Thermoregulatory and cardiovascular responses of male and female adolescents to continuous and intermittent exercise in a hot humid environment

Doug Hillis
University of Wollongong

Recommended Citation

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au
THERMOREGULATORY AND CARDIOVASCULAR RESPONSES
OF MALE AND FEMALE ADOLESCENTS
TO CONTINUOUS AND INTERMITTENT EXERCISE
IN A HOT HUMID ENVIRONMENT

by

Doug Hillis, B.Ed.

A thesis submitted for the degree of
Master of Science (Hons)
University of Wollongong,
New South Wales,
Australia,
August, 1990
ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Dr. Karen Chad, for her continued interest, wealth of suggestions, critical analysis of my writing and never ceasing encouragement throughout all phases of this investigation.

Many thanks to the Department of Human Movement Science for their ongoing encouragement and support throughout my post graduate studies at the University of Wollongong. My sincere thanks go to all the subjects who gave of their valuable time to participate in the experiments and the Illawarra Academy of Sport for all their assistance in providing subjects. Above all, to all of those who assisted me during my work, no one mentioned, no one forgotten, I owe you my many thanks.
ABSTRACT

The purpose of this study was to determine the thermoregulatory and cardiovascular responses of male (15.09±0.94 years) and female (15.08±0.79 years) adolescents during continuous and intermittent exercise. The relationship between the sexes completing two different exercise protocols in the hot humid environment was also investigated.

Thermoregulatory (core and skin temperature, sweat rate, metabolic heat production) and cardiovascular (oxygen consumption, heart rate, blood plasma volume) responses were studied in eleven male and twelve female physically fit (males = 53.45±4.87 ml·kg⁻¹·min⁻¹; females = 44.42±4.56 ml·kg⁻¹·min⁻¹) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment. One week prior to performing the two exercise protocols, anthropometric measurements were taken of each subject and a maximum oxygen uptake test on a cycle ergometer was performed in order to determine relative work loads for the continuous and intermittent exercise periods.

The exercise was performed in a climate chamber under the following environmental conditions: Temperature\textsubscript{wet} bulb/Temperature\textsubscript{dry} bulb = 31/27 °C; relative humidity = 73%;
Wet Bulb Global Temperature = 28.2 °C. Following a 15 minute rest period in the hot environment, subjects cycled at 60 rpm for one hour at 50% $\dot{V}O_2$ max during continuous exercise. In order to equate total work load between the two exercise protocols, subjects also cycled at 60 rpm for one hour during the intermittent exercise, with alternating 5 minute intervals of active-rest at 30% $\dot{V}O_2$ max and work at 70% $\dot{V}O_2$.

The results showed that core temperature was not significantly ($p \leq 0.05$) different between the continuous and intermittent protocols in both sexes in the hot wet environment. Although skin temperature was similar throughout both exercise protocols in the male and female adolescents, a significant ($p \leq 0.05$) difference was observed between intermittent and continuous exercise at the 45th and 55th minute in the male subjects. Heart rate responses were significantly different between continuous and intermittent exercise in both the male and female subjects, although no sex difference was observed. When the heart rates were averaged over the entire 60 minutes of exercise the results showed that continuous and intermittent exercise produced a similar cardiovascular response in both the male and female adolescents.

During intermittent exercise sweat rates of the males were not statistically different from those observed during continuous work. The sweat rate differences between the two protocols in females were significant ($p \leq 0.05$) with the
intermittent exercise producing a greater sweat rate than the continuous protocol. The results also showed that males produce significantly \( p \leq 0.05 \) more sweat than females in both the continuous and intermittent exercise bouts. The percent change in blood plasma volume was greater \( p \leq 0.10 \) in both the male and female adolescents during intermittent exercise when compared with the percent change in blood plasma volume observed following continuous exercise.

