carbon in a ratio to hydrogen and oxygen as found in water. Carbohydrates have been classified on the basis of chemical structure carbohydrate, being either monosaccharides, such as glucose and fructose, disaccharides, such as sucrose, or polysaccharides such as starch. The availability of blood glucose after carbohydrate ingestion is usually assessed by the glycaemic index (Jenkins et al., 1981). The glycaemic index is a measure of the extent to which blood glucose is elevated above basal level over a given period of time after the ingestion of a standard carbohydrate meal. Studies have been published on the glycaemic index response and metabolic changes during exercise after simple (Massicotte et al., 1986; Guezennec et al., 1989; Sherman et al., 1989) and complex (Guezennec et al., 1993) carbohydrate meals were ingested before exercise. The results of these studies showed that carbohydrate with a high glycaemic index, such as glucose, enhances the insulin response which in turn promotes muscle CHO uptake and utilisation during exercise (Guezennc et al., 1993). However, carbohydrate with a low-glycaemic index decreases early endogenous CHO utilisation at the onset of exercise, and contributes to the maintenance of euglycaemia by greater reliance upon lipid utilisation (Guezennec, 1995).

2.5.2. Effect of carbohydrate ingestion on exercise performance

Carbohydrate is the most important nutrient in the athlete's diet because it is the only metabolic substrate that can provide fuel for intense exercise over prolonged periods. Carbohydrate stores in the body are relatively small and after 1-3 h of continuous exercise at approximately 60-80% VO_{2max}, athletes experience fatigue due to CHO depletion. A reduction in blood glucose may result in diminished muscle glucose uptake, a decrease in the rate of CHO oxidation, and reduced exercise performance capacity (Coggan and Coyle, 1987). Conversely, enhanced work output corresponds well with elevated CHO oxidation values and blood glucose levels are maintained as a result of CHO ingestion (Coggan and Coyle, 1987; Sherman et al., 1989).

2.5.2.1. Pre-exercise CHO ingestion

Pre-exercise CHO ingestion is proposed as an effective mean of enhancing muscle glycogen availability and improving endurance performance (Karlsson and Saltin, 1971). The most practical method of glycogen loading has been proposed by Sherman et al. (1981). This regimen is advocated to increase muscle glycogen stores by approximately 20-40% above normal, and benefits athletes participating in endurance exercise. In addition, athletes in heavy training should be encouraged to maintain a high dietary CHO intake to allow for muscle glycogen resynthesis between strenuous training sessions (Costill, 1988; Sherman and Wimer, 1991).

Although the benefits of glycogen loading for high intensity exercise remain uncertain, it has been reported that muscle glycogen loading improves performance during maximal exercise of only several minutes in duration (Maughan, 1990) as well as during endurance exercise (Bosch et al., 1993). Recently, Pizza et al. (1995) have reported an improved time to exhaustion in high intensity, short duration exercise performance after a 3-day high CHO diet compared to a low CHO diet.

It has been recommended that CHO should not be consumed during the hour before exercise because of a possible insulin-induced sudden drop in blood glucose, and thereby an impaired exercise performance (Costill et al., 1977; Foster et al., 1979). Nevertheless, the increase in CHO availability and oxidation as a result of the CHO ingestion during the hour before exercise is thought to prevent any decrement in exercise performance. For example, Gleeson et al. (1986) showed that endurance time to exhaustion was improved by 13% when 75 g of CHO was consumed 45 min before exercise, despite elevated insulin concentrations at the start of exercise and a drop in blood glucose early in exercise. Similarly, Sherman et al. (1991) found that exercise performance was improved by 12.5% when cyclists consumed approximately 75 g of CHO 60 min before 90 min of submaximal cycling followed by an intense time trial performance. The improvements in exercise performance are possibly due to increased CHO availability and maintenance of CHO oxidation resulting from gastric emptying of the pre-exercise CHO feeding.

2.5.2.2. Ingestion of CHO during exercise

Depletion of muscle glycogen is considered responsible for the development of fatigue during prolonged strenuous exercise (Bergstrom and Hultman, 1967). Numerous studies have demonstrated increased exercise time before reaching fatigue (Coggan and Coyle, 1987; 1989), enhanced power output (Coggan and Coyle, 1988), and improved sprint performance following prolonged exercise (El-Sayed et al., 1995) when CHO was ingested during exercise. Notably fatigue occurring during exercise without CHO feeding coincides with a substantial decrease in blood glucose and muscle glycogen level, and a subsequent fall in CHO oxidation (Coyle et al., 1986;

Mitchell et al., 1989). Hargreaves et al. (1984) showed a reduced muscle glycogen depletion and enhanced sprint performance at the end of prolonged exercise when solid CHO feedings were given repeatedly. Recent studies have consistently shown that the decline in muscle glycogen is reduced and performance improved when CHO was provided during 2 h of cycling exercise at 50% VO_{2max} and 3 h of cycling at 75% VO_{2max}, respectively, followed by a fatigue trial at 80% VO_{2max} (Yaspelkis et al., 1991; 1993b). Putting the evidence together, it appears that the beneficial effects of CHO ingestion on exercise performance are related to the maintenance of blood glucose levels and a high rate of CHO oxidation at a time when muscle glycogen levels are low.

2.5.3. Carbohydrate feeding during intermittent exercise

It does not appear that carbohydrate feeding alters the net rate of decline in muscle glycogen concentration during prolonged exercise maintained at a constant high intensity (Coyle et al., 1986; Hargreaves and Briggs, 1988; Slentz et al., 1990). However, carbohydrate ingestion may positively affect intermittent exercise performance. It has been demonstrated in animals and in humans that carbohydrate feedings given during low-intensity exercise which followed prolonged high intensity exercise can promote glycogen resynthesis within non-active muscle fibres with low glycogen concentration (Kuipers et al., 1987). Therefore, it is possible that carbohydrate provision throughout prolonged exercise which varies from high to low intensity, or which includes rest periods such as in handball, soccer and basketball may result in a further decline in muscle glycogen concentration. Brouns et al. (1989) reported that in a laboratory simulation of the Tour de France, which utilised intermittent exercise of varying intensity, the decline in muscle glycogen was reduced by ingesting large amounts of carbohydrate during exercise. It is not clear if this was due to decreased glycogenolysis or increased glycogen resynthesis during exercise or both.

There seems to be a good rationale for ingesting carbohydrate during intermittent exercise to reduce the amount of glycogen depletion. Carbohydrate intake is also beneficial during team sports involving high intensity intermittent exercise such as soccer and handball which causes fatigue due to glycogen depletion (Muckle, 1973; Foster et al., 1986; Simard et al., 1988). The ingestion of carbohydrate solutions throughout the game, and during the half-time rest period, may result in less reliance on muscle glycogen stores and this will spare muscle glycogen and increase sprinting ability towards the end of the game compared to when no carbohydrate is ingested and muscle glycogen remains low.

2.5.4. Effect of carbohydrate ingestion in team sports

2.5.4.1. Importance of pre-exercise glycogen stores

It is likely that CHO is the major macronoutrient required in games. This is because the higher the exercise intensity, the greater the utilisation of carbohydrate, whilst fat comes into play as an important fuel as exercise is prolonged. Saltin (1973) examined the effect of pre-exercise muscle glycogen levels on work-rate of nine (9) subjects during soccer play and found that 4 players with lower muscle glycogen levels (45 $mmol.kg^{-1}$) performed at a lower work-rate compared to the 5 players with normal muscle glycogen levels (96 mmol.kg^{-1}). The low level of muscle glycogen in the four players was due to the fact that they had a hard training session the day before the match and had not consumed enough CHO. Muscle glycogen content has been reported to approach complete depletion after a Swedish First Division match (Shephard and Leatt, 1987). Conversely, muscle glycogen depletion was less in players who drank 500 ml of a 7% glucose polymer solution 15 min before a match and again at half time than in the players who only drank water (Leatt and Jacobs, 1986). Saltin and Hermansen (1967) suggested that a high carbohydrate intake during periods of intensive training or competition is very important especially since glycogen cannot be resynthesised from fat or protein.

2.5.4.2. Carbohydrate ingestion before, during and after team sports

Handball is a sport that requires intermittent high intensity bouts of exercise as does soccer, basketball, hockey, volleyball squash and tennis. To get an insight into the specific requirements of a handball player, and because of the lack of literature pertaining to handball, this review will focus mainly on the other ball games such as soccer, basketball and hockey. Many events are time-consuming with regards to both training and competition; however, physical activity during competition is often not continuous but intermittent. For example, short bursts of vigorous exercise are followed by rest or low-intensity exercise. Soccer and handball are both examples of this kind of activity. Ekblom (1986) reported that on average the players cover approximately 10 km during a 90 min soccer game, even despite the many changes in activity. It has been estimated that top class English Premier League players walk and run a total of 10.5 km (Drust, 1997). Reilly (1994) reported that the physiological demands of soccer play are represented by the exercise intensities at which the myriad of activities during match play are performed. The overall distance covered by outfield players during a game ranges between 8-12 km. This overall distance covered by outfield players during the match consisted of 25% walking, 37% jogging, 20% cruising submaximally, 11% sprinting and 7% moving backwards.

It is important for elite handball and soccer player to have large glycogen stores in order to maintain optimum physical performance during training or competition. Recent studies further confirm that the consumption of a high carbohydrate diet for two or more days prior to an endurance event enhances performance. For example, Bangsbo (1992) reported that relative to a 39% carbohydrate diet for two days, a 65% carbohydrate diet enhanced soccer players' performances on a treadmill test designed to mimic the varying intensities of a soccer match. Similarly, Muckle (1973) reported an improved team performance as measured by the number of goals scored, especially during the second half of play after CHO ingestion. Kirkendall et al. (1988) showed that carbohydrate feeding during a game increased the total distance run as well as the distances run at high velocities. Simard et al. (1988) found that ice hockey players who ingested carbohydrate during a game increased the distance skated by 10% and the speed by 4% compared to placebo group.

Coggan and Coyle (1991) observed that the improved performance as a result of carbohydrate feeding during intermittent exercise was similar to that observed during continuous cycling or running at an exercise intensity corresponding to 70% VO_{2max}. Karlsson et al. (1969) examined the muscle glycogen levels of soccer players before, at half time, and after the game. Although, muscle glycogen levels were fairly low by half-time, there were depleted after the completion of the game in all players. It is suggested that carbohydrate ingestion during intermittent exercise can be used to resynthesise glycogen during the periods of rest and low intensity exercise (Constable et al., 1984; Kuipers et al., 1987; Brouns et al., 1989).

Numerous investigators have demonstrated the importance of glycogen utilisation during exercise to improve energy metabolism at high exercise intensities. For example, Costill et al. (1973), Hermansen et al. (1967) Jacobs et al. (1982) and Maughan and Poole (1981) found a substantial reduction in muscle glycogen in response to intermittent exercise. Green and co-workers (1978) found that the glycogen levels in the vastus lateralis muscle were reduced to 40% of the pre-exercise level following an ice hockey game. Foster et al. (1979) found that carbohydrate feeding 30-45 min before endurance exercise increased the rate of carbohydrate oxidation and reduced the mobilisation of free fatty acids. Saltin and Karlsson (1971) reported that many team sports require the athlete to perform both endurance and sprint exercise during a game with the rate of glycogen utilisation increasing exponentially with increasing in exercise intensity.

In summary, participants in team sports such as handball, soccer, basketball, volleyball and hockey players are required to train and to compete in irregular exercise intensities. Therefore, it seems appropriate for elite players in team sports to have large glycogen stores and ingest CHO before and during a game to maintain optimum physical performance. It is not known whether the shorter duration of handball (60 min) compared to soccer (90 min) affects those recommendations.

2.5.5. Carbohydrate ingestion during intermittent exercise in the heat

Exercise in the heat requires the body to attempt to cope simultaneously with competing demands for cardiovascular homeostasis, thermoregulatory control and maintenance of muscle energetics. It is generally agreed that even low levels of dehydration (e.g. equivalent to less than a 2% loss of body weight) impair cardiovascular and thermoregulatory responses (Montain and Coyle, 1992a). In this regard, prevention of dehydration and hyperthermia are the main aims of fluid ingestion and the supplementation of CHO as an energy source may be a secondary purpose during exercise in a hot environment. The following sections will focus on the effects of CHO ingestion on physiological responses during intermittent exercise in the heat.

2.5.5.1. Thermoregulation responses

Fluid ingestion is widely recommended during prolonged and intense exercise to attenuate the increase in core temperature that accompanies dehydration. As dehydration progresses and plasma volume decreases, peripheral blood flow and sweating rate are reduced and thermoregulation becomes progressively more difficult. Therefore, fluid ingestion during exercise in hot environments will help enhance blood flow to the skin for more effective cooling. Montain and Coyle (1992b) have highlighted the inconsistent effects of fluid ingestion on core temperature and sweat rate. Typically, core temperature and heart rate are reduced and peripheral blood flow is maintained following fluid administration compared with no fluid ingestion. This therefore strongly suggests that fluid balance is a key factor determining exercise tolerance in a hot environment. During moderate to intense exercise in the heat, the combined increased demands for muscle blood flow to a working muscle and of the skin can result in difficulties in meeting both requirements (Maughan et al., 1996). With hypohydration, peripheral blood flow is usually reduced and heart rate increased in an attempt to maintain central venous pressure. A reduction in peripheral blood flow will reduce the ability to lose heat causing body temperature to rise.

Murray et al. (1987) reported that physiological functions during intermittent exercise in a warm environment are maintained as well by consuming carbohydrate beverages as by consuming a placebo. The thermoregulatory response (core and skin temperature), circulatory response and fluid homeostasis, heart rate, change in plasma volume and metabolic response (respiratory exchange ratio, percent $VO_{2\ max}$, minute ventilation, and blood lactate) behaved similarly among the varied beverage treatments. The major differences between the placebo and the carbohydrate beverages were higher plasma glucose concentrations during the later stages of exercise with different carbohydrate beverages. As the performance-enhancing effect of carbohydrate feeding has commonly been attributed to sparing of muscle glycogen levels, the investigators attributed the improved performance to a significant reduction in muscle glycogen utilisation resulting from carbohydrate feeding. Some investigators reported no difference between water, low glucose and high glucose treatment on the body temperature changes during exercise in the heat. In contrast to the previous statement, Costill et al. (1970) Costill and Saltin (1974), Candas et al. (1986), Owen et al. (1986) Carter and Gisolfi (1989), Murray et al. (1989), and Ryan et al. (1989) reported that fluid replacement drinks containing up to 15% carbohydrate can support thermoregulation as effectively as water when exercise is performed in a thermally stressful environment.

2.5.5.2. Rectal temperature (T_{rec})

Kruk et al. (1991) assessed the metabolic and thermoregulation responses to intermittent exercise in a warm environment (30°C) in hockey players, given glucose solutions before and during exercise. Results indicated no significant difference between three consecutive intermittent exercise bouts in rectal temperature changes during glucose and placebo trials. A progressive increase in rectal temperatures was noted as a function of time during exercise bouts.

Yaspelkis and Ivy (1991) examined the effect of CHO supplements of different concentration on thermoregulation and plasma volume during performed exercised for 2 h in a hot condition (33.0 ± 0.1°C and 51.7 ± 1.4 % relative humidity). The subjects received 3 $ml.kg^{-1}$ body mass of water or a 2.0 % or 8.5 % glucose polymer solution every 15 min. The average rectal temperature was 37.1°C at rest which increased to a steady-state level of 38.2 °C by 90 min of exercise and this temperature was maintained for the duration of exercise bout. The 85% CHO supplementation regulated body temperature and prevented disturbance in fluid homeostasis as effectively as water while maintaining CHO oxidation and reducing the rate of decline in muscle glycogen during low-intensity exercise in the heat.

Yaspelkis et al. (1993a) reported similar results during submaximal exercise in a warm environment with temperatures ranging from 23.5°C - 33.7 °C. Exercise in the heat significantly increased rectal temperature, heart rate and reduced body mass and plasma volume beyond those observed during exercise in a normal environment. Febbraio et al. (1996) examined the effect of three different concentrations of carbohydrate solution on rectal temperature during exercise in cold and hot conditions. No significant effect in rectal temperature was found at rest or during exercise for each of the drinks consumed. The rectal temperatures continued to rise throughout the exercise and were identical at the point of fatigue in the first trial of 14 % CHO solution at 33 °C or 5 °C (HT1) and second trial at 33 °C with 4.2 % CHO solution or placebo (HT2).

Handball is frequently played outdoors in hot conditions. If its intensity is broadly similar to the work-rate in soccer, it is likely to induce thermoregulatory stress. This has implications for dehydration in addition to energy provision for handballers. There are few data in the literature on the energetic or thermoregulatory stress in handball games.

2.5.5.3 Skin temperature (T_{sk})

Kruk et al. (1991) observed that the skin temperature was increased during the first 15 min exercise trial to a similar level in the subjects given glucose solution and those given tea without glucose and then remained unchanged until the end of both experiments. No significant differences in skin temperature were found between tea and glucose trials. At the end of the experiment there was a tendency toward higher values of skin temperature in the water test than in the glucose test. At the end of the third exercise trial the difference in the mean skin temperature between the two conditions was 7.2%. Murray et al. (1987) reported that no difference in the mean skin temperature occurred among subjects in response to varied beverages and placebo in a 33 °C environment. As the few studies concerned with the skin temperature responses to intermittent exercise in a hot environment with CHO ingestion have been inconclusive, the present study was designed to investigate the effect of CHO and placebo solutions on skin temperature during different environmental temperatures.

2.5.5.4 Heart rate response

Kruk and co-workers (1991) reported that during three exercise bouts of the same intensity corresponding to 60 % VO_{2max} for 15 min, the exercise heart rate values were similar when subjects were provided with water (179 ± 2 beats.min^{-1}) and glucose (179 ± 2.0 beats.min^{-1}). However, during the last exercise bout the heart rate was higher in the water trial than in the glucose trial.

Yaspelkis and Ivy (1991) examined the effect of different CHO concentration supplementation compared with water on 12 subjects in an environmental temperature of 33.7 °C. They found that heart rate was similar among all beverages treatments, although all treatments exhibited heart rate drift of 20 beats.min^{-1} by the end of the exercise bout. Yaspelkis et al. (1993a) reported that exercise in the heat (33.7 ± 0.01°C) significantly elevated rectal temperature and heart rate also and reduced body weight and plasma volume below that produced during exercise in thermoneutral environmental condition (23.5 ± 0.6°C). Heart rate was at a similar level initially for both treatments and rose throughout the exercise bout; exercise in the heat resulted in a larger increase in heart rate than that which occurred in the neutral environment. The larger increase in heart rate during the trial in the heat resulted in an overall treatment effect that was significantly greater than that of the neutral trial.

In summary, some evidence exists to support the view of no significant influence of glucose compared to placebo on rectal temperature changes during intermittent exercise. There are also reports of no differences in rectal temperature at rest or during exercise for different beverages consumed. Some investigators reported that at the end of the exercise there was a tendency toward higher values of skin temperature when water was given than when glucose was provided. No difference in the mean skin temperature occurred in response to varied beverages and placebo during exercise in a warm environment. However, ingestion of different beverages had no significant effect on heart rate during intermittent exercise in a hot environment although, heart rate may be higher at the end of the exercise when given water rather than carbohydrate. This may be due to a faster absorption of fluid at certain energy concentrations.

2.4.5.2. Metabolic responses

Kruk et al. (1991) reported that there was no significant difference in VO_2 during glucose or placebo trials in 30°C room temperature, but the higher value of VO_2 occurred in the water trial as compared with the glucose test. Although there was no difference in respiratory exchange ratio between the two exercise tests with and without glucose during the first and second exercise stages, during the third exercise stage the respiratory exchange ratio was higher in the glucose trial than in the water trial.

Febbraio et al. (1994) reported that no difference in oxygen uptake was observed when exercise in a 40°C environment was compared with exercise in 20°C. In contrast, exercise in a temperature of 40°C resulted in higher mean heart rates and respiratory exchange ratio compared with responses in 20°C environments. Also Febbraio et al. (1996) found there was no difference in mean VO_2 or heart rate during ingestion of different beverages with different CHO concentrations in different ambient temperatures.

Kruk et al. (1991) reported that blood glucose concentration decreased to a level less than 3.0 $mmol.l^{-1}$ in three out of seven subjects exercising without glucose supplementation. In the test with glucose ingestion, blood glucose concentrations were maintained well above the pre-exercise level during the second and third stages. There was no significant difference between the two tests in blood lactate concentration measured at the end of each 15 min exercise bout, although the blood lactate value was higher during the test with glucose ingestion than that with water (1.93 ± 0.16, 1.67 ± 0.19 $mmol.l^{-1}$). MacDougall et al. (1974) reported that when individuals exercised in high ambient temperatures the blood lactate increased during prolonged exercise. This suggests that both CHO provision and heat stress increase the utilisation of glycogen by the active muscle.

2.6. SUMMARY

Nutrition is one of a number of factors which can have profound effects on an athlete's physical performance. Carbohydrates can be categorised according to their ability to increase blood glucose concentration. It has been demonstrated that carbohydrate ingestion helps thermoregulation during higher intensity exercise in the heat. Also fluid ingestion during exercise in hot environments will increase blood flow to the skin for more effective cooling. Core temperature and heart rate are reduced and peripheral blood flow is maintained following fluid administration compared with no fluid ingestion. This strongly suggests that fluid balance is a key factor determining exercise tolerance in a hot environment. Physiological and thermoregulatory responses during intermittent exercise in a warm environment are at least as well maintained by consuming carbohydrate beverages as by consuming a placebo. It is important for elite competitors such as handball and soccer players to have large glycogen stores and fluid provision in order to maintain optimum physical performance during match-play and to optimise their nutritional preparation for training and competition.

CHAPTER 3

DESCRIPTIVE STUDIES

3. DESCRIPTIVE STUDIES

3.1. THE ORGANISATION OF THE RESEARCH

Five main studies have been completed for this thesis. In the first a kinanthropometric profile was produced to establish the characteristics of elite male handball players and explore any discrete characteristics associated with success in the game. The measurements were taken during the 12th Asian Games in Hiroshima in 1994 from members of 5 national handball teams, in addition to a reference group represented by players from the English national handball team. In parallel with this work on male players was a study of the kinanthropometric profile of Asian female handball players. The measurements that were needed to compile this profile were taken from female participants from 4 different countries during the Asian handball championships held in 1994 at the 12th Asian Games.

The second study was an investigation of the physiological capacities of handball players. A comprehensive fitness profile of English and Kuwait handball players was completed. Measurements were taken from members of both the English and Kuwaiti handball national teams.

The third study entailed measuring the heart rate of male handball players during training and friendly matches. The study was extended to an investigation of estimated energy expenditure in the game by utilising the relation between heart rate and oxygen uptake established during measurement of VO_{2max}. This provided a framework for the adoption of a continuous and intermittent exercise protocol, incorporating partial representation of the exercise intensities of competitive handball using the heart rate response as the criterion.

These descriptive stages formed the basis for the conduct of the experimental investigations described in section 4. The experimental stage of the work included two studies in which, firstly, the exercise protocol and the environmental conditions were manipulated 4.1 and secondly, the provision of energy to active subjects was investigated 4.2. Both studies were designed to shed further light on the physiological responses to exercise that mimicked exercise intensities of handball established in the final study within this section (section 3). The relevance of the exercise protocol to game was checked by means of motion analysis of handball and soccer in a fifth and final study.

3.2. KINANTHROPOMETRIC PROFILE OF MALE HANDBALL PLAYERS

3.2.1 Introduction

Kinanthropometry measurements relevant to human movement gained formal recognition as a discipline with the inauguration of the International Society for Advancement of Kinanthropometry in 1986. Kinanthropometrists of all continents have participated in several major multidisciplinary studies that are being or have been conducted to assess the physical condition of people. This theme is also appropriate in the evaluation of physical fitness. Kinanthropometry has been defined as the quantitative interface between human structure and function (Ross et al., 1980). This interface is examined through the measurement and analysis of age, body size, shape, proportion, composition and maturation as they relate to gross body function. Previous reports have shown that body structure and morphological characteristics are very important determinants of performance in many sports. Results of novel kinanthropometric research have tended to suggest that certain physical impressions such as body composition (body fat, body mass, muscle mass) and physique (somatotype) could significantly influence athletic performance (Carter, 1984).

Handball is one of the Olympic Games team sports which requires a high standard of preparation in order to complete 60 min of competitive play and to achieve success. In this game movement patterns are characterised as intermittent and continuously adapted to different offensive and defensive situations. Kinanthropometric factors and morphological structure of the elite athlete have been widely studied. Several authors have shown that kinanthropometric characteristics are very important for different sports groups (Carter, 1970; Reilly, 1990). Kinanthropometric profiles may contribute to understanding the suitability of players for the sport of handball, particularly at a high standard of play.

Carter (1980, 1984) concluded that somatotype could explain from 25% to 60% of variance in physical fitness tests. The author reported that handball players should be classified as “endomorphic”. Deng et al. (1990) suggested that the ideal somatotype for male Chinese handball players should be muscular, strong and tall and female handball players should be higher than normal in body mass. Despite the game’s world-wide popularity, there have been few other investigations of kinanthropometric and physiological characteristics of elite handball players.

The purpose of this study was to establish kinanthropometric characteristics of successful handball players in the Asian handball championship for males and identify any positional variations between players from five different countries. In addition, the English handball team was used as a reference group for comparison.

3.2.2. Methods

3.2.2.1. Subjects

Sixty three players in the 12th Asian Games in Hiroshima (Japan) participated in this study from the following teams; 17 players were from the Kuwait national team (age 26.0 ± 3.0 years), 16 players from Japan (age 26.0 ± 2.0 years), 13 players from Saudi Arabia (age 25.0 ± 3.0 years), 10 players from China (age 25.0 ± 3.0 years), 7 players from South Korea (age 25.0 ± 2.0 years). Eight players from the English national squad (age 20.0 ± 2.0 years) formed a reference group.

3.2.2.2. Procedures

Measurements were made of height, body mass, skinfold thicknesses and muscle mass. The height was measured by means of stadiometry to the nearest 0.5 cm and a hydraulic scale (Jonelle) was used to measure body mass to the nearest 0.1 kg. Adiposity was measured by means of Harpenden skinfold calipers, using the sum of five anatomical sites - the biceps, triceps, sub-scapular suprailiac and anterior thigh.

The biceps skinfold was taken vertically from the front of the arm, at the mid-point between the shoulder and the elbow. The triceps skinfold was taken vertically from the back of the arm, at the mid-point between the acromion and olecranon processes. The subscapular skinfold was measured at an angle of 45 degrees to the vertical, running laterally and downward in the natural cleavage line of the skin at the inferior angle of the scapula. The suprailiac skinfold was obtained superior to the iliac crest on the midaxillary line. The anterior thigh skinfold consisted of a vertical fold on the anterior aspect of the thigh, midway between the hip and knee joints (on the front of the thigh half-way between the hip joint where the leg bends when the knee is lifted, and the middle of the knee). Adiposity was indicated by the sum of five sites according to the position statement of the British Olympic Association (Reilly et al., 1996).The percentage body fat was estimated by calculating the average of three measurements taken for each of four sites according to Durnin and Womersley (1974).

The calculation of percent body fat considered the following :

a) the sum of the four skinfold thickness (biceps, triceps, sub-scapular suprailiac);

b) the age of the subject;

c) the sex of the subjects.

The kinanthropometric measurements used to estimate muscle mass were skinfold thickness at the front thigh and medial calf, and the circumferences of the forearm, thigh and calf (Martin et al., 1990). The front thigh skinfold was taken as explained before. The medial calf skinfold was taken vertically on the posterior aspect of the calf in the midsagittal plane 5 cm inferior to the fossa poplitea. The forearm circumference was taken at the proximal part of the forearm (within 5 cm of the elbow). The subject stood erect with arm extended in the horizontal plane. The experimenter stood behind the subject's arm and moved the tape up and down the forearm perpendicular to the long axis until the maximum circumference of the forearm was located. The mid-thigh girth was taken at the midpoint between the trochanterion and the tibiale laterale. The calf girth was taken when the tape was moved up and down the calf perpendicular to the long axis until the greater circumference was located. The estimated percent muscle mass was calculated using the Basic computer package in DOS programme.

3.2.2.3. Technical error of measurements

The kinanthropometric measures were performed by the author, with the one exception of muscle mass measures for one group which were done by one of the supervisors. The author trained by two supervisors according to procedures of the International Society for Advancement of Kinanthropometry (Eston and Reilly, 1996), one each in England and Kuwait. In addition to the check on the author's expertise, the technical error of measurement was calculated for the major kinanthropometric variables (see Table 3.2.1). This was done using the formula: $s_e = \sqrt{\Sigma d^2 / 2N}$, the square root of the sum of the squared differences of replicate measurements divided by twice the number of pairs (Siegel et al., 1996).

The data used in the calculation of technical errors of measurement consisted of the first duplicate observations on 16 subjects.

Table 3.2.1 Technical error (S_e) of measurement for variables used to estimate kinanthropometric profiles (n = 16 players).

Variables	S_e	Variables	S_e
Biceps skinfold (mm)	0.06 (1.6%)	Front thigh skinfold (mm)	0.18 (2.4%)
Triceps skinfold (mm)	0.06 (1%)	Calf circumference (cm)	0.23 (0.6%)
Subscapular skinfold (mm)	0.07 (0.9%)	Forearm circumference (cm)	0.28 (1%)
Suprailiac skinfold (mm)	0.15 (2.8%)	Thigh circumference (cm)	0.38 (0.7%)
Medial calf skinfold (mm)	0.22 (4.6%)		

$S_e = \sqrt{\Sigma d^2 / 2N}$, the square root of the sum of the squared differences of replicate measurements divided by twice the number of pairs (Siegel et al., 1996).

All the technical errors are well within the range of those in several United States health surveys and several studies done at the University of Texas (Malina and Merrett, 1995). Given the small magnitude of technical errors, the intra-observer measurement variability on kinanthropometric components was thus negligible.

3.2.2.4. Statistical analyses

The statistical analyses of data were carried out using one-way analyses of variance (ANOVA). Levene's test was first carried out to examine the homogeneity of variances. Tukey-HSD post hoc test was applied when an F statistic indicated a significant difference to determine which of the ordered means were significantly different from each other. Statistical significance was set at the $P < 0.05$ level.

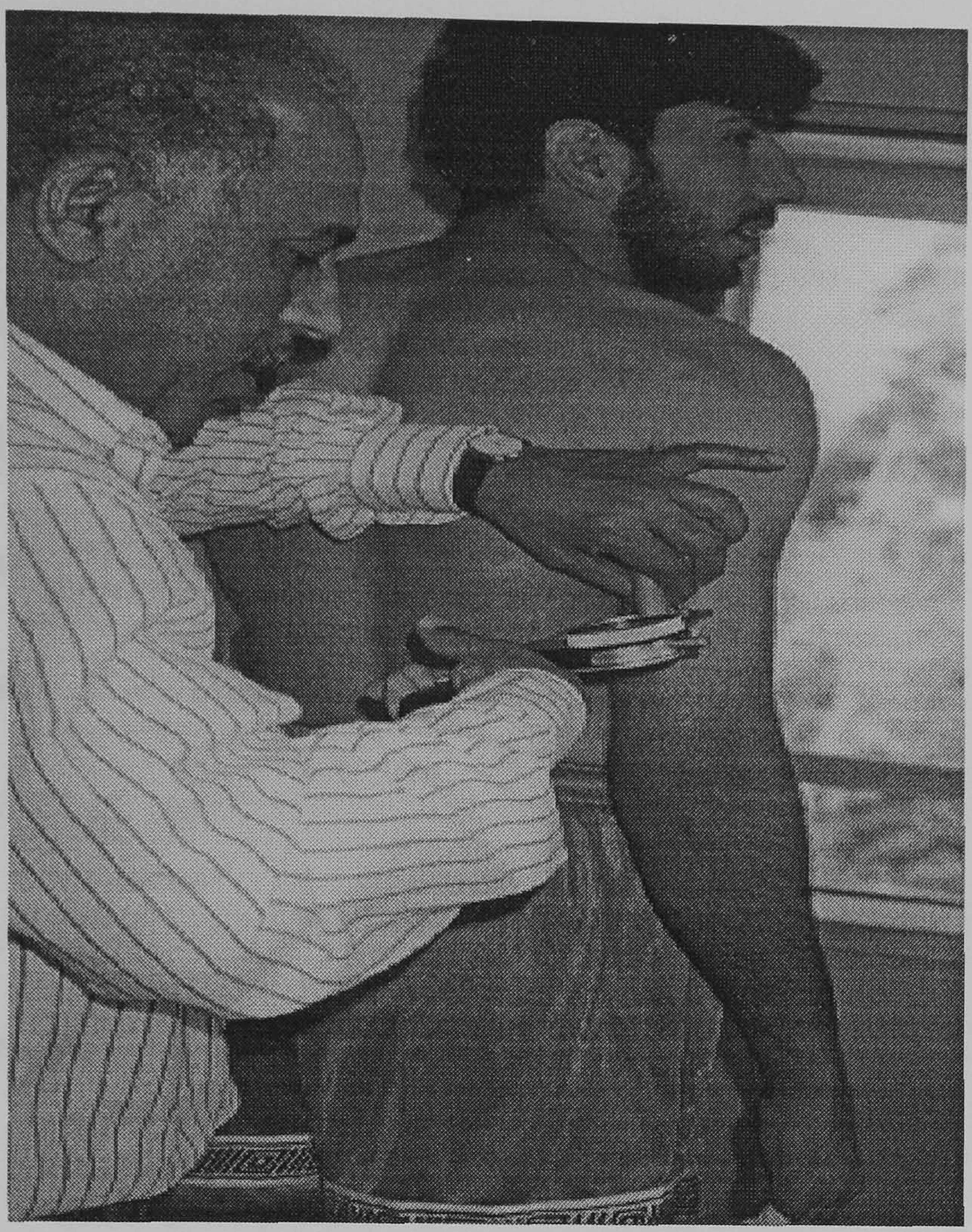


Plate 3.2.1. Measurement of skinfold thickness at the triceps as one of four sites for calculating the % body fat (Harpenden skinfold caliper)

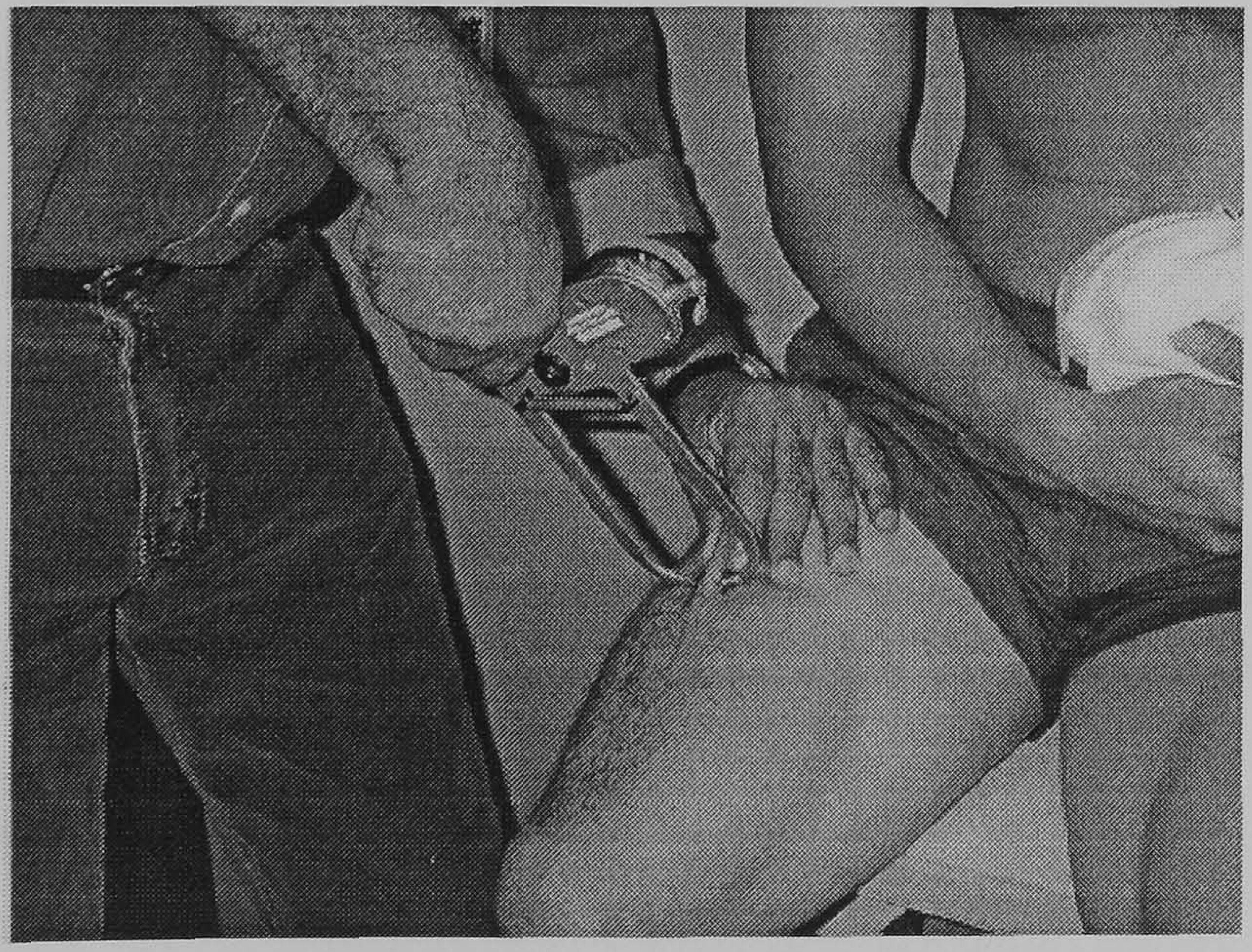


Plate 3.2.2. Measurement of skinfold thickness at the front thigh for calculation of the sum of skinfold and estimation of the muscle mass (Harpenden skinfold caliper)

3.2.3. Results

Table 3.2.2. and 3.2.3. summarise the mean and standard deviation of kinanthropometric characteristics and body composition of the subjects. The results of analyses of variance demonstrated significant differences in height ($F_{5,65} = 6.44$; $P < 0.001$), body mass ($F_{5,65} = 3.7$; $P < 0.05$), percent body fat ($F_{5,65} = 3.23$; $P < 0.05$), adiposity ($F_{5,65} = 3.72$; $P < 0.001$) and muscle mass ($F_{5,65} = 3.14$; $P < 0.05$) between teams. There was no significant difference between Asian groups in age, but the mean of the English team was significantly lower than that of Asian groups; however, the English and Kuwaiti handball players had more adiposity as indicated by the sum of five skinfolds (46.5 ± 18.5, 41.5 ± 15.4 mm) and a higher percentage body fat (13.4 ± 5.1, 12.9 ± 4.3 mm) than the other teams.

The Chinese players were significantly taller on average than the other teams, Chinese players' heights ranging from 176.5 to 200 cm. The Japanese and the Korean players were significantly taller than the Kuwaiti, Saudi and English players ($F_{5,65} = 6.44$; $P < 0.01$). The measurement of body mass showed that the Kuwaiti players had highest body mass values. The Japanese had the lowest adiposity and estimated % body fat and along with the Chinese had a group mean of less than 10% body fat.

The Kuwaiti players had significantly more muscle mass than all the groups ($F_{5,65} = 3.14$; $P < 0.05$). However, the Kuwaiti, Chinese and Korean had more muscle mass than the Saudi and English players. The Kuwaiti (55.3%), Korean (54.7%) and Chinese (54.5%) had the higher relative muscle mass values, the lower values being observed in the Japanese (49.0%) and Saudi Arabia (46.0%) players.

Table (3.2.2) Kinanthropometric characteristics of male handball players grouped according to their nationality (mean ± S.D). (China = 10, England = 8, Japan = 16, Korea = 7, Kuwait = 17 and Saudi Arabia = 13 players.

Teams	Age (Years)	Height (cm)	Body mass (kg)
China	25.0 ± 3.0	190.0 ± 7.4	85.4 ± 10.0
England	20.0 ± 2.0	174.2 ± 5.4	77.5 ± 11.5
Japan	26.0 ± 2.0	185.4 ± 6.7	80.6 ± 3.9
Korea	25.0 ± 2.0	184.6 ± 5.3	85.4 ± 8.7
Kuwait	26. ± 3.0	181.6 ± 5.0	87.6 ± 10.3
Saudi	25.0 ± 3.0	182.1 ± 7.0	75.8 ± 8.1
Mean ± SD	25±3.1	183.2 ± 7.0	82.2 ± 9.6

Table 3.2.3. Body composition of male handball players according to their nationality (mean ± S.D) (China = 10, England = 8, Japan = 16, Korea = 7, Kuwait = 17 and Saudi Arabia = 13 players).

Teams	Body fat (%)	Sum 5 skinfolds (mm)	Muscle mass (%)	Muscle mass (kg)
China	9.6±2.8	30.9±7.8	54.5±8.8	46.5±7.5
England	13.4±5.1	46.5±18.5	47.8±8.0	37.0±6.2
Japan	9.2±2.0	28.8±5.3	49.0±5.9	39.5±4.8
Korea	11.2±2.7	37.0±9.1	54.7±6.8	46.7±5.8
Kuwait	12.9±4.3	41.5±15.4	55.3±10.5	48.4±9.2
Saudi	10.3±2.8	35.6±9.4	46.0±6.0	34.9±4.5
Mean ± SD	11.0 ± 3.6	36.2 ± 12.7	51.2 ± 9.6	42.1± 7.9

Teams were divided in three groups according to the geographical location. These were West Asia (Kuwait and Saudi Arabia), East Asia (China, Japan and South Korea) and Europe (England). The mean age of the European (English) players was significantly lower than the East Asia and West Asia handball players ($F_{2,68} = 15.3$; $P < 0.001$). Also they had a significantly higher % body fat ($F_{2,68} = 4.79$; $P < 0.05$). Body mass and muscle mass were not significantly different, although height was significantly different between the three groups ($F_{2,68} = 16.37$; $P < 0.001$), where the East Asian were taller than the West Asian and European players, while West Asian players were taller than the European group (see Table 3.2.4 and 3.2.5).

Table 3.2.4. Characteristics of male teams players according to the geographical location (East = 33, West = 30, Europe = 8).

Group	Age (years)	Height (cm)	Body mass (kg)
East Asia	25.0±0.0	181.9±0.4	81.7±8.4
West Asia	25.0±1.0	186.7±2.9	83.8±2.8
Europe	20.0±2.3	174.2±5.4	77.5±11.5

Table 3.2.5. Body composition of male Asian handball players according to the geographical location (East = 33, West = 30, Europe = 8).

Group	Body fat (%)	Sum 5 skinfolds (mm)	Muscle mass (%)	Muscle mass (kg)
East Asia	11.9±6.6	32.2±4.3	50.6±6.6	41±5.4
West Asia	10.0±1.1	38.6±4.2	52.8±3.22	44.2±2.7
Europe	13.4±5.1	46.5±18.5	47.8±8.0	37.0±6.2

The players from Kuwait, Japan, and China, Korea and Saudi Arabia were divided according to the players' position into goal-keeper, back, centre and wing. One-way analysis of variance was used to analysis of data for the five teams. There was no significant difference in age, height, body mass, percentage body fat, adiposity (sum of five skinfolds) and muscle mass ($F_{3,16}$ = 1.24, 0.02, 0.27, 0.46, 0.30; $P > 0.05$), respectively. This demonstrates that handball teams from the east and west Asian group were relatively homogeneous in kinanthropometric make-up and body composition, without any unique requirements other than skills for positional roles (see Table 3.2.6, 3.2.7).

Table 3.2.6. Characteristics of male Asian team's players according to the players' position (G.Keeper = 12, Back = 15, Centre = 18, Wing = 18)

Positions	Age (years)	Height (cm)	Body mass (kg)
Goalkeeper	25.0±1.9	186.5±4.4	80.8±7.0
Back	24.0±1.5	185.8±4.7	82.5±5.0
Centre	26.0±1.9	183.7±2.4	84.7±8.9
Wing	25.0±0.8	184.2±5.5	81.6±7.4

Table 3.2.7. Body composition of male Asian team's players according to the position play (G.Keeper = 12, Back = 15, Centre = 18, Wing = 18)

positions	Body fat (%)	Sum 5 skinfold (mm)	Muscle mass (%)	Muscle mass (kg)
G.Keeper	10.5±3.3	33.9±11.4	49.8±5.5	40.2±4.4
Back	10.5±1.7	34.2±6.9	52.2±7.3	43.3±6.0
Centre	10.8±3.3	41.7±11.5	53.8±7.7	45.6±6.5
Wing	10.4±2.6	31.9±5.4	51.2±6.2	41.8±5.0

Team were divided in two groups according to the results of the Asian Games. These were successful teams which finished first, second and third (South Korea, Japan and China) and the unsuccessful teams which did not gain medals (Kuwait and Saudi Arabia). Analysis of variance was used to determine whether the kinanthropometric profile and body composition differed between the successful and unsuccessful teams at an elite level of handball play. No significant difference in age, body mass and muscle mass was found between the two groups (see Table 3.2.8). However, the successful players were taller ($F_{1,61} = 12.51$; $P < 0.001$) and had a lower body fat percentage ($F_{1,61} = 6.19$; $P < 0.05$) and less adiposity ($F_{1,61} = 8.97$; $P < 0.05$) than the unsuccessful players (see Table 3.2.9.).

Table 3.2.8. Characteristics of male teams players according to the results of the Asian Games (successful N = 33 was medal winners, the unsuccessful N = 30 did not gain medals).

	Age (years)	Height (cm)	Body mass (kg)
Successful	25.0±0.0	186.7 ±2.9	83.8±2.8
Unsuccessful	25.0±1.0	181.9±0.4	81.7±8.4

Table 3.2.9. Body composition of male teams players according to the results of the Asian Games (successful = 33 were medal winners, the unsuccessful = 30 did not gain medals).

Team	Body fat (%)	Sum 5 skinfold (mm)	Muscle mass (%)	Muscle mass (kg)
Successful	10.0 ± 1.1	32.2 ± 4.3	50.6 ± 6.6	41.3 ± 5.4
Unsuccessful	11.9 ± 1.8	38.6 ± 4.2	52.8 ± 3.2	44.2 ± 2.7

3.2.4. Discussion

Previous reports have shown that body structure and morphological characteristics are very important determinants of performance in many sports. Results of novel kinanthropometric research have tended to suggest that certain physical impressions such as body composition (body fat, body mass, muscle mass) and physique (somatotype) could significantly influence athletic performance (Carter, 1984). The knowledge of the physical characteristics of handball players could provide insight into those morphological factors which influence performance of the players' skills.