The findings from the present study suggest that male and female adolescents are very similar in their thermoregulatory and cardiovascular function while exercising in a hot humid environment. The sweat rate and plasma volume changes observed in the study indicate that intermittent exercise appears to induce a greater thermoregulatory stress than does continuous exercise, thereby requiring a closer monitoring of dehydration during intermittent exercise with this specific age group.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>vii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>x</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xi</td>
</tr>
<tr>
<td>CHAPTER I: Introduction</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER II: Review of Literature</td>
<td>7</td>
</tr>
<tr>
<td>CHAPTER III: Methods</td>
<td>33</td>
</tr>
<tr>
<td>CHAPTER IV: Results</td>
<td>41</td>
</tr>
<tr>
<td>CHAPTER V: Discussion</td>
<td>71</td>
</tr>
<tr>
<td>CHAPTER VI: References</td>
<td>86</td>
</tr>
</tbody>
</table>
LIST OF TABLES

CHAPTER IV

Table 1a  -  Physical characteristics of female subjects
           (n=12)........................................................................43

Table 1b  -  Physical characteristics of male subjects
           (n=11)........................................................................44
CHAPTER IV

LIST OF FIGURES

Figure 1 - Mean workloads of male (n=11) and female (n=12) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment

Figure 2 - Energy expenditure (kJ·m⁻²·hr⁻¹) of male (n=11) and female (n=12) adolescents following 60 minutes of continuous and intermittent exercise in a hot humid environment

Figure 3 - Metabolic heat production (kJ·m⁻²·hr⁻¹) of male (n=11) and female (n=12) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment

Figure 4 - Metabolic heat production (kJ·m⁻²·hr⁻¹) of male (n=11) and female (n=12) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment

Figure 5 - Core temperature responses of males (n=11) and females (n=12) at rest and during 60 minutes of continuous exercise in a hot humid environment
Figure 6  - Core temperature responses of males (n=11) and females (n=12) at rest and during 60 minutes of intermittent exercise in a hot humid environment..........................53

Figure 7  - Core temperature responses of males (n=11) at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment............................................54

Figure 8  - Core temperature responses of females (n=12) at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment............................................55

Figure 9  - Skin temperature responses of males (n=11) and females (n=12) at rest and during 60 minutes of continuous exercise in a hot humid environment............................................57

Figure 10  - Skin temperature responses of males (n=11) and females (n=12) at rest and during 60 minutes of intermittent exercise in a hot humid environment............................................58

Figure 11  - Skin temperature responses of males (n=11) at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment............................................59

Figure 12  - Skin temperature responses of females (n=12) at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment............................................60
Figure 13 - Heart rate responses of males (n=11) and females (n=12) at rest and during 60 minutes of continuous exercise in a hot humid environment.................................................62

Figure 14 - Heart rate responses of males (n=11) and females (n=12) at rest and during 60 minutes of intermittent exercise in a hot humid environment......................................................64

Figure 15 - Heart rate responses of males (n=11) at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment...............................................................65

Figure 16 - Heart rate responses of females (n=12) at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment...............................................................66

Figure 17 - Sweat rate (g·m⁻²·hr⁻¹) responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.................................................68

Figure 18 - Percent change in plasma volume of male (n=11) and females (n=12) after 60 minutes of continuous and intermittent exercise in a hot humid environment......................................................70
CHAPTER I

INTRODUCTION
INTRODUCTION

An increasing number of children and adolescents is engaging in a variety of outdoor physical activities. Although there is considerable literature on the physical, psychological and social aspects of children and adolescents in sport, our knowledge regarding the criteria for safe participation, the risk to health, and the long-term effects on Australian children and adolescents is incomplete (National Health and Medical Research Council, 1988). This is particularly the problem during summer months when adolescents are often exposed to prolonged physical activity in hot conditions.

Climate may affect exercise performance and the general well-being of the exercising individual. Although there is information on adult exposure to the climatic stress experienced in industry, the military, or sports, the data on child and adolescent responses are scarce. Since children and adolescents are habitually more active than adults and spend much of their leisure time outdoors, recent concern has been expressed for obtaining a better understanding of the effects of climate on the exercising child and adolescent (American Academy of Pediatrics, 1982). Although the Academy and
others (Bar-Or, 1984; National Health and Medical Research Council, 1989) claim that children thermoregulate less efficiently than adults, the question of whether these deficiencies are associated with an increased health risk to the adolescent age group, participating in a hot climate, is less definitive.

It has been suggested that thermoregulation differences may be influenced by the following characteristic differences between younger age groups and adults in hot conditions: (1) a larger surface area per body mass unit; (2) a higher oxygen cost of walking and running; (3) a lower cardiac output at a given oxygen uptake; and (4) a lower sweating rate in the younger age groups compared to the adult population (Bar-Or, 1980; Astrand, 1952; Haymes et al., 1975; Drinkwater et al., 1977 and Drinkwater et al., 1979). It is interesting to note that these morphological and functional characteristics of the younger age groups, which make them less efficient thermoregulators when exercising in the heat than adults, have predominantly been observed when the exercise is performed in a continuous manner. The major impetus to the increased number of children and adolescents involved in physical activity is due to a worldwide increase in a high level of organized sport (and hence the growing concern in physiology of the exercising child) (Bar-Or, 1980), which is predominantly
intermittent in nature. It is questionable, therefore, whether a continuous exercise protocol of past laboratory studies answers in full the thermoregulatory responses that exist between younger age groups and adults. Several investigators (Lind, 1963; Ekblom et al., 1971; Drinkwater, 1976) have hypothesized that the thermoregulatory system might respond differently to work in hot environments if the work were performed intermittently (alternating cycles of work and rest) rather than continuously. Lind (1963) found increased thermoregulatory responses at temperatures equivalent to 29 and 32 °C (WBGT) following eight hours of continuous and intermittent work,

equated in terms of total energy expenditure. Similarly, Ekblom et al. (1971) observed a 0.35 °C increase in core temperature during intermittent exercise compared to one hour of continuous exercise at 60% \( \dot{VO}_2 \) max on a cycle ergometer, when total work was equated. Drinkwater (1976) also suggested that the cardiovascular responses to intermittent work might differ from continuous exercise if the intermittent exercise resulted in a cumulative increase in body heat content during the work periods. In her study, however, Drinkwater (1976) found that although the rectal temperature and oxygen uptake were successively higher in each intermittent exercise period, the subjects had returned to their resting levels by the
end of the recovery periods, and there was no observed cumulative effect of the combined stressors across time. It should be noted, however, that Drinkwater (1976) did not directly compare intermittent and continuous exercise protocols but examined only the commutative effects of three work-rest periods. It is, therefore, difficult to draw any conclusions regarding the differences that may exist between intermittent and continuous exercise. The 20 minute rest period in a neutral environment where the subjects adopted a semi-reclining position could have prevented the additive effects of thermal heat load as suggested earlier by Drinkwater (1976).

The obvious question, however, is at what ratio of work to rest does the thermal load make itself felt? In organized sport, which is predominantly intermittent in nature, the aerobic training work-rest ratios are commonly one to one with recovery periods substantially less than the 20 minutes reported by Drinkwater (1976) or Lind (1963). As well, during the "rest" periods of intermittent sport the adolescents would be remaining on the field, court, etc. with an active rest being performed between movement patterns (ie. alternating cycles of work and active rest). To address this issue the present study was designed to incorporate an active-rest period (rather than a non-active rest phase), along with an intense
work interval that would help simulate a more realistic intermittent type exercise bout. This would, therefore, further add to our knowledge regarding the thermoregulatory responses of the younger age groups participating in organized sport, which is predominantly intermittent in nature.

Moreover, while no significant differences have been observed in thermoregulatory strain during continuous exercise in hot climatic conditions between males and females (Weinman et al., 1967; Paolone, et al., 1977), there have been no such comparisons made between the sexes in adolescents during intermittent exercise.

The purpose of this study was, therefore, to determine the thermoregulatory and cardiovascular responses of male and female adolescents during continuous and intermittent exercise, equated in terms of total work output.
CHAPTER II

REVIEW OF LITERATURE
Humans are homeothermic beings. In order to survive they must keep their internal temperature relatively constant, withstanding fluctuations in the environmental temperature and variations in the degree of muscle-generated heat. When the body temperature extends beyond its critical range (ie. approximately 40 °C), irreversible damage to the living cells and possibly, death may occur (Hardy, 1961).

The primary mechanisms of heat dissipation (when environmental temperatures rise above skin temperature) involve the circulatory system and evaporation. When a person works or plays in a hot and dry environment, cooling of the skin is brought about by evaporation of sweat. It is important to note, however, that cooling the skin is not the desired end result; it is the internal environment that must be cooled at all costs. This is achieved by increasing blood flow through the skin and subcutaneous tissues, resulting in a greater volume of blood in and close to the skin for better transfer of heat to the evaporative surface, and thus in better cooling. However, this improved cooling is met only through a great cost to the circulatory system. To maintain a constant cardiac output for the demands of both exercising muscles and skin
circulation, the heart rate must increase (Saltin, 1964; Williams et al., 1962; Haymes and Wells, 1986; Harrison, 1988). Because increases in heart rate may reduce cardiac efficiency, exercise at temperatures close to or above skin temperature can impose very severe loads upon the cardiovascular system, even when the air is relatively dry. Since the entire process of heat dissipation now depends upon elimination of water in perspiration, it is obvious that dehydration is a distinct possibility. The importance of this factor has been outlined by Harrison (1988).