Kinanthropometric characteristics are very relevant for handball players because the game of handball entails physical contact in which specific physiques with a high level of strength and power may provide an advantage. The physical characteristics of handballers play an important part in the choice of players to implement the game plan. The most striking comparison of kinanthropometric make-up of handball players in the present study was between backs, centres and wings. On average the backs were taller than the centre and the wings, probably because most teams use the backs to score from outside the 9 m area.

The values for muscle mass were not exceptional, being slightly below the average 58.4 ± 5 % for the 48 competitive sportsmen measured by Coldwells et al. (1993) The more muscular make-up of the successful players would give them an advantage in contesting possession of the ball whilst the greater fat free mass would imply greater economy in moving body mass vertically to jump for the ball and in running around the court. In this investigation Kuwaiti players had higher muscle mass than all the groups but their ranking in the unsuccessful teams means that muscle mass did not affect the performance of Asian handball players, based at least on success in this tournament.

In the present study the Japanese had the lowest sum of skinfolds (28.8 ± 5.3 mm) and along with the Chinese had a group mean of less than 10% body fat. This is compatible with values reported for endurance athletes (Carter and Heath, 1990), but higher than the 7.8 ± 1.2 % recorded for 131 elite Nigerian players (Mathur et al., 1985). The extent to which their race affected the estimation of body fat in the Nigerian handballers cannot easily be determined.

In comparison with the study by Jeschke and Haber (1995) of European handball players during the world championships in 1995 in Iceland, the average height of the European handball players was 190.7 cm and the mean value of body mass was 89.3 kg. They reported that there were significant differences in height and body mass between the continents' players; however, Europeans were represented by a large number of teams participating, while Asia, Africa and Pan-America had very few teams. It was concluded that European players were mostly taller and heavier than Asian and African players. It seems that the excellent playing standard of Egypt and Korea has been reached through high technical and tactical performance rather than body size. The results of the present study showed that the mean height (183.20 ±7.3 cm) and body mass (82.2 ± 9.6 kg) values were lower than in the Asian players than are found in European handball players.

In conclusion, the main observations in this study were:- i) There was a significant differences between Asian teams in kinanthropometric characteristics; therefore the East Asia group was taller and had less adiposity than the West Asia group. ii) In consideration of the players' position, the Asian handball teams were homogenous in kinanthropometric characteristics. iii) There were no differences between successful and unsuccessful teams in body mass and muscle mass, but the successful teams were taller and had lower % body fat and less adiposity than the unsuccessful players, demonstrating that height did play a role in successful performance in the handball tournament of the Asian Games. iv) The results of this study showed that percent body fat was compatible with observations in endurance athletes in previous studies. v) Finally height and body mass in the present study of Asian players were lower than in the European handball players studied previously.

3.3. KINANTHROPOMETRIC PROFILE OF ASIAN FEMALE HANDBALL PLAYERS

3.3.1. Introduction

Due to the success of the men's handball at the Munich Olympic Games in 1972, women's handball was included in the Montreal Olympic Game programmes in 1976 and handball became one of the most popular team sports of the games. Therefore the International Olympic Committee increased the number of women's teams in the handball tournament to ten teams for the 2000 Olympic Games in Sydney.

Similar to soccer, basketball, volleyball, and hockey, handball calls for intermittent activity of varying intensities from walking to sprinting and jumping. The game for women is the same as for the men in that it consists of two 30 min halves with a half-time break of 10 min. The physiological fitness required to complete 60 min of competitive play and to achieve success at international level, includes a good aerobic and high anaerobic capacity. The women's handball game is intermittent in activity demands which are continuously adapted to different offensive and defensive situations. Kinanthropometric profiles contribute to the suitability of players for the sport of handball at a high level of play. The requirement for a significant correlation between kinanthropometric profile and game demands may be more acute in women than in male players in view of the more recent development of the game for women. Hirata (1979) described the kinanthropometric basic parameters of height and body mass for women handball players at the Montreal Olympic Games and found that the players in the medal-winning teams were taller than the others. Thus the importance of height for success in handball was illustrated. It is unclear whether this feature of successful women players still obtains.

The purpose of this study was to establish kinanthropometric characteristics of female handball players in the Asian handball championship during the 12th Asian Games and identify any positional variation between players from four different countries. The measurements taken were age, height, body mass, skinfold thickness and estimation of percentage body fat and muscle mass.

3.3.2. Methods

3.3.2.1. Subjects

Sixty players in the 12th Asian Games in Hiroshima participated from the following teams; 14 players were from China (age 21.0 ± 3.0 years), 16 players from Japan (age 24.0 ± 2.0 years), 14 players from Kazakhstan (age 23.0 ± 4.0 years) and 16 players from South Korea (age 21.0 ± 2.0 years). South Korea won the championship with China second, Japan third and Kazakhstan fourth.

3.3.2.2. Procedures

Measurements were made of height, body mass, skinfold thicknesses and estimated muscle mass. The measurements were performed using the same standard procedures as employed when measuring the elite male players. Similarly, the estimating of percent body fat and muscle mass was completed according to Durnin and Womersley (1974) and Martin et al. (1990).

3.3.2.3. Statistical analyses

The statistical analyses of data were carried out using analyses of variance one-way (ANOVA). Levene's test was first carried out to examine the homogeneity of variances Tukey-HSD post hoc method was applied when an F statistic indicated a significant difference to determine which of the ordered means were significantly different from each other. Statistical significance was set at the $P < 0.05$ level.

3.3.3. Results

Analysis of variance demonstrated significant differences between teams in age ($F_{3, 56} = 3.99$; $P < 0.05$), height ($F_{3,56} = 2.92$; $P < 0.05$), body mass ($F_{3, 56} = 3.06$; $P < 0.05$), muscle mass ($F_{3, 56} = 7.54$; $P < 0.05$) estimated percentage body fat ($F_{3, 56} = 7.54$; $P < 0.05$) and adiposity ($F_{3, 56} = 7.54$; $P < 0.05$). In comparing the teams, Chinese and Korean players were the youngest, but the Chinese players were tallest and they had greatest muscle mass. The Japanese players were shortest, lightest and they had least percentage body fat and adiposity but the Kazakhstan players were the oldest and heaviest and the Korean players had higher percentage body fat and greater adiposity values (see Table 3.3.1 and 3.3.2).

Table 3.3.1. Characteristics of female handball players according to the nationality (China = 14, Japan = 16, Kazakhstan = 14, Korea = 16 players)

Country	Age (years)	Height (cm)	Body mass (kg)
China	21.0 ± 3.0	174.6 ± 3.5	64.8 ± 6.1
Japan	23.0 ± 2.0	168.1 ± 7.4	60.6 ± 5.7
Kazakhstan	23.0 ± 4.0	171.9 ± 9.0	68.7 ± 11.5
Korea	21.0 ± 2.0	169.4 ± 5.0	64.7 ± 4.7
Mean (SD)	22.2 ± 2.9	170.8 ± 6.8	64.6 ± 7.7

Table 3.3.2. Body composition of female handball players according to the nationality (China = 14, Japan =16, Kazakhstan = 14, Korea = 16 players)

Country	Body fat (%)	Sum 5 skinfold (mm)	Muscle mass (%)	Muscle mass (kg)
China	18.9±3.0	45.0±9.7	41.8±5.7	27.1±3.7
Japan	18.5±4.0	42.2±10.9	37.2±4.0	22.5±2.4
Kazakhstan	21.4±5.5	56.2±21.9	41.3±6.4	28.4±4.4
Korea	24.2±2.2	62.5±8.6	38.7±4.0	25.0±2.6
Mean (SD)	20.8 ± 4.4	20.8 ± 4.4	39.6 ± 5.2	25.5 ±3.3

When the teams were divided according to the players' positions (for Korea, Japan, China and Kazakhstan) into goal-keeper, back, centre and wing, one-way analyses of variance revealed no significant difference in age, height, body mass percentage body fat, adiposity and muscle mass (P >0.05). This demonstrates that a female handball team is relatively homogeneous in kinanthropometric make-up and body composition and without any unique requirements other than the skills for positional roles, same as for the male teams (see Table 3.3.3 and 3.3.4).

Table 3.3.3. Characteristics of female Asian handball players according to their position of play (G.Keeper = 11, Back = 24, Centre = 13, Wing = 12)

	Age (year)	Height (cm)	Body mass (kg)
G.Keeper	23±2.1	175.8±1.9	68.3±6.3
Back	22±1.4	169.3±2.9	62.2±2.1
Centre	23±4	171.8±4.4	66.9±4.5
Wing	21±2	170±8.3	63.5±7.9

Table 3.3.4. Body composition of female handball players according to their position play (G.Keeper = 11, Back = 24, Centre = 13 and Wing = 12)

Position	Body fat (%)	Sum 5 skinfolds (mm)	Muscle mass (%)	Muscle mass (kg)
G.Keeper	23.3±2.8	56.±11.9	42.6±3.7	29.1±2.5
Back	19.4±2.4	49.7±9.4	38.8±3.7	24.1±2.3
Centre	20.6±3.0	50.9±9.8	40.5±2.5	27.1±1.7
Wing	21.8±2.9	52.4±7.8	38.3±4.0	24.3±2.5

Plate 3.3.1. Measurement of body mass for one of the Asian women handball players (Hydraulic scales, Jonelle)

3.3.4. Discussion

The present findings may be compare with data cited by Reilly et al. (1990) who in their review reported that the Japan's women gold medallists at the Montreal Olympic Games of 1976 ranged in height from 169 cm to 180 cm. Puhl et al. (1982) and Fleck et al. (1985) reported that elite female volleyball and basketball players had a comparatively low percentage body fat i.e. 11.7 - 18.3% and 15.4 - 20.1%, respectively. However, Spurgeon et al. (1980) found higher body fat percentages (i.e. 21.4-25.7% and 15.5 - 26.9%) for volleyball and basketball, respectively. In comparing kinanthropometric and body composition data of male and female handball players from China, Japan and Korea, Chinese men and women were found to be taller than those from the other countries (see section 3.2). This may be the result of a systematic sports selection process in China.

A limitation of the comparisons of muscle mass is that the prediction of muscle mass was based on the approach of Martin et al. (1990) whose formula was derived from measurements on male cadavers, although the increase in the error of prediction is unknown. Nevertheless, the method can be applied to females as well as males. Several methods are based on the geometric model of extremity girth describing a circle and single skinfold as representative of a constant subcutaneous layer overlying a circular muscle mass. A simple formula predicts the skinfold combined with muscle and bone tissue (Hawes, 1996), as follows:

$$\text{Muscle and bone area} = \pi\,[(\,c / 2\pi\,) - (SF / 2\,)]^2$$

where c = girth measure (cm), SF = skinfold (cm).

Consequently, the effects of gender on the relative thickness of subcutaneous adiposity is taken into account.

Hlatky et al. (1993) examined 38 women handball players from the best handball teams in three European countries Austria, Norway and Lithuania. They found that the difference between the groups in the mean value for body mass and height was negligible; they concluded that top-class women handball players have an average height of between 174 to 176 cm and an average body mass of between 70 to 72 kg. The present study showed that the mean height value for Asian women was 170.8 cm and the mean value of body mass was 64.6 kg. For the Olympic Games in Montreal in 1976, the average height was 171.9 cm and the average body mass was 67.3 kg of the three winning women handball team players (Khosla and McBoom, 1984). In a comparison between the two studies, Hlatky et al. (1993) found that top-class women handball players were heavier 2.7 kg and taller 3.4 cm than women handball players at the Olympic Games in Montreal. Therefore Asian women handball players were shorter and had less body mass than European players, even though the Korean team was the winner of the last world championships and second during the Olympic Games in Atlanta 1996.

The female handballers can be compared to normal average college women according to their mass and their height. The mean body mass for mean height comes within the normal range for USA college women based on tables published by Fox et al. (1993). This likely means that their lower than normal percent body fat was compensated for by a higher than average muscle mass.

It seems that elite female handball players are homogeneous in kinanthropometric measurements. Chinese women, like their male counterparts, were the tallest among all the countries studied, and the Korean men and women players had the highest percentage body fat. When comparing players by position, the study showed no influence of positional role for either the women or the men.

One way of establishing whether either the males or females are kinanthropometrically unique to the sport of handball is to compare the two groups to the unisex phantom of Ross et al. (1980). The phantom values for height and body mass were 170.18 cm and 64.58 kg. The Asian players may be compared to the reference phantom by means of the formula previously described by Ross and Wilson (1974):

$$z = \frac{1}{s}\left[v \left(\frac{170.18}{h} \right)^{d} - p \right].$$

S is the standard deviation from a hypothetical human population for variable (V);

P is the designated phantom value for that variable;

The ratio 170.18/ h scales subjects stature (h) to the phantom stature constant;

D is a dimensional exponent (for stature D = 1, for mass D = 3)

The results of this comparison are shown in Table 3.3.5 expressed as distance from the phantom value comparison. When the comparison was made, height and body mass in female handball players were nearer to the values reported by Ross et al. (1980) than were the male players. These results fulfilled aim 1 and indicate that the females demonstrated a more unique kinanthropometric make-up than their male counterparts. The shift in body composition of the females to a higher muscle mass and a lower adiposity compared to reference values may be linked with their sports specificity.

Table 3.3.5 The difference in mean values (±SD) between the Asian handball players and the Phantom values in height and body mass.

Handballers	Body mass (kg)	Height (cm)
Men	18.2±9.3	13.9±6.5
Women	-0.01±7.7	0.65±6.8

In summary the main observations in the female handballers were as follows:- i) There was significant difference between Asian female teams in kinanthropometric characteristics. ii) Female handball players in Asia were homogeneous in kinanthropometric make-up and body composition irrespective of the players' position. iii) The Asian female handball players were shorter and had less body mass than reported for the European handball players. iv) The mean mass for mean height of female handball players was within the normal range of USA college women.

3.4. FITNESS PROFILE OF ENGLISH AND KUWAIT MALE HANDBALL PLAYERS

3.4.1. Introduction

As explained earlier, handball is a team game similar to basketball and other games which are played by hand. It is distinct from soccer more notably in the use of the hand and it played on a 40 × 20 m court for the 60 min duration with a small ball which must have a circumference of 58 - 60 cm and 54-56 cm for men and women, respectively and a weight of 425-474 g and 325-400 g for men and women, respectively (International Handball Federation, 1997). The handball game is characterised by a high frequency of physical contact, the modes of tackling, the means of winning the ball, playing position and scoring. Therefore, game performance relies on tactical issues, interplay of individuals in tactical moves, the competence of players in the skills of catching, passing, tackling, jumping and scoring and also factors specific to playing position. The game skills require a combination of fast reactions, speed, agility, muscle strength, anaerobic and aerobic power. The pace of the game is fast but variable, with sudden accelerations (involving anaerobic processes) followed by periods of static inactivity during recovery or by low intensity locomotion. Very few studies have been reported in the literature which have concentrated on handball activities, task analysis and work-rate, duration of walking, jogging and sprinting and or on the fitness profile of handball players.

The purposes of this study were (1) to investigate the physiological demands of handball play; (2) to obtain fitness profiles of both English and Kuwaiti national handball players (3); to estimate the energy expenditure during training and matches from the HR-VO_2 relation established during measurement of the actual $VO_{2\,max}$.

In the first instance it was necessary to establish the maximal aerobic power (VO_{2max}) of national level players. The HR-VO_2 relation could be determined during test measurements of responses to the incremental test used to elicit $VO_{2max.}$ The VO_{2max} test was complemented by a battery of tests to provide fitness profiles.

3.4.2. Methods

Thirty eight subjects volunteered to participate in the study. They included eight English handball players of the North West national squad (mean age 20.0 ± 2 years), seventeen Kuwaiti male handball players of national level (mean age 25.0 ± 3 years) and thirteen physical education students from a college of basic education in Kuwait as a control group (22.0 ± 3 years). The study protocol and procedures were approved by human Ethic Committee of Kuwait University and Liverpool Johon Moores University. Before data collection each subjects gave inform consent to the procedure following a detailed explanation of protocol and purpose of the study (see Appendix 2) Measurements were made of height, body mass, skinfold thicknesses and estimated muscle mass (see table 3.4.1 pg. 106). Hand grip strength, leg and back strength, leg power (standing long jump and vertical jump) and aerobic power (maximal oxygen consumption, VO_{2max}), VO_{2max} predicted from a 20 m shuttle run, were employed in the test battery (see Table 3.4.2).

The height was measured by means of stadiometry to the nearest 0.5 cm and a hydraulic scale (Jonelle) was used to measure body mass to the nearest 0.1 kg. Skinfolds were measured by means of Harpenden skinfold calipers using the sum of five sites, the biceps, triceps, subscapular, suprailiac and thigh (see previous section 3.2.2.). The percentage body fat was estimated by calculation the mean of three measurements taken for each site, according to Durnin and Womersley (1974). Kinanthropometric measurements used to estimate muscle mass were skinfold thickness at the front thigh, medial calf and the circumference of the forearm, thigh and calf (Martin et al., 1990) (see previous section 3.2.2.).

Hand grip strength was measured by means of a Takei (Tokyo) hand grip dynamometer to an accuracy ± 19.6 (N) in 490 (N). Leg and back strength were assessed by means of a Takei (Tokyo) dynamometer to an accuracy ± 29.4 (N) in 1470 (N). Anaerobic performance was indirectly assessed by the standing long jump measured to the nearest 1 cm and the vertical jump measured by using the Takei (Tokyo) Jump meter; its range was from 5- 99 cm and the errors in measurement ± 0 - 2 cm. The highest of three trials was accepted.

Maximal oxygen consumption (VO_{2max}) and maximal heart rate (HR) were determined to indicate the level of aerobic power of the handball players. Heart rate was recorded by short-range radio telemetry (POLAR Sport Tester, Finland) throughout the test. The predicted $VO_{2\ max}$ was measured by means of the 20 m shuttle run (Leger and Lambert 1982) with the subject being encouraged to exercise to volitional exhaustion.

To evaluate the actual maximum oxygen uptake, an incremental laboratory test (Saltin and Astrand, 1967) was performed on a motorised treadmill. The subjects began the test with 5 min warm-up at 7.5 $km.h^{-1}$ and the test speed of 10 $km.h^{-1}$ was increased by 2 $km.h^{-1}$ every 2 min at a constant elevation until the subject reached 16 $km.h^{-1}$. Thereafter the speed was kept constant and the inclination was increased 2.5 degrees every 2 min until the subjects reached voluntary exhaustion. Three of the BASES criteria (Hale et al., 1988) were required in establishing maximum oxygen uptake as follows: 1) A final respiratory exchange ratio of 1.15 or above; 2) A final heart rate within 10 beats.min^{-1} of the age-related maximum; 3) A plateau in the oxygen uptake/exercise intensity relationship, as an increase oxygen uptake of less than 2 ml.kg^{-1}.min^{-1} or 3% with an increase in exercise intensity 4) Subjective fatigue and volitional exhaustion.

Two different devices were used to determine the $VO_{2\ max}$ for the English and Kuwaiti players. During the measurement of VO_{2max} for the English players, expired air was collected continuously every 20 s for measuring VO_2 (ml.kg^{-1}.min^{-1}), and for calculating both the respiratory exchange ratio and minute ventilation (l.min^{-1}) (VE). This was done by means of an on-line metabolic analyser (SensorMedics, California). Prior to assessment of each subject, the analysers were calibrated with two gases of known percentages and the ventilation was checked by means of a 3 l syringe.

During the measurement of VO_{2max} for the Kuwaiti players, expired air was collected continuously every 30 s for measuring VO_2 and VCO_2 (ml.kg^{-1}.min^{-1}), respiratory exchange ratio, minute ventilation (l.min^{-1}) (VE). This was done by using an automated Quinton Q-plex 1 system, manufactured by Quinton Instrument Co (Washington USA). Gas analysers were automatically calibrated using room air and the calibration gases, Lo cal and Hi cal gas mixtures (Lo cal contains 0% CO_2 , 10%O_2 and 90% N_2 and Hi cal contains 5% CO_2, 25% O_2 and 70% N_2). A Quinton - Q65 motorised treadmill was used. Heart rate was measured by monitoring of a 12- lead ECG using Quinton Q5000 manufactured by Quinton Instruments Co (Washington, USA)

3.4.2.1. Statistical analyses

The statistical analyses of data were carried out using one-way analyses of variance (ANOVA). Levene's test was first carried out to examine the homogeneity of variances. Tukey-HSD post hoc method was applied when an F statistic indicated a significant difference to determine which of the ordered means were significantly different from each other. Statistical significance was accepted at the $P < 0.05$ level.

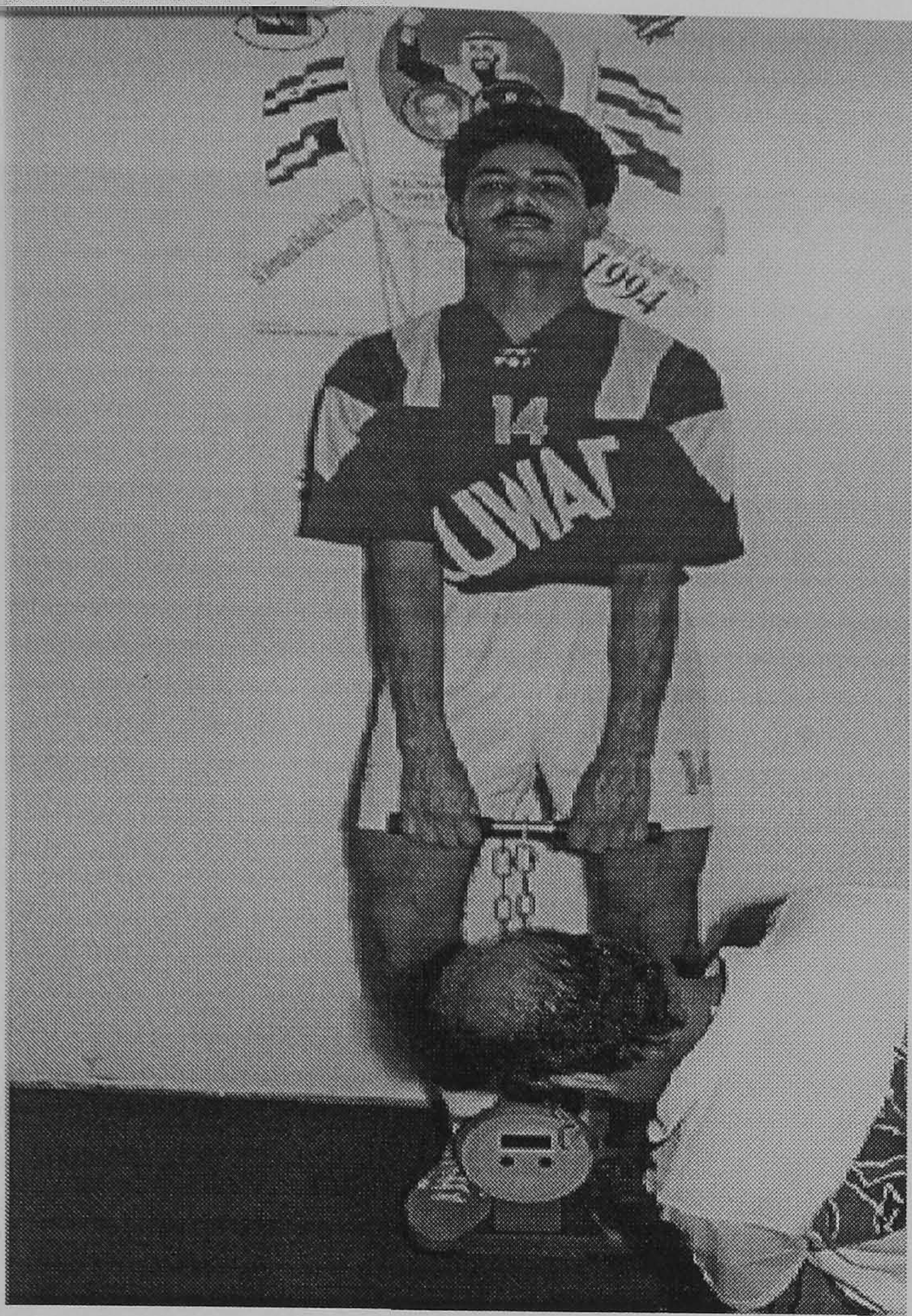


Plate 3.4.1. Measurement of leg strength for one of the Kuwaiti handball players (Takei instrument Tokyo)

Plate 3.4.2. Measurement of standing long jump anaerobic performance for one of the Kuwaiti handball players (Scaled gymnastic mattress)

Plate 3.4.3. Assessment of VO_{2max} in one of the Kuwaiti handball players (Quinton Q-plex 1 and Quinton Q65 treadmill)

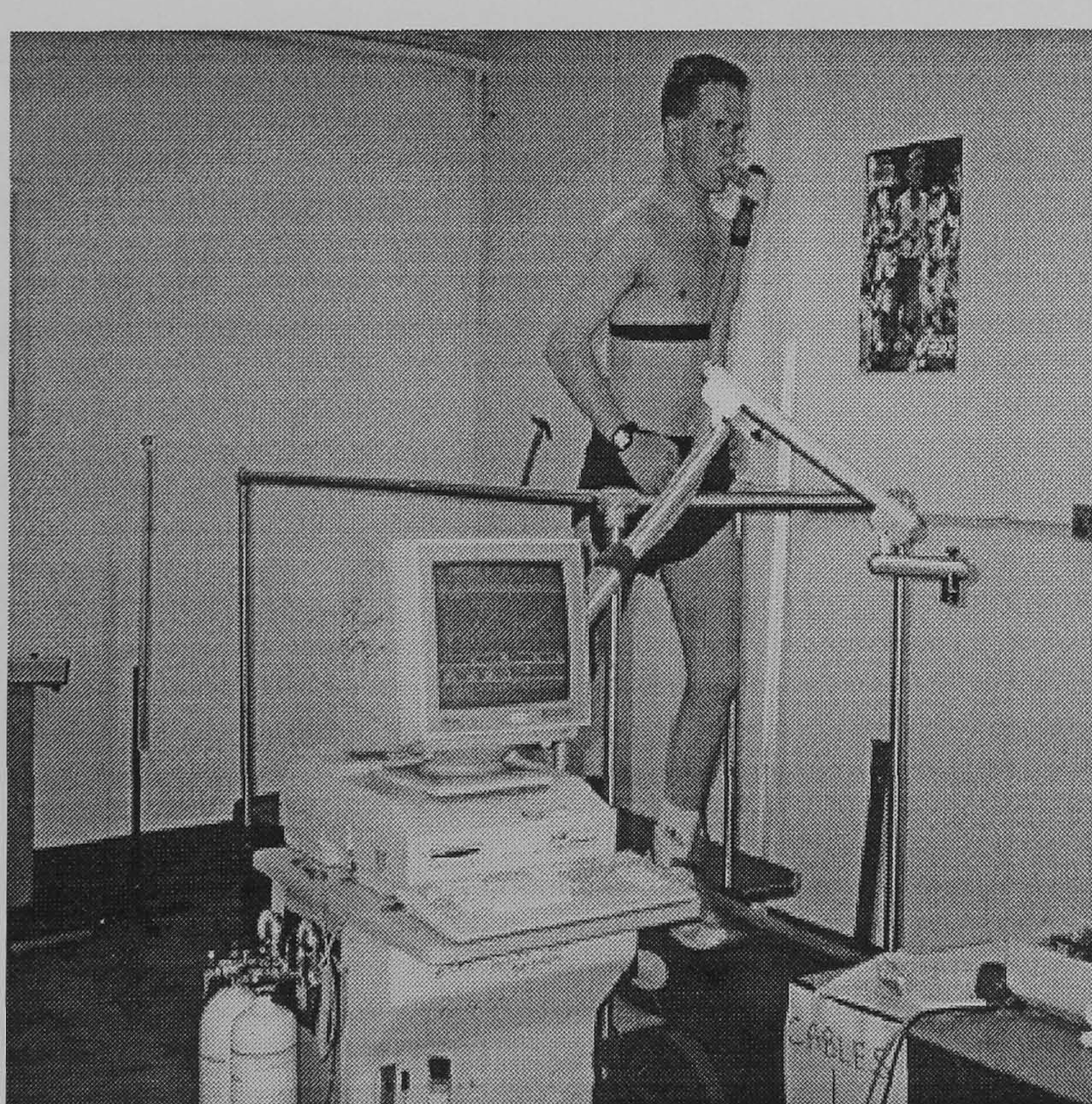


Plate 3.4.4. Assessment of VO_{2max} in one of the English handball players (SensorMedics 2900, California)

3.4.3. Results

The mean and standard deviation values for kinanthropometric characteristics, anaerobic and aerobic variables are presented in Tables 3.4.1, 3.4.2 and 3.4.3. for the English, Kuwait handball players and control group. The analysis of variance (ANOVA) demonstrated a significant difference between the English, Kuwaiti players and the control group in age ($F_{2,35}$ = 9.1; P <0.001), height ($F_{2,35}$ = 13.69; P <0.001) and body mass ($F_{2,35}$ = 10.4; P <0.001). The mean age, height and body mass of English players and the control group were significantly lower than that of the Kuwaiti handball players. The Kuwaiti players were significantly the older, taller and heavier. Muscle mass was also significantly different between the three groups ($F_{2,35}$ = 5.2; P <0.05); Kuwaiti players had more muscle mass than the English players and the control group. The percent body fat was not significantly different (P >0.05) between the English, Kuwaiti handball players and the control group (13.4 ± 5.1%, 12.9 ± 4.3% and 12.9% ± 4.2%), respectively.

The data for hand grip strength showed there was no significant difference (P >0.05) between English (518± 99 N and 475 ± 83 N), Kuwait handball players (556 ± 92 N and 501 ± 77 N) and the control group (494 ± 72 N and 494 ± 6.0 N) for right and left hand respectively. Similarly there were no significant differences in leg and back strength between the English and Kuwaiti players. However, the control group had higher leg and back strength; this high result was probably due to errors during the measurement because the measurements for this group were undertaken by inexpert helpers. Long jump (166.3 ± 33.7, 237 ± 23.9 and 212. ± 0.2 cm) and vertical jump (56.3 ± 6.04, 70.0 ± 7.5 and 66.5 ± 6.8 cm) performances were compared for English, Kuwaiti players and the control group, respectively; the difference was highly significant for long jump ($F_{2,35} = 19.93$; $P < 0.001$) and vertical jump ($F_{2,35} = 10.56$; $P < 0.001$), the Kuwaiti players achieving higher values in both long and vertical jump tests than the English and the control group. Furthermore, the control group had higher long and vertical jump than the English players.

Maximum heart rate was 197 beats.min^{-1} for English players, 176 beats.min^{-1} for Kuwaiti players and 182 ± 12 beats.min^{-1} for the controls, with the difference significant ($F_{2,35} = 11.1$; $P < 0.001$). The Kuwaiti players had lower maximum heart rates than the English players and the reference control group, also lower heart rates at rest 71± 6 beats min^{-1}, 82 ± 10 beats. min^{-1} and 72 ± 8 ($F_{2,35} = 5.7$; $P < 0.05$). There was a significant difference ($F_{2,35} = 3.6$; $P < 0.05$) in predicted maximal oxygen consumption between the reference group (53.5 ± 7.5 ml.kg.min^{-1}) and English (49.2 ± 6.3 ml.kg.min^{-1}) and Kuwaiti players (47.2 ± 5.3 ml.kg.min^{-1}); the reference group had higher predicted maximal oxygen consumption than the two handball teams, but there was no significant difference between English and Kuwaiti players. There was no significant difference in actual VO_{2max} ($F_{2,35} = 1.9$; $P > 0.05$) between English players (51.04 ± 5.5 ml.kg.min^{-1}), Kuwait players (47.02 ± 3.62 ml.kg.min^{-1}) and the reference control group (47.18 ± 6.33 ml.kg.min^{-1}). There was no difference between the two handball teams, even though the Kuwaiti players were preparing for the world handball championship and it was expected that they would have higher values of physiological fitness than the English team.

Table 3.4.1. Mean ± SD of kinanthropometric characteristics of English (n = 8), Kuwaiti handball players (n = 17) and the control group (n = 13)

	Age (years)	Height (cm)	Body mass (kg)	Body fat (%)	Muscle mass (%)
English	20.0 ± 2.0	174.2 ± 5.4	77.5 ± 11.50	13.4 ± 5.1	47.8 ± 8.0
Kuwait	25.0 ± 3.2	181.7 ± 4.9	87.70 ± 10.40	12.9 ± 4.3	55.3 ± 10.5
Control	22.0 ±3.0	172.1 ± 5.5	70.9 ± 8.70	12.9 ± 4.2	44.5 ± 8.2

Table 3.4.2. Mean ± SD of anaerobic measurements of English (n = 8), Kuwaiti handball players (n = 17) and control group (n = 13).

	Strength (N)				Performance	
	R. hand	L. hand	Leg	Back	L.jump (m)	V.jump (cm)
English	518 ± 99	475 ± 83	2060 ± 424	1390 ± 393	1.66 ± 0.3	56.3 ± 6.0
Kuwait	556 ± 92	501.± 77	1804 ± 463	1533 ± 359	2.37 ± 0.2	70.0 ± 7.5
Control	494 ± 72	494.4 ±6.0	3372 ± 925	2618 ± 376	2.12 ± 0.2	66.5 ± 6.81

Table 3.4.3. Mean ± SD of aerobic measurements of English (n = 8), Kuwaiti handball players (n = 17) and control group (n = 13).

	Heart rate (beats.min^{-1})		Actual $VO_{2\ max}$		Predicted $VO_{2\ max}$
	(rest)	(max)	(ml.kg^{-1}.min^{-1})	(l.min^{-1})	(ml.kg^{-1}.min^{-1})
English	82 ± 9.6	198 ± 9.7	51.0 ± 5.5	3.9 ± 0.4	49.2 ± 6.3
Kuwait	71 ± 6	176 ± 9.1	47.0 ± 3.6	4.1 ± 0.3	47.2 ± 5.3
Control	72 ± 8	182 ± 12.8	47.2 ± 6.3	3.3 ± 0.6	53.5 ± 7.6

3.4.4. Discussion

The kinanthropometric characteristics of Kuwait elite handball players studied were significantly different from those of a group of English handball players and a control group of non-handballers. The Kuwaiti players used in this study were representative of elite handball within Kuwait, but the English players could be more appropriately classified sub-elite players. The Kuwaiti players were significantly older, taller, greater body mass and had more muscle mass than the English players and the reference control group.

There were no significant differences in hand grip strength between the two handball teams. The grip strength was similar to that of English league professional soccer players reported by Reilly (1997) for whom the mean value was 494.4 ± 11.77 N or Japanese professional soccer players whose average was 510.1 N. Also leg and back strength were not significantly different between the English and Kuwaiti handball players. However, the Kuwait players had higher (1533.3 N) and the English handball players had lower (1390.8 N) values than the average back strength of Japanese international soccer players (1459.9 N) which was equivalent to results obtained for 20-year olds in the general Japanese population.

The Kuwaiti players had the better long jump (2.37 ± 0.2 m to 1.66 ± 0.3 m) and vertical jump (70.0 ± 7.5 cm 56.3 ± 6.0) performances (Figure 3.4.1. p 107). Therefore, the poorer performance in the power test (vertical and standing long jump) in the English players suggests lower muscularity than the Kuwaiti players. These differences reflect the systematic training and competition of handball players in Kuwait, which is not always available to English handball players. In Gaelic football the players use their hands both to catch the ball high in the air and play it to a team-made; it therefore offers a convenient comparison with handball. When comparing the data obtained in this study with the English elite Gaelic football players tested by Keane et al. (1997) (Figure 3.4.1)in vertical and long jump, the Gaelic football players had a superior long jump than the English and Kuwaiti handball players (2.44 ± 0.21 m to 1.66 ± 0.3 m and 2.37 ± 0.2 m respectively), while Kuwaiti handball players had higher vertical jump performance than the English handball and the Gaelic football players (70.0 ±7.5 cm to 56.3 ± 6.0 cm and 58.4 ± 6.4 cm). Also Kuwaiti players had higher vertical jump than the Australian Soccer World Cup team (50 cm) and the English League professionals (58 cm) (Figure 3.4.2.) reported by Reilly (1990). This comparison indicates that the elite handball players had superior vertical jump than Gaelic football players and soccer players; this is probably due to the game skills and requirements for success in the match. The match style in the handball game requires players to jump vertically to catch the ball and to deliver the ball powerfully to get a goal.

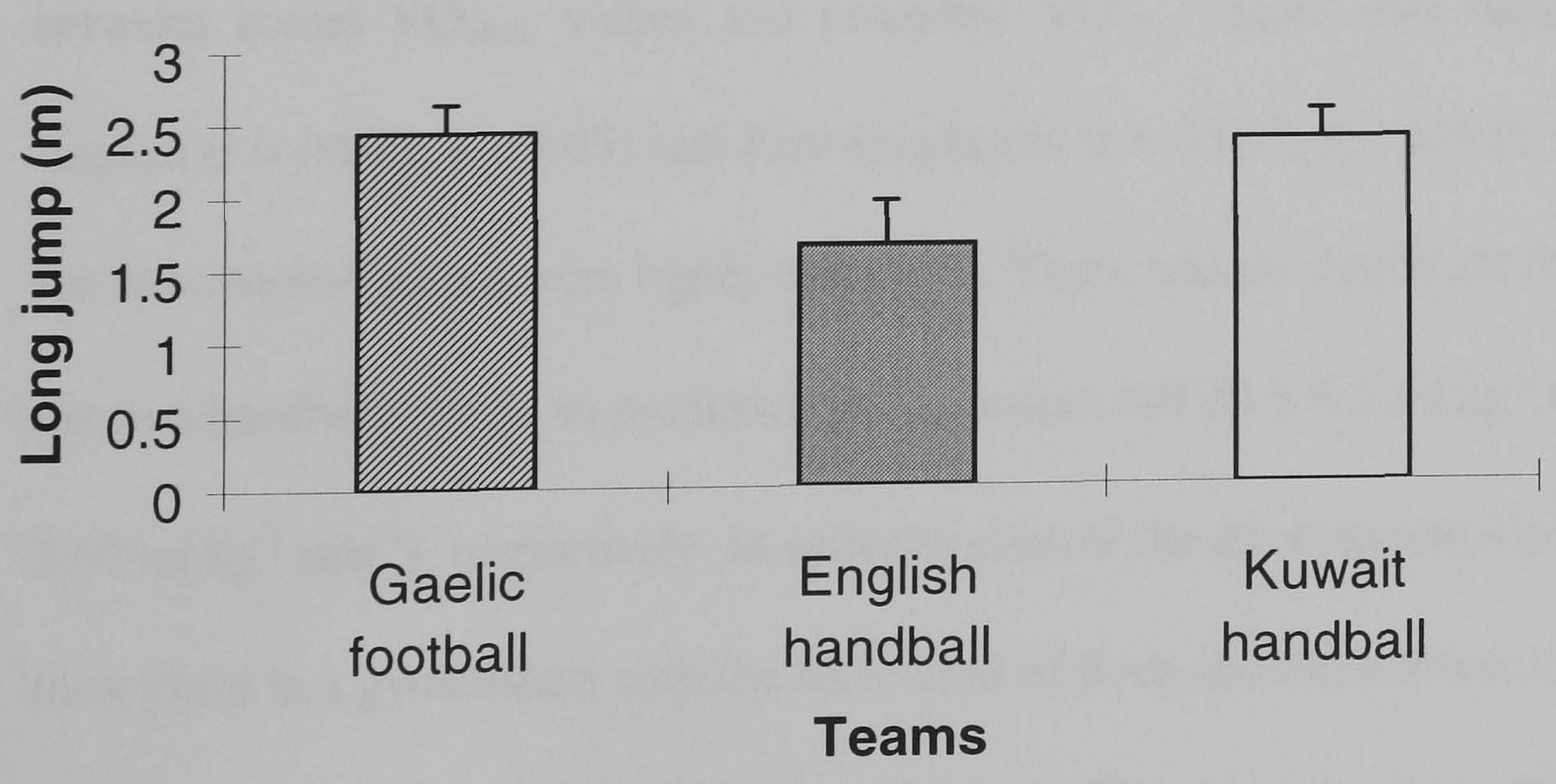


Figure 3.4.1. Mean (± SD) differences in long jump between English, and Kuwaiti handball players and Gaelic football players (Keane, 1997)

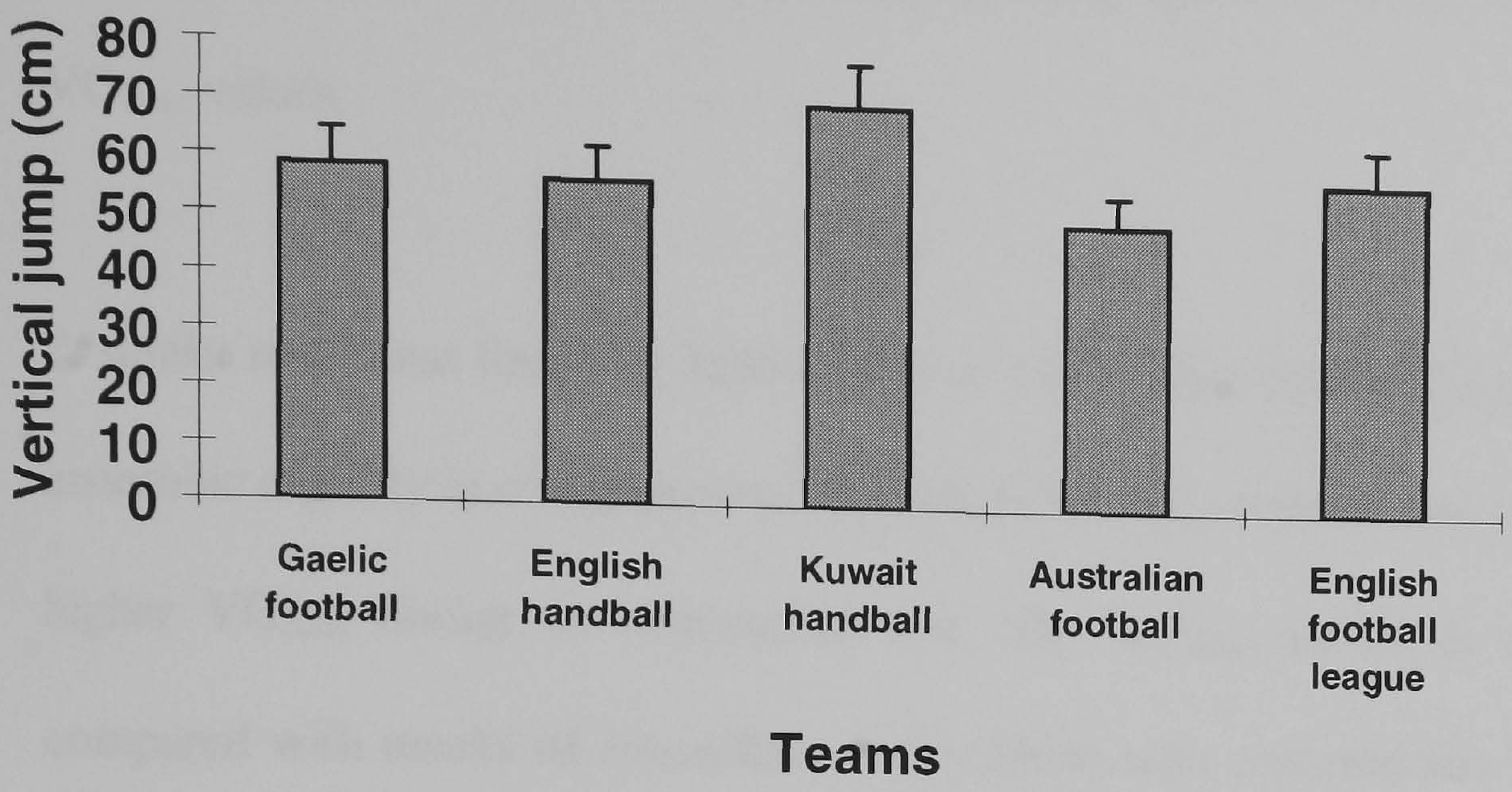


Figure 3.4.2. Mean (± SD) differences in vertical jump between three sports groups (English and Australian football), handball players (English and Kuwaiti) and Gaelic football players.

The maximal oxygen consumption representative of elite sport was evident in the handball players tested for this research. The data showed that there was no significant difference in absolute $VO_{2\,max}$ between the English (51.04 ± 5.46 $ml.kg^{-1}.min^{-1}$) and Kuwait (47.24 ± 5.31 $ml.kg^{-1}.min^{-1}$) handball players. The common calibration routines would have made any differences due to the analytical machines highly unlikely. The correlation analysis between actual VO_{2max} values and predicted VO_{2max} values was highly significant for English ($r = 0.973$; $P < 0.05$) and Kuwaiti players ($r = 0.937$; $P < 0.001$); this suggests that the two measurements were highly correlated. There was no significant difference between the two handball groups in predicted VO_{2max} values (49.20 ± 6.3 $ml.kg^{-1}.min^{-1}$ and 47.02 ± 3.62 $ml.kg^{-1}.min^{-1}$), respectively. In order to control the environmental conditions, all tests took place in a gymnasium with the same kind of floor and the ambient temperatures were 18 ± 2 °C in England in summer time and 20 ± 2 °C in Kuwait where the gymnasium was air-conditioned. The order of testing was the same on each occasion and all players were well familiarised with the experimental methods used in the present study. The Kuwaiti players were preparing for the World Championship and were expected to have the higher VO_{2max} values.

A similar result was found by Jaskolska et al. (1990) that handball players were similar in anaerobic capacity in comparison to Physical Education students, but handball players had higher VO_{2max} during an incremental test. The VO_{2max} values in this study may be compared with results of Jousselline et al. (1984) who reported the VO_{2max} of handball ($57.2 \pm 5.$ $ml.kg^{-1}.min^{-1}$) and soccer players (63.9 ± 5.5 $ml.kg^{-1}.min^{-1}$). However, VO_{2max} values of the handballers monitored in this thesis were lower than those of Jousselline et al. (1984). Therefore, it is likely that the handball players in this study had concentrated more in their training on anaerobic power rather than aerobic power, whereas the soccer players had concentrated on both aerobic and anaerobic power.