When the air surrounding an individual is not only hot but is loaded with moisture, evaporative cooling is impaired. Evaporation cannot take place unless volumes of air are available to take up the water vapor given off. Therefore, although the problems in a hot dry environment are related to increasing cardiovascular loads and dehydration, if water intake is insufficient in a hot humid climate the same problems exist but are aggravated by a lessened ability to unload water vapor into an already loaded ambient atmosphere.

Although the general principle (conduction, radiation, convection, evaporation) governing thermoregulation across the different populations are similar the way in which they are implemented within the population varies. This complicates
the calculation of heat content of the body and makes it
difficult to apply temperature guidelines across age groups.
Significant to this is the investigation of the
thermoregulatory responses of exercising children and
adolescents. In order to understand how the thermoregulatory
responses of this younger age group may differ, a comparison
between the younger age groups and adults is necessary.

Thermoregulation of Exercising Children and Adults

Exercising children in relation to adults have some
thermoregulatory constraints. A number of morphological and
functional characteristics of children make them less
efficient thermoregulators than adults. These include: (1) a
larger surface area per body mass unit; (2) a higher oxygen
cost of walking and running; (3) a lower cardiac output at a
given oxygen uptake; and (4) a lower sweat rate (Bar-Or, 1980,
1984).

Surface Area Per Body Mass Unit: Surface area to mass ratio
affects the rate at which heat is lost from the skin. A person
with a large surface area to mass ratio loses heat more
rapidly than a person with a small ratio because the heat will
be closer to the surface (Haymes and Wells, 1986). A young
child has about 32% to 40% more surface area per kilogram of body weight than an adult (Bar-Or, 1980; Haymes and Wells, 1986). The implications of this larger body surface area to mass ratio is that a significantly greater heat transfer between the skin and the environment through conduction, convection and radiation will occur in the child than in the adult. When ambient temperature is warm, but not exceeding skin temperature, this smaller ratio of body mass to surface area can be an advantage as heat is lost by convection at a faster rate due to the ambient temperature being less than the skin temperature. Docherty (1986) found that adults with a surface area per mass ratio less than 240 cm\(^2\)-kg\(^{-1}\) were at a greater risk than 11 to 12 year old boys (320 cm\(^2\)-kg\(^{-1}\)) when exercising in a hot (ambient temperature = 30 °C), humid (80% relative humidity) environment. This also may be the case when the child is performing a high level of exercise in a cool environment (Bar-Or, 1980). However, when the air temperature exceeds skin temperature, the child will be at a distinct disadvantage. Although children will still lose heat by evaporation of sweat, they will gain heat by convection more quickly than adults. The greater heat transfer to or from the skin now becomes a liability to the child (Bar-Or, 1980).

*Metabolic Heat Production:* The metabolic heat production in a rested individual is approximately 315 kilojoules (75 kilocalories) per hour (Haymes and Wells, 1986). During
exercise, however, this heat production can increase 20 times above resting levels. Under such conditions, in order to keep body temperature within normal levels, this extra metabolic heat must be dissipated. Because the core temperature is elevated in relation to skin temperature, the thermal gradient favours the loss of metabolic heat via the mechanisms of radiation, conduction, and convection. In addition, muscular contraction stimulates thermal sweating. This increases the temperature gradient between the deep tissues and the skin surface, providing evaporation takes place. Therefore, as long as the surrounding air remains cool, and the solar load is not excessive and sweat secretion keeps up with evaporation, temperature regulation provides no threat to the exercising individual. However, when exercise is performed under hot environmental conditions that add an external heat load or prevents the loss of body heat and leads to an elevated core temperature, adequately regulating body core temperature becomes a problem. Under these conditions the methods of dissipating increased metabolic heat are limited. Deep body heat is no longer able to flow to the surface for release to the environment and therefore, the body must rely exclusively on the sweat mechanism and the evaporative power of the environment for removal of excess metabolic heat.

The implications for children regarding metabolic heat production is that they may expend 20% to 30% more energy
per kilogram of body weight than adults at the same workload (Bar-Or et al., 1969; Haymes et al., 1974; Astrand, 1952). The result is that children will produce more metabolic heat than the adult for an equal task or bout of exercise. This places the child at a distinct disadvantage, particularly during strenuous athletic activities and when climatic heat stress is superimposed. An increased strain is, therefore, imposed upon the heat dissipating systems of the child. Wagner (1972), comparing the metabolic heat exchange of adult men and pre- and post-pubertal children in 49 °C heat, found that children produced more metabolic heat (5.43 kcal·kg·min⁻¹) and absorbed more heat by radiation and convection, when walking on a treadmill at 5.6 km/hr for 40-90 minutes, than the adults. The children were not in thermal equilibrium and were continuously increasing their core (rectal) temperature over time as more heat was stored in their bodies. It was, therefore, concluded that children have limited thermoregulatory abilities under these conditions.

Exercise Cardiac Output: By directing blood flow away from the core tissues to the peripheral tissues, it is possible to redistribute and/or to remove heat that could be deleterious to survival. The cardiovascular system, and in particular, the cardiac output, therefore plays an important role in regulating body temperature during exercise and environmental heat stress. Haymes and Wells (1986) suggest that the
cardiovascular system of the child is not as well developed as the adult. Regardless of whether children are exercising in a neutral or a hot environment at a given metabolic rate, the cardiac output and stroke volume of children is lower than that of adults (Bar-Or et al., 1971; Drinkwater et al., 1977). This results in children being somewhat limited in their ability to bring internal heat to the surface of the body for dissipation to the environment. Bar-Or (1984) further adds that this lowered cardiac output in children presents a major problem during intense physical activity under hot environmental conditions when the demand for increased blood flow to the myocardium, skeletal muscles, and lungs may not be met. Not only will an insufficient supply of blood to the skin impede the convection of heat from the body core to the periphery, but an insufficient perfusion of the lungs and muscles may inhibit oxygen transport during vigorous physical activity. Apart from a lowered cardiac output and stroke volume attributing to the reduced capacity of the cardiovascular system of the child in comparison to the adult, Bar-Or (1983) also showed that the heart volume is smaller at the same oxygen uptake in children compared to young adults. By making this relative to body weight, Nobel (1986) found that the heart volume (ml.kg-1) of trained pre-pubertal children was smaller than trained young adults. The end result is a relatively smaller stroke volume and a greater heart rate at all metabolic rates, which are magnified under hot environmental conditions.
Sweat Rate: Sweating is an effective means by which the body loses heat, providing that the sweat secretions evaporate. As mentioned earlier, when the ambient temperature exceeds the skin temperature, the temperature gradient favours heat gain, and evaporation of sweat is the only mechanism by which the body can dissipate internal heat. Under such conditions, the other avenues of heat exchange (radiation, conduction, convection) will result in heat gain. When relative humidity is high or when there is insufficient air flow past the skin surface, evaporation is limited. When both air temperature and relative humidity are high, the body will soon reach its limit of heat tolerance.

Sweating rates in children are lower than in adults when performing similar physical tasks in hot environments under laboratory conditions (Drinkwater et al., 1977; Haymes et al., 1975; Inbar, 1978; Wagner et al., 1972) or in the field (Sohar and Shapira, 1965; Van Beaumont, 1965). In the past it was thought that this difference stemmed from a smaller number of active sweat glands. However, since the work of Kawahata (1960) and Huebner et al. (1966), it was shown that the absolute number of sweat glands become fairly constant by age two. Therefore, due to their smaller surface area, children should have a greater density of glands per unit surface area.
than adults. Further work by Inbar (1978) suggested that the lower sweat rate in children may be accounted for by a lower production of sweat per gland. Inbar (1978) found that although 8-10 year old children activated 56% more glands, their sweating rate per unit of surface area was 48% lower than in adults. Furthermore, the secretion per gland in the adults was nearly 2.5 times as high as it was in the children. The data from Kawahata (1960) and Huebner et al. (1966) also supported these findings.