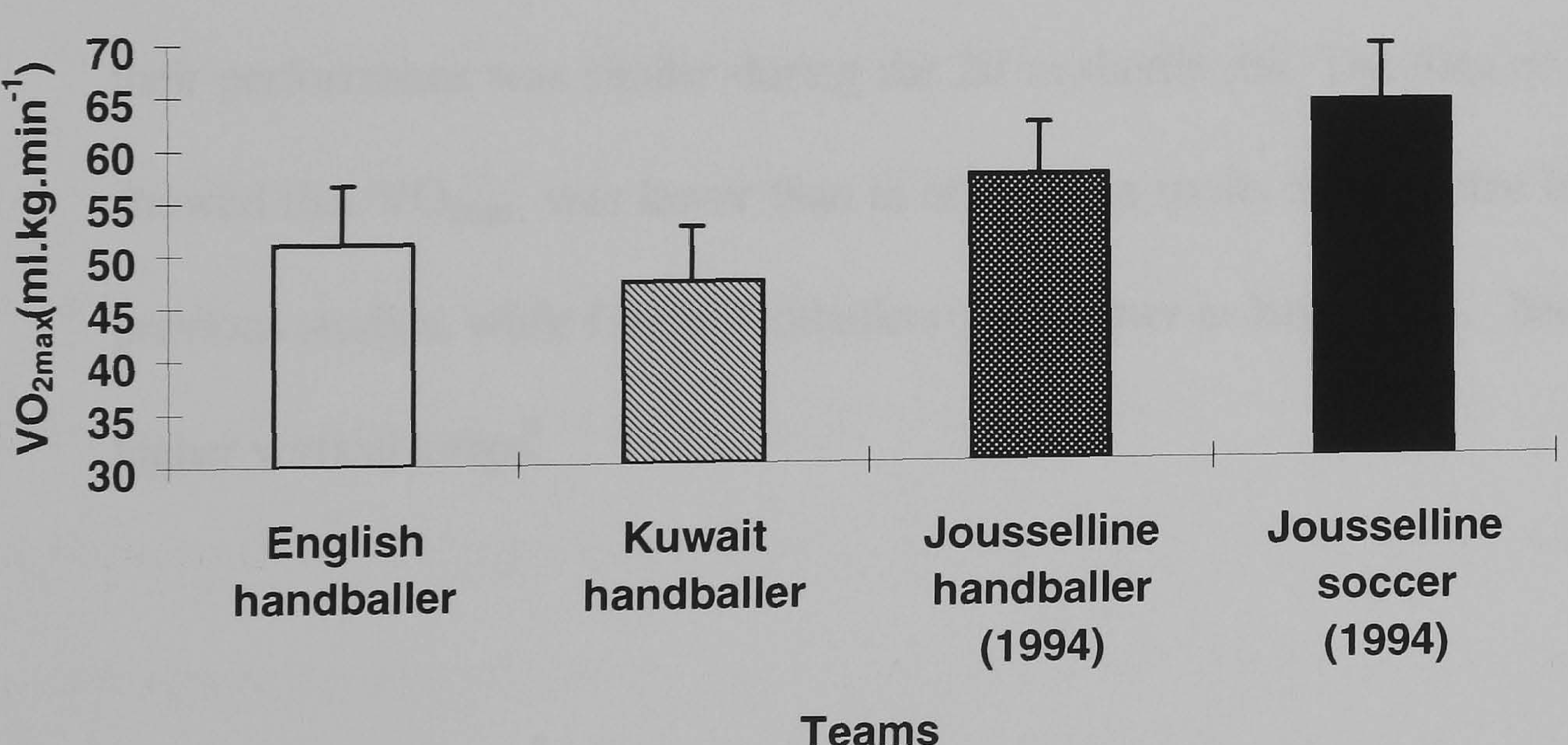


Figure 3.4.3. The difference in mean VO_{2max} between handball and soccer players.

The measured VO_{2max} values did not differ significantly from those estimated from performance in the 20 m shuttle run. This means that the shuttle run can be used with confidence in field testing of handballers. This indicates that the handball players had similar VO_{2max} values irrespective of the test modality .

The Kuwaiti players also had lower resting heart rates and maximum heart rates. They showed only slightly lower aerobic fitness than the English players during the actual VO_{2max} test but were similar in VO_{2max} when estimated by the mean of 20 m shuttle run.

In conclusion, the data of the present study showed that the Kuwaiti handball players were larger in body high and mass than the English players and the control group. The two handball teams were similar in upper muscular strength, but the Kuwaiti players did significantly better in lower limb muscle performance (in long jump and vertical jump). Maximal aerobic power did not differ significantly between the two handball teams and their performance was similar during the 20 m shuttle run. The data of the present study showed that VO_{2max} was lower than in other team sports and for elite handball players in previous studies, while Gaelic footballers were better in long jumps, handball players had higher vertical jumps.

3.5. HEART RATE OF ELITE MALE HANDBALL PLAYERS DURING NON-OFFICIAL MATCHES AND TRAINING SESSION

3.5.1. Introduction

The heart rate has for many decades been employed as an index of physiological response. In earlier studies heart rate has been recorded after the end of full games or during friendly games of soccer (Reilly and Thomas, 1979). It has been stated by several investigators that heart rate measured immediately after a game does not reflect the mean heart rate during the game of basketball (Ramsey et al., 1970). The development of lightweight electronic devices to record and transmit impulses by radio telemetry has facilitated the study of different physiological responses during recreational activities and competitive athletic events such as individual sports and team games. Several researchers have used telemetred heart rate recordings for assessing work load during match-play in different sports such as basketball (McArdle et al., 1971), Gaelic football (Florida-James and Reilly, 1995), handball (Soares, 1988) and soccer (Reilly and Thomas, 1979; Van Gool et al., 1983 Reilly 1986; Rohde and Espersen, 1988; Bangsbo, 1993). Most of the researchers mentioned above have provided heart rate data for the players during training and friendly matches. Also over the last two decades a for expression scientific data has been accumulated regarding the physiological characteristics of the individual athlete, and the physiological demands of a specific athletic event. These types of information have been useful for the selection of athletes, and also for the improvement of sport techniques and training methods.

Generally speaking, most ball games, including handball, represent intermittent physical exercise with frequent interchanges of short bursts of physical effort interspersed with brief stoppages. The energy expenditure in sports has been assessed by various methods. Several techniques such as heart rate telemetry have been used as a means of estimating energy expenditure, indirectly rather than directly collecting expired air and analysing content for oxygen (O_2) and carbon dioxide (CO_2). It is obvious that the latter techniques may interfere with locomotion patterns during play.

Use of heart rate to estimate energy expenditure during games has been used by some investigators (Bangsbo, 1994b; Reilly and Thomas, 1979). For each person, heart rate and oxygen uptake tend to be linearly related throughout a wide range of aerobic exercise intensities. If this precise relation is known, the average heart rate for the match can be used to estimate oxygen uptake (and then to compute energy expenditure from the respiratory exchange ratio) during the game. This method has been used when the oxygen uptake could not be measured during the game.

Heart rate measurement is the simplest and most extensively used method for the estimation of energy expenditure during exercise. Therefore the present study was designed to measure heart rate during non-official handball matches and training sessions using short range radio telemetry and estimate energy expenditure from heart rate. This required establishing a regression line relating heart rate to VO_2 during the incremental exercise test used to elicit VO_{2max}. Heart rate values obtained were employed to design a laboratory-based exercise protocol similar in physiological demands to a handball match in order to examine the effect of heat exposure and carbohydrate supplementation on selected physiological and metabolic indices.

3.5.2. Materials and methods

In this study the method entailed monitoring heart rate continuously during handball matches and training sessions. Then heart rate was related to oxygen consumption by means of individually determined regressions of heart rate on oxygen consumption.

Nine handball players from club teams in Kuwait volunteered to participate in this investigation, The study protocol and procedures were approved by human Ethic committee of Kuwait University. After being fully informed of the nature and the beneficial outcome of the study. Heart rate (Polar Sports Tester, Finland) measurements were obtained during a non-official match (nine players), during nine matches and also during six training sessions (six players) same players monitored when the players were preparing for the national club league. All subjects wore the heart rate monitor according to the instructions specified by the manufacturer, and heart rate was measured every 15 s throughout the matches and the training sessions.

The relation between heart rate and VO_2 (HR-VO_2) had been established during the incremental exercise test for measuring maximal oxygen consumption in the laboratory (see chapter 3.4). Estimation of energy expenditure during a handball match was by means of a regression line relating heart rate and VO_2 obtained by using the average heart rate during match-play and referring to the individual's regression line for the oxygen uptake corresponding to the particular value of heart rate. If the precise relation is known, the match heart rate can be used to estimate oxygen uptake and then to compute energy expenditure during handball match. To estimate the VO_2 and to compute energy expenditure during handball match, the following procedures was carried out.

1) Estimating VO_2 for one of the handball player during handball match was completed by means of regression formula:

$VO_2 = 0.5184 \times HR - 36.509$

$VO_2 = 0.5184 \times 152 - 36.509 = 42.28\ ml.kg^{-1}.min^{-1}$

2) The VO_2 $ml.kg^{-1}.min^{-1}$ was converted to VO_2 $l.min^{-1}$ by multiply the VO_2 $ml.kg^{-1}.min^{-1}$ by body mass, then divided by 1000 (e.g. 42.28 x 72/ 1000)

3) Energy expenditure was estimating as following

a) The VO_2 ($l.min^{-1}$) was multiplied by caloric equivalent for non protein respiratory exchange ratio (RER) according to the Carpender (1964) and updated by McArdle et al 1991)

Energy expenditure = VO_2 x caloric equivalent (RER)

Energy expenditure = 3.09 x 4.862 = 14 78 $kcal.min^{-1}$

Energy expenditure during handball match was 14.78 x 60 min = 886.80 kcal.match.

The conversion factor for kcal to kJ was 4.186.

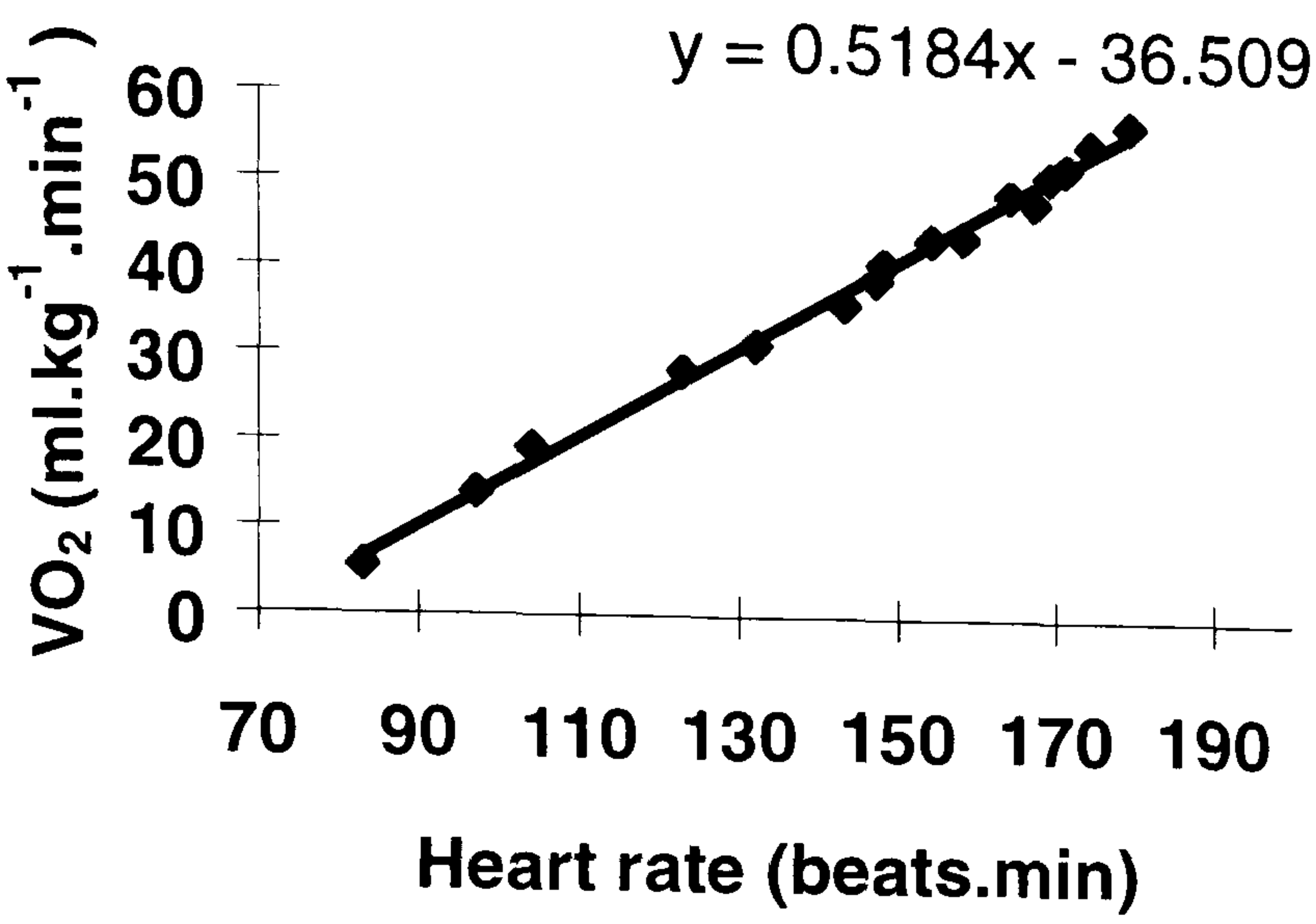


Figure 3.5.1. Illustration of the relation between HR-VO_2 obtained from the incremental exercise test ($VO_{2\,max}$) used to estimate the VO_2 during a handball match for one player.

3.5.2.1. Statistical analysis

Linear regression analyses were carried out to establish the relationship between HR and VO_2 (absolute and relative to body mass). The average heart rate value during the game was used to estimate the VO_2 and then the respiratory exchange ratio (RER) was used to estimate energy expenditure. Also the statistical analysis of the data was carried out using one-way ANOVA to compare the mean value of heart rates between the matches and training, and also between the first and second halves of the matches. The alpha level of $P < 0.05$ was the minimum required to reject the null hypothesis.

3.5.3. Results

Heart rate ranged from 71 ± 2 to 172 ± 14 (beats.min^{-1}) and 77 ± 2 to 178 ± 12 (beats.min^{-1}) during six training session (6 players) and 9 match-play (9 players) , respectively. Heart rate during the handball training session reached a mean value of 136 ± 5 (beats.min^{-1}). The mean value of heart rate during the match was 143 ± 6 beats.min^{-1}; the mean value of the heart rate during the match was significantly higher ($P < 0.05$) than that observed during training by 7 beats.min^{-1}.

The mean value of the energy expenditure during the handball match (60 min) was estimated to be 826 ± 147 kcal (3458 ± 714.9 kJ) based on the oxygen uptake relation to heart rate (HR-VO_2) and the prevailing RER. This corresponded to an energy expenditure of 13.99 kcal (57.7 kJ) min^{-1}. The estimated VO_2 was 34.87 ml.kg^{-1}.min^{-1} and the mean % VO_{2max} was 69% (see Table 3.5.2).

Data also revealed that the average heart rate for the first and second halves during the match were 139 ± 10 (beats.min^{-1}) and 145 ± 7 (beats.min^{-1}), respectively. This difference was not statistically significant ($P > 0.05$). Table 3.5.4. and Figure 3.5.2 illustrate the heart rates recorded during the first and second halves and the rest period between the two halves during a handball match in one of the Kuwaiti players. The mean value of estimating energy expenditure of first half was 54.± 10.1 kJ and second half was 59.3 ± 12.0 kJ (see Figure 3.5.4)

Table 3.5.1. Mean (± SD) values of the average and maximal heart rate obtained during the unofficial handball match and maximum oxygen uptake (VO_{2max} $ml.kg^{-1}.min^{-1}$) during the incremental laboratory test.

Subjects	Heart rate (beats.min)		VO_{2max} ($ml.kg^{-1}.min^{-1}$)
	Average	Max	
Kh.M	146	175	49.10
W.H	154	189	57.20
S.A	139	180	57.40
Sm.A	137	167	56.90
R.S	148	187	46.90
T.H	150	186	46.50
R.Z	133	177	45.10
A.H	139	187	48.60
M.S	135	154	47.10
Mean (SD)	143 ± 6	178 ± 12	50.43 ±5.2

Table 3.5.2. Mean (± SD) values of the average of oxygen uptake (VO_2 $ml.kg^{-1}$ $.min^{-1}$) and (VO_2 $l.min^{-1}$), respiratory exchange ratio (RER) and energy expenditure during unofficial match .

Subjects	VO_2 ($ml.kg^{-1}.min^{-1}$)	VO_2 ($l.min^{-1}$)	RER	Energy expenditure ($kcal.min^{-1}$)	Energy expenditure ($kJ.min^{-1}$)
Kh.M	35.00	3.15	0.94	15.7	65.7
W.H	43.30	3.14	0.85	15.3	64.0
S.A	40.26	3.40	0.84	16.5	69.1
Sm.A	37.30	2.70	0.95	13.5	56.5
R.S	29.10	2.20	0.85	10.9	45.6
T.H	36.90	2.70	0.93	13.2	55.3
R.Z	37.99	3.40	0.88	16.6	69.5
A.H	32.0	2.50	0.96	12.5	52.3
M.S	22.00	1.90	0.91	9.7	40.6
Mean	34.87	2.79	0.90	13.77	57.7
S.D	± 6.39	± 0.53	0.05	± 2.46	± 10.30

Table 3.5.3. Mean (± S.D) values of the average and maximal heart rate observed during a 6 handball training session and oxygen uptake (VO_2), respiratory exchange ratio, and the energy expenditure over the 80 min average time, expressed per minute.

Subjects	Heart rate (beats.min)		VO_2 (ml.kg^{-1}.min^{-1})	(l.min^{-1})	RER	Energy expended (kcal.min^{-1})	(kJ.min^{-1})
	Average	Max					
KH.M	130	167	28.60	2.56	0.94	12.8	53.6
W.H	132	153	32.95	2.4	0.85	11.7	49.0
S.A	132	167	36.74	3.11	0.84	15.1	63.2
Sm.A	137	167	37.30	2.70	0.95	13.5	56.5
R.S	140	186	20.99	1.60	0.85	7.9	33.1
T.H	142	189	38.37	2.76	0.93	13.7	57.3
Mean	136	172	32.51	2.52	0.89	12.5	52.1
SD	5	14	6.7	0.51	0.05	2.5	10.4

Table 3.5.4. Mean (± SD) of the average and maximal heart rate and energy expenditure during the first and second half of the handball match.

Subject	Average Heart rate (beats.min^{-1})		Energy expenditure (kcal.min^{-1})		(k.J.min^{-1})	
	First	second	First	second	First	Second
Kh.M	143	148	15.12	16.01	63.33	67.05
W.H	152	157	14.78	15.70	61.90	65.75
S.A	137	140	15.95	16.58	66.80	69.44
SL.A	130	143	11.36	14.80	47.58	61.98
R.S.	147	149	10.62	10.96	44.48	45.90
T.H	148	152	13.09	13.19	54.82	55.24
R.Z	122	143	14.55	18.37	60.94	76.94
A.H	137	140	11.94	12.44	49.97	52.10
M.S	132	137	8.73	9.47	36.56	39.66
Mean	139	145	12.85	14.2	54.0	59.3
S.D	±10	±7	±2.3	±2.9	±10.1	±12.0

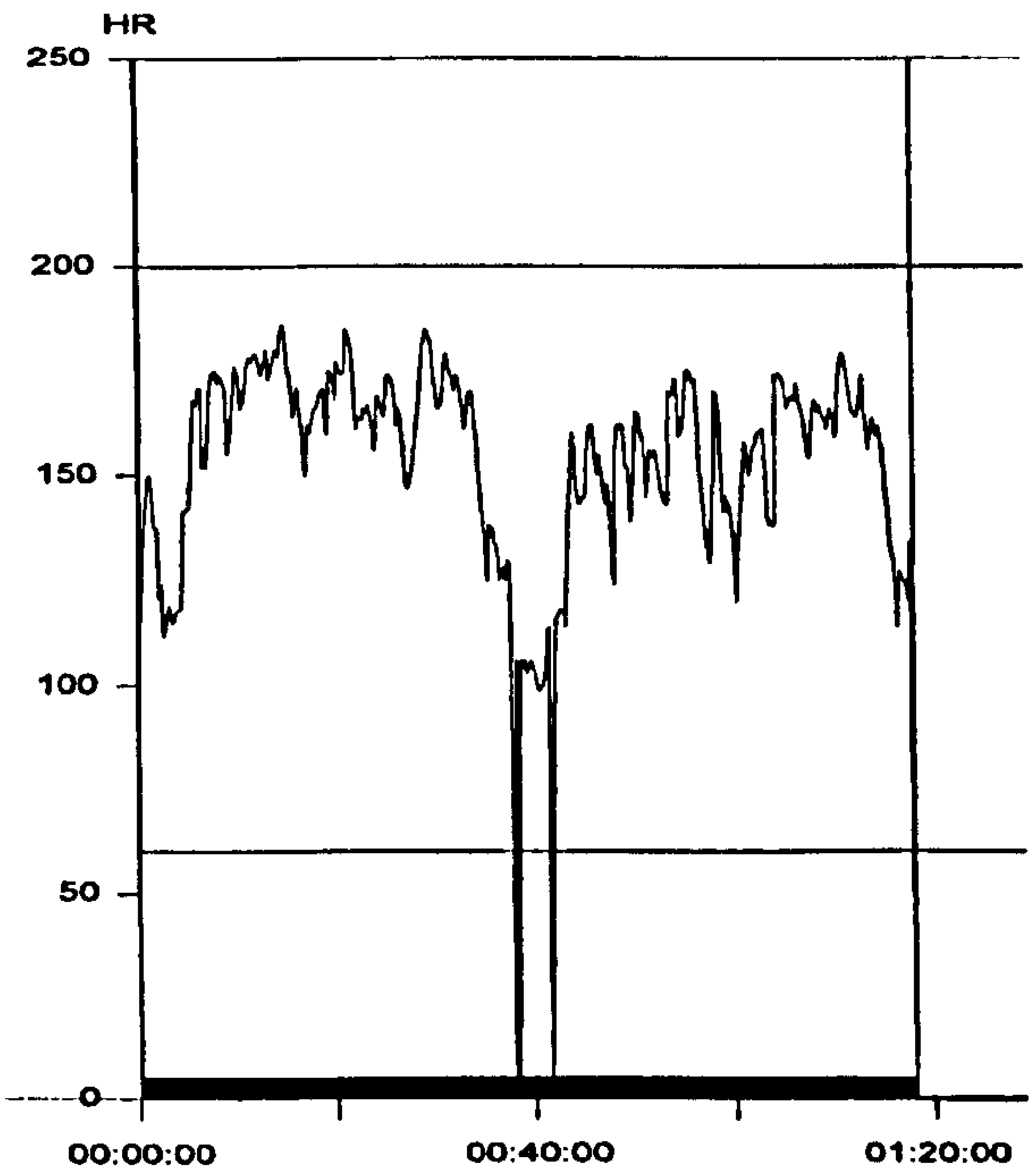


Figure (3.5.2) The heart rate recorded over the first and second halves and the rest period between the two halves of a handball match for one of the Kuwaiti handball players.

3.5.4. Discussion

In field conditions, it is not possible to measure energy expenditure directly without impeding the performance. Therefore previous studies have employed different indirect methods for the assessment of energy expenditure in the actual field situation. The measurement of heart rate is one of these indirect methods. Although the measurement of heart rate to predict energy expenditure is affected by factors such as emotion, heat and mode of exercise, it is still used frequently because it is closely related to the physiological response induced by exercise. This relation between heart rate and energy expenditure is based on the assumption that heart rate and energy expenditure are linearly related. In the present study, heart rate during a handball match and training session was measured using short-range radio telemetry. The average heart rate in itself provides a useful index of physiological strain quite apart from its use in estimating energy expenditure.

When the mean values of heart rate during the handball matches and training sessions were statistically analysed, a significant difference was observed. During the training sessions, players had an average heart rate of 136 ± 5 beats.min^{-1} (range from 130 - 172 beats.min^{-1}). During the match the mean heart rate was 143 ± 6 beats.min^{-1} (range from 135 - 178 beats.min^{-1}). Therefore it is suggested that the physiological response induced by exercise during a handball match was higher than that during training. This difference may indicates that the intensity of training session was lower, probably due to longer passive static time during training than during the match. In the handball study by Polimac (1994), HR during the match was similar to the present finding, being 147 ± 9 and 143 ± 5 beats.min^{-1}, respectively.

These data have implications for the fitness assessment of contemporary handball players. Current data also showed no significant difference in the mean values of heart rate between the first and second halves during the handball match (141 ± 7, 145 ± 5 beats.min^{-1}), thus indicating roughly similar energy expenditures for the two halves. Results of the present study may be compared with observations of Reilly (1996b) who reported that soccer players' mean heart rate during a match ranged from 165 to 170 beats.min^{-1}, work load being 70 - 75 % $VO_{2\ max}$,. However, handball players' heart rates ranged from 135-178 beats.min^{-1} and the relative work load was 69 % $VO_{2\ max}$, thus indicating that handball matches were played at approaching the similar relative intensity of soccer. The VO_2 of 34.9 ± 6.4 ml.kg^{-1}.min^{-1} and 32.5 ± 6.7 ml.kg^{-1}.min^{-1} for match-play and training sessions respectively is close to 29-30 ml.kg^{-1}.min^{-1} for two Japanese soccer players studied by Ogushi et al. (1993) whilst they executed various soccer drills. The corresponding energy expenditure was 57.7 kJ.min and 52.1 kJ.min for both match and training session, respectively, in the present study. Values close to these were reported by Seliger (1968b) for Czech soccer players. However, heart rates during the first and second half in handball were lower than in a Belgian university soccer friendly match, values being 169, 165 beats.min^{-1} for first and second halves respectively (Van Gool et al., 1983); Florida-James and Reilly (1995) reported a decline in work-rate in the second half without a drop in heart rate, the average value of which was 170 beats.min^{-1}. It is generally believed that blood lactate accumulation and lowered pH cause fatigue (Sahlin, 1986; Metzger and Fitts, 1987). However, no blood lactate values are available to confirm if fatigue was evident during the handball matches even though the heart rate level was maintained.

The aim in this chapter was, firstly, to investigate the kinanthropometric characteristics of the Asian handball players and physical fitness of handball players of England and Kuwait. A further aim was to estimate the physiological response and estimate energy expenditure during a handball match from recordings of heart rate and the individual regression of HR - VO_2 observed in the laboratory.

Kinanthropometric characteristics are very relevant for handball players because the game of handball entails physical contact in which specific physiques with a high level of strength and power may provide an advantage. This study demonstrated that handball teams were relatively homogenous in kinanthropometric make-up, without any unique requirements other than skills for positional roles. The results showed that the height and body mass values of Asian groups were lower than those found in European handball players in previous studies. Elite female handball players were also homogenous in kinanthropometric measurements. When comparing players by position, the study showed no influence of positional role.

The results of fitness profile comparisons of English and Kuwaiti handball players indicated that the Kuwaiti handball players were significantly older, taller, more mass and had more muscle mass than the English players and the reference group, although the actual and predicted VO_{2max} were similar for the English and the Kuwaiti handball players. When comparing the VO_{2max} of the present study with previous studies in handball or other sports, VO_{2max} was lower than reported for volleyball, basketball, soccer and well trained international handball players. The anaerobic performance test results (vertical and standing long jump) were higher in Kuwaiti players than in English players.

During competitive handball the mean heart rate was 143 ± 6 beats.min^{-1} (range from 135 - 178 beats.min^{-1}). Therefore it is suggested that the physiological response induced by exercise during handball matches was higher than in training sessions (136 ± 5 beats .min^{-1}. The estimated energy expenditure was 826 ± 147 kcal (3457 ±715 kJ) for the whole of the handball match (60 min) and 995 ± 198 kcal (4839 ± 963 kJ) for a training session (80 min). The indirect assessment of work load on the basis of continuously recorded heart rates revealed a general picture of the overall activity level during handball matches. It is possible to estimate the work load from the heart rate recorded during handball matches, to produce an appropriate work load protocol for laboratory experiments for handball players for the next chapter. This would require an intermittent exercise protocol with the average heart rate of around 143 beats.min^{-1}.

A handball match consists of intermittent exercise bouts which require high intensity efforts. In the study so far, it was assumed that players stay on court for the entire match. This does not usually occur. Players change frequently between substitute and on-court roles and so the average time which engages the players in competition may amount to as little as half of the total time. The game time is often punctuated by breaks in play or relief through substitution. This has implications for the choice of experimental protocol in the experimental investigations to follow. The laboratory based protocol should present physiological challenges approximating competitive handball. The studies completed in this chapter have indicated the average exercise intensity for such generic intermittent exercise models.

SECTION 4

EXPERIMENTAL INVESTIGATIONS

4.1. THE EFFECT OF HEAT STRESS ON SELECTED PHYSIOLOGICAL RESPONSES TO INTERMITTENT AND CONTINUOUS EXERCISE AT THE SAME EXTERNAL WORK-LOAD

4.1.1. Introduction

Physical activity can be broadly categorised as continuous and intermittent in terms of the physiological demands placed on the body. In this respect, many sports involving periods of all-out sprinting interspersed with short recovery periods e.g. handball, soccer and hockey, have been classified as intermittent exercise. More recently, there has been a growing interest in the physiological response to this type of exercise. Various researchers have examined and compared the physiological responses of intermittent exercise to continuous work at the same average intensity in an attempt to evaluate physiological differences between the exercise patterns (Astrand et al., 1960; Essen, 1978). It has been reported that intermittent exercise is associated with higher oxygen uptake, heart rate, ventilation, respiratory exchange ratio and blood and muscle lactate concentrations than those observed in continuous exercise at the same power output (Edwards et al., 1973). Other researchers have failed to note any difference in overall energy cost between intermittent and continuous exercise. For example, Essen (1978) observed a similar metabolic response between intense intermittent exercise (15 s exercise and 15 s rest periods) and continuous exercise performed at the same overall work output for a 60 min period on a cycle ergometer. Oxygen consumption and heart rate were not significantly different between the intermittent exercise and continuous exercise after 5 min or upon the termination of exercise. Similar results were found when intermittent (cycling at a power output of about 150 W for 0.5 to 2.5 min interspersed with 0.5 to 3 min rest) and continuous exercise of equal total energy output were employed (Lockhart and Ruffin, 1994). This discrepancy may partly be due to the differences in methodology, such as exercise protocol, exercise intensity and duration employed in those studies.

Body temperature, has been reported to be significantly greater in intermittent exercise when compared to continuous exercise at an identical intensity (Nevill et al., 1994). This intermittent exercise protocol consisted of 30 min of repeating cycles of 90 s activity at 40 % VO_{2max} followed by 60 s sprint and 24 s passive rest. In addition, hot and humid environments are associated with a greater thermal strain during intermittent exercise compared to continuous exercise of the same average work intensity (Garrett and Boyd, 1995). In contrast, Drust (1997) found no significant difference in rectal temperature during a soccer specific intermittent protocol compared to continuous exercise.

The temperature response depends on type, duration and intensity of exercise. However, the exercise modalities previously investigated in the above studies do not adequately reflect the true intermittent nature of many sporting activities. Furthermore, intermittent sports such as handball and soccer are popular in some countries where the environmental temperature is high. Therefore the aim of this study is to examine the change in physiological function during intermittent exercise undertaken in different environmental temperatures. In order to examine this effect, this study will use a model of intermittent exercise that reflects the heart rate response observed during a handball match (see section 3.5).

4.1.2. Materials and methods

4.1.2.1 Subjects

Seven healthy male subjects were recruited from the Centre for Sports and Exercise Sciences, Liverpool John Moores University to participate in the study. The study protocol and procedures were approved by the Human Ethics Committee of Liverpool John Moores University. Before data collection, each subject gave inform consent to the procedures following a detailed explanation of the protocol and purpose of the investigation (see Appendix 2).

4.1.2.2. Subjects' habituation

Although most of the subjects were familiar with the laboratory environment and test protocol, all subjects underwent two sessions of habituation in order to ensure familiarity with the exercise protocol, the laboratory environment, and testing procedures. Subjects' physical characteristics are shown in Table 4.1.1.

4.1.2.3. Body height assessment

Standing body height measurements were recorded for each subject to the nearest 0.5 centimetre by means of a wall mounted stadiometer (Seca, Germany).

4.1.2.4. Body mass assessment

Nude body mass was determined to the nearest 0.1 kg using a triple beam balance scale (Seca, Germany). Body mass was recorded before and after each exercise trial. Subjects also removed all (unevaporated) sweat from the skin prior to mass measurement. This therefore allowed an estimation of total sweat production assumption mass loss = sweat production rate. Total weight loss was corrected for respiratory water loss according to the method of Mitchell et al. (1972).

Table 4.1.1. Subject physical characteristics (n = 7).

	Mean	± SD
Age (years)	26.0	1.6
Height (cm)	175.9	4.6
Body mass (kg)	76.5	6.9
Body fat (%)	10.5	3.1

4.1.2.5. Percent body fat estimation

The percent of body fat was estimated from skinfold thicknesses according to the method of Durnin and Womersley (1974). Reliability of the technical error of measurement for the major kinanthropometric variables assessed in this thesis have previously been reported in section 3.2.2).

4.1.2.6. Preliminary maximal oxygen consumption test

One week prior to the main experiment, all subjects reported to the laboratory at the same time of day (09:00-10:00 hours), for the determination of maximal oxygen uptake (VO_{2max}). Subjects performed a continuous incremental running protocol on a motorised treadmill (Quinton instruments, Washington, USA). Following a 5 min warm-up at a speed of 7.5 $km.h^{-1}$, the initial treadmill speed was set at 10 $km.h^{-1}$ for 2 min. Thereafter the treadmill speed was increased by 2 $km.h^{-1}$ every 2 min until the subjects reached volitional exhaustion. The attainment of $VO_{2\ max}$ was assessed using the following criteria:-

1. A plateau in the oxygen uptake/exercise intensity relationship, as an increase oxygen uptake of less than 2 $ml.kg^{-1}.min^{-1}$ or 3% with an increase in exercise intensity
2. A final respiratory exchange ratio value of 1.1 or over.
3. A final heart rate within 10 $beats.min^{-1}$ of age predicted maximum.
4. Inability to maintain the required treadmill speed.

Subjects were fitted with a short-range radio telemeter (Sport Tester 3000, Finland) for heart rate measurements. Heart rate was recorded continuously during exercise.

Prior to testing, subjects were fitted with a mouthpiece and nose-clip. Expired gases were measured using a computerised on-line system (Metabolic Measurement Cart, SensorMedic 2900, USA) which had been calibrated using two calibration gases of known concentrations. Table 4.1.2. presents the mean ± SD values for maximal heart rate and maximal oxygen consumption. After completion of the $VO_{2\ max}$ test, the subjects were asked to report to the laboratory on four more separate occasions in order to undertake further submaximal intermittent exercise tests.

Table 4.1.2. Heart rate and oxygen consumption in response to the maximal exercise test of the subjects (n = 7).

HR max (beats.min^{-1})	188 ± 12
$VO_{2\,max}$ (ml.kg^{-1}.min^{-1})	53.59 ± 6.91
$VO_{2\,max}$ (l.min^{-1})	4.08 ± 0.33

HR max = maximum heart rate, $VO_{2\,max}$ = maximum oxygen consumption

4.1.2.7. Design of the intermittent exercise protocol

In the section 3.5 the average heart rate measured during a handball matches was 143 ± 6 beats.min^{-1}. This pilot study was conducted in order to examine the reliability of using the following intermittent protocol to simulate an exercise intensity reflective of that generally observed in handball matches. The protocol was a modification of that employed by Drust (1997) for football. The football protocol consisted of exercising at 4 velocities 6, 12, 15 and 18 km.h^{-1}, the handball protocol was consisted of 3 exercising velocities at 6, 12 and 15 km.h^{-1} this was because the handball court is shorter than football pitch and the handball activities were played between the two 6 m lines in each half of the court. This area was approximately 28 m length. This limited the handball player maximal speed to sprint to 18 km.h^{-1}.

4.1.2.7.1. Pilot study

Four subjects separate from those mentioned in 4.1.2.1 (27 ± 2 years, 178 ± 6.5 cm, 83.0 ± 15.3 kg) from the Centre for Sport and Exercise Sciences in the School of Human Sciences at Liverpool John Moores University were tested. Each subject was required to exercise for two identical 15 min periods separated by 5 min rest on a motorised treadmill. Each section of 15 min protocol comprised of 6 discrete bouts of walking, 6 bouts of jogging and 3 bouts of running (Table 4.1.3). This included the time spent alternating between different velocity, (Table 4.1.4). In total, walking accounted for 32 %, jogging 45 % and sprinting 23 % of the test time.

Table 4.13. Exercise intensities used during intermittent exercise protocol.

Velocity ($km.h^{-1}$)	12	6	15	6	12	15	6	12
Duration (s)	45	32	46	32	45	46	32	45
Velocity ($km.h^{-1}$)	6	15	12	6	12	6	12	
Duration (s)	32	46	45	32	45	32	45	

Table 4.1.4. Mean (± SD) of the duration taken (s) for treadmill velocity changes ($km.h^{-1}$) incorporated in the protocol.

Velocity changes ($km.h^{-1}$)	Duration (s)	N	Mean ± SD
Dec. 15 to 12	9.6	1	9.6 ± 0.15
Des. 12 to 6	90.0	4	22.5 ± 0.86
Ace. 6 to 12	96.8	4	24.2 ± 0.80
Ace. 12 to 15	10.4	1	10.4 ± 1.21
Des. 15 to 6	59.2	2	29.6 ± 0.93
Ace. 6 to 15	66.8	2	33.4 ± 0.20

Des = Deceleration and Ace = acceleration treadmill velocity

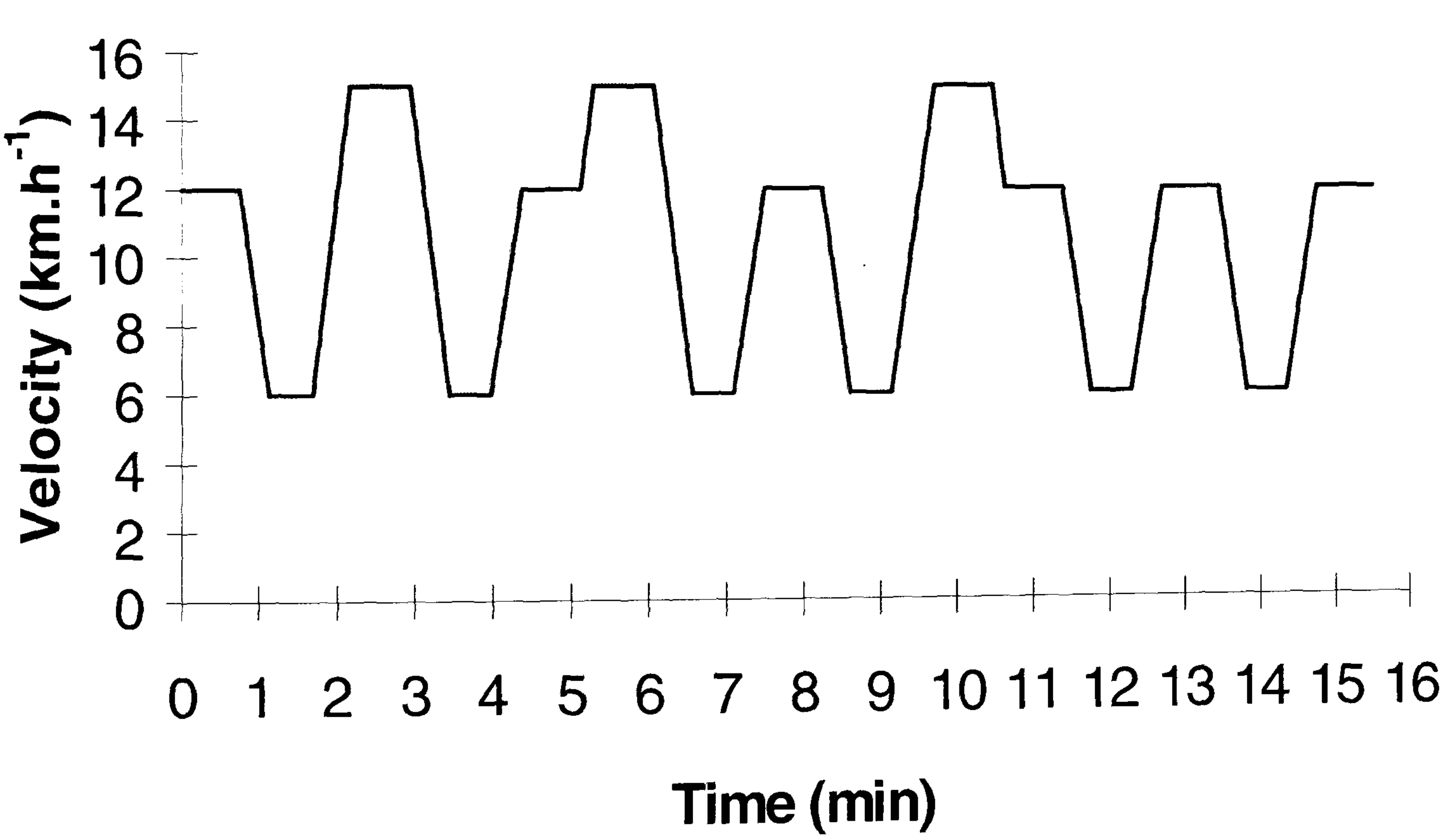


Figure 4.1.1. A graphical display of changes in exercise velocity.

Subjects were fitted with a radio telemetry monitor (POLAR, Sport Tester, Finland). Heart rate was recorded at rest and every 15 s during the exercise test. Data were stored and downloaded by the Polar computer interface. Heart rate data for Kuwaiti handball players (N = 9) during unofficial match-play and the subjects' pilot study (N = 4) were analysed by t test for independent sample to examine any differences between the simulation students (N = 4) protocol and game handball players (N = 9).

4.1.2.7.1.1. Results

The average heart rate of the 30 min intermittent exercise of the pilot study was 141± 9 beats. min^{-1}. Heart rate for the first 15 min was 142 ± 10 beats.min^{-1} and 140 ± 8 beats.min^{-1} for the second 15 min (see figure 4.1.2).

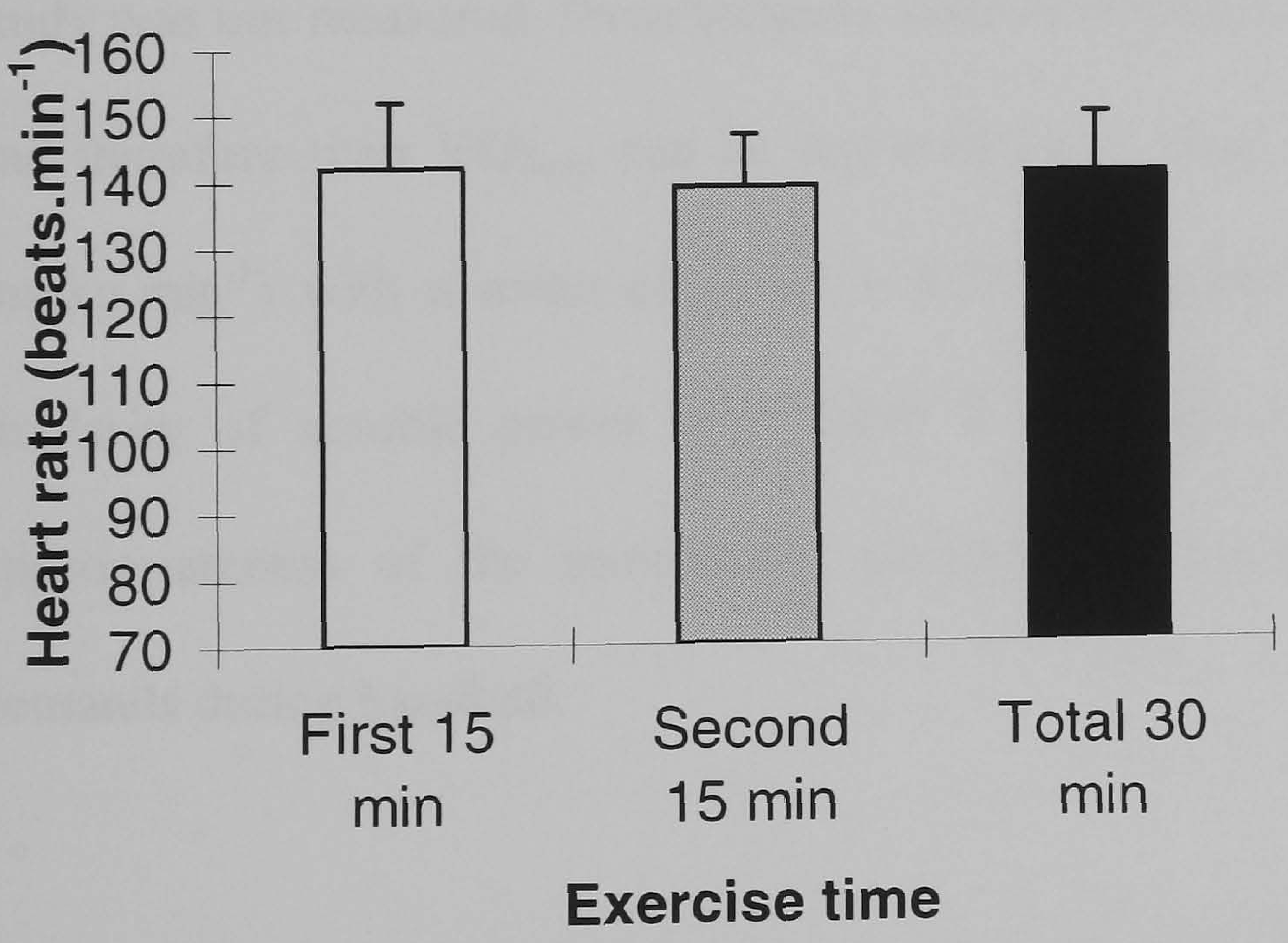


Figure 4.1.2. Mean (± S.D) heart rate responses to intermittent exercise for 30 minute of the pilot study.

4.1.2.7.1.2. Discussion

Mean heart rate during the intermittent protocol (141 ± 9 beats.min^{-1}) was not significantly different from that observed during handball match-play (143 ±6 beats.min^{-1}). This is equivalent to exercising at 73 % and 76 % of HR_{max} during the pilot study and match-play respectively. The similarities of both absolute and relative HR suggest that this intermittent protocol provides an adequate representation of the cardiovascular strain experienced during the sport of handball.

Despite the similarity in HR response, it is possible that any differences in HR during the intermittent exercise protocol and match-play were masked by differing fitness level of the subjects and players. Although the VO_{2max} of the subjects used in the pilot study was not measured, these subjects were involved in other studies at the same time and therefore their VO_{2max} can be reported here. Their values ranged from 40 to 62 (ml.kg.min^{-1}) with a mean of 49.95 ± 8.25 (ml.kg.min^{-1}). These data suggest some similarity of aerobic power (see Table 3.4.3. page 106) and further support the appropriateness of the intermittent protocol as a representation of physiological demands during handball.

4.1.2.8. Exercise procedures (in normal and hot conditions)

The seven healthy male subjects previously described (see Table 4.1.1 pg. 128) randomly performed four identical sub-maximal tests approximately seven days apart, in order to examine the effect of heat stress on selected thermoregulatory and cardiovascular responses to a 30 min laboratory-based intermittent and continuous treadmill exercise protocol. The intermittent protocol used is shown in Figure 4.1.1. pg. 132. The mean velocity of the subjects when performing this exercise was 11 $km.h^{-1}$. Therefore, the continuous 30 min protocol was completed at this same velocity, that each subject performed the same total absolute external work load during both exercise conditions. The intermittent and continuous treadmill exercise tests were conducted at the same time of day and under normal (18 ± 2°C) and hot (32 ± 2°C) conditions. The relative humidity was similar for normal (46 ± 2%) and hot (48 ± 2%) conditions. Prior to exercise in the heated condition, room temperature was regularly assessed from 08: 00 hours until 11: 00 hours. Heat output was adjusted accordingly using five heaters (7000 k Watt) in order to maintain the desired experimental temperature.

Each subject was instructed to follow his normal diet and daily life activity pattern and abstain from exercise for 24 hours before each test. When subjects reported to the laboratory, nude body mass was measured, a rectal probe (Grant, Squirrel meter, Cambridge) inserted to a depth of 10 cm beyond the external anal sphincter (the thermoster was held in position by tying a bandage around the probe and attached this to a waist band), and the heart rate was recorded at rest and every 5 s interval by short range radio telemetry (POLAR, Sport Tester, Finland). Skin temperature was measured by thermistors (Grant Squirrel meter, Cambridge). Thermistors were attached to the skin at the following four sites: (a) chest (over the sternum), (b) mid-front arm, (c) mid-front thigh and (d) exterior mid-calf and secured by medical tape (see Plate 4.1.1) and mean skin temperature calculated according to Ramanathan (1964). Rectal and skin temperatures were monitored continuously and recorded at the end of every 5 min interval during the exercise test. The intermittent test began with a warm-up period for 5 min at speed of 7.5 $km.h^{-1}$ and increased to 12 $km.h^{-1}$ during the last 30 second. The continuous exercise test began at 7.5 $km.h^{-1}$ and increased to 11 $km.h^{-1}$. Expired gases were measured continuously.

During each experimental trial, ratings of perceived exertion scaled (0 to 10) (Borg, 1982), were recorded every 5 min during intermittent and continuous exercise. Expired air was collected continuously every 20 s for the measurement of VO_2 ($ml.kg^{-1}.min^{-1}$), respiratory exchange ratio and minute ventilation. From these measurements the energy expenditure during each test trial was calculated (see 3.5).

Immediately after the completion of the first 15 min stage of the intermittent exercise test, subjects were seated on a chair (placed on the treadmill) for 5 min. Subjects were then asked to continue the second 15 min stage of the test using the same protocol as in the first stage. Following the completion of 15 min of the second stage of the intermittent test and 30 min continuous exercise, subjects were allowed to recover for 15 min sitting on a chair placed on the treadmill, and rectal and skin temperature were recorded every 5 min. Following that, the subject left the treadmill, the rectal probe was removed, and the subject's nude dry body weight was recorded.

4.1.2.8.1. Assessment of oxygen uptake, respiratory exchange ratio, minute ventilation during intermittent and continuous exercise test

On each test, expired air was collected continuously every 20 s for measurement of VO_2 ($ml.kg^{-1}.min^{-1}$), respiratory exchange ratio, minute ventilation by mean of an one-line system (SensorMedics 2900, California). It was calibrated by means of two calibrated gas cylinders containing 26% O_2, 0% CO_2 and 16% O_2 with 4% CO_2. The procedures were the same as described for the descriptive study in chapter 3.4.

4.1.3. Statistical analyses

The statistical analyses of data were carried out using 2 x 2 x 2 nested factorial design (exercise, duration, and conditions) with repeated measures. Statistical significance was accepted at the $P < 0.05$ level. When a significance difference was found, data were further analysed using a Tukey post-hoc test. All data are reported as mean ± SD.

Plate 4.1.1. Measurement of rectal and skin temperatures (Grant, Squirrel meter)

4.1.4. Results

4.1.4.1. Corrected verses uncorrected mass loss

Figure 4.1.3 shows the mean (± SD) values of corrected (for respiratory water loss) and uncorrected mass loss during intermittent and continuous exercise in normal conditions. There are small differences between corrected and uncorrected mass loss during intermittent (9.3%) and continuous (7%) exercise in the normal condition. Despite these reductions, the pattern of the weight loss change remains similar when corrected values are used. In the present study, VO_2 was not measured during intermittent exercise in the heat and for this reason, uncorrected weight loss values were not compared in the heat. Although this is not strictly correct, such correction does not alter weight loss values appreciably and so the pattern of response remains identical suggesting that any error involved is likely to be negligible. In addition, the size of error will be reduced in hot and humid environments where respiratory water loss is less.

4.1.4.2. Mass loss in response to intermittent and continuous exercise in normal and hot conditions

Figure 4.1.4 shows the mean (± SD) values of mass loss (i.e body mass after - body mass before) during intermittent and continuous exercise in normal and hot environmental conditions. The mean values of mass loss after intermittent exercise were -0.59 ± 0.16 and -1.33 ± 0.21 kg in normal and hot conditions respectively, while the mean values after continuous exercise in normal and in hot environment conditions were - 0.86 ± 0.25 and -1.07 ± 0.38 kg, respectively. In the normal condition mass loss after continuous exercise was significantly greater ($F_{1,13} = 5.88$; $P < 0.05$) than observed after intermittent exercise.

Mass loss after intermittent exercise in the hot condition was significantly greater ($F_{1,13} = 57.5$; $P < 0.001$) than observed after intermittent exercise in normal conditions. In contrast, the weight loss during continuous exercise in both conditions was not significantly different ($F_{1,13} = 1.54$; $P > 0.05$).

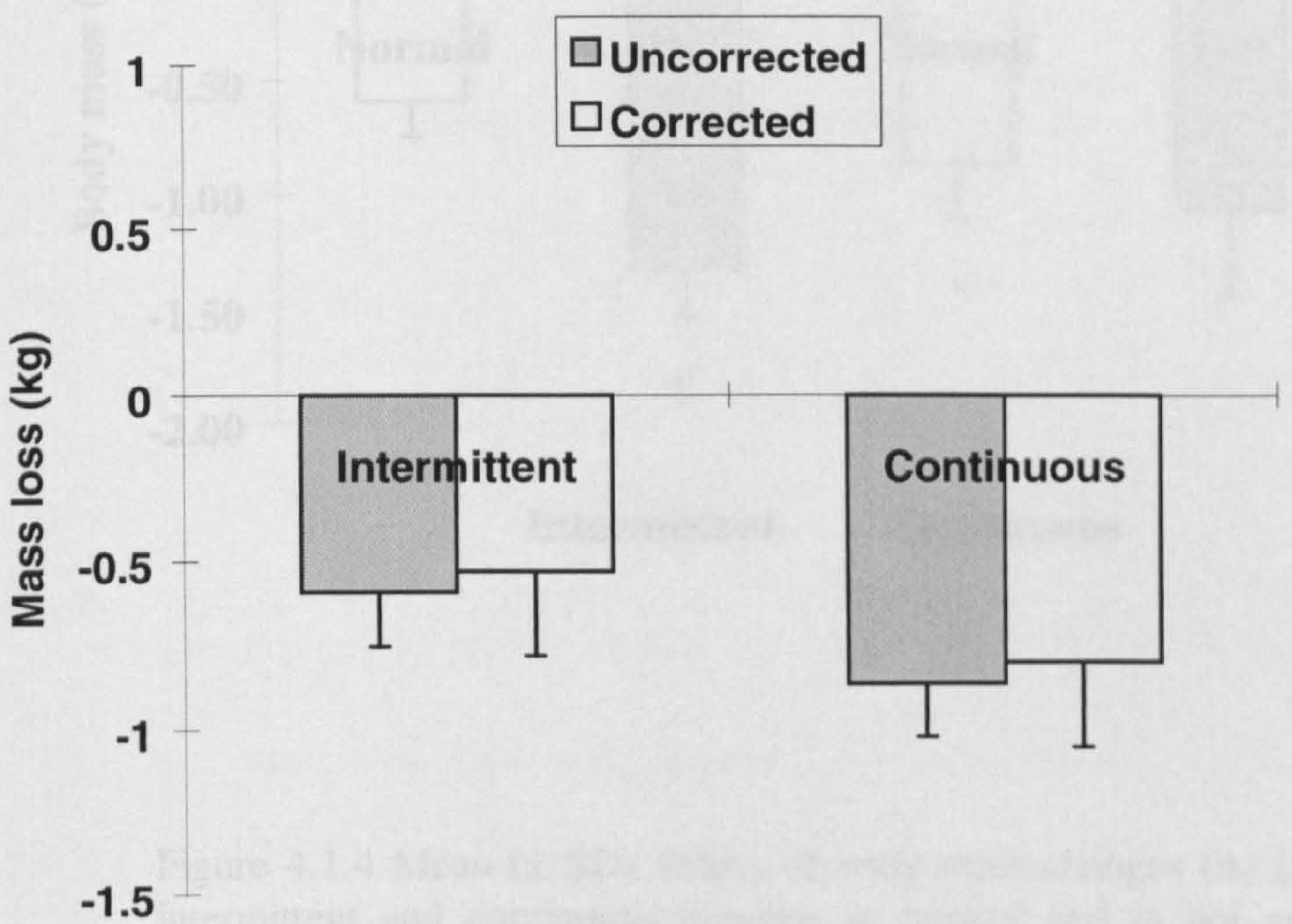


Figure 4.1.3. Mean (± SD) values of mass loss (corrected and uncorrected for respiratory water loss) during intermittent and continuous exercise in normal conditions.

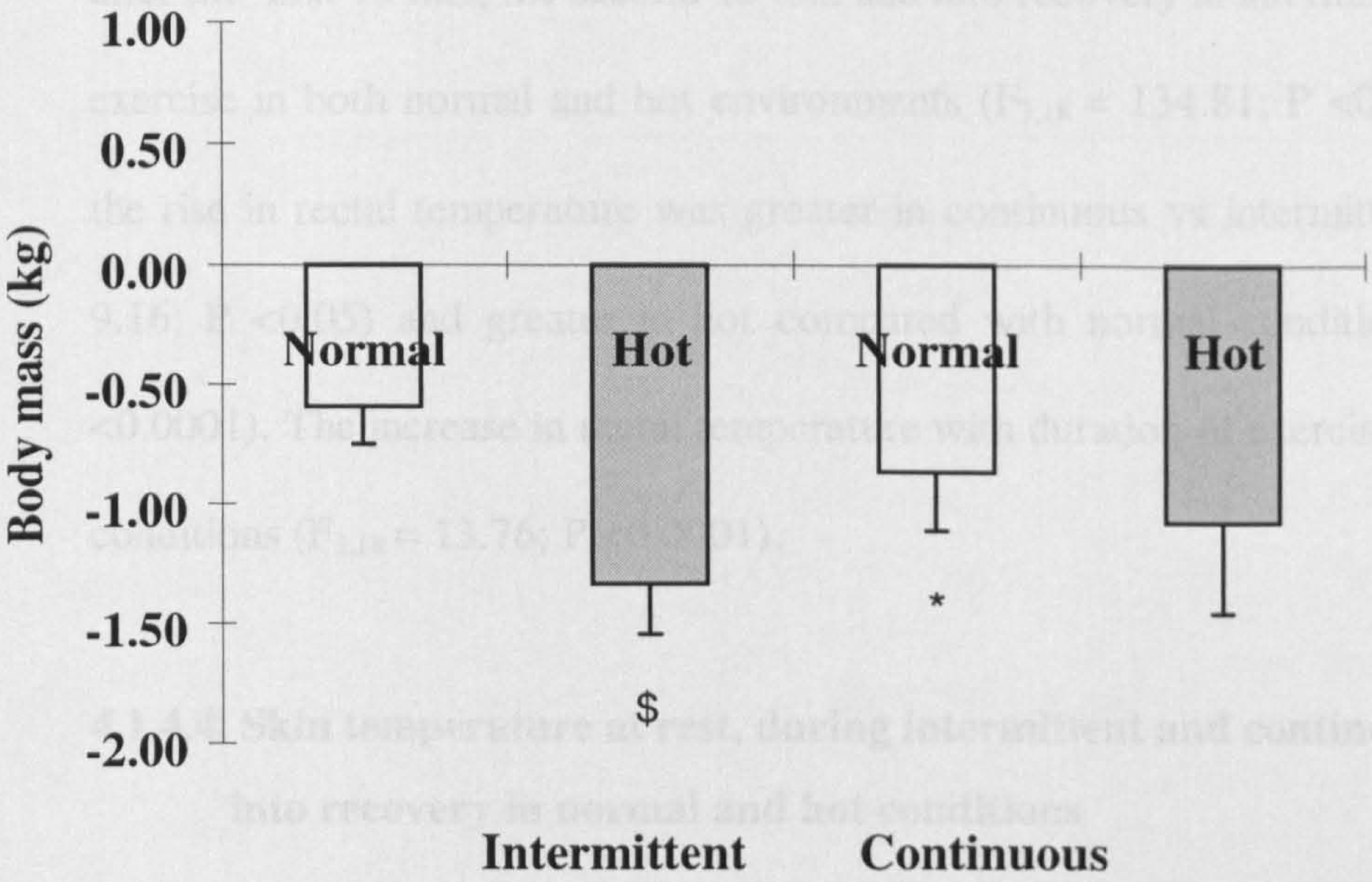


Figure 4.1.4 Mean (± SD) values of body mass changes (Δ) (after - before) following intermittent and continuous exercise in normal and in hot conditions. * Significantly higher value than that observed in the normal condition for intermittent exercise. $ Significantly higher value than that observed in the normal condition during intermittent exercise.

4.1.4.3. Rectal temperature at rest, during intermittent and continuous exercise and into recovery in normal and hot conditions

Figures 4.1.5. a (comparison between intermittent vs continuous) and Figure 4.1.5. b comparison between normal vs hot conditions) show the mean (± SD) values of rectal temperature at rest, at the end of first 15 min, at the end of second 15 min exercise and 15 min into recovery. Compared to rest, rectal temperature was increased significantly after the first 15 min, the second 15 min and into recovery in intermittent and continuous exercise in both normal and hot environments ($F_{3,18} = 134.81$; $P < 0.0001$). In addition, the rise in rectal temperature was greater in continuous vs intermittent exercise ($F_{1,6} = 9.16$; $P < 0.05$) and greater in hot compared with normal condition ($F_{1,6} = 60.61$; $P < 0.0001$). The increase in rectal temperature with duration of exercise was greater in hot conditions ($F_{3,18} = 13.76$; $P < 0.0001$).

4.1.4.4. Skin temperature at rest, during intermittent and continuous exercise and into recovery in normal and hot conditions

The mean (± SD) values of skin temperature during exercise and recovery in intermittent and continuous exercise protocols in normal and in hot conditions are presented in Figure 4.1.6. (A intermittent) and (B continuous). Skin temperature was significantly higher in the hot environment ($F_{1,6} = 289.58$; $P < 0.001$) at rest, during exercise and into recovery, for both intermittent and continuous protocols. There was an interaction effect between environmental temperature and duration of exercise ($F_{3,18} = 4.73$; $P < 0.05$).

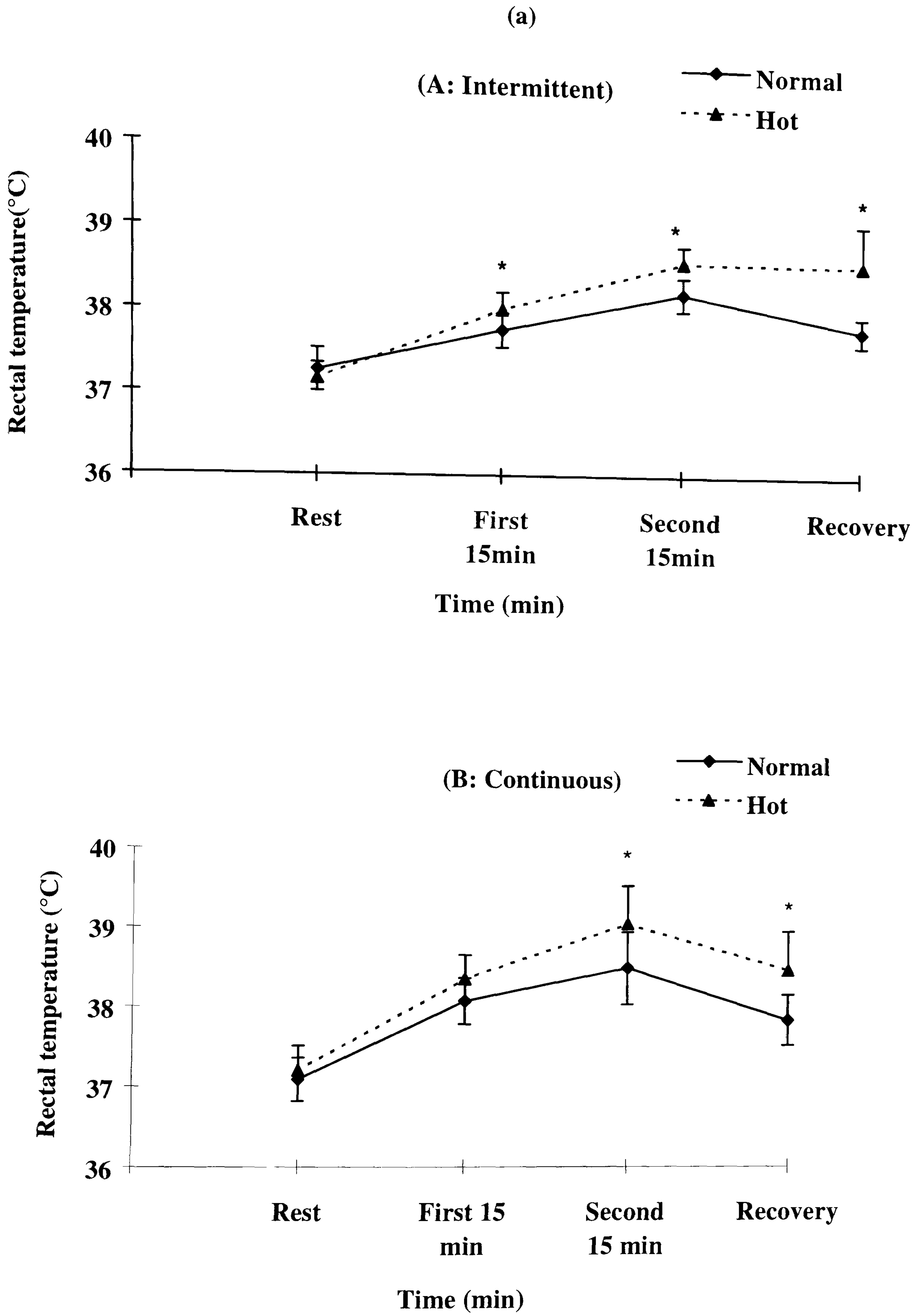
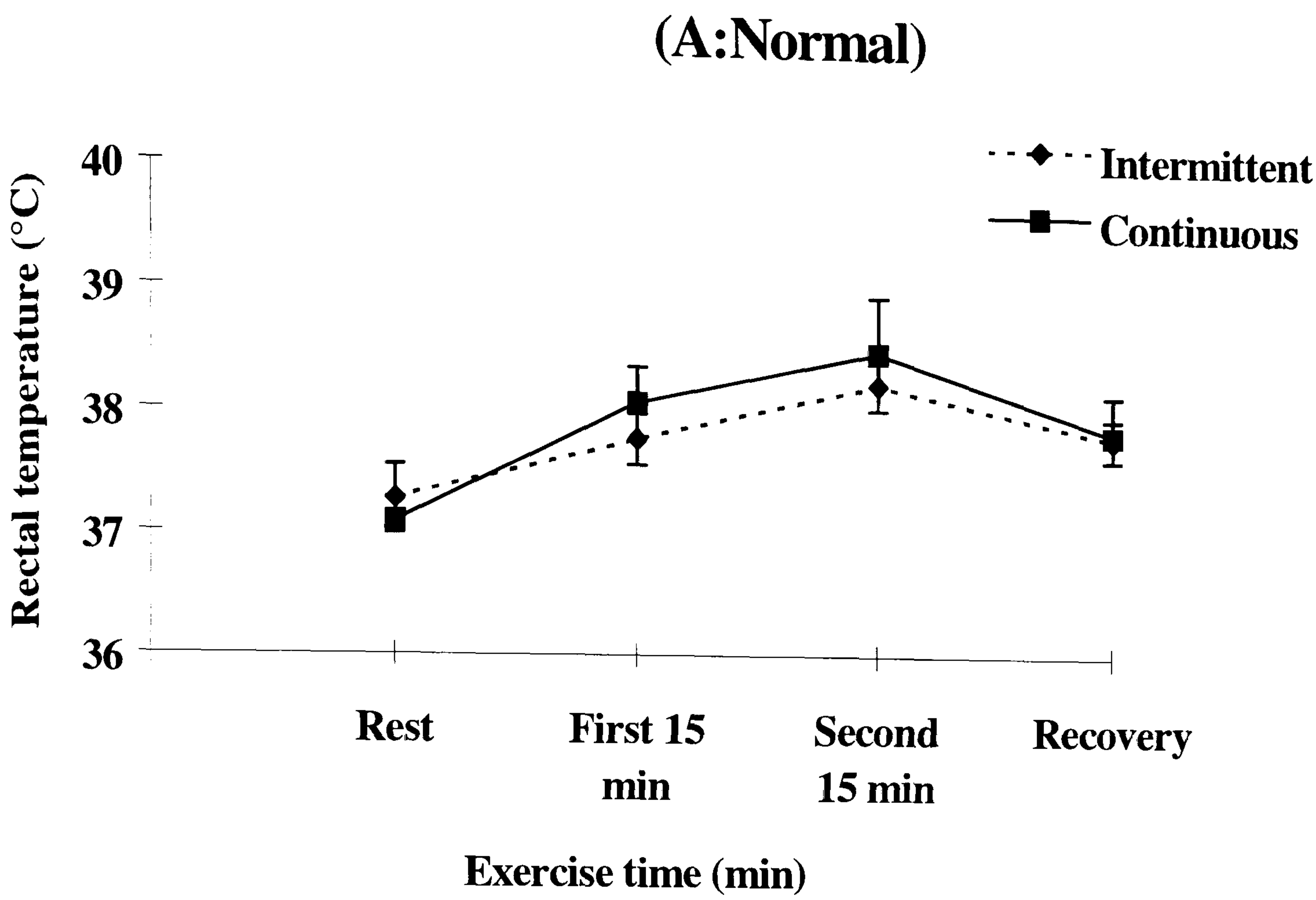


Figure 4.1.5. (a) Mean (± SD) values of rectal temperature at rest during intermittent (A) and continuous (B) exercise in the first and second 15 min and into recovery in normal and hot conditions. Rectal temperature significantly greater in heat ($F_{1,6} = 60.61$; $P<0.0001$)

(b)



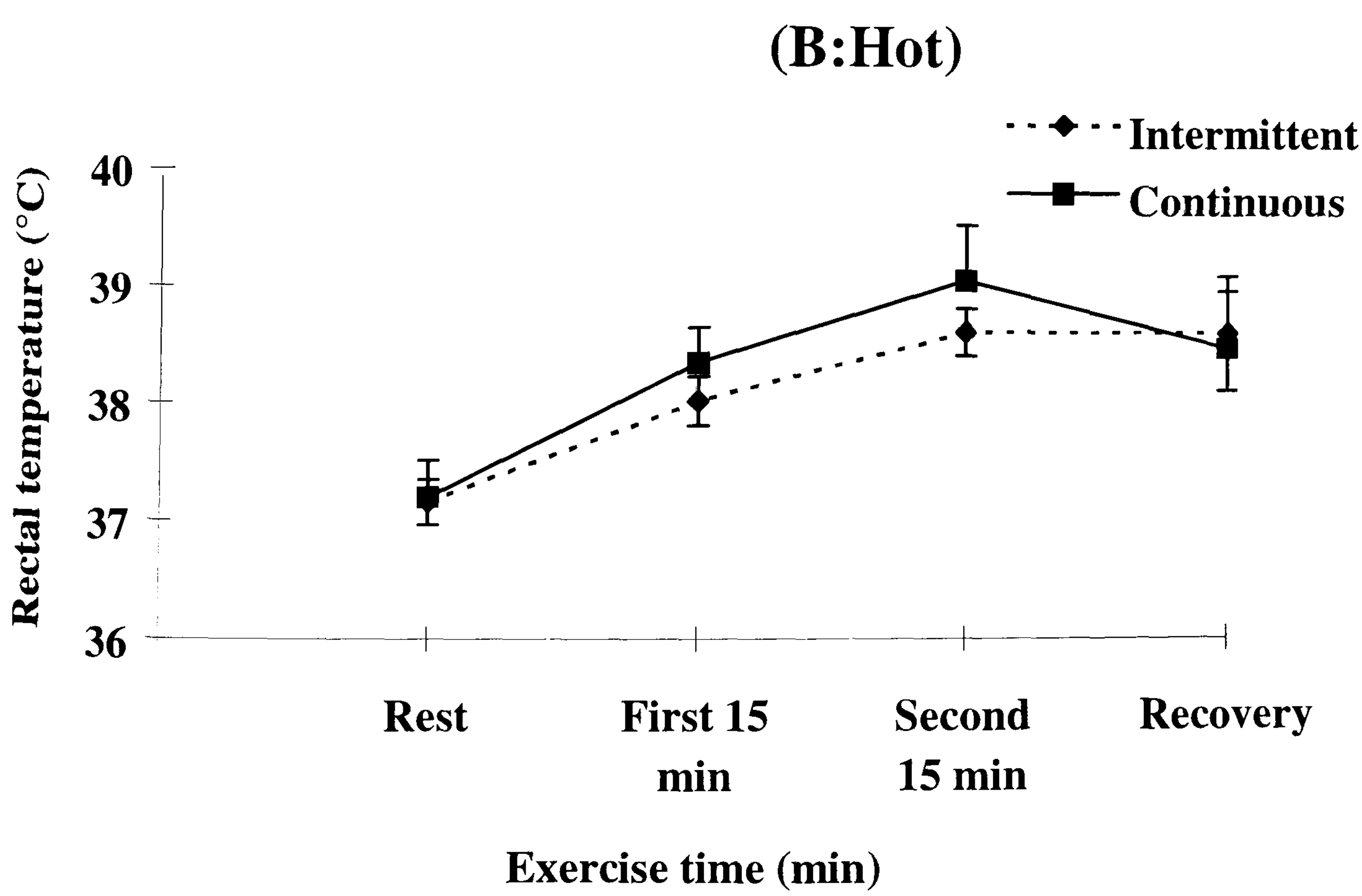


Figure 4.1.5. (b) Mean (± SD) values of rectal temperature at rest, first for the 15 min, second 15 min during intermittent and continuous exercise and into recovery in normal (A) and hot (B) environments. Rectal temperature was greater in continuous exercise ($F_{1,6} = 9.16$; $P < 0.05$).

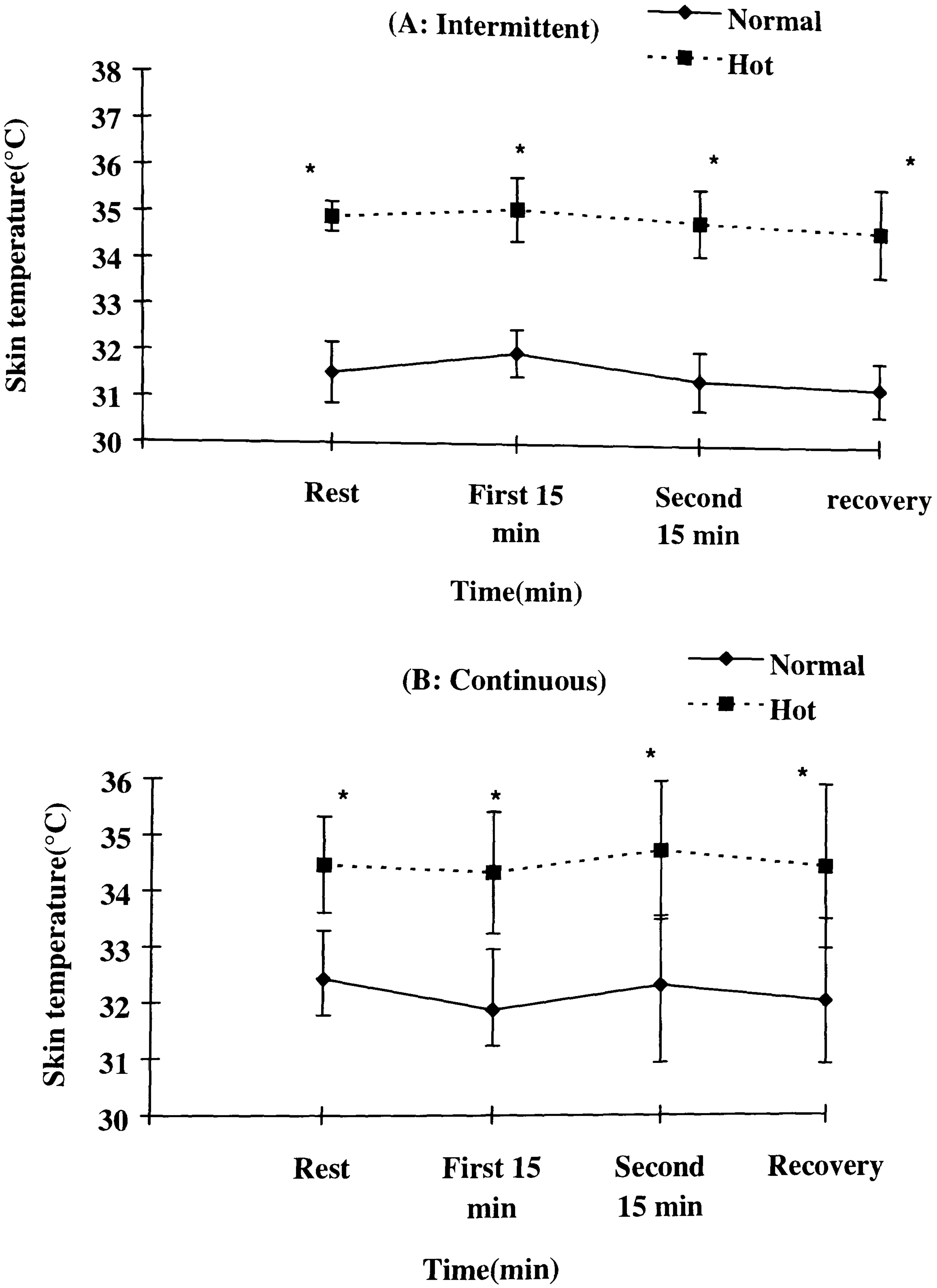


Figure 4.1.6. Mean (± SD) values of skin temperature at rest, for the first and second 15 min during intermittent (A) and continuous (B) exercise and into recovery in normal and hot conditions. * Significantly ($P < 0.05$) higher mean value than observed in the normal condition.

4.1.4.5. Heart rate during intermittent and continuous exercise in normal and hot conditions

Figure 4.1.7 show the mean (± SD) of the heart rate during intermittent and continuous exercise in normal and in hot conditions. The heart rate response is dependent on the mode of exercise and the environmental temperature. The HR was significantly increased ($F_{1,6}$ = 35.14; P <0.001) during continuous exercise in both environments. In addition, HR was significantly elevated ($F_{1,6}$ = 65.57; P <0.0001) during exercise in the heat in both continuous and intermittent activity. In all treatments HR increased with the duration of exercise ($F_{6,36}$ = 239; P <0.0001).

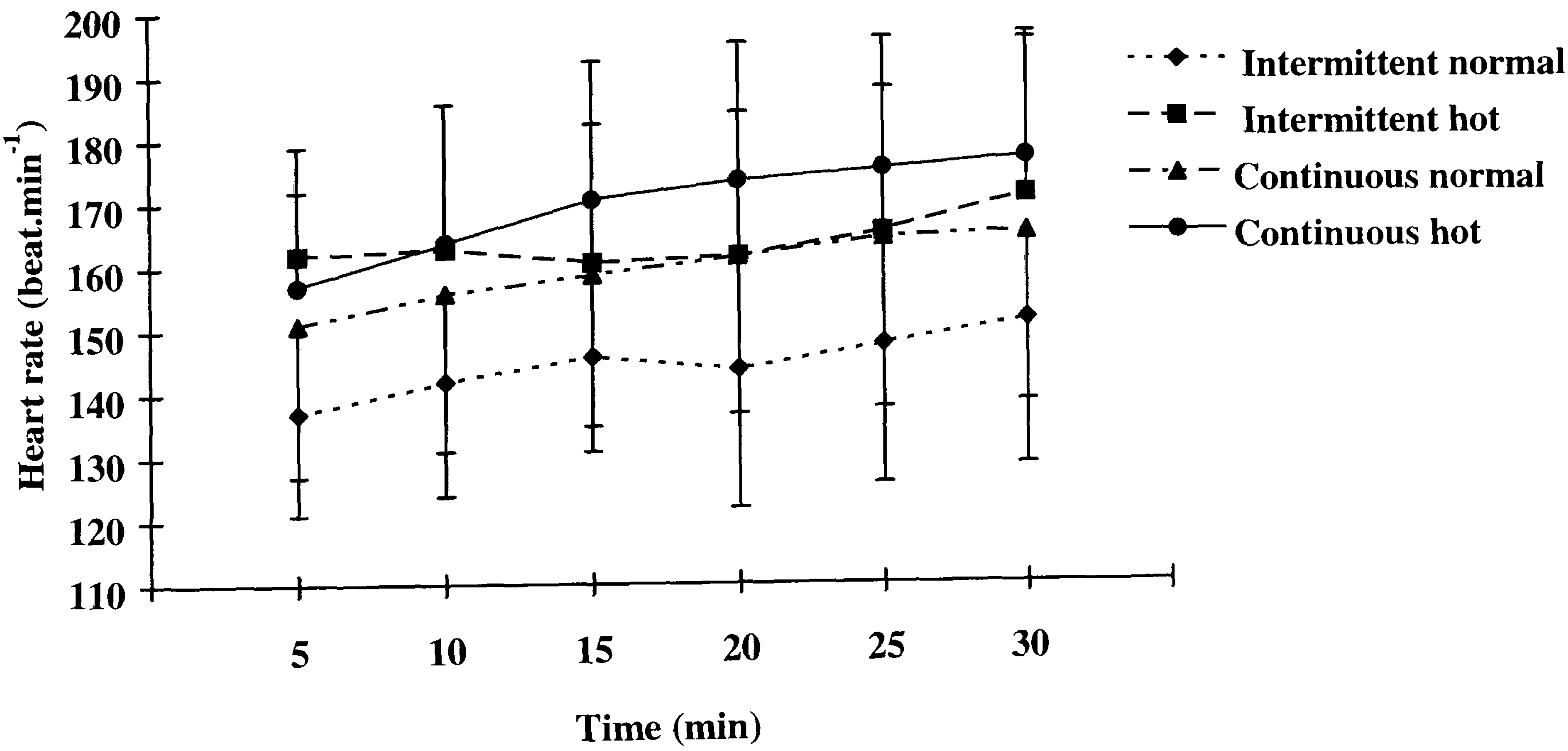


Figure 4.1.7 Mean (± SD) values of heart rate every 5 min interval during intermittent and continuous exercise in the normal and hot conditions.

4.1.4.6. Oxygen uptake during intermittent and continuous exercise in normal and hot conditions

Figure 4.1.8. represents the mean (± SD) values of VO_2 ($l.min^{-1}$) at 5 min intervals during both intermittent and continuous exercise. Oxygen uptake ($l.min^{-1}$) was significantly greater ($F_{1,6} = 29.55$; $P < 0.05$) during continuous exercise than intermittent exercise in the normal condition. However, there was no significant difference in VO_2 ($l.min^{-1}$) during continuous exercise in normal and hot conditions. The VO_2 was not measured in the hot condition during intermittent exercise.

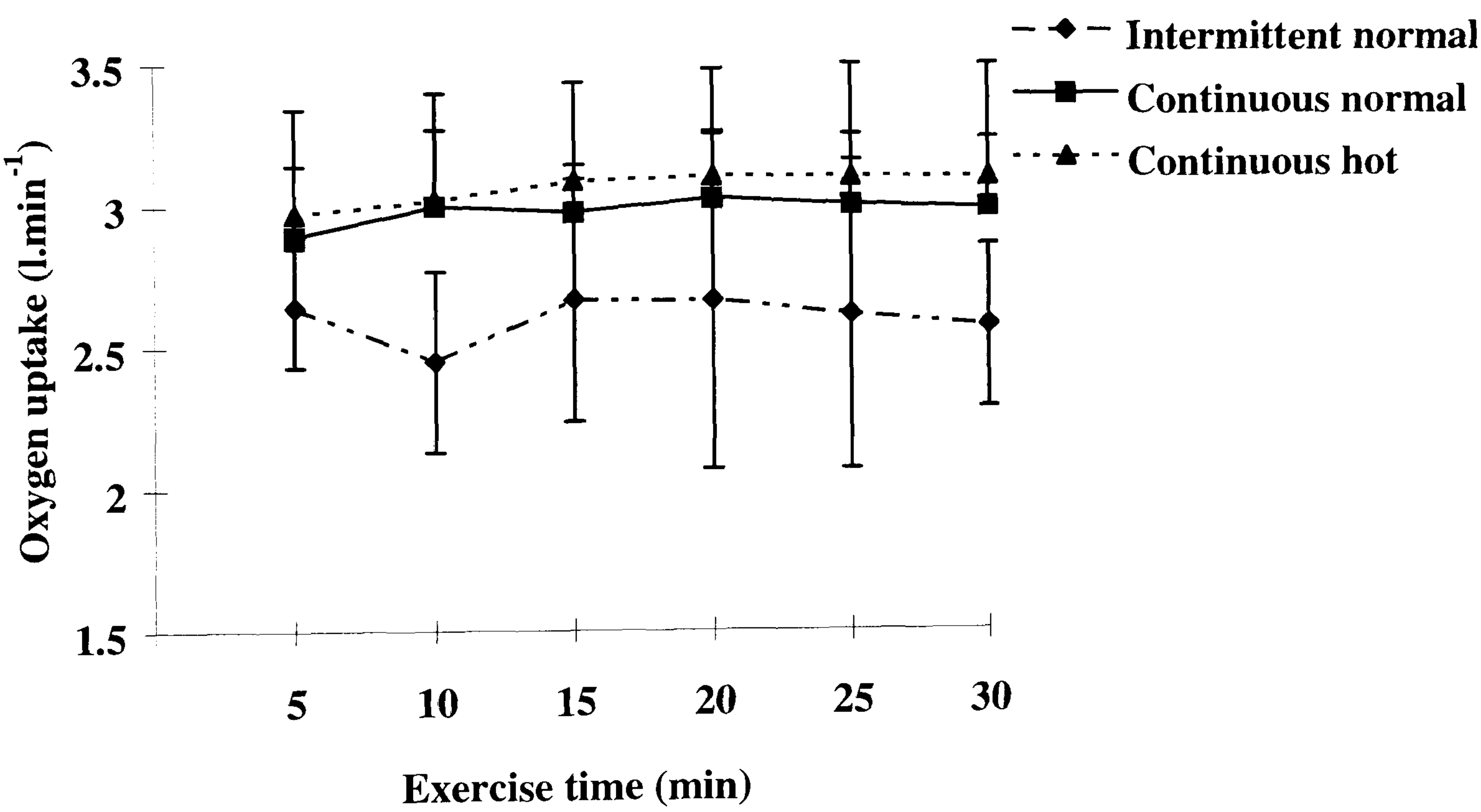


Figure 4.1.8. Mean (± SD) values of oxygen uptake ($l.min^{-1}$) every 5 min interval during continuous and intermittent exercise in the normal conditions and for continuous exercise in the heat.

4.1.4.7. Respiratory exchange ratio at 5 min intervals during intermittent and continuous exercise in normal condition

Figure 4.1.9. represent the mean (± SD) value of RER during intermittent and continuous exercise in normal conditions. There was no significant difference in RER between continuous and intermittent exercise ($F_{1,6} = 3.43$; $P = 0.113$). With increasing duration of intermittent exercise, there was a significant decrease in RER ($F_{5,30} = 4.08$; $P < 0.05$).

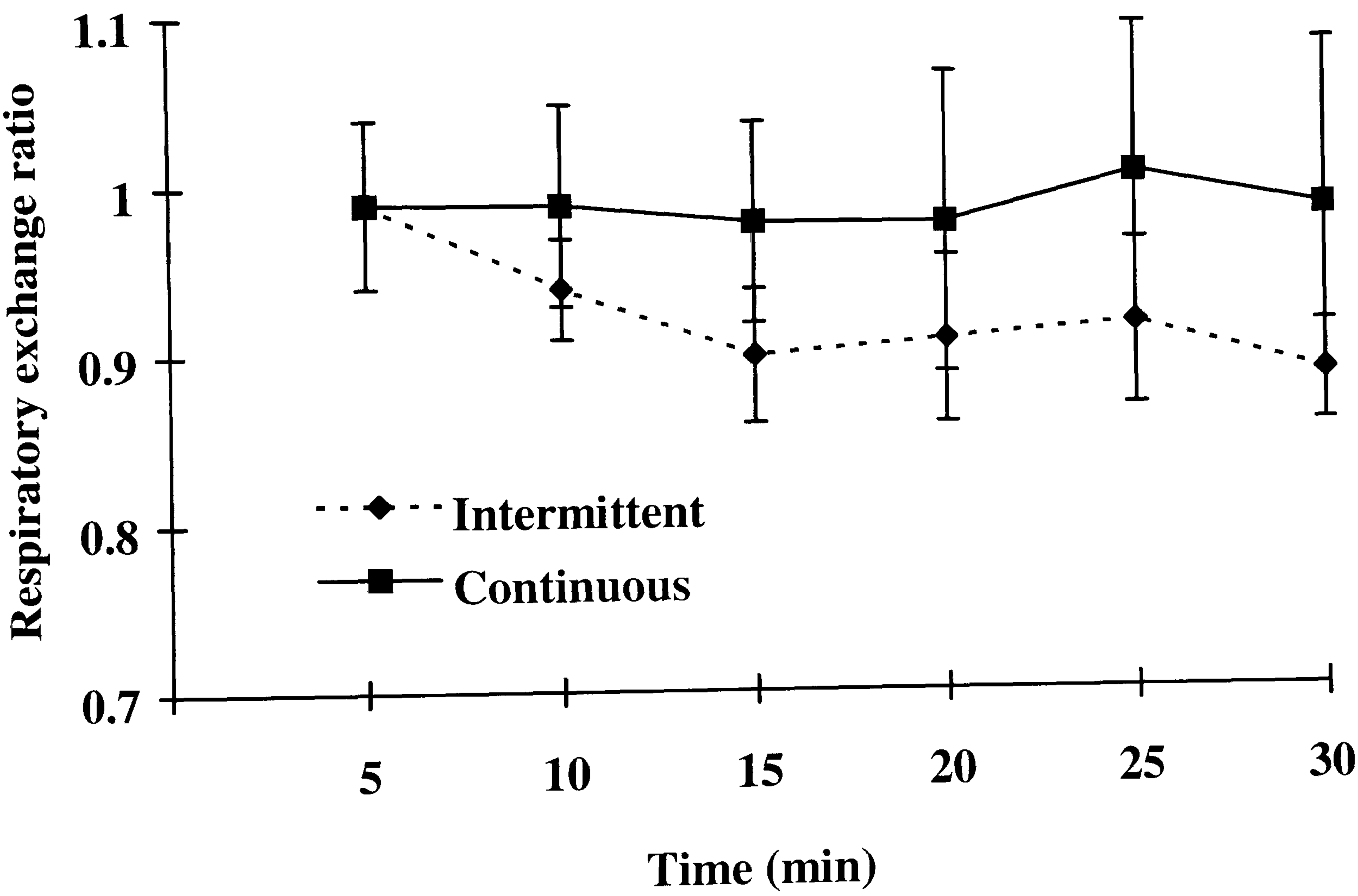


Figure 4.1.9. Mean (± SD) values of respiratory exchange ratio during intermittent and continuous exercise in the normal condition.

4.1.4.8. Minute ventilation at 5 min intervals during intermittent and continuous exercise in normal conditions

Figure 4.1.10. represents the mean (±SD) value of minute ventilation during intermittent and continuous exercise in the normal condition. Higher values were observed during continuous exercise than those observed during intermittent exercise in the normal condition ($F_{1,6}$ = 33.88; P >0.001).