Wagner (1972) compared the heat exchange of adult men and pre- and post-pubertal children while they walked on a treadmill at 5.6 km/hr for 40-90 minutes in 49°C heat. The results showed that more metabolic heat was produced in pre-pubertal (5.43 kcal·kg·min⁻¹) and post-pubertal (5.87 kcal·kg·min⁻¹) children. It was also shown that both these young age groups absorbed more heat by radiation and convection but they compensated by a greater evaporative rate and more storage than the adults. The children were not in thermal equilibrium and were continuously increasing their core (rectal) temperature over time as more heat was stored in their bodies. It was concluded that children have limited thermoregulatory abilities under these conditions because they have reached maximal sweat rate, whilst the adults achieved thermoequilibrium at a lower sweat rate.
Later results of Gullestad (1975) seem to be in conflict with the rest of the literature and the American Academy of Pediatrics (1982) which support a lower sweating rate in children, and hence a different thermal response during exercise between children and adults. Gullestad (1975) tested eleven year old boys at different metabolic heat loads with an ambient temperature of 22 °C and concluded that children regulate their body temperature during exercise in the same way as adults. He found that the boys' sweat rate was directly proportional to the heat production and that the regression coefficient between sweat rate and heat production were not significantly different when compared to adults. Gullestad’s findings are in question by later studies on the basis of the high body surface area to weight ratio found in children compared with adults. Davies (1981) states that the expectant result of children exercising in hot climatic conditions would be a greater proportion of the heat produced during work to be dissipated by convection and radiation with correspondingly less in evaporative sweat loss compared to adults.

Further evidence to support this lower sweat rate in children was shown by Drinkwater et al. (1977) who compared five pre-pubertal females and five college women walking on a treadmill at approximately 30% \( \dot{V}O_2 \) max for two fifty minute
periods in three environments (28 °C, 45% humidity; 35 °C, 65% humidity; and 48 °C, 10% humidity). Although direct comparisons of evaporative sweat rates between groups were not possible due to differences in absolute workload, Drinkwater et al. (1977) found that during exercise in 48 °C climatic conditions the only girl able to start the second fifty minute exercise period and the two women able to complete the 100 minutes of work were those that had the highest evaporative sweat rates within their groups during the first 50 minute work period.

Davies (1981) later showed that the thermal response of children are quantitatively different to adults. He found that after comparing children and adults exercising heavily (68% \( \dot{V}O_2 \) max), with an ambient temperature of 21 °C, the children dissipated approximately half their heat load by convection and radiation and half by evaporation of sweat, while the adults dissipated two thirds of their heat load by evaporation. The children had higher skin temperatures (+3 °C) and lower sweat rates than their adult controls. It was suggested that, due to the possible advantage of a higher body surface area to weight ratio, children are excellent convectors and radiators of heat and in consequence have a relatively poorly developed and/or insensitive sweat mechanism. At high temperatures, in particular air temperatures over 40 °C, the relatively larger
surface area of children is a disadvantage as they absorb heat faster by convection than adults.

The Thermoregulation System During Continuous and Intermittent Exercise

The National Health and Medical Research Council (1989) and the American Academy of Pediatrics (1982) have acknowledged the fact that the environment predisposes children to serious illness or injury, with high temperatures and humidity levels possibly leading to heat stroke and dehydration. Although it cannot be justified to restrict exercise in general because of this risk, the risks can certainly be minimized by providing guidelines which could govern participation under these climatic conditions. Although guidelines have been established, based on scientific research as mentioned above, most of these investigators, while studying temperature regulation in children, have monitored the subjects during continuous exercise of 30 minutes or more or during activities of similar work durations but with a non-active rest period in between. No information is available on the ability of children to sustain high intensity, short duration exercise in the heat. It has been hypothesized that the thermoregulatory system might respond differently to work in hot environments if the work were performed intermittently rather than continuously.
This hypothesis has been based on previous findings (Christensen et al., 1960) that the cardiovascular and respiratory responses to exercise differs considerably when the exercise is performed continuously or when the total work load is divided into alternating cycles of work and rest. Christensen et al. (1960) found that less work was able to be accomplished with continuous work as compared to intermittent exercise due to an increased cardiovascular and respiratory strain placed upon the subjects. This was evidenced by near maximal oxygen uptake values being achieved, higher heart rates, greater respiratory minute volumes, and a total core temperature increase of 2 °C observed during the continuous exercise compared to the intermittent protocol. It should be noted, however, that total work was not equated but rather a set speed of 20 km/hr was used. The subjects were not able to tolerate this high intensity work rate for the 20 minute duration that was able to be maintained in the intermittent protocol, due to the excessive lactic acid build up. It should not be overlooked, however, that the extremely short work periods in the intermittent protocol (ie. 5, 10 and 15 sec) may have been just as responsible for the differing physiological responses observed between the continuous and intermittent exercise bouts. This was supported by Astrand et al. (1960) who found that the length of the individual work period is most critical whereas the length of the rest pauses and total work output might be of secondary importance as far as the physiological
load is concerned. In order to accomplish the same amount of work in the same period of time, exercise during intermittent work must be performed at a higher, often supramaximal, metabolic rate. A proper ratio of work-rest time intervals, however, allows the subject to perform the work without excessive strain on either the circulatory or respiratory systems as shown by Christensen et al. (1960) and Astrand et al. (1960). The same may be true in the thermoregulatory system when exercise is performed intermittently in a hot environment.