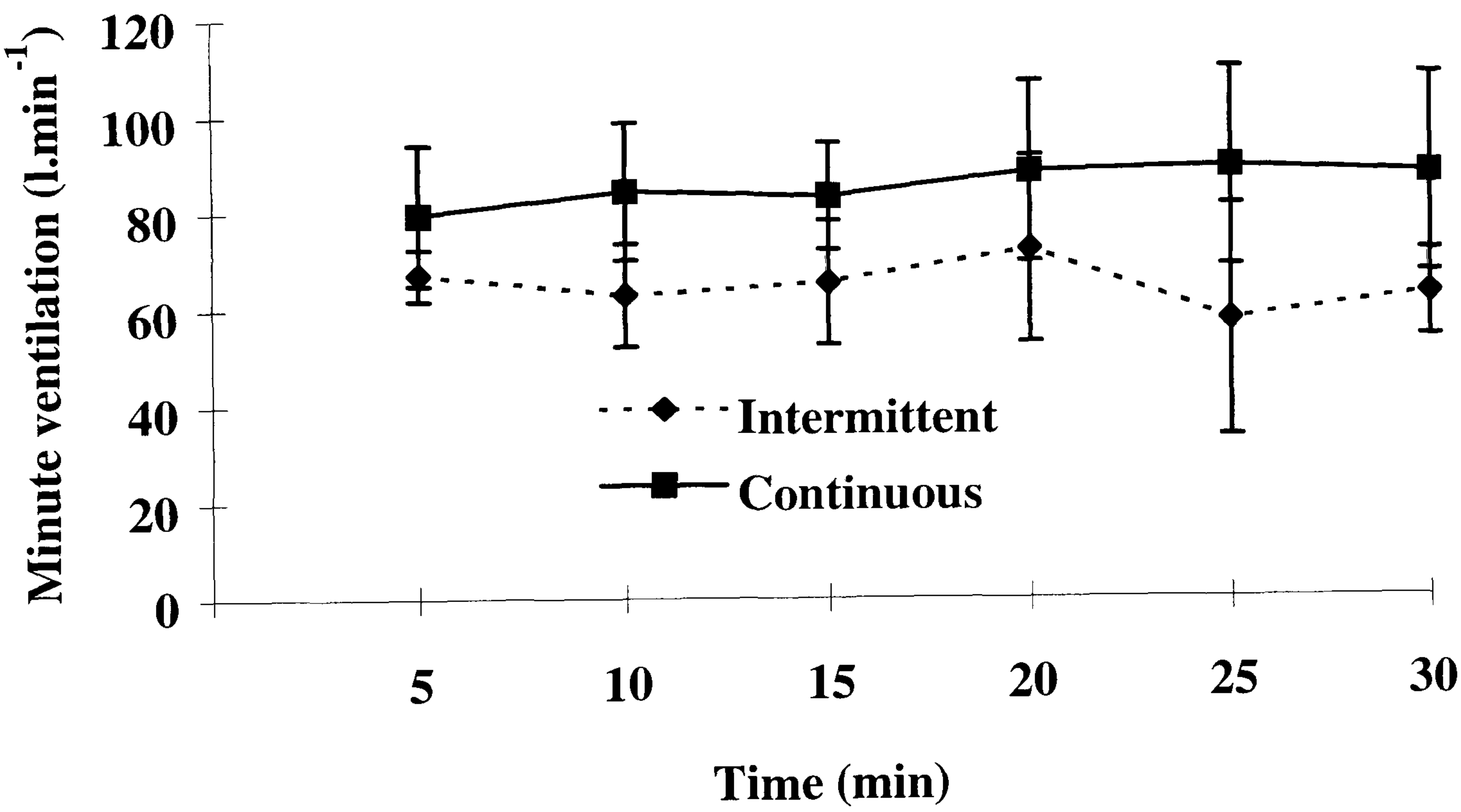


Figure 4.1.10. Mean (± SD) values of minute ventilation during intermittent and continuous exercise in the normal condition.

4.1.4.9. Estimation of energy expenditure in the first 15 min and second 15 min intermittent and continuous exercise in normal conditions

Figure 4.1.11. shows the mean (± SD) values of energy expenditure during the first 15 min, second 15 min and total energy expenditure for the two stages of exercise. Energy expenditure was higher (t = -3.61; P <0.05) after the end of the second 15 min than after the end of the first 15 min of continuous exercise. In contrast it was not significantly different during intermittent exercise. Although, energy expenditure was greater during continuous exercise than intermittent exercise at the end of the first 15 min and the second 15 min, no significant difference in total energy expenditure was found between intermittent and continuous exercise.

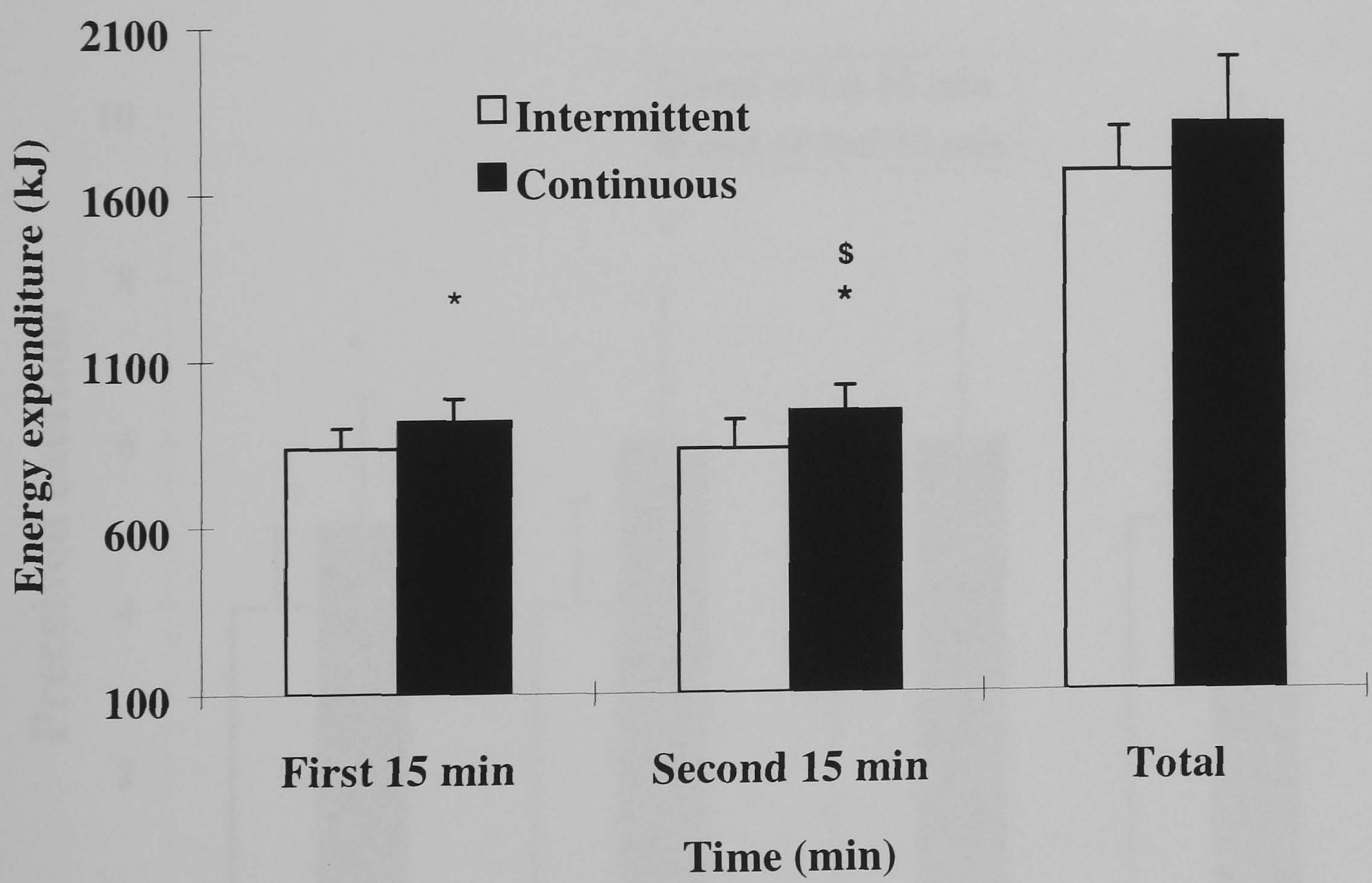


Figure 4.1.11. Mean (± SD) values of energy expenditure for first 15 min, second 15 min and total energy expenditure during intermittent and continuous exercise in normal condition. * Significantly (P <0.05) higher value observed than during intermittent exercise. $ Significantly (P <0.05) higher value observed than during in the continuous exercise.

4.1.4.10. Mean of perceived exertion value for each 5 min period during intermittent and continuous exercise at 5 min intervals in normal and hot environments

Figure 4.1.12. illustrates the mean (± SD) values of perceived exertion at 5 min intervals during intermittent and continuous exercise in normal and hot environmental conditions. Perceived exertion was higher at the end of the first 15 min and second 15 min exercise during continuous and intermittent exercise in the hot condition than in the normal condition ($F_{5,30}$ = 10.87; P <0.0001). In addition PE tended to be greater in the heat ($F_{1,6}$ = 5.98; P = 0.05) and there was an interaction between environmental temperature and duration of exercise ($F_{5,30}$ = 4.36; P <0.05).

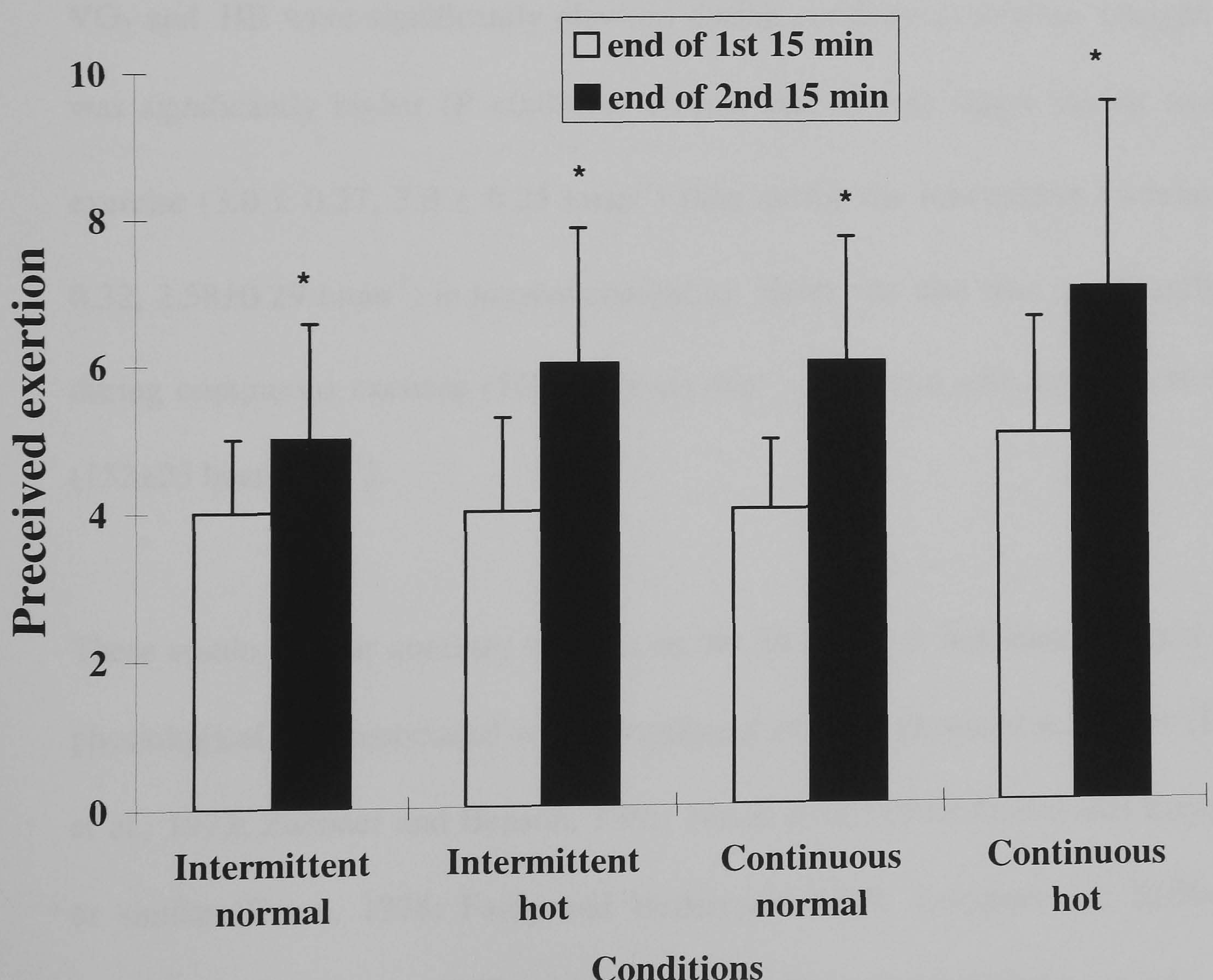


Figure 4.1.12. Mean (± SD) values of perceived exertion every 5 min during intermittent and continuous exercise in the normal and the hot environment.* Significantly (P <0.05) higher value observed than in the normal condition during intermittent and continuous.

4.1.5. Discussion

The purpose of this study was twofold: firstly to compare the physiological and thermoregulatory response to intermittent and continuous exercise protocols in normal laboratory conditions, and secondly to compare the effect of elevated environmental temperature on the exercise response during these models of activity. At present little information exists on the thermoregulatory implications of performing multiple-sprint type intermittent exercise in the heat.

For continuous and intermittent exercise (normal condition) in this study, subjects exercised using the same total external work-load in an attempt to quantify differences in cardiorespiratory and thermoregulatory demands of these forms of exercise. The VO_2, and HR were significantly elevated during continuous exercise. Oxygen uptake was significantly higher ($P < 0.05$) at 10 min and 30 min stages during continuous exercise (3.0 ± 0.27, 3.0 ± 0.25 $l.min^{-1}$) than during the intermittent exercise (2.45 ± 0.32, 2.58 ± 0.29 $l.min^{-1}$) in normal conditions. Heart rate also was significantly higher during continuous exercise (166 ± 27 $beats.min^{-1}$) compared with intermittent exercise (152 ± 23 $beats.min^{-1}$).

These results appear contrary to those in the literature. It has been reported that the physiological cost associated with intermittent exercise protocol is greater (Edwards et al., 1973; Zaunner and Benson, 1981; Nevill et al., 1994; Garret and Boyd; 1995) or similar (Essen, 1978; Fardy and Hellerstein, 1978; Lockhart and Ruffin, 1994; Bangsbo, 1994b; Drust; 1997) to that measured during intermittent exercise.

These contradictory results may reflect differences in the experimental protocol used. The previous studies used intermittent formats that consisted of high intensity work of a fixed period separated by passive recovery. The protocol used in this study more accurately simulates the demands of intermittent team sports by interspersing bouts of walking, jogging and running. Because this protocol does not contain any passive recovery during exercise periods, it is likely the VO_2 kinetics are markedly different from those experienced when moving from rest to the high intensity exercise used in prior research. In addition, in previous studies, continuous and intermittent work intensities have been derived such that subjects exercise at equivalent VO_2 values and therefore it is hardly surprising that VO_2 and heart rate were comparable between modes. By standardising total external loading, this study allows a direct comparison of any differences in physiological demand.

Alternatively the quantitative differences between this study and previous work may be explained by the protocol used. Although subjects performed continuous and intermittent exercise at the same external workload (i.e. same average velocity for similar duration), when performing the intermittent mode there was a 5 min cessation of exercise after 15 min activity. Subsequently when recommencing the second 15 min period, VO_2, HR and energy expenditure may have been transiently below the values observed in continuous exercise, therefore accounting for the differences in physiological demand to reflect more accurately the work rate profile of intermittent exercise.

The significantly lower VO_2 values observed during intermittent exercise at 10 and 30 min can also be explained by examining the speeds used in the intermittent protocol (see Figure 4.1.1). In the minute immediately preceding these time points, subjects were exercising at the lowest speed of 6 $km.h^{-1}$. It is therefore likely that the VO_2 measured at this time would be significantly lower that measured whilst running at 11 $km.h^{-1}$ in the continuous protocol.

The decrease in body mass was significantly greater ($P < 0.05$) after the continuous exercise (-0.86 ± -0.25 kg) in normal conditions than for intermittent exercise (-0.59 ± -0.16 kg) suggesting that the sweat production rate during continuous exercise was significantly higher than for intermittent exercise under normal conditions. Since sweat production rate is dependent on the absolute work load performed, this may suggest that during continuous exercise subjects exercised at a greater intensity. This is supported by the significant increase of oxygen uptake (VO_2 $l.min^{-1}$) (1.2%) and heart rate (HR) (1.2%) in continuous exercise compared with intermittent exercise in the present study (see section 2.2 intermittent vs continuous in review of literature). This is contrary to a number of previous investigations.

Rectal temperature was significantly higher during both intermittent and continuous exercise in the heat compared to the normal conditions. This finding was similar to the data of Ekblom et al. (1971), Kraning and Gonzalez (1991) and Drust (1997). However, contrary to normal conditions, the rise rectal temperature was significantly greater during continuous exercise. Once again this may merely reflect the greater heat production during the continuous exercise mentioned above. However, it is interesting to note that in the hot condition the sweat production was greater during intermittent exercise which may indicate that there was an increased heat loss and therefore a lower rectal temperature during this form of exercise. The data are comparable with those reported by Maxwell et al. (1996). Twelve subjects were studied under three environment trials: i) a standardised warm up in a cool environment and repeated sprints in a cool environment (CC), ii) a standardised warm up in a cool environment and repeated sprints in a hot environment (CH) and iii) a standardised warm up in a hot environment and repeated sprints in a hot environment (HH). They found that mean rectal and skin temperatures were higher after warming up in the heat than after warming up in the cool environment. Rectal and skin temperatures were significantly different following the repeated sprint tests in the three trials (For CC 37.6 ± 0.12 °C, CH 38.0 ± 0.09 °C and HH 38.2 ± 0.12 °C) with the greatest thermal strain observed during exercise in the heat.

In the present study skin temperature was significantly ($P < 0.05$) higher in the hot condition at rest, during exercise and into recovery in the intermittent exercise. Drinkwater et al. (1976) examined the effects of three different environmental temperatures (28 °C, 35 °C and 48 °C) during intermittent exercise. The results showed the skin temperature was higher in 48 °C than 35 °C and 28 °C. They found that skin temperature was higher during exercise than into recovery but skin temperature was higher during the recovery period than the initial resting values for all three temperature conditions. In addition, Drinkwater et al. (1976) reported that heart rate was constant for three different environmental temperatures (175 ± 3, 179 ± 4 and 179 ± 3 beats.min^{-1}) respectively; however, heart rate in the current study was

170 ± 25 and 178 ± 25 beats.min^{-1} during intermittent and continuous exercise in the hot environment.

Heart rates are elevated in the heat as the demands for blood flow in both the skin and muscle are high and this presents the problem of providing sufficient circulation to both of these vascular beds and preserving arterial pressure. An interesting observation in this study is that under normal conditions the sweat production was greater in continuous exercise than in intermittent exercise, whereas in the hot condition the reverse was true. This was possibly related to the frequent alternations between low and high intensity exercise resulting in oscillations in vasoconstrictor tone of peripheral vessels. This may result in a reduction in skin blood flow which limits heat loss and which, specifically in hot conditions, places increased emphasis on the sweat production during intermittent exercise. This observation of greater sweat production rates during intermittent exercise has important ramifications for games players competing in the heat. This evidence suggests that under these condition there will be a greater demand for sweating which may cause larger reductions in plasma volume and hence lead to dehydration. Although, further research is required to confirm these observations, if players are not allowed to rehydrate during match-play there could be significant reduction in performance.

In conclusion, whilst the results of this study contradict previous work, they demonstrate that intermittent exercise in the heat results in a significantly greater sweat production compared to continuous exercise or in a cooler temperature.

When playing in hot conditions, players may therefore be exposed to high sweat losses, placing high demands on their stores of body fluid. It is therefore recommended that fluid replacement strategies be used by these athletes, although it is not presently known what effect such fluid replacement has during this particular form of exercise. This however, required further investigation.

4.2. THE EFFECT OF CARBOHYDRATE INGESTION ON SELECTED PHYSIOLOGICAL RESPONSES TO INTERMITTENT EXERCISE IN NORMAL AND HOT CONDITIONS

4.2.1. Introduction

The nutritional status of habitual exercisers and athletes is generally considered as one of a number of factors which can have a profound effect on physical performance. An optimum diet in terms of quantity and quality, before, during and after training and competition will enhance performance. Williams and Devlin (1992) clearly demonstrated the importance of carbohydrate availability during prolonged exercise and the potential influence of dietary carbohydrate intake on endurance exercise performance. Since the beginning of the 20th century, scientists have examined the interrelationships between carbohydrate consumption, metabolic substrate utilisation and the onset of fatigue (Coggan and Coyle, 1991). Therefore, the effects of different carbohydrates feeding regimens on exercise performance capacity have been extensively studied (Gleeson et al., 1986; Murray et al., 1989) and reviewed recently by El-Sayed et al. (1997). The majority of these studies have shown that carbohydrate ingestion before and during exercise contributes significantly to energy provision (Mitchell et al., 1988; Coggan and Coyle, 1991). Carbohydrate stored as glycogen in skeletal muscle also plays an important role in the production of energy during exercise (Bangsbo, 1991b).

It should be noted that most of the previous studies have employed prolonged continuous exercise protocols in normal environmental conditions to determine the influence of carbohydrate supplementation on metabolic substrate utilisation and exercise performance capacity. The effects of a high ambient temperature on physiological and thermoregulatory responses during prolonged continuous exercise have been extensively studied (Davis et al., 1988; Millard, 1992; Below et al., 1995) However, in many sports such as handball, basketball and soccer for example, the mode of exercise is not continuous but intermittent and is usually associated with a large decrease in muscle glycogen levels (Leatt and Jacobs, 1988). Sometimes the game is performed outdoors in a hot environment. The energy requirement during ball-games encompassing intermittent exercise varies depending on the intensity and duration of the game and the environmental conditions. In addition, metabolic fuels and performance capacity are generally influenced by carbohydrate availability and the amount of glycogen stored in the muscle (Jacobs et al., 1982).

Carbohydrate feeding during soccer helped players to increase the total distance run in a match as well as the amount run at top velocities (Muckle, 1973; Kirkendall et al., 1988). These findings are similar to those reported by Simard et al. (1988) in players during a hockey match. Muscle glycogen utilisation during a handball match was examined by Saltin (1979) and the results showed that glycogen depletion was most pronounced in the throwing arm and the jumping leg. No information seems to be available regarding the effect of carbohydrate feeding on the physiological and thermoregulatory responses during this ball-game, particularly in a hot environment in which the metabolic demands could be elevated. Therefore the present study was designed to determine the effect of fluid and carbohydrate ingestion on selected physiological and thermoregulatory changes in response to a generic intermittent exercise protocol in normal and hot conditions.

4.2.2. Materials and methods

4.2.2.1. Subjects

Twelve healthy male subjects were recruited from the Centre for Sports and Exercise Sciences, Liverpool John Moores University (n = 10) and Liverpool Handball Club (n = 2) to participate in the study. The study protocol and procedures were approved by the Human Ethics Committee of Liverpool John Moores University. Before data collection began, each subject signed an informed consent form whereby the nature and purpose of the investigation had been fully stated and explained (see Appendix 2)

Although most of the subjects were familiar with the laboratory environment and test protocol because they had previously participated in similar studies, all subjects underwent two sessions of habituation in order to ensure familiarity with the exercise protocol, the laboratory environment, and testing procedures. Subjects' physical characteristics are shown in Table 4.2.1.

Standing body height measurements were recorded for each subject to the nearest 0.5 centimetre by means of a wall mounted stadiometer (Seca, Germany).

Nude body mass was determined to the nearest 0.1 kilogram using a triple beam balance scale (Seca, Germany). Body mass was recorded before and after each exercise trial.

Table 4.2.1. Mean (± SD) values of the subjects' characteristics (n = 12).

	Mean	± SD
Age (years)	25	2.7
Height (cm)	176	4.4
Body mass (kg)	74.8	6.6
Body fat (%)	11.9	3.5

The percent body fat was estimated from skinfold thicknesses according to the method of Durnin and Womersley (1974). Reliability of the technical error of measurement for the major kinanthropometric variables assessed in this thesis have previously been reported in section (3.2.2).

4.2.2.2. Preliminary maximal oxygen consumption test

One week prior to the main experiment, all subjects reported to the laboratory at the same time of day (09:00-10:00 hours), for the determination of maximal oxygen uptake (VO_{2max}). Subjects performed a continuous incremental running protocol on a motorised treadmill (Quinton instruments, Washington, USA) to determine VO_{2max}. Following a 5 min warm-up at a speed of 7.5 km.h^{-1}, the initial treadmill speed was set at 10 km.h^{-1} for 2 min. Thereafter the treadmill speed was increased by 2 km.h^{-1} every 2 min until the subjects reached volitional exhaustion. The following criteria were employed to ensure the attainment of $VO_{2\,max}$:

1. A plateau in the oxygen uptake/exercise intensity relationship, as an increase oxygen uptake of less than 2 ml.kg^{-1}.min^{-1} or 3% with an increase in exercise intensity

2. A final respiratory exchange ratio value of 1.1 or more.

3. A final heart rate within 10 beats.min^{-1} of age predicted maximum.

4. Inability to maintain the pre-assigned treadmill speed.

Subjects were fitted with a short-range radio telemeter (Sport Tester 3000, Finland) for continuous heart rate monitoring. Prior to testing, subjects were fitted with a mouthpiece and nose-clip. Expired gases were measured using a computerised on-line system (Metabolic Measurement Cart, SensorMedics, USA) which had been calibrated using three calibration gases of known concentrations. Table 4.2 2. presents the mean ± SD values for heart rate and maximal oxygen consumption during the exercise test protocol. After completion of the $VO_{2\ max}$ test, the subjects were asked to report to the laboratory on four more separate occasions in order to undertake further submaximal intermittent exercise tests.

Table 4.2.2. Mean (± SD) of heart rate and oxygen consumption at rest and in response to the maximal exercise test of the subjects (n = 12).

	Rest	Maximal exercise
Heart rate (beats.min^{-1})	62 ± 7	187 ± 12
VO_2 (ml.kg.min^{-1})	4.04±0.19	51.4 9± 6.4
VO_2 (l.min^{-1})	0.30±0.02	3.88 ± 0.41

HR = heart rate, VO_2 = Oxygen consumption

4.2.2.3. Intermittent exercise procedures

The subjects randomly performed four identical sub-maximal tests with approximately seven days in between in order to examine the effect of fluid and carbohydrate ingestion on selected thermoregulatory and cardiovascular responses to a 30 min laboratory-based intermittent treadmill exercise protocol. This was conducted in both normal environmental conditions and in an elevated laboratory temperature. Treadmill velocity varied during exercise in an attempt to simulate the true nature and intensity (in terms of physiological response) of handball match-play as previously described in section 4.1. pp 131and 132. The intermittent treadmill exercise tests were conducted at the same time of the day (11:00-14:00 hours) and under normal (18 ± 2 °C) and hot (32 ± 2 °C) conditions. The average relative humidity was similar for normal (46%) and hot (48%) conditions.

Each subject was instructed to follow his normal diet and daily life activity pattern and abstain from exercise for 24 hour before each test. When subjects reported to the laboratory, nude body mass was measured, a rectal probe (Grant, Squirrel meter, Cambridge) inserted to a depth of 10 cm beyond the anal sphincter, and the heart rate was recorded at rest and every 5 s interval by short range radio telemetry (POLAR, Sport Tester, Finland). Skin temperature was measured by thermistors and an infrared device (Grant Squirrel meter, Cambridge). Thermistors were attached to the skin at the following four sites: (a) chest (over the sternum), (b) mid-front arm, (c) mid-front thigh and (d) exterior mid-calf (Ramanathan, 1964). Thereafter, the subject sat on a chair placed on the treadmill for 15 min followed by the procurement of an arterialised finger-tip blood sample for the determination of blood lactate and blood glucose.

Rectal and skin temperatures were monitored continuously and recorded at the end of every 5 min interval during the exercise test. The test began by a warm-up period for 5 min at speed of 7.5 $km.h^{-1}$ and 12 $km.h^{-1}$ in the last 30 s. Thereafter the treadmill was stopped and the mouthpiece inserted. Attachment of the noseclip (for expired air to be analysed during the entire test) preceded the exercise test by 1 min and to check that the computer was working properly.

During each experimental trial, perceived exertion was record on a scale 0 - 10 (Borg, 1982). Subjects were asked to assess the perceived exertion every 5 min. Expired air was collected continuously and analysed on-line every 20 s for the measurement of VO_2, respiratory exchange ratio and minute ventilation. From these measurements the energy expenditure during each test trial was calculated.

Immediately after the completion of the first 15 min stage of the intermittent exercise test, subjects were seated on a chair (placed on the treadmill) for 5 min. At the end of the third minute, a capillary blood sample was taken and at the end of the fifth minute the second drink solution was given. Thereafter the subjects were asked to perform the second 15 min stage of the test which was identical to the first stage.

Following the completion of the second stage of the test, subjects were allowed to recover for 15 min sitting on a chair on the treadmill. A capillary blood sample was obtained and the drink solution was given at the end of exercise. Rectal and skin temperatures were recorded every 5 min and a further capillary blood sample was taken. Following that the subject left the treadmill, the rectal probe was removed and the subject's nude dry body weight was recorded.

4.2.2.4. Preparation and administration of the experimental drinks before, during and after the intermittent exercise test

The two experimental drinks were (a) an artificially sweetened, orange- flavoured, glucose-free placebo and (b) a 7.5% (weight/volume) orange-flavoured glucose solution. The drinks were given in a double-blind and randomised fashion and were served in plastic opaque squeeze bottles at room temperature. Prior to the main experiment, subjects were given a small amount of the two experimental beverages and indicated their inability to distinguish between the two solutions. Subjects ingested an equal volume of the respective drink at exactly the same point in time during the two tests. An initial portion of either glucose or placebo (3 $ml.kg^{-1}$ body weight) was administered 15 min before commencement of exercise. The second and third portions of the drink (3 $ml.kg^{-1}$ body weight) were given after the first 15 min of exercise and immediately upon the completion of exercise. The total volume of fluid administered during each experimental trial was (mean ± SE) 663 ±15.6 ml and the mean total glucose given during the carbohydrate trial was 50 g.

4.2.2.5. Assessment of oxygen uptake, respiratory exchange ratio, minute ventilation during the intermittent exercise test

On each test, expired air was collected continuously every 20 s for measurement of VO_2 uptake, respiratory exchange ratio, and minute ventilation by means of an automated system (Sensor Medics, 2900, California USA). The details were previously given in section 3.5.

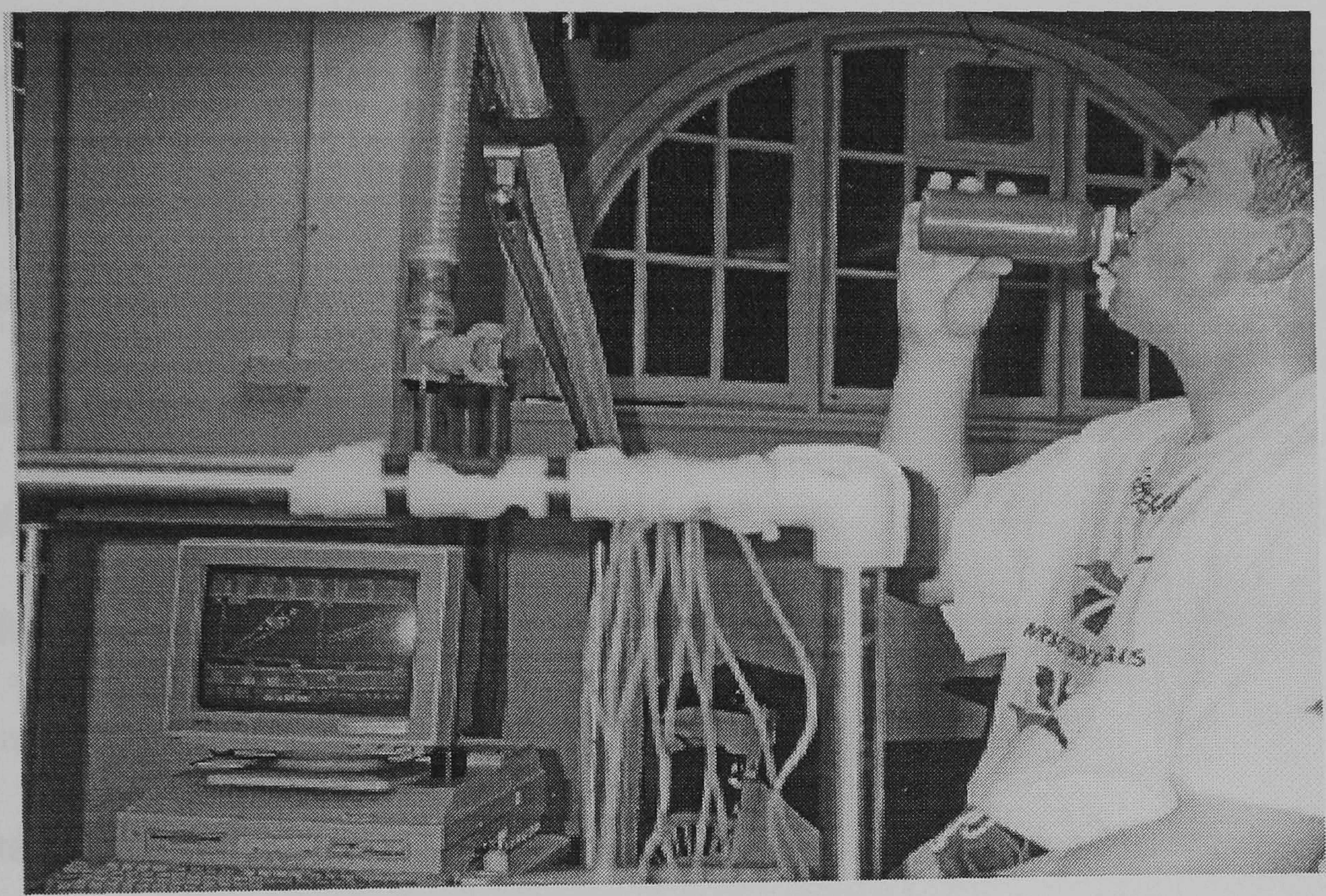


Plate: 4.2.1. Carbohydrate or placebo ingestion

4.2.2.6. Blood sampling procedures

Arterialised capillary blood samples were obtained five times and collected in capillary tubes for measurement of haemoglobin, haematocrit, glucose and lactate. The blood sample was removed after warming the finger and wiping it with a Mediswab. The first drop of the blood was discarded, then the required quantity of free-flowing whole-blood was collected in the capillary tubes. The times at which capillary blood was obtained are shown in Figure 4.2.1. A resting blood sample was taken 3 min before the initial intake of the respective drinks. Blood samples were also taken 15 min after administration of the respective drink, 15 min after the first stage of exercise, 15 min after the second stage of exercise, and at the end of the recovery period. All blood parameters were measured in duplicate and the average value was used in the statistical analysis.

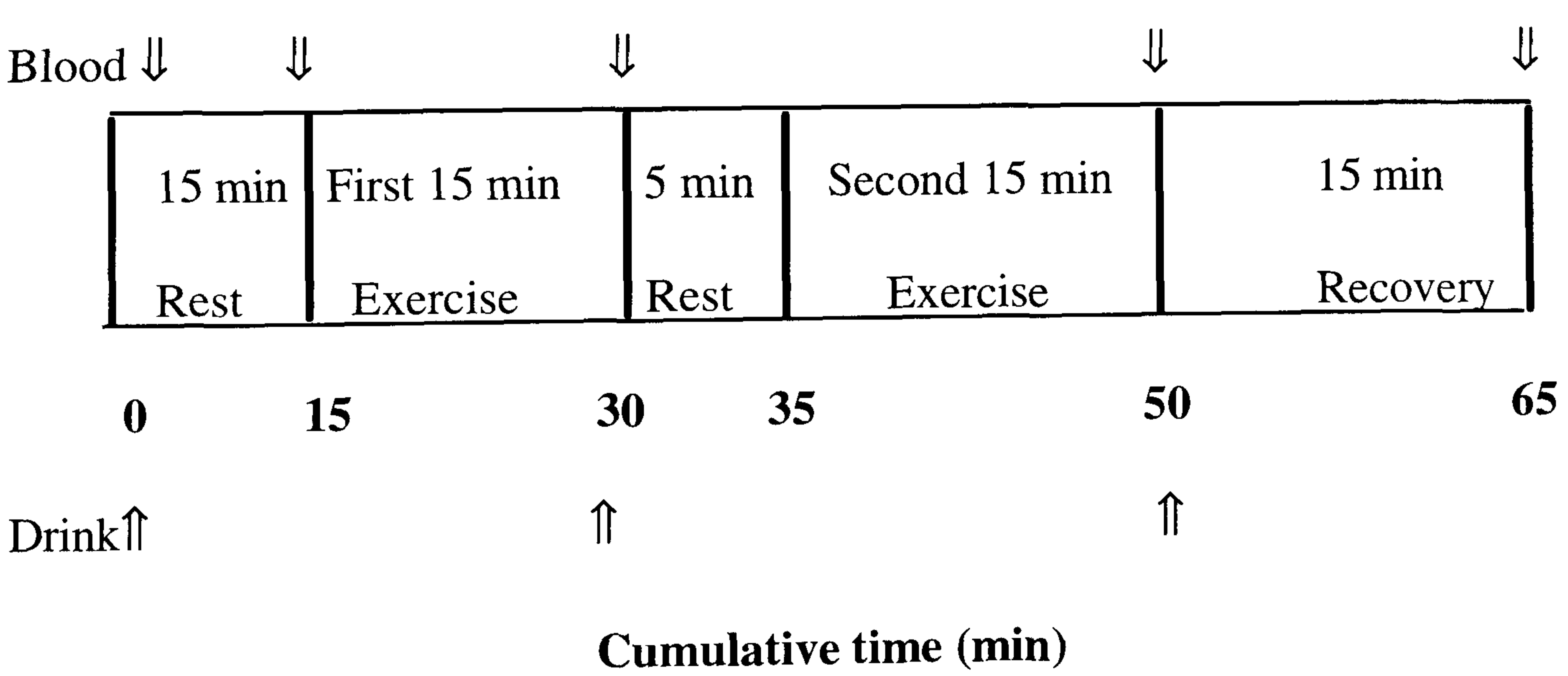


Figure 4.2.1. Schematic presentation of the experimental design. The upper arrows show blood sampling time, while the lower arrows show the time of drink ingestion.

4.2.2.6.1. Haemoglobin measurement

Haemoglobin was measured in duplicate using a HemoCup B- Haemoglobin analyser (Clandon, Angelholm, Sweden) (Plate 4.2.2). Prior to any measurement, the machine was calibrated by control cuvette and the value should be within 1.26 ± 3 g.l. A fresh finger tip sample was drawn by an automatic lancet (Autolix) into a microcuvette. The microcuvette was then placed into the photometric chamber of the analyser. After a steady state was reached, the haemoglobin value was displayed.

4.2.2.6.2. Haematocrit measurement

Haematocrit was measured in duplicate using the micro-method. Fresh and thoroughly mixed finger tip blood was drawn by capillary action in to heparinised micro-haematocrit tubes. The tubes were then secured at one end by sealed wax using a crystalseal tray, and were left to stand vertically until centrifuged for 15 min at 1200 rev min^{-1}. The haematocrit reading was obtained using a Hawksley micro-Haematocrit reader (Plate 4.2.3.) The mean of two measurements was used in all subsequent analysis.

4.2.2.6.3. Estimation of plasma volume loss

The finger tip blood sample was used to estimate the plasma volume change by previous investigator (El-Sayed et al., 1995 and Maughan et al., 1996).

Changes in plasma volume were calculated from haematocrit and haemoglobin reading before and after exercise using the methods described by Dill and Costill (1974). The equation used for the estimation of plasma volume change was as follows:

$BV_A = BV_B (Hb_B/Hb_A)$

$CV_A = BV_A (Hct_A)$

$PV_A = BV_A - CV_A$

plasma volume (%) = $100 (PV_A - PV_B)/PV_B$

The subscript B and A refer to before and after exercise, respectively, and blood (BV_A) defined as blood volume after exercise. Blood volume before (BV_B) exercise was taken to be 100%. The percentage change in plasma volume was then used to correct post-exercise values for lactate and glucose.

4.2.2.6.4. Measurement of blood glucose concentration

Thirty microlitres of fresh finger tip blood were drawn into a Reflotron capillary tube and applied as a drop to the centre of the application zone of a glucose test strip. The strip was then inserted to the Reflotron (Mannheim Germany) instrument (Plate 4.2.4) within 15 s. The glucose concentration was displayed. The average of two readings was used for all the subsequent analyses. Based on 12 determinations of a single blood sample, the coefficient of variation (CV) for glucose measurement was 3.1%.

4.2.2.6.5. Measurement of blood lactate concentration

Blood lactate was measured in duplicate using an automatic lactate analyser (YIS, 1500 SPOTR Yellow Spring, Ohio, USA) (Plate 4.2.5). A lactate solution (YSI Yellow Spring, Ohio, USA) of known concentration (15 $mmol.l^{-1}$)) was used as a single point calibration of the instrument before blood lactate measurements were made. Fresh finger tip blood was drawn into a 25 ul tube and was mixed thoroughly.

Whole-blood was dispensed into the mixing chamber of the analyser using a micropipette (YSI Syringepet Model 1501) and the result was displayed shortly after. The average of two values was used in all subsequent statistical analyses. Similar to blood glucose, the coefficient of variation (CV) of blood lactate concentration was calculated from 12 measurements on a single blood sample. The calculated CV was 2.4%.

4.2.2.7. Statistical analyses

The statistical analyses of the data were carried out using analysis of variance (ANOVA) (time 4 x treatment 3 x conditions 2) factorial ANOVA design nesting (crossed in factor 2 (treatment) with repeated measures in factor 1 (time) and factor 3 (conditions). Statistical significance was set at the $P < 0.05$ level. When a significance difference was found, data were further analysed using a Tukey post-hoc test. All data are reported as mean ± SE unless otherwise specified.

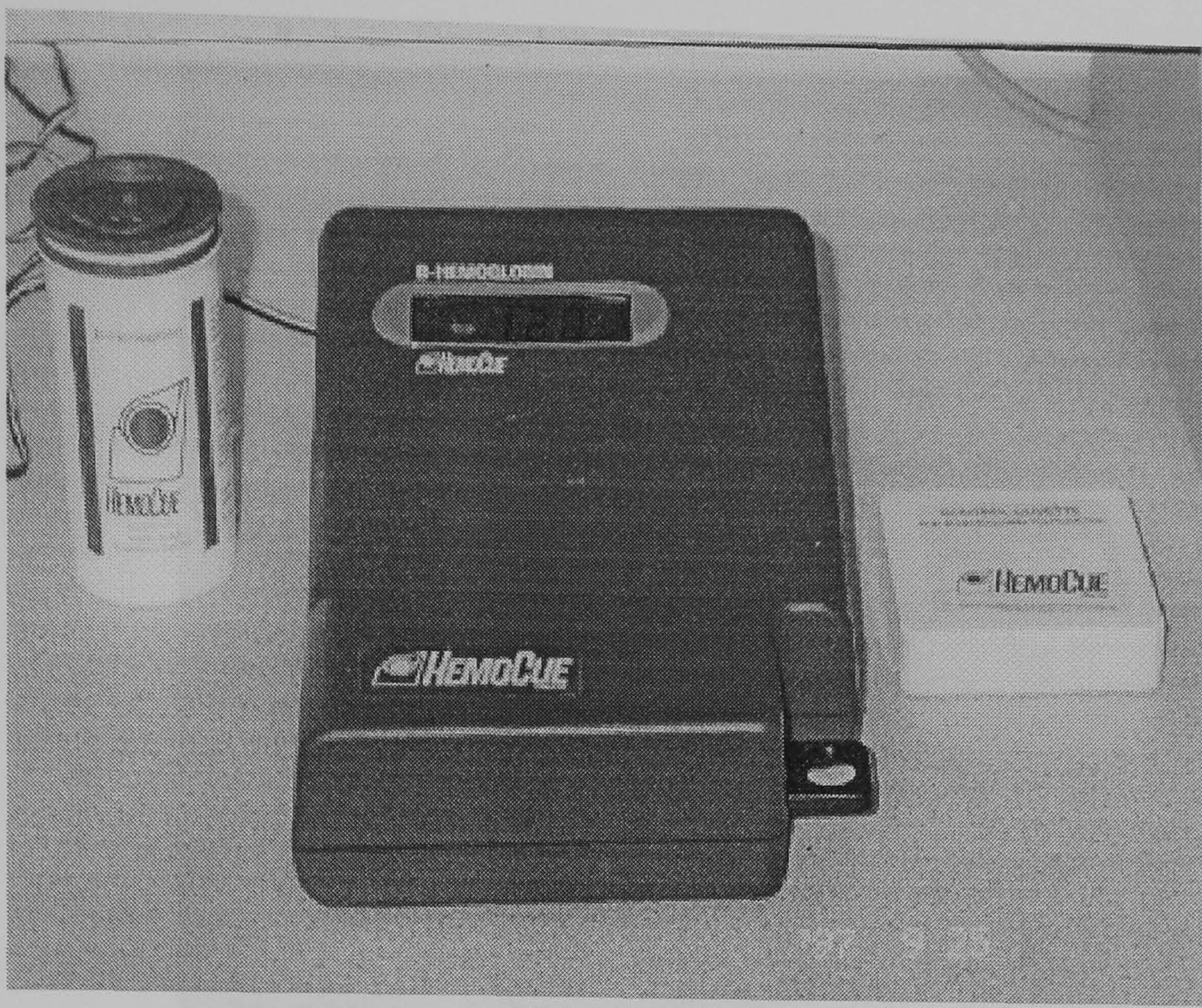


Plate 4.2.2. Haemoglobin measurement.
(Haemoglobin analyser Clandon)

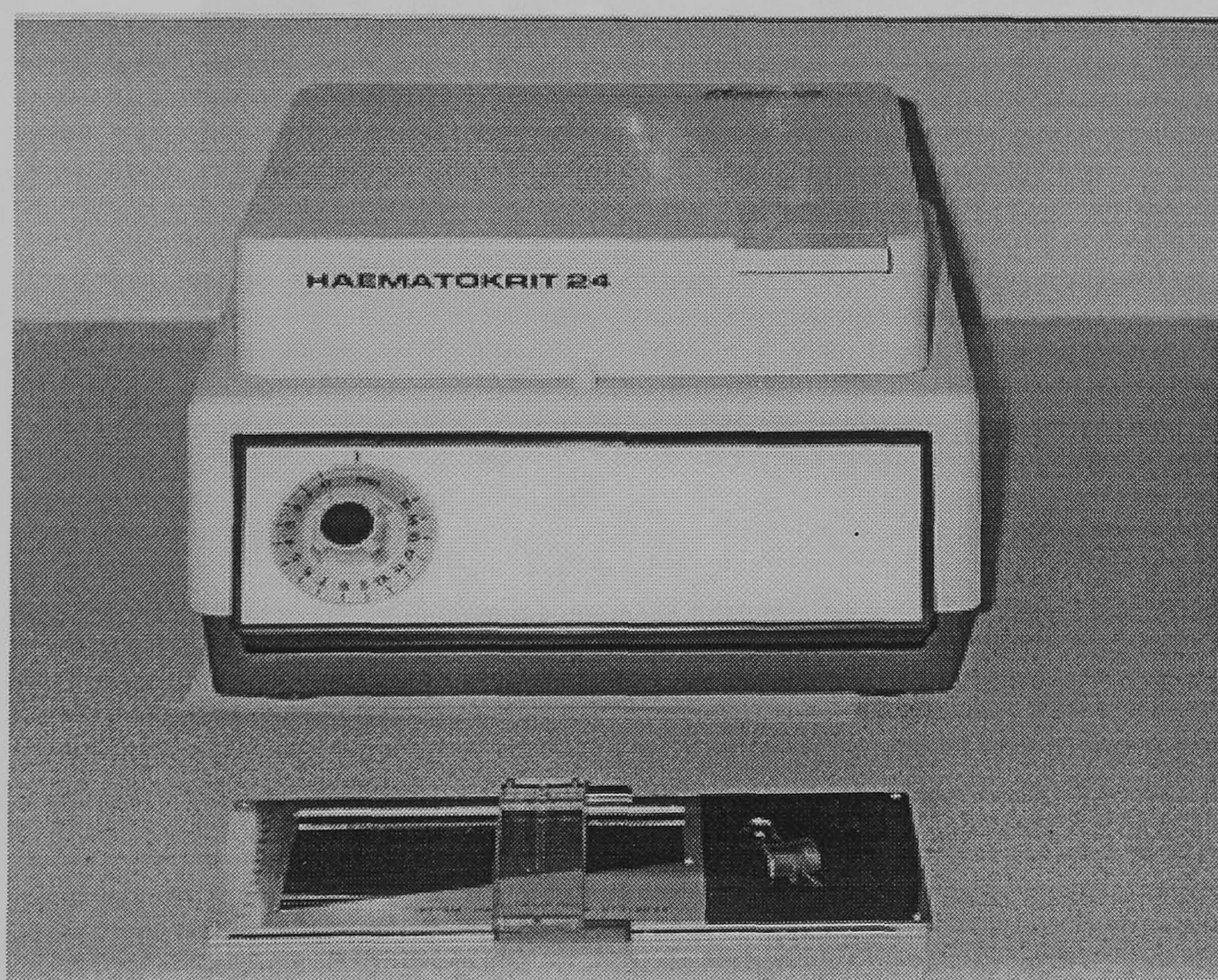


Plate 4.2.3. Haematocrit measurement.
(Centrifuged and Hawksley scale)

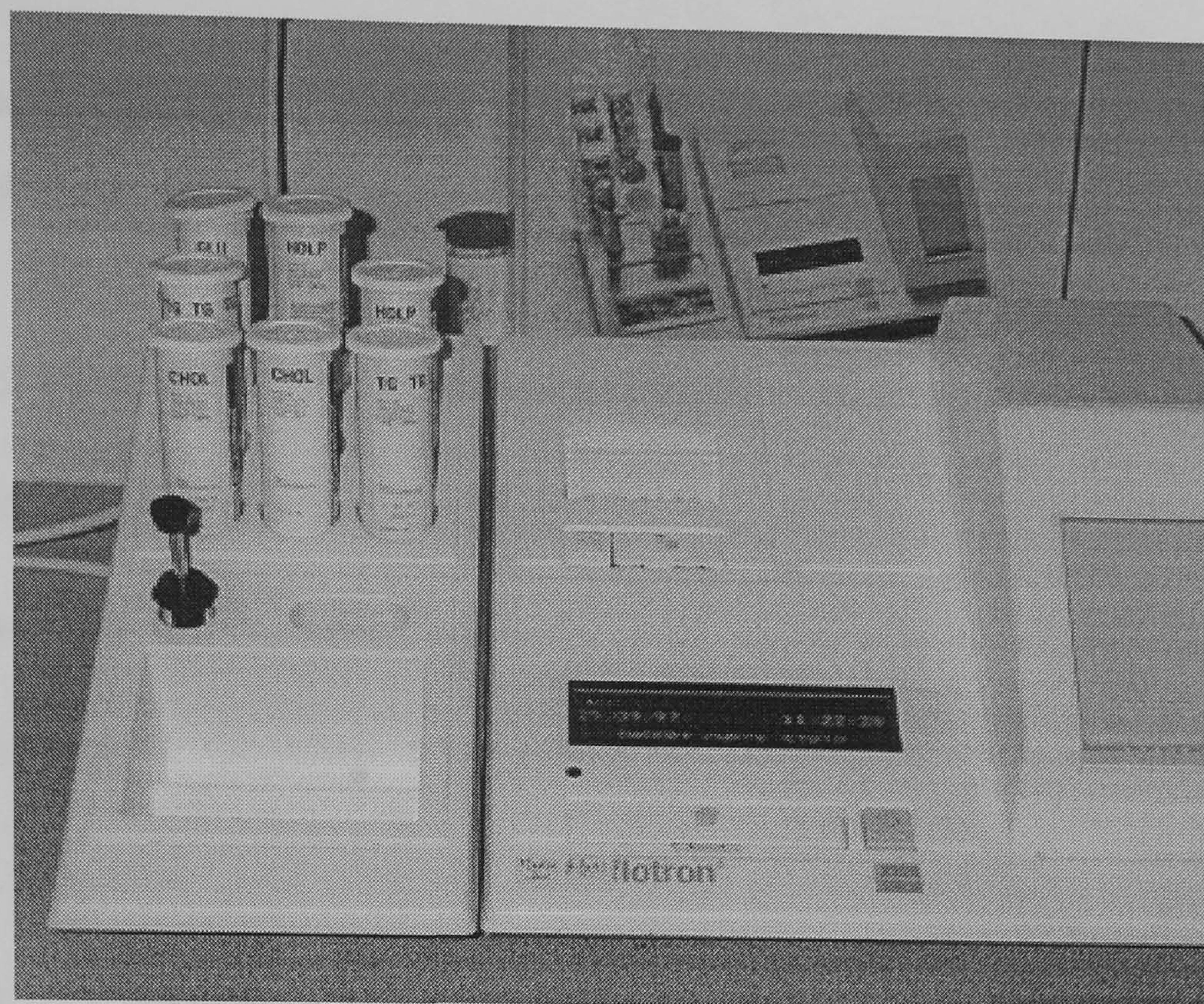


Plate 4.2.4. Reflotron instrument for analysing blood glucose concentration

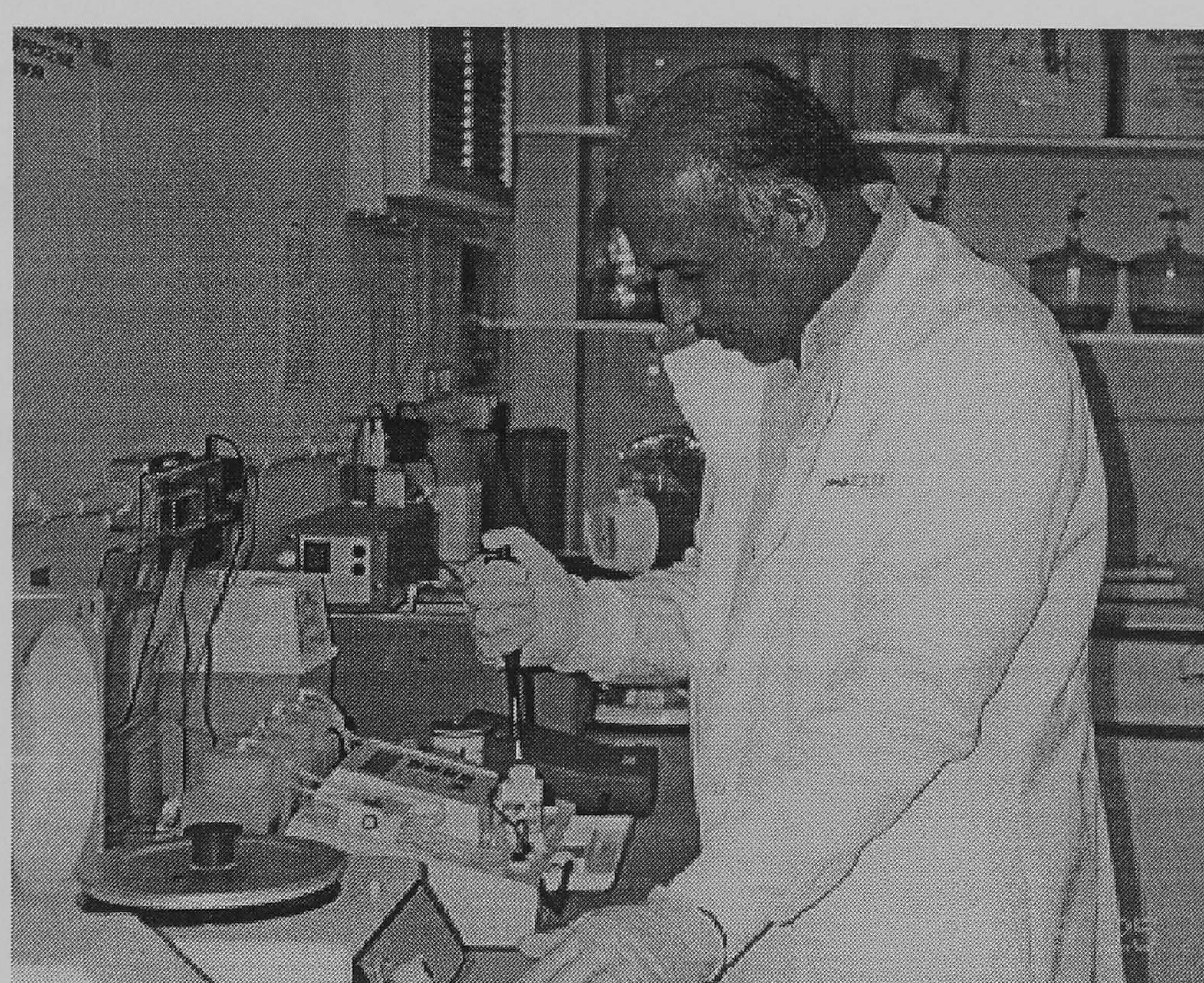


Plate 4.2.5. YIS Yellow Spring instrument used for analysing blood lactate concentration

4.2.3. Results

4.2.3.1. Body mass changes in response to intermittent exercise in normal and hot conditions with and without fluid and carbohydrate ingestion

Figure 4.2.2 and Table 4.2.3. show the mean (± SE) values of the difference in body mass following exercise trials with and without carbohydrate ingestion in normal and in hot conditions. The mean values of body mass did not vary significantly between the trials at rest before exercise. Compared to rest, uncorrected body mass for volume of fluid ingested post-exercise did not decrease significantly in all exercise trials. When the raw data for body mass were corrected for the volume of the fluid ingested, the decrease in body mass post-exercise did not reach significance ($P > 0.05$) in all exercise trials. The average decrease in body mass during carbohydrate (CHO) trial was -0.85 kg, (-1.15%, $P < 0.05$) and -1.1 kg, (-1.5%, $P < 0.05$) and during placebo (PLA) trial was -0.70 kg (-0.9%) and -1.1 kg (-1.5%) for normal and hot conditions, respectively. The decrease in body mass post-exercise was significant in the hot condition than in the normal condition and this occurred in carbohydrate, placebo, and control trials (Figure 4.2.2).

Table 4.2.3. Mean (± SE) of body mass before and after exercise trials (corrected and uncorrected) for carbohydrate, placebo and control in normal and hot conditions.

		CHO		PLA		Control	
		before	after	before	after	before	after
Normal	Corrected	73.8±1.8	72.9±1.8	73.5±1.9	72.6±1.8	73.8±1.8	72.9±1.8
	uncorrected	73.8±1.8	73.7±1.9	73.5±1.9	73.5±1.9	73.8±1.8	73.2±1.8
Hot	corrected	73.7±1.8	72.6±1.8	73.7±1.8	72.6±1.8	73.5±1.8	72.2±1.8
	uncorrected	73.7±1.8	73.3±1.8	73.7±1.8	73.3±1.8	73.8±1.8	73.0±1.8

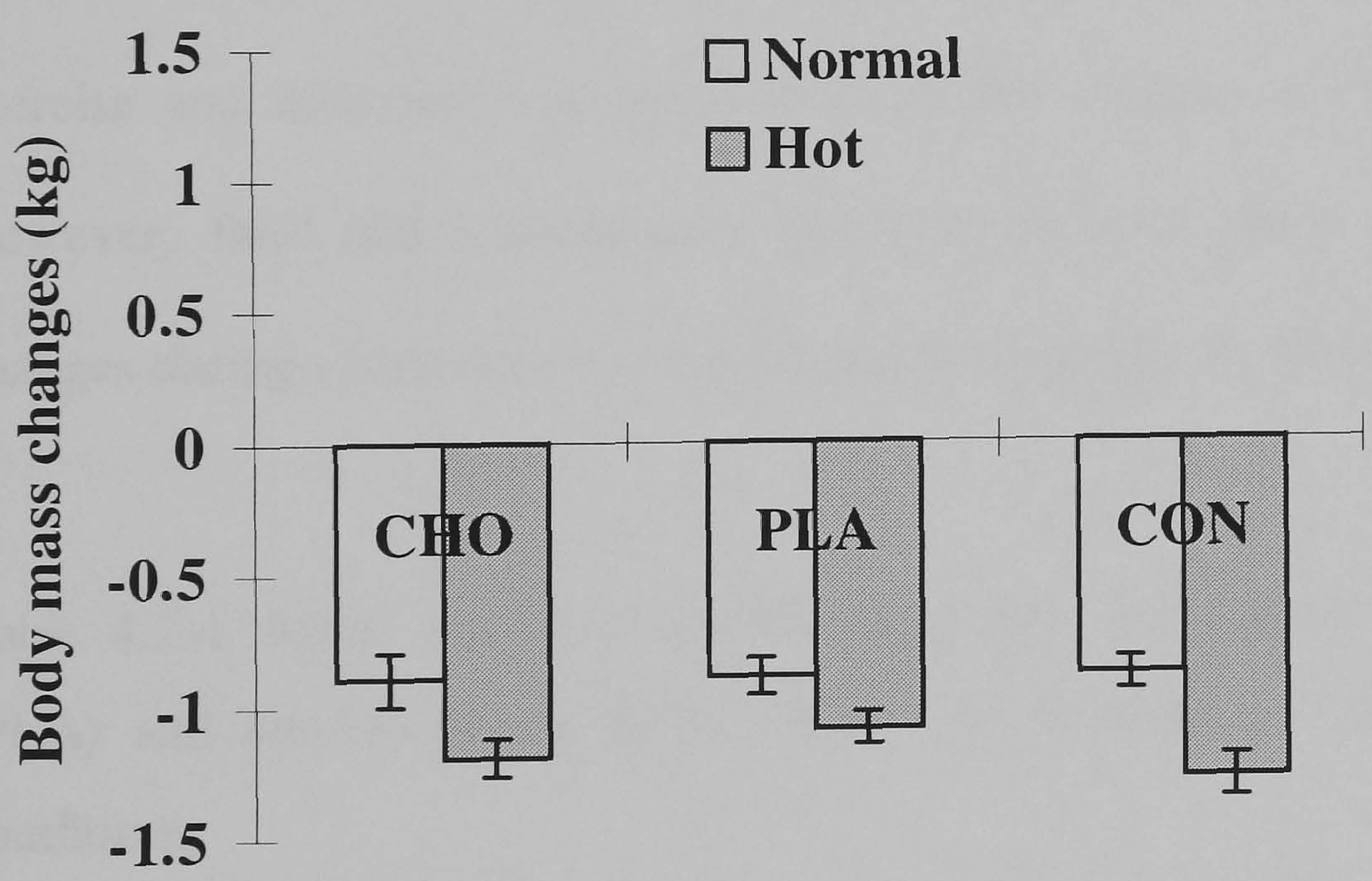


Figure 4.2.2. Mean (± SE) values of Δ body mass (pre-exercise-post-exercise) in response to exercise trials. CHO = fluid and carbohydrate, PLA = placebo; CON = without beverage ingestion.

4.2.3.2. Rectal temperature at rest, during intermittent exercise and into recovery with and without fluid and carbohydrate ingestion in normal and hot conditions

The mean values (± SE) of rectal temperature at rest, during exercise, and into recovery for all test trials are shown in Figure 4.2.3 and Table 4.2.4. Compared to rest, rectal temperature increased significantly ($F_{3,33}$ = 37.63; P <0.05) at the end of the first 15 min of exercise with a further increase being observed at the end of the second 15 min of exercise. Fifteen minutes into recovery, rectal temperature remained elevated both in normal and hot conditions irrespective of the beverage given. Data also showed that rectal temperature was significantly higher ($F_{1,11}$ = 98.7; P <0.05) in the second 15 min compared with the first 15 min during exercise and this occurred in both normal and hot conditions. As expected the increase in rectal temperature during exercise and recovery was significantly in hot compared with normal conditions. However, fluid and carbohydrate ingestion had no effect on rectal temperature changes during exercise or recovery either in normal or in hot environments.

Table 4.2.4. Mean ± (SE) of rectal temperature for carbohydrate (CHO), placebo (PLA) and control group (CON) during intermittent exercise in normal and hot conditions.

Condition		Rest	1st 15 min	2nd 15 min	Recovery
Normal	CHO	37.2±0.08	38.0±0.07	38.4±0.1	37.8±0.12
	PLA	37.3±0.11	38.2±0.11	38.4±0.11	37.8±0.13
	CON	37.3±0.11	37.8±0.08	38.2±0.08	37.8±0.06
Hot	CHO	37.3±0.07	38.3±0.10	38.9±0.15	38.6±0.14
	PLA	37.2±0.08	38.2±0.11	38.9±0.17	38.4±0.14
	CON	37.2±0.07	38.0±0.08	38.6±0.08	38.6±0.18

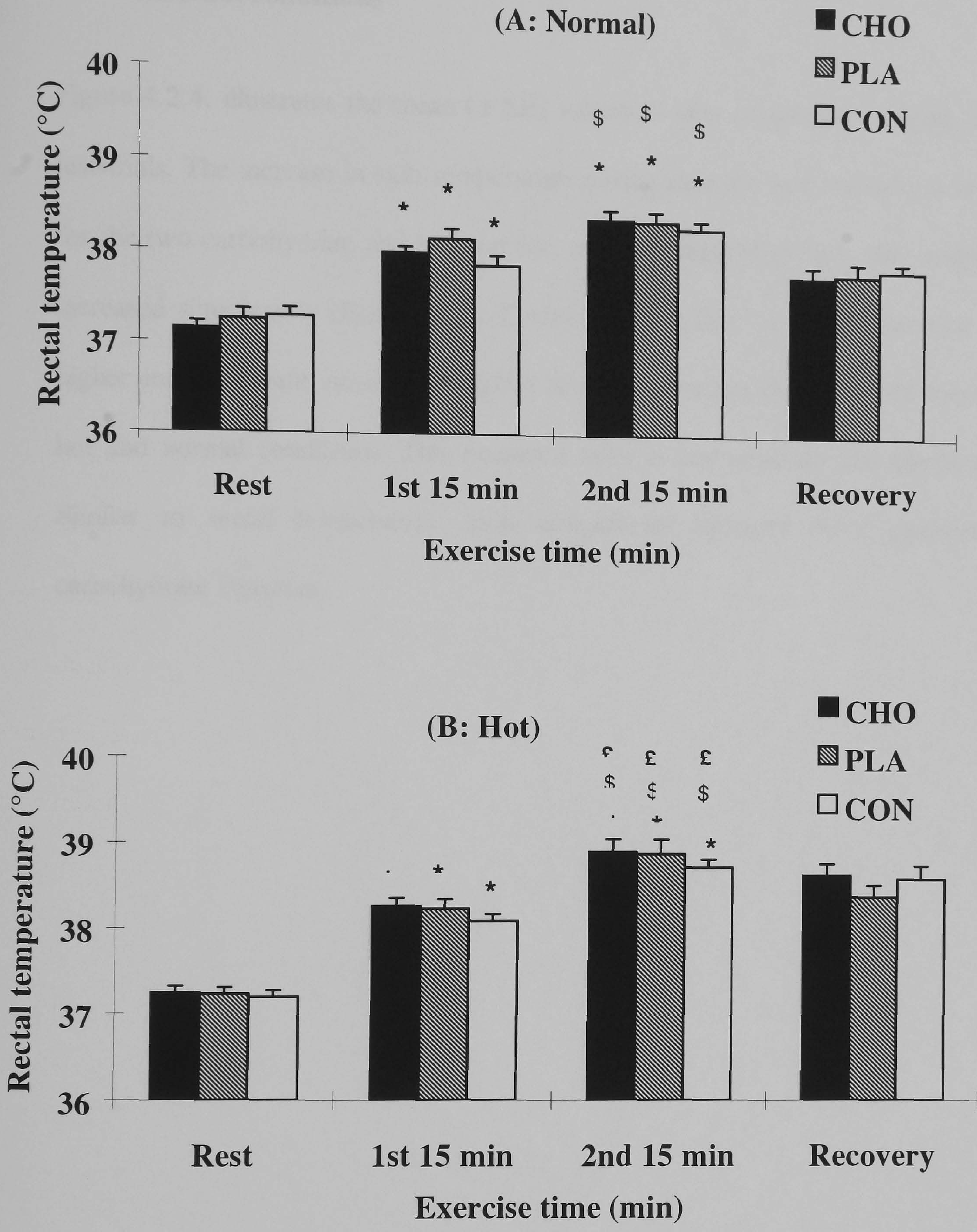


Figure 4.2.3. Mean (± SE) values of rectal temperature at rest during first the 15 min, the second 15 min exercise and into recovery. CHO = fluid and carbohydrate, PLA = placebo; CON = without beverage ingestion. * Significantly (P <0.05) higher mean value than that observed at rest. £ Significantly (P <0.05) higher mean value during hot compared with the normal condition. $ Significantly (P <0.05) higher mean value than that observed after the first 15 min exercise in the hot condition.

4.2.3.3. Skin temperature changes at rest, during intermittent exercise and into recovery with and without fluid and carbohydrate ingestion in normal and hot conditions

Figure 4.2.4. illustrates the mean (± SE) values of skin temperature during the four test trials. The increase in skin temperature during exercise and recovery was similar for the two carbohydrate and placebo test trials. Compared to rest, skin temperature increased significantly ($F_{3,33} = 4.56$; $P < 0.05$) in the first 15 min of exercise with a higher and significant increase ($P < 0.05$) being observed in the second 15 min in both hot and normal conditions. This occurred both in carbohydrate and placebo trials. Similar to rectal temperature, skin temperature changes were unaffected by carbohydrate ingestion.

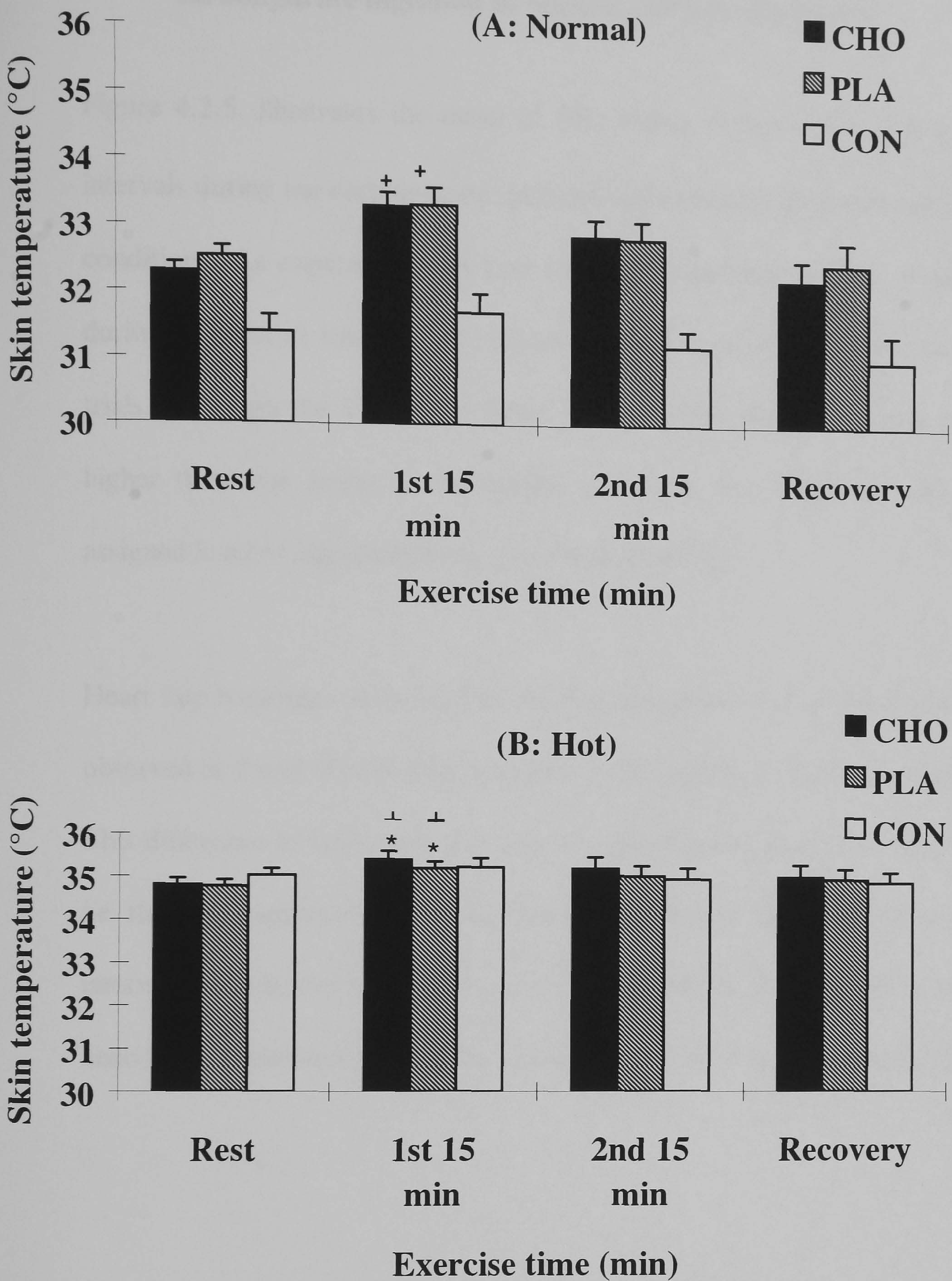
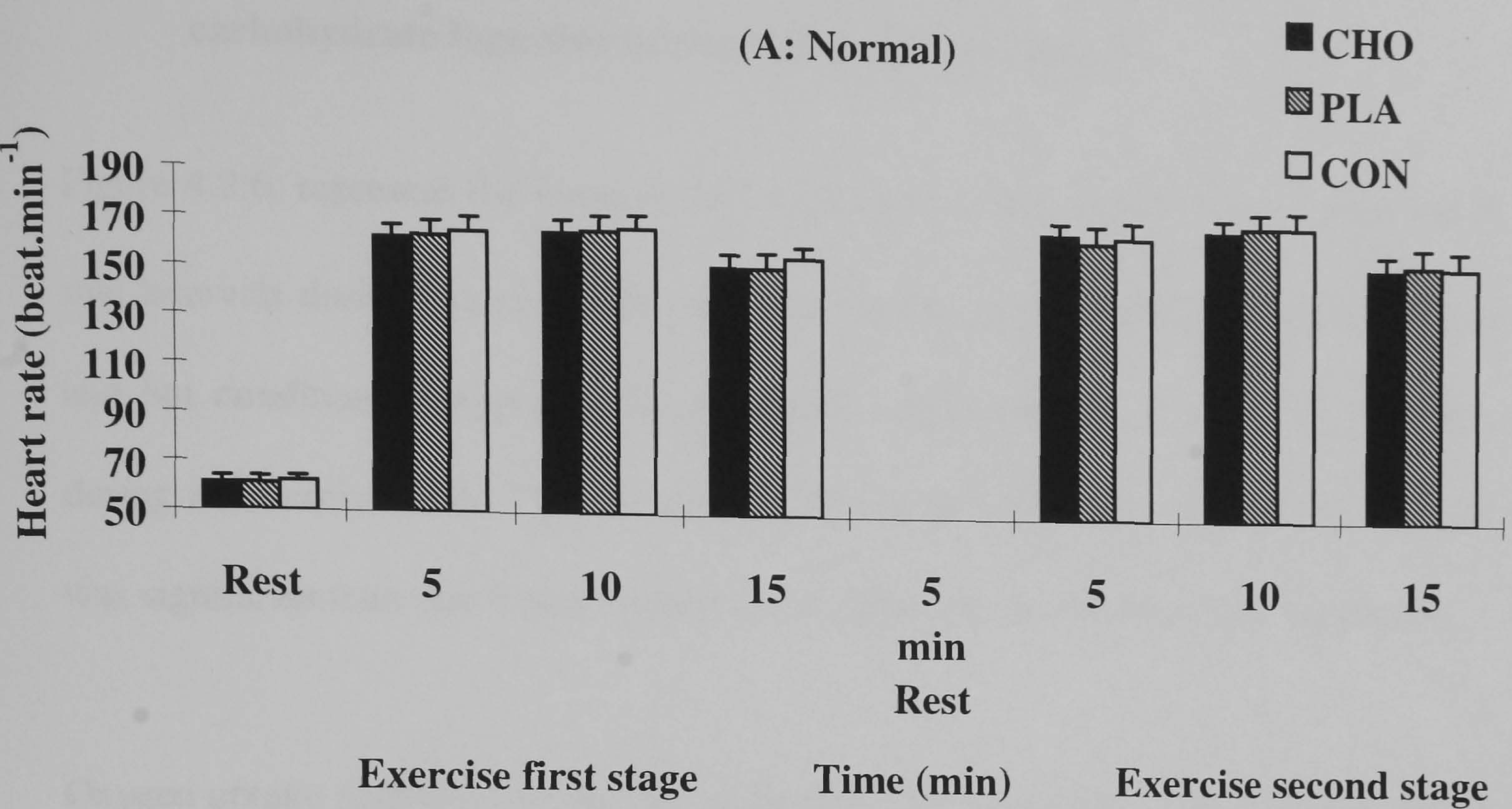


Figure 4.2.4. Mean (± SE) values of skin temperature at rest during the first 15 min, during the second 15 min of exercise and into recovery. CHO = fluid and carbohydrate, PLA = placebo; CON = without beverage ingestion; * Significantly (P <0.05) higher mean value than that observed in hot compared with normal condition. + Significantly (P <0.05) higher value at the first 15 min with CHO ingestion during hot conditions than at rest in the hot condition.

4.2.3.4. Heart rate at rest, during intermittent exercise with and without carbohydrate ingestion in normal and hot conditions.

Figure 4.2.5. illustrates the mean (± SE) values of heart rate at rest, and at 5 min intervals during the carbohydrate, placebo and control trials in normal (A) and hot (B) conditions. As expected, heart rate increased significantly ($F_{6,66}$ = 628.4; $P < 0.05$) during all exercise trials and the pattern of heart rate responses was consistent for all trials. Although the increase in heart rate observed during exercise in the heat was higher than that found in the normal condition, this difference did not reach the assigned level of significance ($F_{1,11}$ = 130.4; $P > 0.05$).

Heart rate responses at the end of the first and second 15 min were lower than those observed at 5 and 10 min during exercise irrespective of the environmental condition. This difference in heart rate response is most probably due to variation in work rate; i.e. the lower speed at the end of exercise was due to the cycles of activity within the intermittent protocol (see Figure 4.1.1). Carbohydrate feeding had no further effect on heart rate responses during exercise in either hot or in normal conditions.



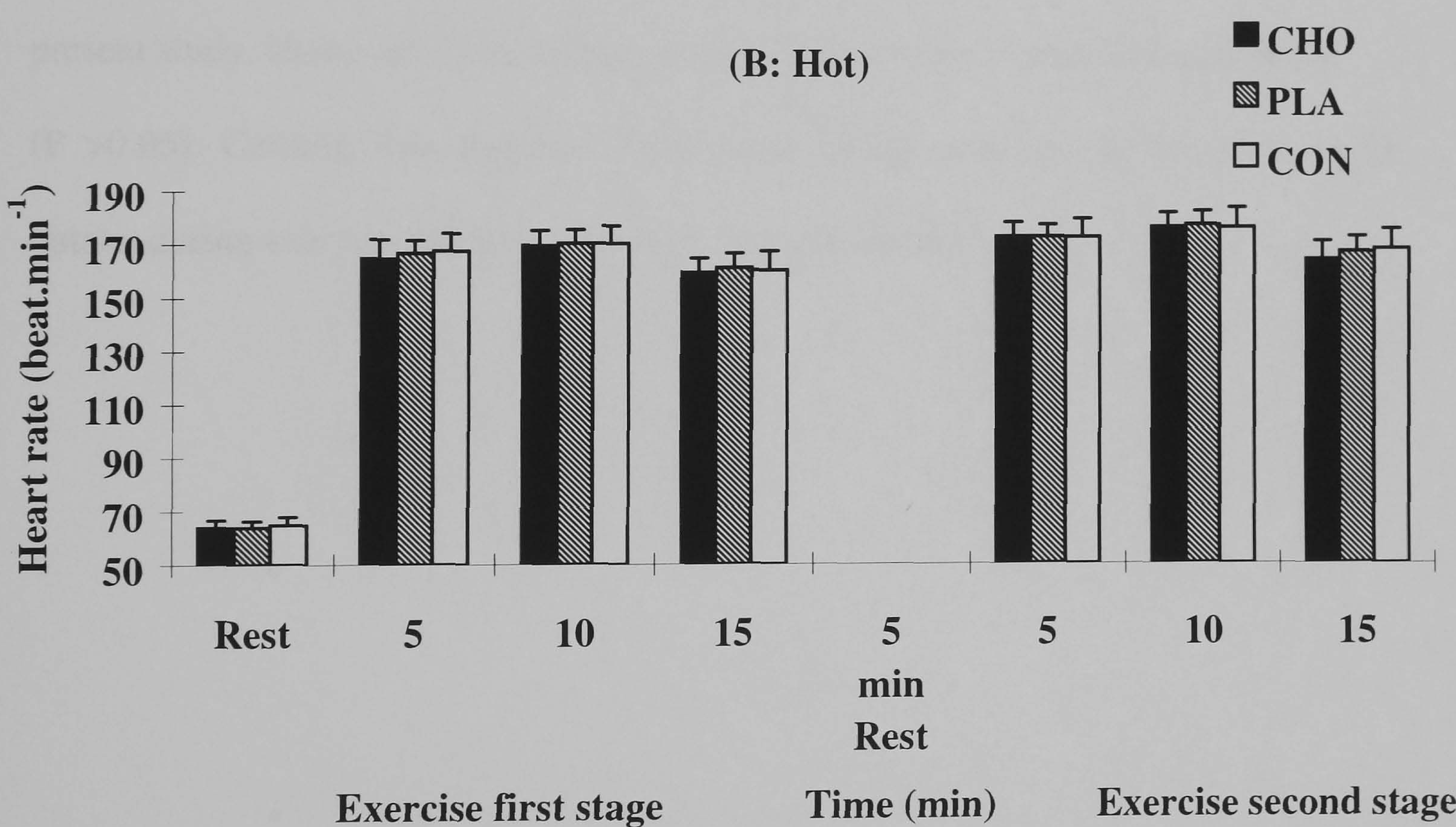
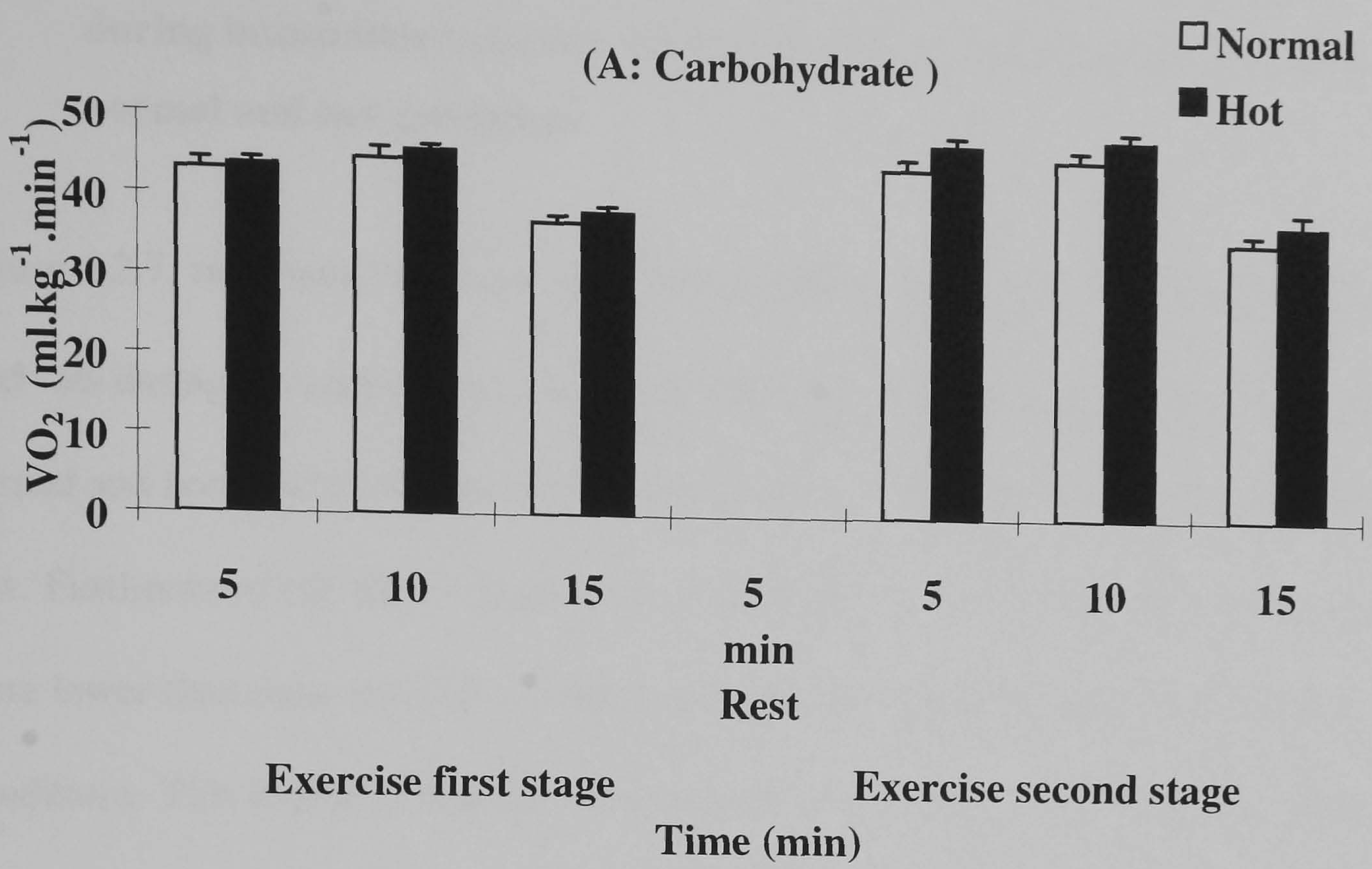


Figure 4.2.5. (± SE) Mean values of heart rate (beat.min^{-1}) at rest and at the end of every 5 min interval during intermittent exercise. CHO = fluid and carbohydrate, PLA = placebo; CON = without beverage ingestion.

4.2.3.5. Oxygen uptake during intermittent exercise with and without carbohydrate ingestion in normal and hot conditions

Figure 4.2.6. represent the mean (± SE) values of oxygen uptake ($ml.kg^{-1}.min^{-1}$) at 5 min intervals during exercise trials with and without carbohydrate feeding in normal and hot conditions. Oxygen uptake increased significantly ($F_{5,55}$ = 121.0; P <0.05) during all exercise trials. This increase in VO_2 observed during exercise in the heat was significant than that found in normal conditions, similar to heart rate responses.

Oxygen uptake responses at the end of the first 15 min and the second 15 min during exercise were lower than those observed at 5 and 10 min during exercise. This is attributed to the nature of the generic intermittent exercise protocol employed in the present study. However, these differences in VO_2 were not statistically significant (P >0.05). Carbohydrate ingestion before and during exercise had no effect on O_2 uptake during exercise in either normal or hot conditions.



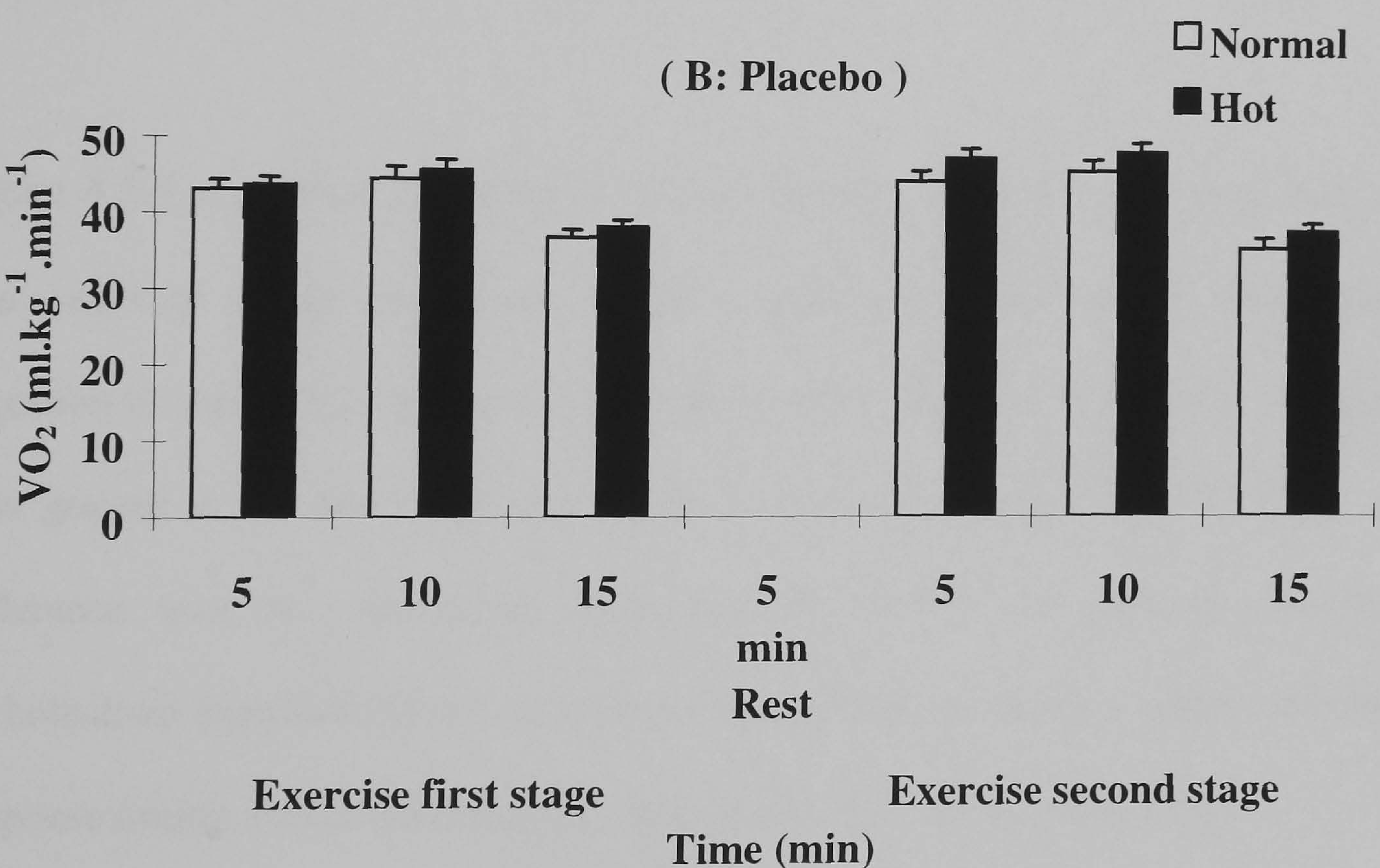
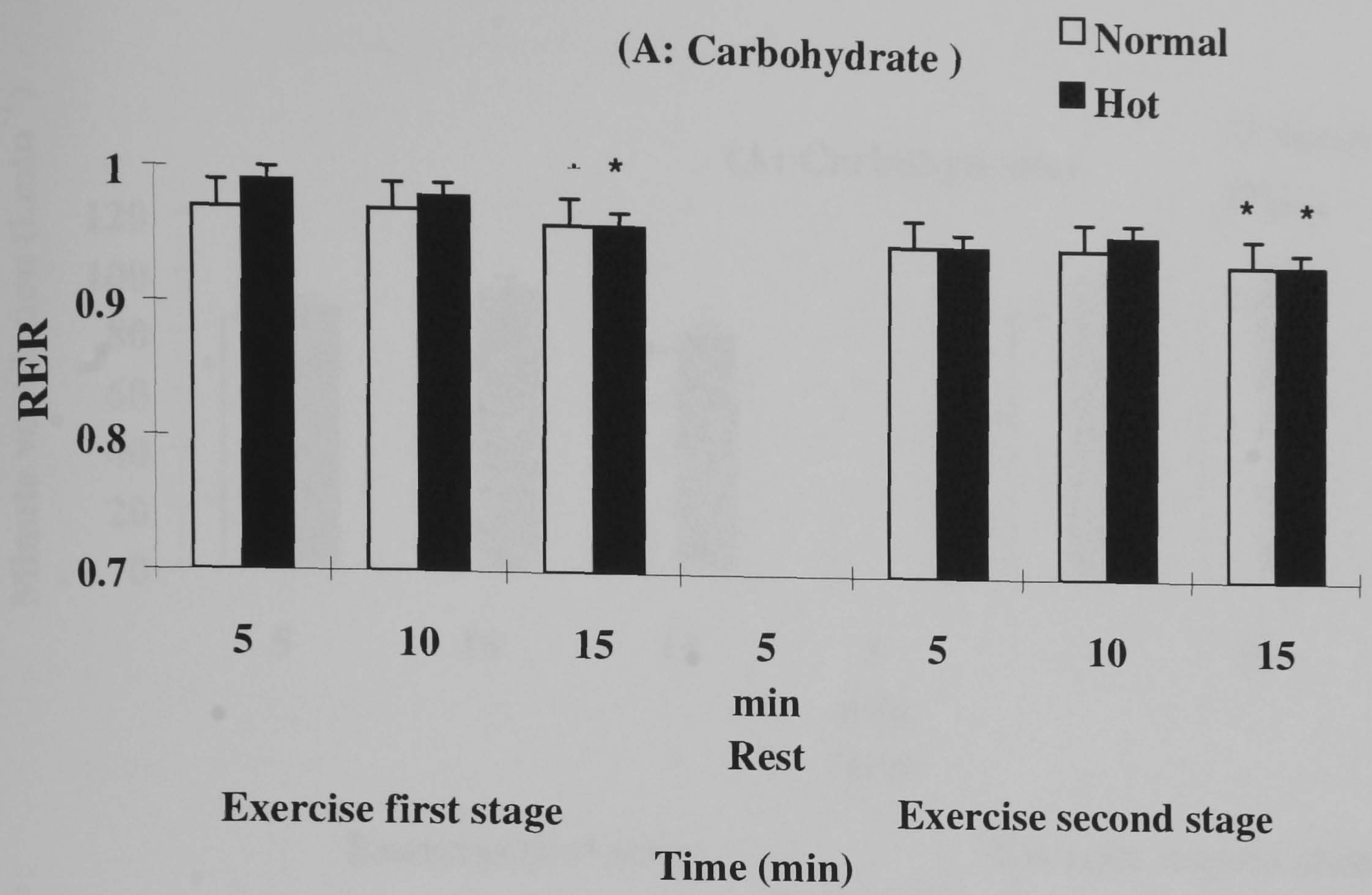


Figure 4.2.6. Mean (± SE) values of oxygen uptake every 5 minutes at the first stage and at the second stage during intermittent exercise. Graph (A) represents carbohydrate while graph (B) represents placebo.