The effect of performing work intermittently in the heat on the thermoregulatory system of an individual is not a new issue. Many researchers have investigated how alternating bouts of work/rest ratios will affect an individual in an industrial setting. More specifically, research in the past has focused on investigating the effect that hot environmental conditions have upon the industrial worker in an effort to help define thermal limits for everyday work. In comparing the practicalities of intermittent versus continuous work in the heat, Lind (1963) studied two fit male soldiers working for eight hours in three climates: (1) 29.4\text{db}, 23.9\text{wb °C}; (2) 36.7\text{db}, 25.6\text{wb °C}; and (3) 41.1\text{db}, 28.3\text{wb °C}. Results showed that when total work was equated the physiological cost of working continuously at a moderate rate or intermittently at a high rate, was similar, as was rectal temperature, pulse rate,
and weight loss in the first two climates. In the third climatic condition, Lind (1963) found that core temperature and pulse rate increased during the intermittent work as compared to the continuous work. He hypothesized that this may have been due to the fact that: (1) this climate was farther beyond the upper limit of the prescriptive zone for the higher rate of energy expenditure in the intermittent work than for the continuous work, and (2) the progressively slower rate of recovery was to be expected during the rest periods of intermittent work as the climatic stress increased.

Similar findings to the industry literature comparing intermittent and continuous work in the heat have been reported in relation to exercise. Nielsen (1968) compared the thermoregulatory responses of intermittent leg work on a bicycle ergometer (30 sec work/rest intervals) to that of continuous work. The same rate of metabolic energy production was maintained between the two types of work, with the workload during the intermittent exercise being double that found during the continuous exercise. Results showed a high correlation between sweat rate and total heat production in both continuous and intermittent exercise. It was also found that the increase in core temperature was approximately equal for the same metabolic rate in continuous and intermittent leg work. Nielsen (1968) further showed that the intermittent exercise average values (work+rest) of heart
rate and pulmonary ventilation was higher than the continuous exercise for the same metabolic energy production. These findings suggest that, although the respiratory and circulatory responses during intermittent and continuous exercise may differ, the thermoregulatory responses do not seem to be influenced by the type of exercise being performed (ie. intermittent versus continuous).

Ekblom et al. (1971) investigated the thermoregulatory responses during intermittent and continuous exercise at the same average metabolic rate. Three well-trained men were studied during moderately heavy (60% \( \dot{V}O_2 \) max) continuous exercise performed on a cycle ergometer for one hour and during intermittent cycling for one hour (30 sec work/30 sec rest). The results showed that although the total heat production was essentially the same in the continuous and intermittent exercise, a higher core temperature (0.35 °C above equilibrium) was observed during the intermittent work. This indicates that during intermittent exercise the level at which body temperature is regulated is related non-linearly to total work rate. These results showing a higher increase in body temperature and a reduced sweat rate indicates that a reduced efficiency in the thermoregulatory system existed during intermittent work. Ekblom et al. (1971) suggested that reflex circulatory adjustments at the onset of exercise or the non-linearity in the contribution of non-thermal inputs at
work rates above 100% of maximal oxygen uptake could account for the relative inefficiency of the thermoregulatory system. The results of Ekbom's et al. (1971) study also showed that average oxygen uptake and heart rates were similar during the continuous and intermittent work bouts.