4.2.3.6. Respiratory exchange ratio and minute ventilation at 5 minute intervals during intermittent exercise with and without carbohydrate ingestion in normal and hot conditions

Figure 4.2.7. represents the mean (± SE) of respiratory exchange ratio (RER) at 5 min intervals during intermittent exercise trials with and without carbohydrate ingestion in normal and hot conditions. The RER was higher at 5 min and 10 min exercise than at rest. Furthermore the RER values at the end of the first and second 15 min exercise were lower than those obtained of the 5 and 10 min exercise in both normal and in hot conditions. This indicates that the exercise protocol velocity were lower at the end of the exercise than at 5 and 10 min during intermittent exercise. However, carbohydrate ingestion before and during exercise had no effect on RER in either hot or in normal conditions.

Figure 4.2.8. represents the mean (± SE) of minute ventilation (VE) responses at 5 min intervals during intermittent exercise trials with and without carbohydrate ingestion in normal and hot conditions. The minute ventilation in response to exercise was greater in the hot environment than in the normal condition; however, this difference was not statistically significant ($P > 0.05$). In addition, exogenous carbohydrate ingestion before and during exercise had no effect on minute ventilation response during intermittent exercise either in hot or in normal conditions.



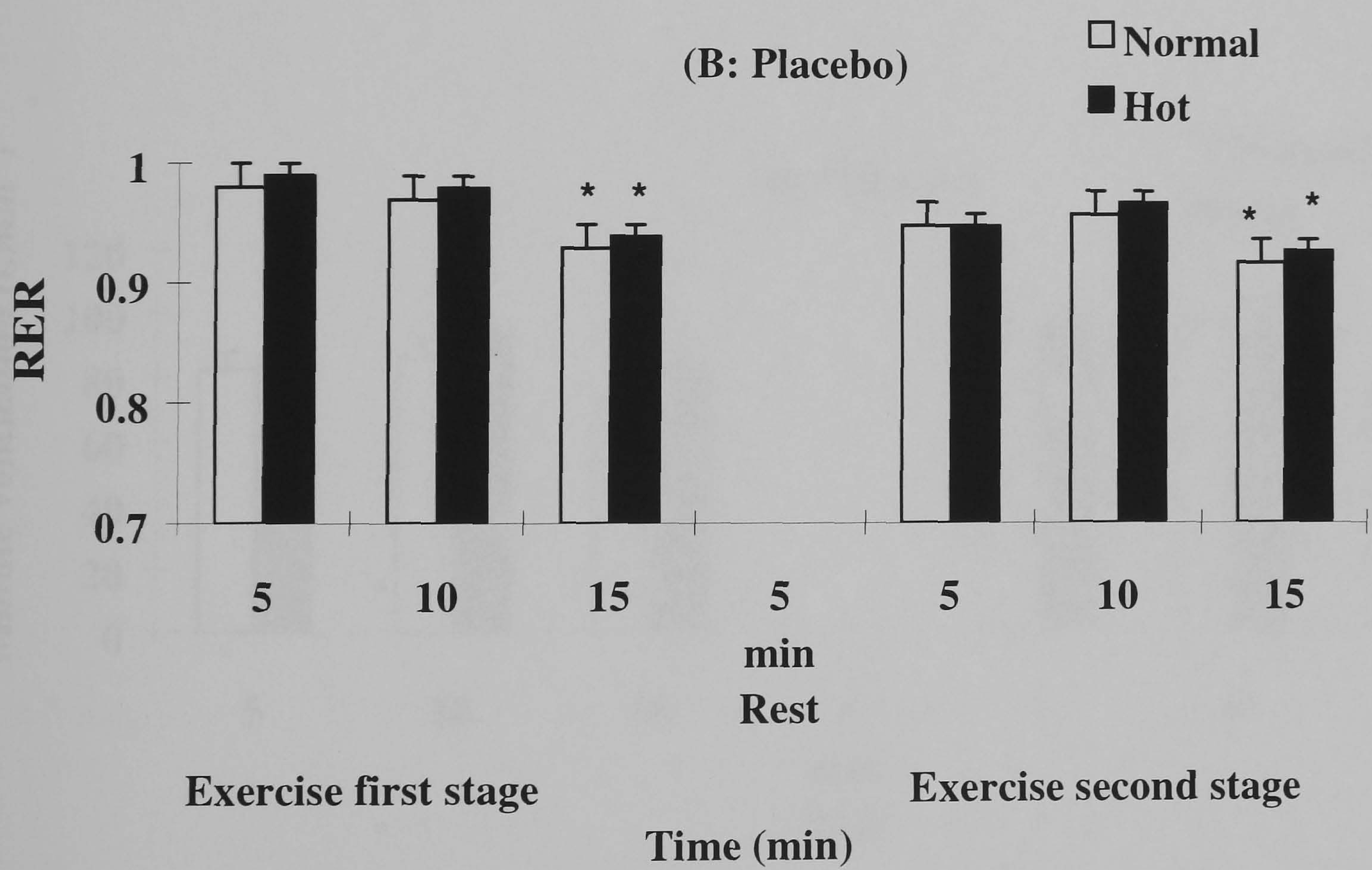
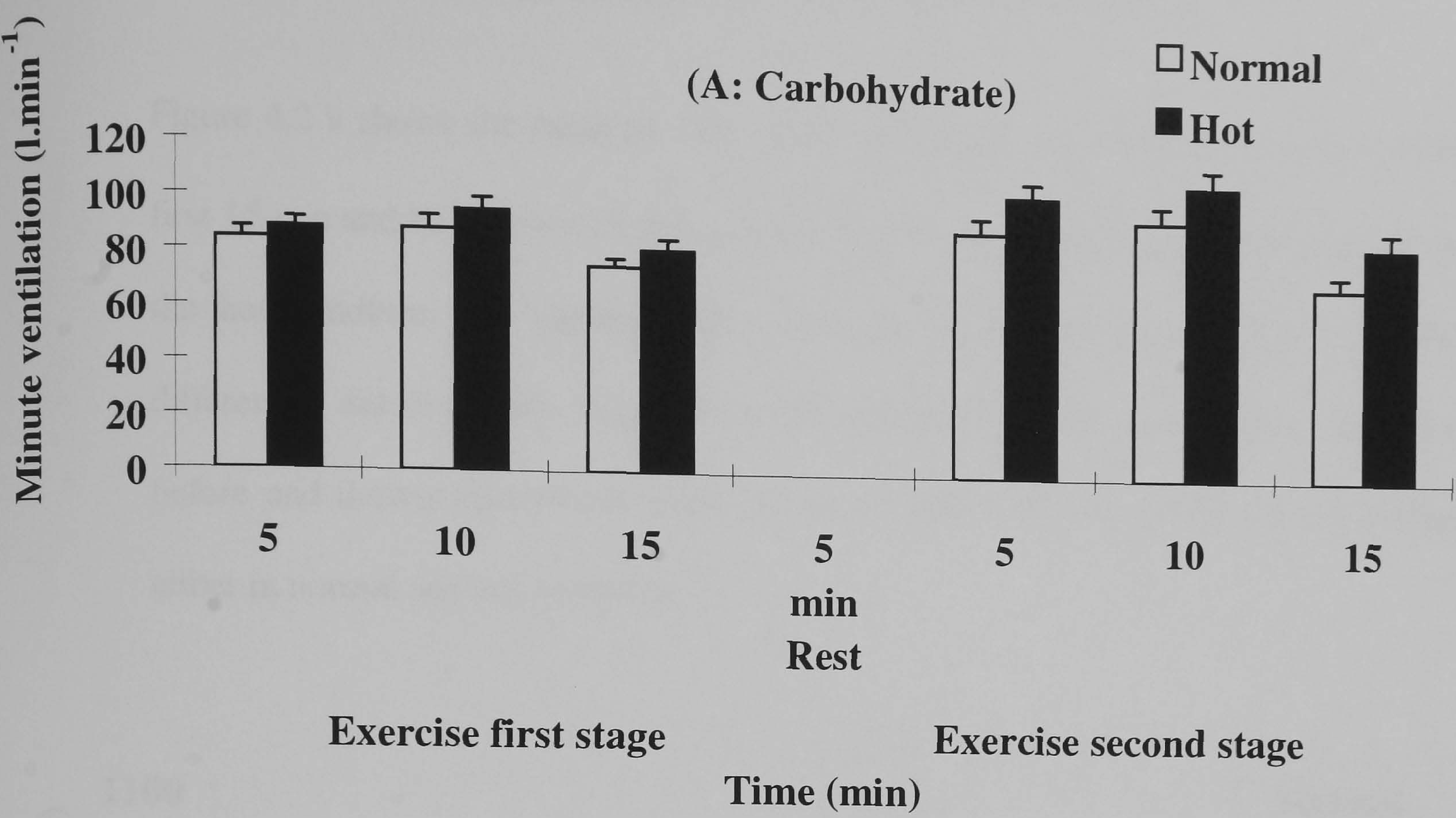


Figure 4.2.7. Mean (± SE) values of respiratory exchange ratio (RER) every 5 minutes at the first stage and at the second stage during intermittent exercise. Graph (A) represents the carbohydrate trial and graph (B) represents the placebo trial .



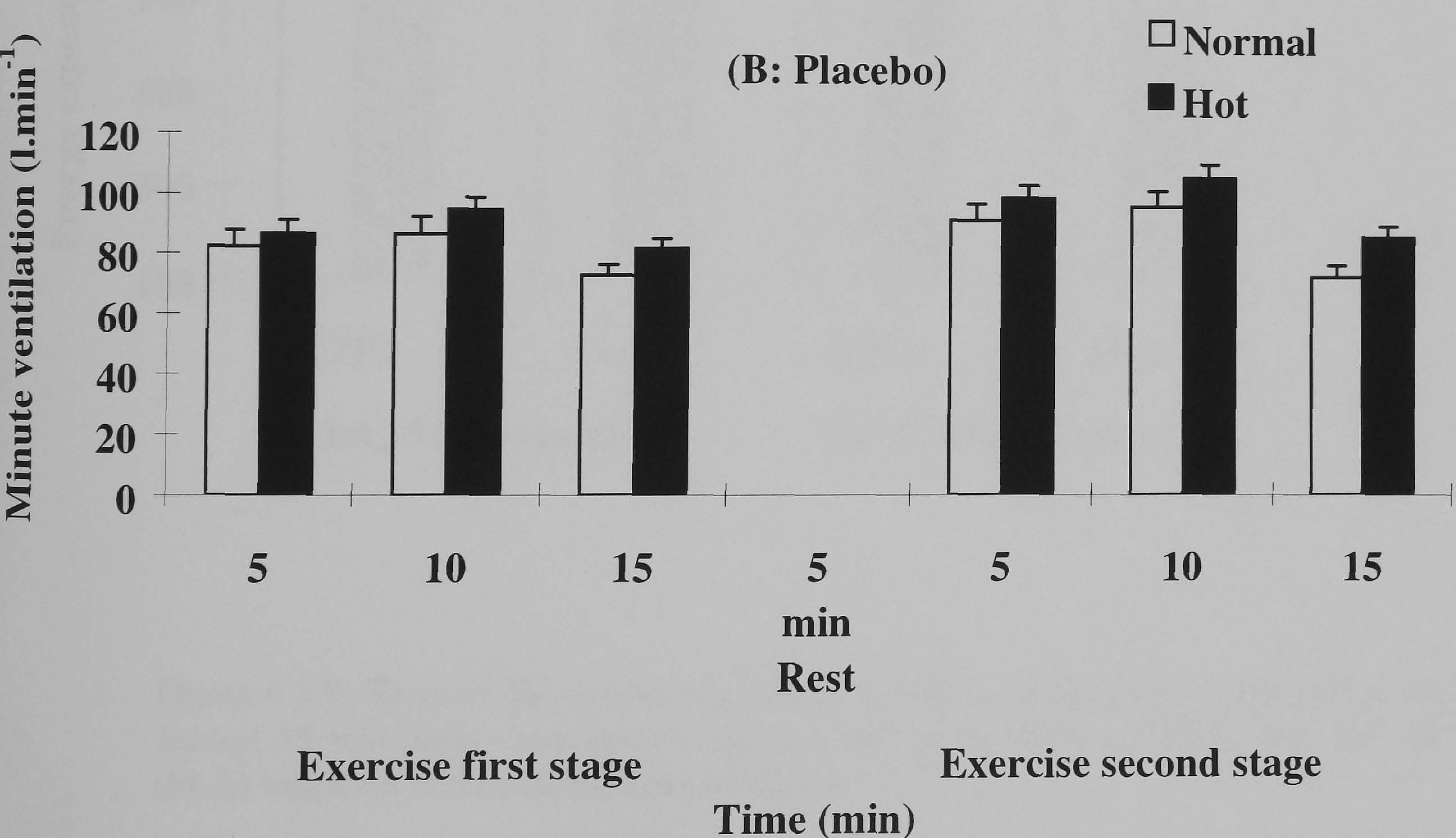


Figure 4.2.8. Mean (± SE) values of minute ventilation every 5 min at the first and at the second stage during intermittent exercise. Graph (A) represents the carbohydrate trial while Graph (B) represents the placebo trial.

4.2.3.7. Estimating energy expenditure during intermittent exercise during first and second stages and in total during 30 minute exercise

Figure 4.2.9 shows the mean (± SE) values of energy expenditure at the end of the first 15 min and the second 15 min of exercise. Energy expenditure during exercise in the hot condition was slightly higher than that in the normal condition, but this difference did not reach significance (P >0.05). Fluid and carbohydrate ingestion before and during intermittent exercise had no effect on energy expenditure during either in normal and hot conditions.

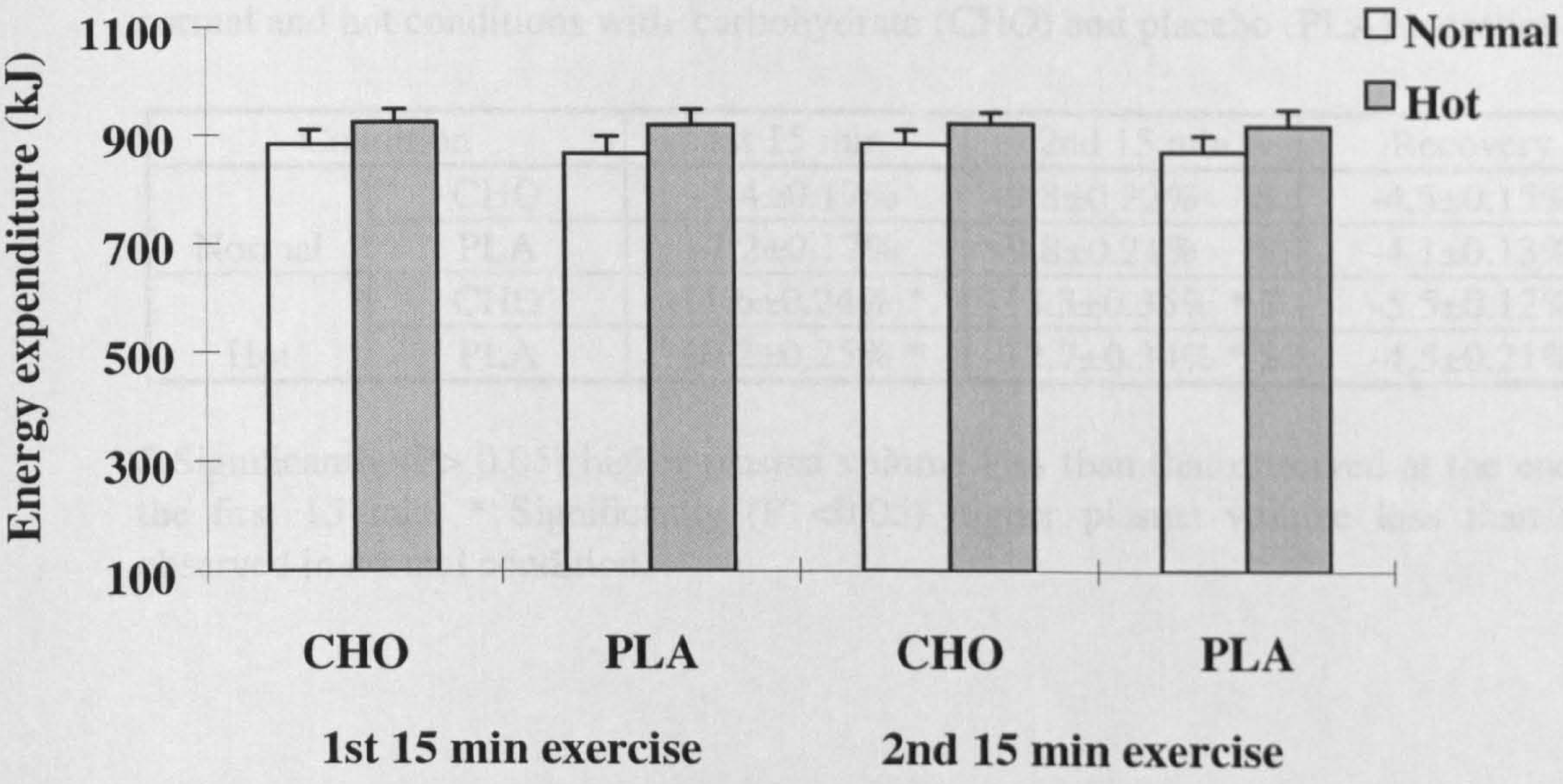


Figure 4.2.9. Mean (± SE) values of energy expenditure at the first 15 min, and at the second 15 min during intermittent exercise with carbohydrate (CHO) and placebo (PLA) ingestion in normal and hot conditions.

4.2.3.8. Plasma volume loss

The mean (± SE) values of plasma volume loss at the first 15 min and second 15 min of exercise, and 15 min recovery are illustrated in Table 4.2.5. A significant ($F_{2,22}$ = 703.19; P <0.05) decrease in plasma volume was found immediately after exercise in both carbohydrate and placebo trials with a significantly (P <0.05) higher value being observed at the end of the second 15 min than the first 15 min in normal and hot condition. Plasma volume at the end of recovery was to a large extent restored, with no statistically significant effect (P >0.05) with the plasma volume at first 15 min.

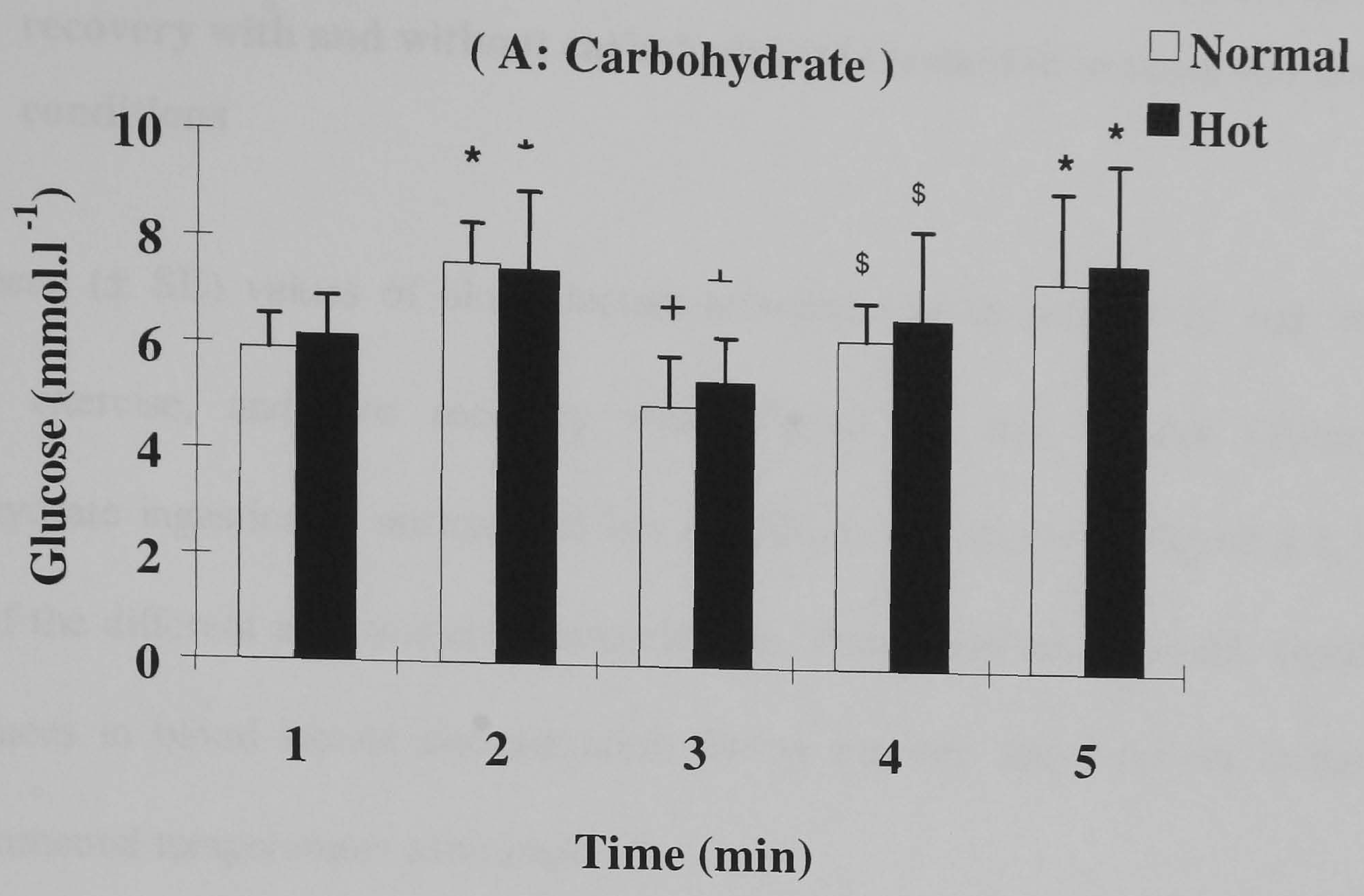
Table 4.2.5. The percentage of plasma volume change during intermittent exercise in normal and hot conditions with carbohydrate (CHO) and placebo (PLA) ingestion.

Condition		1st 15 min	2nd 15 min	Recovery
Normal	CHO	-7.4±0.17%	-9.8±0.22% $	-4.5±0.15%
	PLA	-7.2±0.17%	-9.8±0.21% $	-4.1±0.13%
Hot	CHO	-11.6±0.24% *	-13.3±0.35% * $	-5.5±0.12%
	PLA	-10.2±0.25% *	-12.7±0.34% * $	-4.5±0.21%

$ Significantly (P> 0.05) higher plasma volume loss than that observed at the end of the first 15 min. * Significantly (P <0.05) higher plasma volume loss than that observed in normal condition.

4.2.3.9. Blood glucose concentrations at rest, during intermittent exercise and recovery with and without carbohydrate ingestion in normal and hot conditions

The mean (± SE) values of glucose concentrations at rest, during exercise, and into recovery in normal and hot environments with and without fluid and carbohydrate ingestion, are shown in Figure (4.2.10). Due to unforeseen technical difficulties, blood glucose and lactate measurements were not carried out during the control condition because the blood samples were stored in the freezer for later analysis, unfortunately most of the capillary tubs were broken. Compared with the placebo trial, blood glucose concentration increased significantly ($F_{1,11} = 24.45$; $P < 0.05$) 15 min after the ingestion of the first portion of the carbohydrate drink. This was found in both normal and hot conditions. Blood glucose levels decreased significantly ($F_{4,44} = 11.45$; $P < 0.05$) at the end of the first 15 min of exercise, then increased significantly ($P < 0.05$) at the end of the second 15 min exercise and remained elevated during recovery in normal and hot conditions when subjects ingested the carbohydrate solution. These changes in glucose levels during exercise and recovery occurred in normal and hot conditions with no difference being observed between trials. Furthermore no significant differences were found in glucose concentrations between hot and normal conditions. No significant difference were found in glucose concentrations during placebo trial in both conditions.



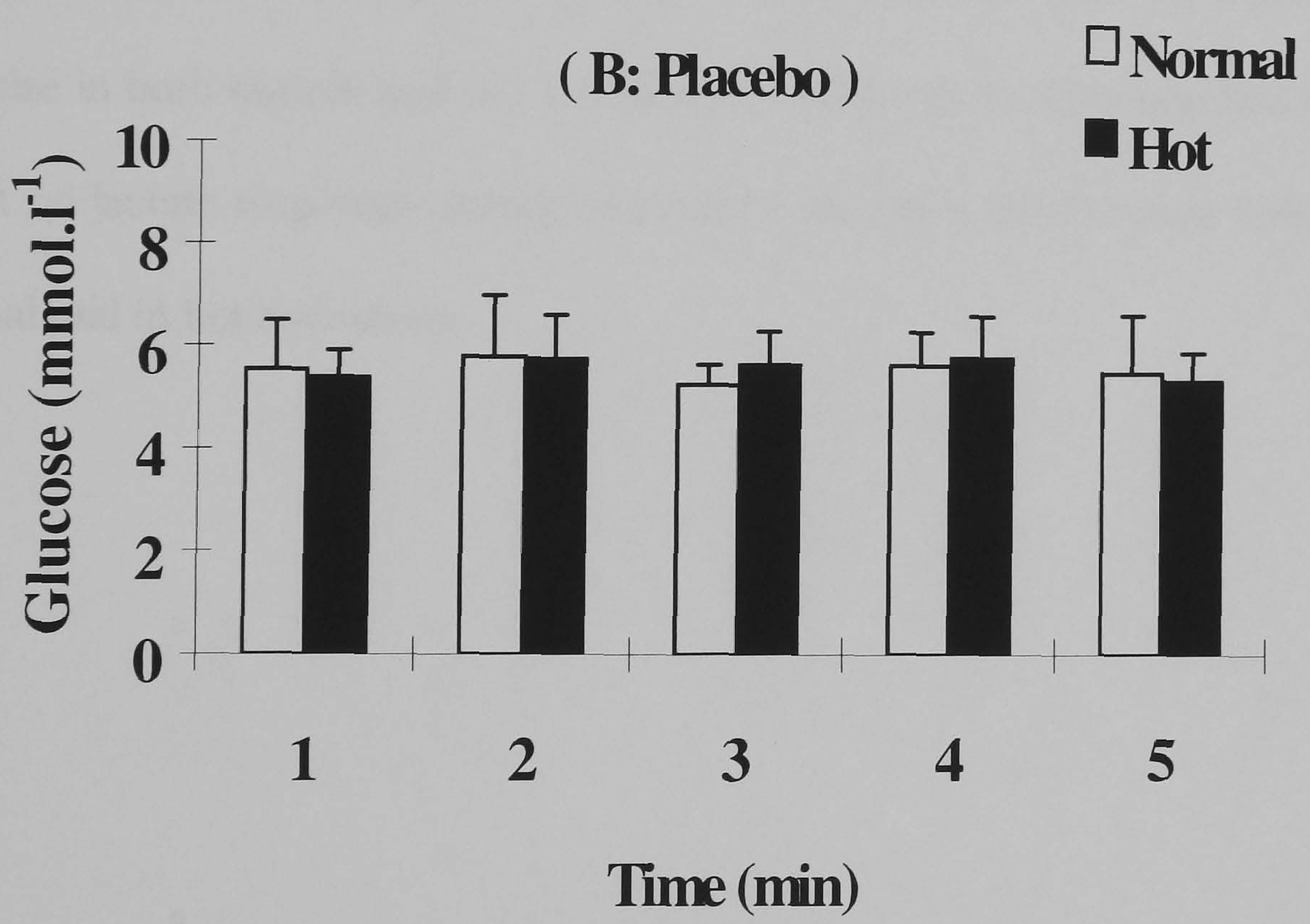
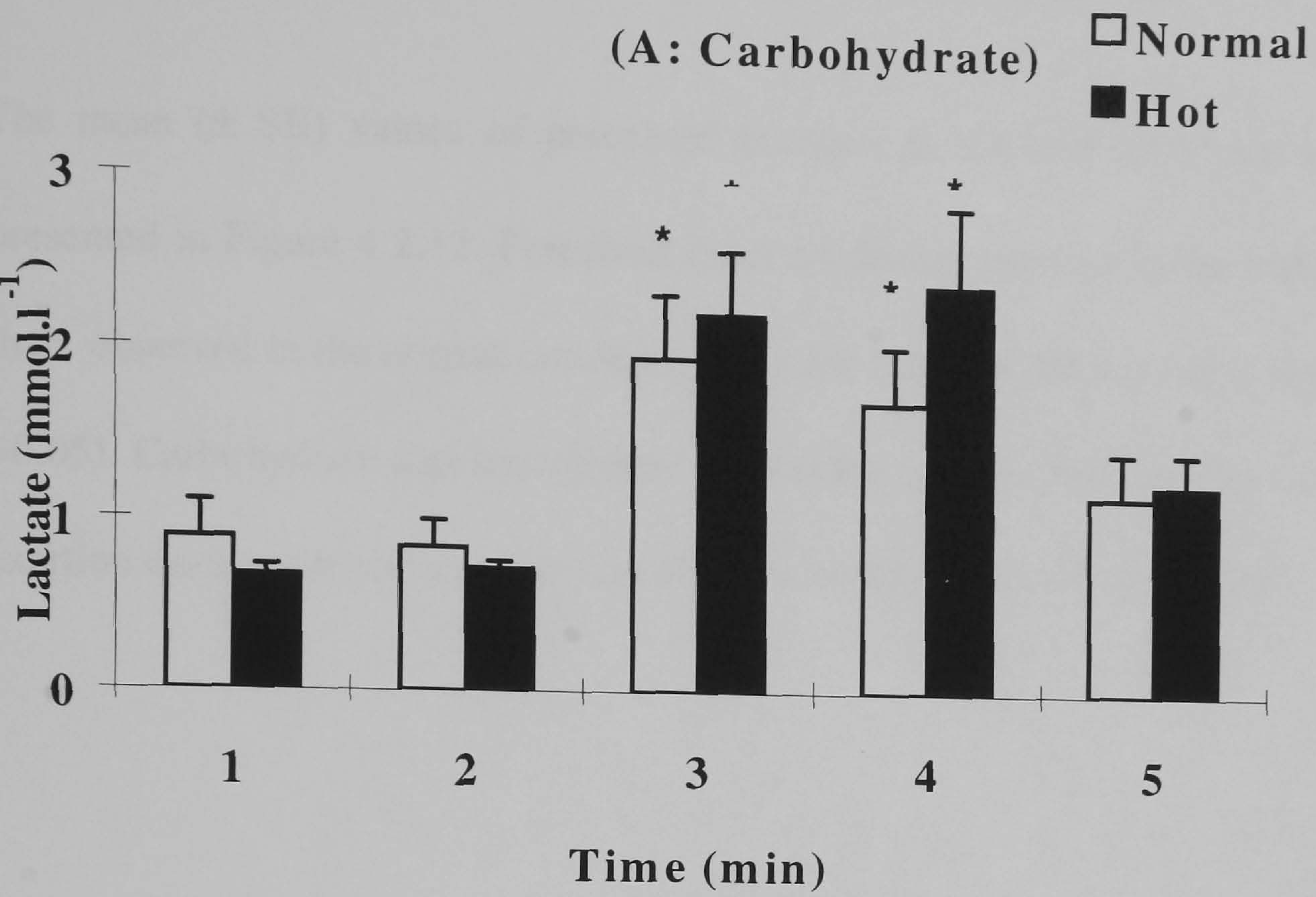


Figure 4.2.10. Mean (± SE) values of glucose concentration at rest (1), 15 min after ingestion of the respective drink (2), 15 min during exercise before the ingestion of the second portion of the respective drink (3), 30 min during exercise before ingestion of the last portion of the respective drink (4) and at the end of 15 min recovery (5). Graph (A) represent carbohydrate trial while graph (B) denotes placebo trial. * Significantly ($P < 0.05$) higher value than that observed at 1,3, and 4. + Significantly lower value than that found at 1,2,4 and 5. $ Significantly ($P < 0.05$) higher value than that found at 3.

4.2.3.9. Blood lactate concentration at rest, during intermittent exercise and recovery with and without carbohydrate ingestion in normal and hot conditions

The mean (± SE) values of blood lactate concentration at rest, at 15 and 30 min during exercise, and into recovery with (Figure A) and without (Figure B) carbohydrate ingestion in normal and hot conditions are shown in Figure 4.2.11. In spite of the different environmental temperatures, there were no detectable significant differences in blood lactate concentration during exercise and recovery in the two environmental temperatures examined.

Compared with rest, blood lactate concentration increased significantly ($F_{4,44} = 19.32$; $P < 0.05$) at 15 min during exercise and remained at the same level until the end of exercise in both normal and hot conditions. Carbohydrate ingestion had no significant effect on lactate responses during exercise or recovery and this was observed in both normal and in hot conditions.



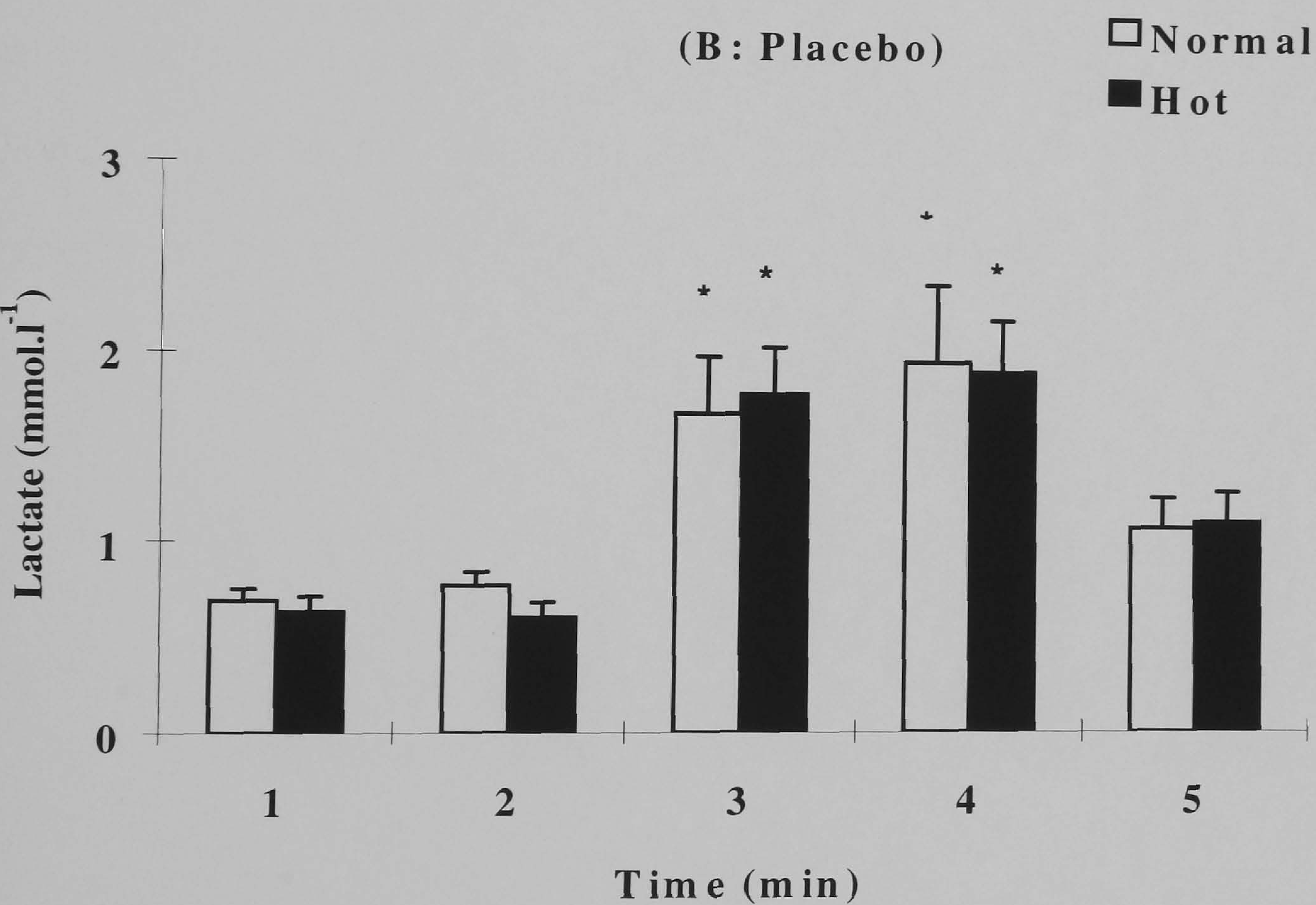


Figure 4.2.11. Mean (± SE) values of blood lactate concentration at rest (1), 15 min after the ingestion of the respective drink (2) 15 min during exercise before the ingestion of the second portion of the respective drink (3), 30 min during exercise before the ingestion of last portion of the respective drink (4) at the end 15 min recovery (5). Graph (A) represents the carbohydrate trial while graph (B) denotes the placebo trial. * Significantly (P <0.05) higher mean value than that observed at 1,2, and 5.

4.2.3.10. Perceived exertion during intermittent exercise with and without carbohydrate ingestion in normal and hot conditions

The mean (± SE) values of perceived exertion at the end of 5 min intervals are presented in Figure 4.2.12. Perceived exertion during exercise in the heat was higher than observed in the normal condition, but, this increase did not reach significance (P >0.05). Carbohydrate ingestion before and during exercise had no effect on perceived exertion during intermittent exercise either in normal or in hot conditions.

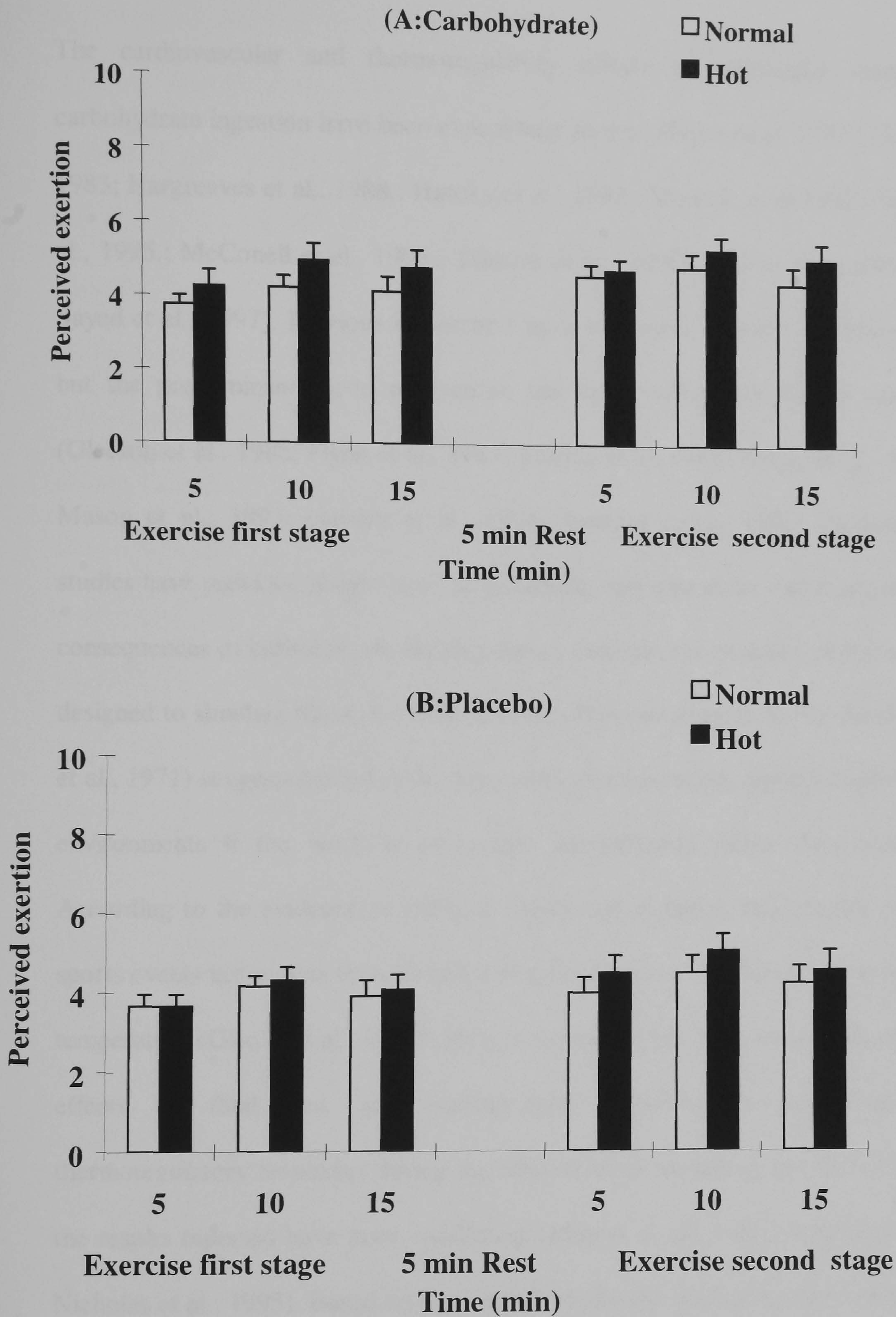


Figure 4.2.12. Mean (± SE) values of perceived exertion every 5 minute interval at the first 15 min stage and at the second 15 min stage during intermittent exercise. Graph (A) represents the carbohydrate trial while graph (B) represents the placebo trial.

4.2.4. Discussion

The cardiovascular and thermoregulatory effects of prolonged exercise with carbohydrate ingestion have been expensively studied (Flynn et al. 1987.; Coyle et al., 1983; Hargreaves et al., 1988.; Hawley et al., 1992.; Montain et al 1992.; El-Sayed et al., 1995.; McConell et al., 1996.; Tsintzas et al., 1996) and recently reviewed (El-Sayed et al., 1997). Previous researchers have employed different exercise protocols, but the predominant mode of exercise has been continuous cycling and running (Gleeson et al., 1986; Flynn et al., 1987; Murray et al; 1989., Coyle et al., 1991.; Lee Mason et al., 1993; Hawley et al., 1994; Tsintzas et al., 1996). Although, these studies have provided insight into the metabolic, cardiovascular and thermoregulatory consequences of carbohydrate feeding during exercise, the majority of them were not designed to simulate the actual field situation. Previous reports (Lind, 1963; Ekblom et al., 1971) suggested that the thermoregulatory adjustments might be different in hot environments if the work is performed intermittently rather than continuously. According to the evidence available, it seems that replacing fluid during exercise or sports events lasting less than 60 min is beneficial because it attenuates the rise in core temperature (Gisolfi et al., 1992). However, few studies have been conducted on the effects of fluid loss and carbohydrate ingestion on cardiovascular and thermoregulatory responses during intermittent exercise lasting less than 60 min and the results reported have been conflicting (Murray et al., 1987; Jenkins et al. 1994; Nicholas et al., 1995). Based on the need to clarify the metabolic and haemodynamic responses to intermittent exercise similar to ball games such as handball, the primary aim of this study was to determine the effect of carbohydrate ingestion on haemodynamic, metabolic and thermoregulatory responses during intermittent exercise protocol similar to handball match. Evidence is also available to suggest that the metabolic and cardiovascular responses to exercise in warm environments are different from those in a normal environment (Febbraio et al., 1994). Therefore the secondary aim of the study was to determine the effect of environmental temperature on the same metabolic and cardiovascular variables in response to intermittent exercise. The results obtained from motion analysis of field matches indicated that the pace of games is relatively fast and most movements of players are performed without the possession of the ball (Reilly, 1997). Although the movement patterns during handball matches are extremely difficult to replicate in a laboratory situation, the physiological stress induced by the generic exercise protocol, as assessed by heart rate, was similar to the average heart rate recorded during handball matches. In addition, the results of the motion analysis study to be described in section 5, should reveal the similarities between the generic exercise protocol used in the laboratory and the actual handball match.

One of the primary findings of this study was that there was an increase in resting blood glucose levels 15 min after the subjects had ingested the first portion of the carbohydrate drink and this occurred in normal and warm conditions. The similarity in blood glucose responses to carbohydrate ingestion at rest in both environmental conditions would suggest that resting in a hot environment at an ambient temperature of 34°C is not stressful enough to elicit significant changes in blood glucose concentration. Compared to the placebo trial, blood glucose levels at 15 and 30 min during exercise decreased significantly in the carbohydrate trial. The analysis of time effects during the carbohydrate trial revealed that at the end of the first 15 min of exercise blood glucose was significantly lower than that observed at rest. This phenomenon is typical of what has been observed in previous investigations, and most likely due to alteration in substrate availability as a result of glucose-induced elevation in pre-exercise insulin secretion (Foster et al., 1979; also see Seifert et al., 1994). The decrease in blood glucose during exercise with prior ingestion of carbohydrate occurred in normal and hot conditions. It is likely that a higher environment temperature may be required to elicit a further significant change in blood glucose concentration.

The blood lactate increased only slightly after 15 min and at the end of exercise. Therefore it is suggested that the exercise intensity employed was not high enough to perturb the equilibrium between lactate production and removal. In addition, blood lactate concentrations exhibited a similar pattern during all the exercise tests and were not significantly different from each other. Lactate values at 15 and 30 min during exercise tended to be slightly higher during the carbohydrate trial compared with placebo, but these differences were not statistically significant. These observations are similar to the results of Kruk et al. (1991) who exercised their subjects using a similar intermittent exercise protocol and reported comparable findings.

The negative shift of plasma volume observed at the end of the first 15 min and at the end of the second 15 min of exercise in all conditions was due to the exercise and environmental temperature effects, and was not influenced by the supplementation treatment. These results are similar to these reported by Maughan (1996) who used finger tip. At the end of 15 min recovery these shifts had persisted but were substantially less than those observed during exercise. The decrease in body mass after exercise is most probably due to body fluid loss mainly as a result of sweating and dehydration. The reduction in body mass was more pronounced when exercise was performed in the hot environment (34°C). It seems likely therefore that the exercise protocol employed in the present study and performed in a heated environment represented, to some extent, a thermal stress to the subjects. Despite this stress, plasma volume responses between conditions during exercise and recovery were similar, thus suggesting that the two supplementation treatments were equally effective in maintaining fluid balance.

Specific physiological modifications take place in the cardiovascular, metabolic and thermoregulatory systems in order to balance heat loss and heat gain when individuals exercise in a hot environment (Drinkwater et al., 1976). It was expected, therefore that the cardiovascular, metabolic and thermoregulatory responses to the intermittent exercise protocol employed in the present study would be affected when exercise was performed in a hot environment. Rectal and skin temperatures were higher in each exercise session and this increase, as expected, was more pronounced when exercise was performed in the heated environment. The ingestion of carbohydrate solution before and during exercise had no further effect on rectal and skin temperatures changes during exercise. This finding supports the previous study by Murray et al. (1987) who showed that different beverages had no significant effect on rectal and skin temperatures. This may be attributed to the moderate intensity and short duration of the exercise protocol used in the present study. The lack of effect of carbohydrate ingestion on the cardiovascular and metabolic responses occurred irrespective of the temperature of the environment. It is suggested therefore that exercise, but not the environmental temperature at 34 °C, is the prime stimulus for body temperature changes during exercise. It is probable that ingesting carbohydrate solutions may have significant effects on cardiovascular and thermoregulatory responses if exercise is performed in a higher environmental temperature than 34°C. Murray et al. (1987) similarly reported that physiological functions during intermittent exercise in a warm environment were well maintained when subjects consumed either carbohydrate or placebo beverages. Also other investigators reported similar findings (Pitts et al., 1944; Costill et al., 1970; Candas et al., 1986; and Owen et al., 1986). Although heart rate and oxygen uptake during exercise and recovery were higher when exercise was performed in the hot environment, the difference in mean values did not reach significance ($P > 0.05$). It is likely that the environmental temperature was not hot enough and/or the exercise protocol (e.g. intensity and duration) was not strenuous enough to elicit significant effects in these parameters. Similar to the results of the present study, Febbraio et al. (1994) found no difference in mean VO_2 when exercising in 40 °C temperature compared with exercising in 20 °C. It was also reported that exercising in 40 °C resulted in a higher mean heart rate and respiratory exchange ratio compared with that in 20 °C.

It should be noted that when subjects in the present study performed the exercise trials in the normal and hot environments, they showed no objective or subjective indications of distress. This finding is supported by the perceived exertion data during exercise in normal and hot environments (Fig. 4.2.12). Similarly, Murray et al. (1987) found no significant effects of different beverages on perceived exertion during intermittent exercise in a warm environment of 33°C. Therefore, it is reasonable to suggest that the exercise protocol used and the ambient temperature chosen were not severe enough to induce significant alterations in the haemodynamic variables measured. This explanation seems unlikely in light of the data of Rowell (1974) who showed that external heat is not a factor in cardiovascular responses during a brief exposure to work in high environmental temperature. It is probable that a longer exercise duration is required to induce significant effects on the haemodynamic variables.

The results of this study also seem to be similar to those previously reported in women who performed different exercise protocols (Drinkwater et al., 1976). It was clearly demonstrated that women exercising in a moderately hot environment regulate the internal body temperature independently of cardiovascular, metabolic and thermoregulatory demands. Although it is recognised that gender-specific differences in temperature regulation may exist, this issue warrants further investigation particularly during exercise in hot environments. It seems obvious, therefore that the main stimulus to the physiological responses to both exercise and recovery in the present study was the metabolic response.

CHAPTER 5

A MOTION ANALYSIS OF WORK-RATE OF ELITE HANDBALL PLAYERS

5. A MOTION ANALYSIS OF WORK-RATE OF ELITE HANDBALL PLAYERS

5.1. Introduction

The application of motion analysis to field games allows the objective recording and interpretation of match events (Reilly, 1994). Some indication of the demands of the game may be realised by determining the physical capabilities of elite players, the assumption being that players have to cope with demands imposed by the game (Bangsbo, 1994a).The work-rate demands of handball can best be examined by making relevant observations during match-play or obtaining physiological measures during real (competitive) and friendly or simulated games.

The heart rate response to playing handball matches were examined previously (chapter 3), the overall average value during a full game being 143 beats.min^{-1}.

Several investigators have used a wide variety of techniques to examine the motion characteristics of games competitors, most notably soccer players (Reilly and Thomas, 1976; Bangsbo et al., 1991a). In soccer and handball there are similar activities in the two sports events which include walking, jogging striding, sprinting, walking backwards, jogging backwards, moving sideways and jumping. Nevertheless, there are major differences, for example the duration of a soccer match is 90 min whereas a handball match is 60 min in duration. Also there are differences in allowing substitutions of players between handball and soccer. In handball the players can be substituted at any time during match-play, and all the named reserves are called on to participate in the game at some time. Therefore the static pauses or rest times of handball players will be more than for soccer players where substitutions are restricted. Unfortunately, no investigation has been done on motion analysis of handball matches, and no data are available on work-rates of elite handball players. Such an investigation is essential for establishing the extent to which the generic intermittent exercise protocol described in Section 4 represents the work-rate as well as the heart rate response to handball play.

The aim of this study was to establish a motion activity profile of handball play and compare the profile with known values for other games. In this way it would be possible to corroborate the validity of the intermittent exercise protocol which was used for studying the physiological stress of games.

5.2. Methods

5.2.1. Subjects

Eight elite male handball players from Kuwait clubs were filmed while competing in the handball league in Kuwait during 1996. Filming was done over eight handball matches for the determination of work-rate profiles, one player being filmed per game. None of the players had any knowledge that he was being filmed. Two players monitored for heart rate during unofficial match in section 3.5. were included in this investigation. These two players were filmed for motion analysis and their heart rate data during a game were concurrently.

5.2.2 Procedure

One player per game was filmed for analysis. The activities of one player during the 60 min of match-play were recorded using a video camera (Sony TR75E, Taiwan). The camera was positioned in a stand overlooking the court and close to the half-way line. Videotapes were replayed on a television monitor and video (Sony Trinitron, Taiwan; Panasonic NV-F77) and analysed using a personal computer (Compusys PC 486) in Generic motion system software (Liverpool). There were eight activities analysed, with the ball and without the ball. These activities were walking, jogging, striding, sprinting, moving sideways, walking backwards, jogging backwards and 'static'. Static time was presented for two kinds of static pauses, first 'static' during play-time was when the ball was out of the play or waiting for the 7 metre throw or also for any injured player to be treated. The second 'static' item was when the player had to leave the playing-court for tactical substitution or was suspended for 2 min twice or was disqualified from play. Data were thus provided on mean (± SD) of the total time covered for each 30 min period in each activity, total distance covered at each activity and frequency of each event. The overall time for each type of activity with and without ball was calculated. Analysis was also linked to a total distance covered for each activity.

In soccer eight full-time professionals players from the English Premier League were filmed during the 1995-96 season for comparative purposes. Filming was done over eight soccer matches for determination of work-rate profiles, one player being filmed per game. None of the players had any knowledge that he was being filmed. The activities of one player during the 90 min of match-play were recorded using a video camera (Sony TR75E, Taiwan). The camera was positioned in a stand overlooking the pitch and close to the half-way line (Drust, 1997). Videotapes were chosen from Drust's (1997) study and replayed on a television monitor and video (Sony Trinitron, Taiwan; Panasonic NV-F77) and re-analysed using a personal computer (Compusys PC 486) in Generic motion system software (Liverpool).

There were eight activities analysed, with the ball and without the ball. These activities were walking, jogging, striding, sprinting, moving sideways, walking backwards, jogging backwards and 'static'. These activities were the same activities analysed for handball to compare work-rates between the two sports.

5.3. Results

5.3.1. Handball

The total distance covered during the handball match was 2478 ± 224 m with and without the ball; this distance which players covered consisted of walking 620 m, jogging 707 m, striding 158 m and sprinting 451 m, and the total actual time when the player was on the playing court was approximately 40 ± 7.2 min. The players spent a long time in walking activity (21.3 ± 5.4 min) both with and without the ball, and the percentage of the total time walking was 53.9%. Also the percentage of the total time jogging was 14.9% of the actual match time, although the high intensity activities (striding and sprinting) made up 2 % and 3.8% respectively of the total actual match-play time. Utility movements accounted for 25.3% of the total time. This aggregate figure was comprised of walking backwards, jogging backwards, moving sideways.

Static time during the handball match was 22.0 min of the total actual time (60 min) the game was played on the court. This time was divided into two periods, the first 'static' category during the play was when the game was stopped (ball out of play). This time was 7.6 min which accounted for 12.7% of the total time. The second 'static' period referred to when the player left the playing court for tactical changes or for 2 min suspension or injury; this static time was 15.4 min which was equal to 25.7 % of the total time.

There were no differences in total time, total distance covered and total frequency between the first and second half in walking, jogging, striding and sprinting activities ($P > 0.05$). The players had relatively long periods of time in specific activities without the ball and very short times with the ball, demonstrating that the pace of handball play is variable. The largest percentage of the total distance was covered jogging (28.5%) with walking forward (with and without the ball) accounting for a further 25.0 % of the total distance. Sprinting made up 18.2 % of the total distance covered and striding accounted for 6.4% of the total distance covered.

The average heart rate during the handball match was 133 beats.min^{-1} and 154 beats.min^{-1} for each of the two players observed. This heart rate was before taking out the static periods. After taking out the static time the average heart rate was found to be 140 beats.min^{-1} and 157 beats.min^{-1}, respectively. The total distances covered for the two players were 2438.7 m and 2685.2 m, respectively. The time of activity for the two players was 52.16 and 55.84 min respectively, both players in this instance staying on court for the entire game

5.3.2. Soccer

The overall distance covered during the soccer match was 6374 ± 798 m with and without ball; this distance which players covered consisted of walking 1028 m (16.1%), jogging 3157.8 m (49.5%), striding 1018.9 m (16.9%) and sprinting 593.4 m (9.3 %). The soccer match lasted 90 min, but the players spent 13.7 min static; that means they were active for 78.2 min, consisting of walking 32.6 min (36.2%), jogging 26.2 min (29.1%), striding 4.9 min (5.4%) and sprinting 1.97 min (2.2%). The utility activities accounted for 24.8 min (27.5%) of the total time. This total figure was comprised of walking backwards, jogging backwards and moving sideways. During utility movement the soccer players covered 576 m or 9 % of the total distance covered. The total frequency count for the activities was 1718 which amounts to a change in activity every 3.1 s. However, the static time overall for the soccer match was 13.7 min (15.2%). There were no differences in total distance covered (3245.5 m, 50% and 3128.9 m, 49.1%), total time (39.7 min 44.2% and 40.1 min, 44.6%) and total frequency (896, 53%, 813, 44%) between the first and second half, respectively. The categories of striding and sprinting can be combined to represent high-intensity and also walking and jogging can be combined to represent low-intensity activity in soccer. The percentages were 5.4% and 2.2 % for striding and sprinting respectively, amounting to a composite figure of 7.6% for high-intensity activities. The percentages were 36.2% and 29.1% for walking and jogging respectively, representing a value of 65.1% for low-intensity activities. Most activity during a game was clearly at low-intensity.

The data obtained in this study demonstrated that most movements of soccer players were without the ball. Around 49.5% of the total distance was covered jogging with 16.1 % walking; this indicated that the soccer players covered more distance in jogging than in any other activity.

5.4. Discussion

The aim of this present investigation was to determine the motion analysis activity profile of handball players. The data from this study were also compared with the work-rate of a sample of elite soccer players filmed by Drust (1997) and re-analysed for purposes of this study. The same procedures were followed as for the handball match analysis so as to evaluate any differences between the work-rates for the total time, total distance covered and total frequency during handball and soccer match-play. Also it was intended to show if the game-specific intermittent protocol used in the laboratory experiments was representative of handball match intensity.

In general, observations for the handball game confirmed that the game is played at a variable pace and requires individuals to perform a high level of activity in order to maintain or regain possession of the ball. The data in the present study demonstrated that most movements of handball players were without the ball. Tactical emphasis is placed on retaining possession and producing quick decisive passing movements when an opportunity is presented or created. Such tactical restraints reduce the need for players to perform a lot of unnecessary activity and thereby may reduce their total distance covered and time active. This consideration applies both to handball and soccer.

The data in the present study did not demonstrate any differences between the first and second halves for the activities classified. This would seem to suggest that the intensity of exercise work-rate is the same for the two halves of a handball match. Consequently, there was no evidence of the fatigue that is generally observed in top class soccer play (Reilly, 1997).

The total frequency counts for the number of discrete bouts of each activity classification for handball players over 40 min actual play was 422. This amounts to a change in activity approximately every 5.7 s (with respect to individual players over 60 min the profile indicates a break in activity every 8.5 s.) The exercise pattern in handball is intermittent and breaks in action occur roughly at the same frequency as recorded in the literature for soccer of about one change at least every 6 s (Reilly, 1979).

Frequent alterations in activity will result in an increase in the total energy demands placed on players. Around 29% of the total distance was covered jogging with 25% walking, utility movement accounting for approximately 22%. The handball players covered 18% of the total distance at a high-intensity (striding and sprinting). In comparison with soccer, there was a difference in the estimated distance covered during the two games, 2478 m and 6374 m for handball and soccer, respectively. The differences were partly a function of the game time but the dimensions of the handball court (40 x 20 m) and the football pitch (110 x 75 m) respectively may also have played a role. The methods used for the analysis of distance may have consistently underestimated the actual distance covered, although the time spent in the various activities and the frequency of events were highly reproducible. The soccer players played for approximately 78 min of the total 90 min, while the handball players played for approximately 40 min out of 60 min, nevertheless the estimated distance covered per minute on the playing pitch or court was 14% greater in soccer than in handball. In both sports, the players had a greater percentage distance covered in jogging than in high intensity activities but the handball players spent relatively more time in walking (53.9 % and 36.2 %) than soccer players.

The high-intensity activities (striding and sprinting) made up 2% and 3.8% of the time-based activity profile for handball and 5.4% and 2.2% for soccer and so, it seems that the two games were roughly similar in high-intensity activities. In addition the utility movements were approximately similar in time (27.6% and 25.3% for handball and soccer games); on the other hand the soccer players covered more distance in utility movements than handball players (21.9% and 9%, respectively). However, events changed in handball once every 5.7 s but in soccer every 3.1 s. This finding was different to the observations of Reilly (1997) who found a change every 6 s on average in soccer. Whereas Reilly (1997) recorded the minute changes in activity, including jumping and tackling that were not of interest in this present study the facility for video play-back in the present study promoted a more precise distinction between event categories and therefore an increased frequency of movement events. It should be taken into consideration that the static time of the handball games was 22.0 min which corresponded to 56.8% of the total time of actual play, 7.3 min (18.3%) was static time during the playing time and the remaining 15.4 min (38.7%) was out of play time. The static time during soccer was 13.7 min of the total match time and accounted for 15.2% of the total time. Therefore, the games were the same in static time, but the difference was because the handball players spent more time out of the court. This was because of the difference in both game style and in game rules. Nevertheless, it seems that the recovery times between bouts of activity are roughly comparable between the games.

Therefore the exercise pattern in handball is both intermittent and acyclical. The patterns include walking, jogging and running activities which are included in the generic intermittent protocol used in sections 4.1 and 4.2. where a regular sequence recurs. Also the absolute times of the activities during the intermittent protocol and handball match-play were 30 min and 37 min, respectively. If the percentage of the total time in each particular movement category for the intermittent protocol and handball match analysis is taken into consideration, it can be seen that around 21.3% and 57% of the total time was in walking, with 30% and 11% of the total time covered jogging and 15% and 6.2% of the total time in running, respectively. The percentage of total distance during the generic intermittent protocol and handball match analysis covered in low intensity (walking and jogging) were 43 % and 53.5% of the total distance, whereas for running the respective values were 20.9% and 24.7% of the total distance covered. These figures indicate the extent of the resemblance of the laboratory protocol to match-play in this regard.

In summary the total time spent and the total distance covered during handball match-play were calculated for the different types of activities. For most of the time during handball match-play, movements were performed without the ball. The work-rate in both halves was the same for handball. There were differences between soccer and handball in the total time and in distance covered, although there was no difference between the two games in the percentage of distance covered in the various activities. This partly explains the higher mean heart rates typically observed in soccer compared to the heart rate response to handball reported in the earlier chapter (section 3). Crucially, rests between activities were equal in the two sports, although changes in activity occurred every 3.1 s for soccer compared with once every 5.7 s for handball.

The heart rate during handball averaged 143 beats min^{-1} when the data for the two players monitored were combined. This corresponded with the heart rate responses to match-play reported in section 3.5. Together with the activity pattern, it corroborates the use of the generic intermittent exercise protocol used in the experiments (chapter 4).

The implications of the present findings for experimental investigations need to be addressed. It does appear that the frequency with which activity changes in team games, and the fact that such changes are highly irregular, make it practically impossible to simulate the competitive demands specific to such games in laboratory conditions. This difficulty is emphasised when the additional burden of games skills with the ball are considered. Nevertheless, generic intermittent exercise models do have a role to play when studying the stresses of games in the laboratory. In these instances it is more realistic to duplicate the physiological stress, such as heart rate, than to claim exact reproducibility of the movement patterns.

The generic intermittent exercise protocol chosen for the study consisted of different exercise intensities to those observed during handball match-play (e.g. for walking, jogging and running). A short rest period was also included on the treadmill. Activities in a handball game involving the performance of backwards and sideways movement were not included in the protocol as a result of the technical limitation of the equipment used. The respective speeds chosen for each activity pattern, based on data obtained during the protocol used in the pilot study, (section 4.1) were walking 6 $km.h^{-1}$, jogging 12 $km.h^{-1}$ and running 15 $km.h^{-1}$. This motion analysis of handball matches indicated that the pace of handball games is relatively fast and most movements of players are performed without possession of the ball. Although the movement patterns during handball matches are extremely difficult to replicate in a laboratory situation, the physiological stress induced by the generic intermittent exercise protocol, as assessed by heart rate, was similar to the average heart rate recorded during handball matches. The motion analysis study revealed some similarities between the generic intermittent exercise protocol used in the laboratory and the actual handball match. This provides evidence that the generic intermittent exercise protocol was valid for evaluating the intensity of handball match-play.

CHAPTER 6

SYNTHESIS AND RECOMMENDATION FOR FUTURE RESEARCH

6.1. SYNTHESIS OF FINDINGS

The aim of this chapter is to describe the results which were obtained within this thesis in relation to the fulfilment of the aims included in chapter 1.3. It provides also an opportunity to reflect on the observations and consider the consequences for interpreting them.

This thesis encompassed a description of kinanthropometric and fitness characteristics of handball players, followed by different studies of physiological demands of handball match-play and laboratory-based intermittent exercise protocols with particular emphasis on the effect of environmental temperature and of beverages containing carbohydrate on selected physiological variables.

6.2. SUMMARY AND CONTEXT OF FINDINGS

It was demonstrated that the height and lower percent body fat of the male Asian handball players were the most important variables in predicting competitive performance, as the successful teams in the 12th Asian Games were taller and had less percent body fat than unsuccessful teams. However, no difference was observed in the kinanthropometric variables measured according to the players' position. Although the kinanthropometric characteristics of the handball teams studied were statistically different, this occurred irrespective of any unique requirement other than skill for positional roles. It is suggested therefore that handball players of different playing positions were relatively similar in kinanthropometric characteristics, at least within the population of players studied.

Female Asian handball teams, in the continent's championship, showed variability in kinanthropometric characteristics. Comparison between male and female Asian handball players demonstrated that elite females were shorter, lighter and had less muscle mass than the males, but male players had less % body fat than female players. These kinanthropometric differences reflect gender differences in the general population.

The studies serve to highlight that there are inherent difficulties in attempting to identify key kinanthromometric determinants of success from measurement of sports people at particular major international tournaments. These include the heterogeneity of races and ethnic differences as well as experience and skill in the game. There is also the problem presented by finding an appropriate reference group. Nevertheless, the classical work of Carter (1970) led to the identification of key factors in size and shape of elite performers in a range of sports. In the present studies of Asian handball players it was possible to establish that height and muscularity are highly relevant to the sport, and more so in female than in male players. Additionally, there is now a database, albeit not yet extensive, of kinanthropometric measures for elite male and female handballers.

The aerobic fitness measures indicate that the male handball players of Kuwait and English were rather unexceptional. The lack of difference between the estimated and measured VO_{2max} values indicates that the 20 m shuttle run can be used as a field test for handballers. The relatively modest correlation would suggest that the 20 m shuttle run test should not be substituted for VO_{2max}, but it does provide a field-based performance alternative to a laboratory-based test of aerobic power.

Important results were also obtained regarding the kinanthropometric, aerobic and anaerobic performance of Kuwaiti and English handball players using field test and laboratory-based assessments. These results fulfil aim 2. The Kuwaiti handball players were taller, heavier and had more muscle mass than the English players. Furthermore, Kuwaiti players achieved higher values in anaerobic performance as assessed by both long and vertical jump, and had lower resting and maximal heart rates. These differences may be linked with more emphasis on the anaerobic strand of training and competitions of handball players in Kuwait. In contrast no difference was observed either in actual or predicted VO_{2max} between the English and Kuwaiti handball players. It is likely that training programmes in the two countries were equally effective in the development of aerobic power.

As heart rate was measured throughout handball matches, there was an opportunity to examine any trends as the game progressed. The average heart rate of handball players during the first and second half was similar, thus suggesting that the two halves required the same energy expenditure. The estimated energy expenditure of a handball match for its complete duration, as derived from the HR-VO_2 relationship, was 3457 kJ. The average heart rate during unofficial matches was similar to previous handball studies (Polimac, 1994) but was below that measured during other team sports such as soccer (Reilly, 1996). These results may indicate that handball matches are lower in intensity compared to soccer and that the average heart rate did not vary with the duration of the game. These results realise aim 3. These inferences may be made when heart rate is used as an index of physiological strain. They are open to criticism when used to estimate energy expenditure in games from the HR-VO_2 relation established during the incremental test used to measure $VO_{2max.}$ Neither HR nor VO_2 reach a steady-state in the laboratory test and the activity changes even more dynamically in the game situation. The estimates rely on an averaging procedure and also disregard factors such as environmental temperature, mode of exercise and emotional state that influence HR but not $VO_{2.}$

The overall average heart rate during a handball match was 143 beats.min^{-1}. This value of average heart rate was used to develop a laboratory-based intermittent exercise protocol similar to the actual handball match. Comparison between this intermittent exercise protocol with a continuous exercise protocol was made in normal and hot environmental conditions at the same level of overall external work (distance covered). The physiological, thermoregulatory and metabolic responses to the laboratory-based intermittent exercise test were assessed in normal and hot environmental conditions. These experiments were completed prior to the conduct of motion analysis of real games which was done later as a check on the compatibility of the intermittent exercise protocol and activity within a competitive game.

In conducting laboratory based simulations, it is never possible to replicate fully the demands of the game. Every game has specific activities, such as throwing, jumping, walking backward, jogging backward and moving sideways. These types of activities are difficult to include in the laboratory intermittent exercise protocol due to the technical limitation of the equipment and practical circumstances. However, it is possible to devise a protocol that adequately reflects the overall **physiological** strain induced during the game. This was confirmed when the physiological demands of the game (see 3.5) were compared with the physiological demands of the intermittent protocol (see 4.1).There were no significant differences between the mean heart rate during handball match-play (143±6 beats.min^{-1}) and the average heart rate elicited during the intermittent exercise protocol (145±18 beats.min^{-1}). Similar observations were found for VO_2 and RER during match-play (2.79±0.53 l.min^{1}, 0.90±0.05) and during the intermittent exercise protocol (2.70 ±0.2 l.min^{-1}, 0.93±0.03) ($P>0.05$). The estimated energy expenditure also was not significantly different between match-play (57.8±10.5 kJ.min^{-1}) and the intermittent exercise protocol (64.5±8.1 kJ.min^{-1}). These results confirmed that the generic intermittent exercise protocol was reflective of the intensity of a competitive handball match.

In summary the above data strongly suggest that the protocol used in 4.1, 4.2 is a valid and reliable instrument for the investigation of the physiological responses to intermittent-type exercise associated with sports such as handball, and as such can be used to examine the effect of heat stress and carbohydrate supplementation. At the same average external work-load continuous exercise placed a significantly greater demand on the cardiorespiratory system than intermittent exercise in normal conditions. This was evidenced by elevations in VO_2 and HR during the continuous protocol and by a significantly higher core temperature. Whilst these results contradict the literature, they are likely to reflect the fact that the present protocol more accurately simulates work profiles experienced in intermittent activities with more subtle changes of speed, rather than a cycle of high intensity work/ rest alternations.

The major new finding in 4.1 was the more marked increase in sweat production when the intermittent work context was moved from normal to hot environments compared with the change observed from the continuous protocol. This suggests that during intermittent exercise in the heat there may be a greater dependence on evaporative cooling in order to protect against thermal injury. This will presumably result in a greater loss of plasma volume, an increase in the level of dehydration and ultimately lead to decrements in performance. The recommendation arising from this research would be that athletes involved in intermittent exercise in the heat should pay careful attention to fluid balance and take every opportunity to ensure that replacement strategies are observed. This finding fulfilled aim 4 and indicates that heat stress affects the physiological and thermoregulatory responses to a generic intermittent exercise protocol which reproduces the physiological strain of handball match-play. Furthermore the experiment generated data on body mass losses, during the intermittent exercise protocol that would assist in devising fluid-replacement strategies in future work related to sports consisting of acyclical intermittent exercise

The effect of carbohydrate ingestion on physiological, metabolic and thermoregulatory responses to the designed laboratory-based intermittent exercise protocol were examined in normal and hot environments. The results obtained helped to fulfil aim 5. It was observed that there was an increase in blood glucose during the rest period after ingestion of carbohydrate in normal and hot conditions, while after

15 min exercise the blood glucose level was significantly lower than at rest pre-exercise. The ingestion of carbohydrate before and during intermittent exercise had no effect on rectal and skin temperatures. It was suggested that the cardiovascular, metabolic and thermoregulatory responses to intermittent exercise would be affected when exercise is performed in a hot environment. However, no significant differences in responses were found when different beverages were consumed.

The motion analysis of handball provides the foundation upon which a reasonable simulation of the movement patterns associated handball might be laid. Nevertheless, it is likely that the activity profile would be helpful only in part e.g. in determining the frequency and intensity of sprints and recovery in between in order to study anaerobic responses. Refinements in the design of this intermittent exercise model would further enable anaerobic endurance and aerobic responses to be studied on a more systematic basis than is currently possible for any team game.

Within the limitation of the present study the following is tentatively concluded:

- certain kinanthopometric characteristics of handball players seem to be related to performance success.
- anaerobic performance appears to be more important than aerobic power for handball players.
- handball match-play induces an average heart rate of about 143 beats.min^{-1} and an estimated energy expenditure equivalent to 57.6 kJ.min^{-1} .

- physiological responses to a bout of intermittent exercise representing the average physiological intensity of a handball match were similar to those evoked during continuous exercise at the same level of energy output.

-physiological stress induced by exercise and environmental temperature seem to be the main factors responsible for the cardiovascular, metabolic and thermoregulatory alterations during 30 min of a generic intermittent exercise protocol.

-exogenous carbohydrate feeding before and during exercise (resembling the exercise intensity of handball) appears not to influence the physiological, metabolic and thermoregulatory responses during the same exercise protocol.

-handball match-play is comprised largely of low level activity without the ball and periodic bouts of high intensity efforts with changes in activity every 6 s.

6.3. RECOMMENDATIONS FOR FUTURE RESEARCH

The studies completed within this thesis provided an overview of the characteristics of handball players and the physiological demands of the game. The experimental studies provided some indications of the value of thermoregulatory and nutritional interventions. The motion analysis of the game yielded activity profiles relevant to both future experimental investigations and training theory for the game. In achieving the aims of this thesis some issues have arisen and certain findings have prompted the formulation of recommendations for further research.

(1) The kinanthropometric measurements have proved that there was a relationship between these characteristics and the performance of handball players. However, the studies concentrated on Asian men and women handball players. Future research

should be concerned with a wider population of handball players, for example during the world handball championships.

(2) The significant differences between English and Kuwaiti handball players in most characteristics and physical fitness variables were evident probably because the English players were not participating in any world championship. English players are therefore not representative of elite handball players. This prompts further research to evaluate the aerobic and anaerobic capacities needed by international handball players during world handball championships for men and women, to determine the real requirements for handball players at the highest level.

(3) There were no significant differences between English and Kuwaiti handball players in hand grip, leg and back strength. These measurements are limited to isometric strength and do not include dynamic strength measured by isokinetic devices. Therefore invitations should be extended for further research to examine the leg, back and ankle strength by means of isokinetic dynamometers.

(4) The heart rate data from chapter 3.5 in this thesis provided good indications of work-rate and energy expenditure during handball match-play. Further research could be devoted to measuring blood lactate concentration and sweat production rate in field conditions.

(5) The data in 4.1 suggest that intermittent exercise in the heat places greater demands on fluid balance than does continuous exercise. Future studies should

prolong the intermittent protocol to investigate if such changes do have ramification for performance. In such studies the volume of content of the fluid provided could be matched more closely to physiological needs than was realised in the studies reported in this thesis.

(6) Methodological problems relating to blood sampling techniques present difficulties for the determination of the anaerobic contribution to the demands of handball-specific intermittent exercise performance. More frequent blood sampling interspersed with control periods of activity would provide some evidence of the lactate contribution to energy demands during intermittent exercise. Muscle biopsies obtained before, during and after exercise would also help to improve the understanding of the demands of handball match-play. This has not been attempted systematically by any research group in the context of handball.

(7) The decrease in blood glucose during exercise with prior ingestion of carbohydrate occurred in normal and hot conditions. Blood lactate increased slightly after 15 min and at the end of exercise. This increase was statistically significant compared to rest. It is suggested that the exercise intensity employed was not high enough to disturb the balance between lactate production and removed during exercise. The ingestion of carbohydrate before and during exercise had no further effect on rectal and skin temperatures changes during exercise. This may be attributed to the moderate intensity and short duration of the exercise protocol used in the present study.

It is likely that the environmental temperature was not hot enough and/or the exercise work rate (e.g. intensity and duration) was not strenuous enough to elicit significant physiological effects in the present study and to elicit a significant change in blood glucose concentration. Further research could examine the effect of carbohydrate ingestion during heat stress in the laboratory with an increase in the duration of intermittent specific-handball match to an equal the total time corresponding to a handball game. Also the heat stress might be increased, for example as found in certain outdoor conditions in Africa and the Middle East.

(8) The limited information from the analysis of handball match-play creates difficulty in estimating the work-rate and energy expenditure of handball players. Techniques of TV recording and motion analysis could be further refined to determine work-rate, total distance covered and different activities during match-play among international handball players. Such data would provide more information on the demands of the handball game at high levels and would give guidance for training and competition for developing handball match-play in the future.

(9) It would be useful to test handball players in field situations with ingestion of beverages to determine the effects of fluid ingestion on actual performance of handball players in certain conditions in Africa and the Middle East. This could be done by means of an interdisciplinary study incorporating both match analysis and physiological methods.

At the outset of this thesis, it was clear that the scientific literature relating to handball was sparse. The sport lagged considerably behind others, such as soccer, which now has a rich history of scientific studies to underpin it. The work in this thesis represents descriptive kinanthropometric and fitness characteristics of handballers, monitoring the physiological strain associated with playing the game and generating activity profiles of players during real matches. The experimental investigations represented an attempt to progress from the classical models of intermittent exercise to a protocol more appropriate for games. The findings make it obvious that there is considerable more work to be done in linking laboratory and field studies related to handball. This thesis should therefore be seen as a starting point rather than the culmination of research devoted to handball.

CHAPTER 7

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Appendix 1

LIVERPOOL JOHN MOORES UNIVERSITY
SCHOOL OF HUMAN SCIENCE
Centre of Sports & Exercise Science

DATA COLLECTION FORM

Name :			
Date :			Tel :
Age :	Height :		Weight :

HANDALL BACKGROUND DETAILS :-

Position:	Club:
Number of Years playing Handball:	Number of Years in National Team:
Number of Local Matches played:	Number of Intl. Matches played:
Number of Goals scored:	Number of Goals scored:

BODY FAT :-

Biceps:	Triceps:	Subscap:	Suprailiac:	Total:	Persentage:

ANTHROPOMATIC :-

SKIN FOLD:	Form thigh:		Calf:	
	1-		1-	
	2-		2-	
	3-		3-	
GRITH:	Forarm:	Thigh:	Calf:	
	1-	1-	1-	
	2-	2-	2-	
	3-	3-	3-	

STRENGTH :-

HAND	Left:	Right:	LEG:	BACK:
	1-	1-	1-	1-
	2-	2-	2-	2-
	3-	3-	3-	3-

POWER :-

Long Jump:	1-	Vertical Jump:	1-
	2-		2-
	3-		3-

HEART RATE :-

Rest:	St.:	Training:	Game:	Laboratory:	Recovery:

MAXIMAL OXYGEN UPTAKE :-

Predicted rom 20m Shuttle Run	LAB:	HR:	

LIVERPOOL JOHN UNIVERSITY

SCHOOL OF HUMAN SCIENCE

Centre for Sport and Exercise Science

DATA COLLECTION FORM

Name	Date
Age HEIGHT	Weight

Handball Background detail

Position	Club
years of playhandball	Years of play with national team
Number of International Matches	Numbers of GOALS

BODY FAT

Biceps Triceps Subscap	Suprailiac Total %

STRENGTH

Hand Leg	Back

BOWER

Long Jump	Vertical Jump

HEAR RATE

Rest Training	Game

MAXIMAL OXYGEN UPTAKE

Predicted from 20 m Shuttle Run	LAB

verpool John Moorers University
entre for Sports and Exercise Sciences
ermittent and continuous exercise test form

me: Date: / / 96 Protocol Condition

dy mass

for (kg) After (kg) Age (y) Height (cm) Rest HR (b/min)

e (min.	Rectal	Room	Skin Temperature				Tympanic Tem		P.E.S
Before	Temper	Temper	1	2	3	4	Grunt	Genius	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
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13									
14									
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xercise									
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3									
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9									
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LIVERPOOL JOHN MOORES UNIVERSITY
Centre for Sport and Exercise sciences

CARBOHYDRATE AND PLACEBO DURING INTERMITTENT AND CONTINUOUS PROTOCOL DURING HEAT AND NORMAL CONDITION

PROTOCOL...CONDITION..............................

Subject's name...................................Age.......................(y) Height................(cm)

Bodymas...............(kg)

Date ..../........ / 1996 Time ....(am. pm)

Skinfold	1	2	3	Sum
Biceps				
Triceps				
Subscapula				
Supariliac				

% Body fat.....................

VO2 uptake...........................(ml/kg/min)

Rest heart rate.......................(beat/min)

Glucose intake.......................(gm)

Drink......................................(ml)

	Hb (g %)	Hct (%)	Glucose (mmol/l	Lactate (mmol/l
Before				
After 15 min rest				
After 15 min exercise				
After 30 min exercise				
After 15 min recovery				

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Intermittent with water and carbohydrate exercise test form

Name: Date: / / 96 Protocol Condition

Body mass

before (kg) After (kg) Rest HR(b/min)

Drink time			0 min		15min Ex		30min	
Water (placebo)								ml
Carbohydrate								(gm)

Time (min.)	Room	Rectal	Skin Temperature				Tympanic Tem		P.E.S
Before	Temper	Temper	1	2	3	4	Grunt	Genius	
1									
2									
3									
4									
* 5									
6									
7									
8									
9									
* 10									
11									
12									
13									
14									
* 15									
Exercise									
* 1									
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3									
4									
* 5									
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7									
8									
9									
* 10									
11									
12									
13									
14									
* 15									

Rest	Room	Rectal	1	2	3	4	Tympanic Tem		P.E.S
1							Grunt	Genuis	
2									
3									
4									
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Exercise									
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Appendix 2

Liverpool John Moores University
Centre for Sports and exercise Sciences

Subjects Consent Form

Researcher Ahmed Hasan
Supervisors. Prof. T.Reilly
Dr. T. Cable

Energy expenditure and anaerobic performance and aerobic power during training and Competition in elite handball players

This series of studies is designed to estimate the energy expenditure and anaerobic performance and aerobic power of elite handball players both during training and in competition. This will allow an assessment of the contribution of various fuel system used in this sport and provide coaches with important information regarding the most efficient training methods.

As a subjects in this study you will be asked to attend the exercise physiology laboratory where your cardiorespiratory endurance capacity and hand, leg and back muscle strength well be measured. Endurance capacity will be measured using an incremental exercise protocol on a treadmill. During the running test your expired gases will be collected using a snorkel like mouthpiece, and the intensity of the exercise increased at regular intervals until you can no longer keep pace with the treadmill. At this point the test will stop . Hand grip, leg and back strength will measured. This whole process will require your attendance for approximately two hour.

Additionally your boy composition and fitness levels will be measured at regular intervals at training session and anaerobic performance (long and vertical jump) will measured .20 m shuttle run also will be measured. at some training session heart rate will also be monitored using a radio telemetry device placed around the chest wall. Hear rate will be measured during competitive games using the same technique during training session. None of these procedures will interfere with your ability to perform the exercise task in your usual manner.

I.. have read this consent form and gained further clarification of any points that I was uncertain of. I retain this right to withdraw my consent at any period of this study

Name Signed

Date ....

اقرار بالموافقة

==========

كمية الطاقة المستهلكة وتاثير درجة الحرارة اثناء التدريب والمباريات للاعبى كرة اليد

لقد صممت هذه الدراسات لقياس الطاقة المستهلكة للاعبى كرة اليد اثناء التدريب والمباريات وهذه الدراسة ستسمح بمعرفة مختلف انظمة الطاقة التى سوف تستخدم فى هذه الرياضة والتى سوف تزود المدربين بالمعلومات الهامة عن اكثر طرق التدريب فعالية لرياضة كرة اليد .

وأنت كأحد لاعبى كرة اليد وكمشارك فى هذه الدراسة سوف يطلب منك الحضور الى مختبر الفسيولوجى والذى سيتم فيه قياس قدرة كفاءة الجهاز الدورى التنفسى ، وسوف يتم قياس قدرة الجهاز الدورى التنفسى باستخدام جهاز السير المتحرك (تردميل) ، وخلال اختبار الجرى سيتم قياس كمية الاكسجين القصوى باستخدام كمام للفم ، وسيتم زيادة فترة الجهد على مراحل منتظمة حتى تفقد القدرة على مجاراة جهاز الجرى وحتى درجة الاجهاد .

وعند هذه النقطة ينتهى التمرين ، وبالاضافة لذلك سوف يتم قياس النمط الجسم ومستوى اللياقة البدنية على فترات زمنية منتظمة اثناء التمرين ، وتشمل هذه الاختبارات قياس نسبة الدهن فى الجسم ، الجرى المكوكى انواع الوثب .. وفى اثناء بعض التمارين سيتم قياس معدل ضربات القلب باستخدام جهاز التليمترى (القياس من بعد) والذى سيوضع حول الصدر .

كما سيتم قياس معدل ضربات القلب اثناء المباريات الرسمية باستخدام الاساليب ذاتها ، ولن تؤثر أى من هذه الاختبارات على قدرتك على القيام بالتدريبات بالاسلوب المعتاد .

اننى على علم تام بأن الاشتراك فى هذا الفحص اختيارى وأنه بامكانى الانسحاب فى أى وقت متى رغبت فى ذلك دون أى مسئولية .

أنا قد قرأت هذه الاقرار وحصلت على كل هذه الايضاحات اللازمة حول النقاط التى لم أكن متأكدا منها .

التوقيع	المشارك	الباحث

التاريخ

Liverpool John Moores University
Centre for Sports and Exercise Sciences

Subject Information Sheet

Researcher: Ahmed Hasan
Supervisors Prof. T. Reilly
Dr. M. El-sayed
Dr.T. Cable

Title The effect of heat stress on selected physiological responses during intermittent and continuous exercise protocol

This study is designed to examine the effect of heat stress on selected physiological parameters (heart rate, VO2 uptake , body temperature, skin temperature, blood lactate and glucose concentration) in response to intermittent and continuous exercise protocols.

The purpose of this form is to provide you with the necessary information relating to the experiments you are about to undertake. It is important that you read it all carefully and understand the procedures involved. Any questions relating to the procedures will be answered on request.

The experiments will require you to attend the sports science laboratories of Liverpool John Moores University on 5 difference occasions. On each visit you will be required to refrain from exercise for 24 hour prior to testing and have not eaten for at least 3 hours.

Testing protocol and experimental procedures:

1- VO_2 max test

You will be tested for maximal oxygen uptake on treadmill in normal condition using an incremental exercise protocol. Following a warm-up period of 5 minutes at 7.5 km/h, the initial treadmill speed will be 10 km/h for two minutes. Thereafter the speed will be increased by 2 km/h every two minutes until exhaustion.

2-Intermittent exercise protocol

The intermittent exercise session will be performed for 30 minutes encompassing sprinting (15 km/h) jogging (12 km/h) and walking (6 km /h) in durations similar to those usually performed during handball match . The exercise protocol is shown in table 1.

3- Intermittent exercise in the heat.

This exercise protocol is similar to that performed in the normal condition. However the experiment will be conducted in a heated room at temperature of 32 ± 2 °C.

Table 1. Intermittent protocol ✳

Stages	1	2	3	4	5	6	7	8
Speed	12	6	15	6	12	15	6	12
Time(sec)	**45**	**32**	**46**	**32**	**45**	**46**	**32**	**45**
Stages	9	10	11	12	13	14	15	
Speed	**6**	**15**	**12**	**6**	**12**	**6**	**12**	
Time(sec)	**32**	**46**	**45**	**32**	**45**	**32**	**45**	

✳ *A five minutes warm-up period on the treadmill at speed of 7.5 km/h will be performed prior to the commencement of the exercise protocol.*

Experimental procedures.

✪ Before you start the test your body mass will determined using hydraulic scale.

✪ you will be required to place the heart rate transmitter belt on your chest and the monitor will be tightly strapped around your wrist. Your heart rate will be recorded continuously at rest and during exercise

✪ Tempanic and rectal temperatures will be recorded at rest and during exercise .

✪ Capillary blood samples will be obtained at rest and during exercise . The site of sampling will be either from fingertip or earlobe.

✪ You will be required to place the skin temperature leads on the following sites of your body.

a- Over the Sternum

b- Mid front arm

c- Mid front thigh

d- Exterior mid calf

✪ A mouth piece and a nose-clip will be fitted during the exercise test for the determination of oxygen uptake

I have read and understood the information detailed in information sheet. To my knowledge I have no physical condition or injuries which may affect my participation in this study , and I realise I am free to withdraw from the study at any stage without prejudice.

Name .... witness........................ Date......................

signed.........................

Liverpool John Moores University
Centre for Sports and Exercise Sciences

Ref: Intcarbo

Subject Information Sheet

Researcher: Ahmed Hasan
Supervisors Prof. T. Reilly
Dr. M. El-sayed
Dr.T. Cable

Title The effect of carbohydrate ingestion on exercise performance during intermittent treadmill running in the heat.

This study is designed to examine the effect of water placebo or glucose on selected physiological parameters (heart rate, VO_2 uptake, body temperature, skin temperature, blood lactate and glucose concentration) in response to intermittent exercise protocol in normal and hyperthermic conditions.

The purpose of this form is to provide you with the necessary information relating to the experiments you are about to undertake. It is important that you read it all carefully and understand the procedures involved. Any questions relating to the procedures will be answered on request.

The experiments will require you to attend the sports science laboratories of Liverpool John Moores University on 5 separate occasions. On each visit you will be required to refrain from exercise for 24 hour prior to testing and have not eaten for at least 3 hours.

Testing protocol and experimental procedures

1- VO_2 Max test

You will be tested for maximal oxygen uptake on treadmill in normal condition using an incremental exercise protocol. Following a warm-up period of 5 minutes at 7.5 km/ h, the initial treadmill speed will be 10 km/h for two minutes. Thereafter the speed will be increased by 2 km/h every tow minutes until exhaustion.

2-Intermittent exercise protocol in normal condition (18 ± 2 °C)

The intermittent exercise session will be performed for 30 minutes encompassing sprinting (15 km/h) jogging (12 km/h) and walking (6 km /h) in durations similar to those usually performed during handball match . The exercise protocol is schematically illustrated in table 1.

3- Intermittent exercise protocol in the heat (32 ± 2 °C).

This exercise protocol is similar to that performed in the normal condition.

Table 1. Intermittent protocol ✳

Stages	1	2	3	4	5	6	7	8
Speed	12	6	15	6	12	15	6	12
Time(sec)	**45**	**32**	**46**	**32**	**45**	**46**	**32**	**45**
Stages	9	10	11	12	13	14	15	
Speed	**6**	**15**	**12**	**6**	**12**	**6**	**12**	
Time(sec)	**32**	**46**	**45**	**32**	**45**	**32**	**4**	

✳ *A five minutes warm-up period on the treadmill at speed of 7.5 km/h will be performed prior to the commencement of the exercise protocol.*

Experimental procedures.

✪ Before you start the test your height and body mass will determined using hydraulic scale.

✪ Body fat will be measured by skinfold calepr taken from four sites (Biceps, Triceps, Subscapula and Supariliac.

✪ A heart rate transmitter belt will be plated on your chest and the monitor will be tightly strapped around your wrist. Your heart rate will be recorded continuously at rest and during exercise

✪ Tempanic and rectal temperatures will be recorded at rest and during exercise .

✪ Capillary blood samples will be obtained during rest , exercise and recovery period as shown in the diagram.

Blood ↓ ↓ ↓ ↓ ↓

15 min Rest	First15min Exercise	10min Rest	second15min Exercise	15min Recovery

Time 0 15 25 40 55

Drink↑ ↑ ↑

✪ The two experimental drink are (a) an artificial sweetened orange flavoured., glucose -free placebo and (b) a 7.5% (W/V) orange - flavoured glucose. The experimental drink will given in double - blind and randomised fashion. Subjects an equal volume of the respective drink will be ingested at exactly the same point in time during the two testing trial. An initial portion of either glucose or placebo (3 ml/kg body weight) will be administered 15 min before commencement of exercise. The second and third portion of drink (3ml/kg body weight) will be given at 15 min during the intermittent exercise and immediately after exercise.

✪ Skin temperature leads will be applied to the following sites of your body.

a- Over the Sternum

b- Mid front arm

c- Mid front thigh

d- Exterior mid calf

✪ A mouth piece and a nose-clip will be fitted during the exercise test for the collection of the expired air and the determination of oxygen consumption.

I have read and understood the information detailed in information sheet. To my knowledge I have no physical condition or injuries which may affect my participation in this study , and I realise I am free to withdraw from the study at any stage without prejudice.

Name .... witness........................ Date.....................

signed........................

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