**Sex Differences**

Thermoregulatory and Cardiovascular measures: Our knowledge of human heat tolerance and temperature regulation is based almost entirely on experiments with male subjects. In the past decade, however, interest in the possible sex differences in the thermoregulatory responses observed during exercise in the heat has increased, possibly due to the assumption that women are more susceptible to heat illness than men. The results of past studies (Dill et al., 1973; Morimoto et al., 1967; Wyndham et al., 1965) have suggested that women were less tolerant of exercise in hot environments when compared to their male counterparts. In these earlier studies the women were observed to have higher heart rates and rectal temperatures, and perceived to be under a greater thermoregulatory and cardiovascular strain in comparison to the male subjects. Because both heart rate and rectal temperature during exercise are proportional to the percent of maximal oxygen consumption (Saltin and Hermansen, 1966),
the women's higher heart rates and rectal temperatures in the early studies could have been due to their lower fitness levels. For example, past studies have compared young male army trainees with less-active army nurses, who were somewhat older and more obese. Since the most important physiological factor in regard to one's ability to tolerate heat, and particularly exercise in the heat, is cardiovascular efficiency, it is obvious that the army nurses were not nearly as cardiovascularly fit as the young men after training camp. It should be noted that because the women were not as fit as the men, they were probably exercising harder in relation to their capacity than the men, since they were assigned standardized work tasks. More recent studies that have assigned exercise tasks on the basis of percentage of individual maximal oxygen uptake and that had subjects who had similar cardiovascular efficiency indicated that women tolerated heat at least as well as the men (Paolone et al., 1977; Wells, 1977; Wells and Paolone, 1977). Several other recent studies who compared men and women with similar aerobic capacities have reported few differences between the sexes in response to heat stress (Avellini et al., 1980; Frye and Kamon, 1981; Horstman and Christensen, 1982; Shapiro et al., 1980; Wells, 1980). It is, therefore, now assumed that differences in the cardiovascular and thermoregulatory responses observed during exercise in the heat between men and women are a result of variations in the sample population of the male and female subjects chosen for studies, rather than an actual sexual differences.
Although it is apparent that cardiovascular fitness is more important than gender in heat tolerance, several observations about women exercising in the heat have been verified. One is that women do not generally sweat as much as men, even though they have as many sweat glands (Frye and Kamon, 1981; Hortsman and Christensen, 1982). It has been suggested that the sex hormones account for this difference because testosterone being anabolic in nature stimulates sweating while estrogen, being catabolic in nature, inhibits sweating (Kawahata, 1960). It should be noted, however, that this has not been satisfactorily tested.

*Anthropometric Measures:* Another sexual difference is the stature of women compared to that of men. Although the average woman is shorter, weighs less and has a smaller surface area than males, the surface area to weight ratio (BSA/wt) is larger. When the ambient temperature exceeds skin temperature (in general, approximately greater than 36 °C), heat will be gained from the environment through radiation and convection more rapidly in people with a larger BSA/wt ratio. When the ambient temperature is below skin temperature, as in a warm humid environment (not exceeding 36 °C), smaller people will lose heat to the environment through the skin (radiation plus convection plus evaporation)
more rapidly than larger people because of their larger BSA/wt ratio (Robinson, 1942; Shvartz et al. 1973). In dry climates where evaporation is the major avenue of heat loss, women are at a disadvantage because of their lower total body water. Because women generally weigh less and have a higher percent body fat than men, both the absolute and relative water content of women are less than in men. Therefore, if women sweat at the same rate, women will lose a higher percentage of their body water. As this relative dehydration increases in women there will be a reduction in blood volume, and therefore, a greater strain on the cardiovascular system of women compared to that of men (Senay, 1975).

Women are also disadvantaged due to their greater percent body fat than men. Since water has a higher specific heat than fat, body temperature will increase at a higher rate in women with a higher percent body fat than men, when working at the same metabolic rate per kg.

In hot humid environments, the fact that women have a larger BSA/wt ratio and sweat rate is not a limiting factor, women would be expected to perform as well, if not better, than men. Although men sweat more than women in humid climates (Avellini et al., 1980; Morimoto et al., 1967; Wyndham et al., 1965; Paolone et al., 1977), high humidity limits evaporation.
Research has shown that sweat rate was suppressed more in women than men after the first hour of exercise (Avellini et al., 1980). Avellini et al. (1980) thought that sweat gland suppression was related to skin wetness. It was also found that there was no significant difference between the sexes in the threshold for sweating (Avellini et al., 1980).

Women have lower heart rates and rectal temperatures than men when exercising in hot humid environments (Avellini et al., 1980; Shapiro et al., 1980; Paolone et al., 1977). However, when men and women are matched for BSA/wt ratios, there is no significant difference in rectal temperatures or heart rates between the sexes (Shapiro et al., 1980). The results suggest that women's advantages in hot humid environments are due to their larger BSA/wt ratios, which facilitate heat loss through radiation and convection, because metabolic heat production was similar to that of the men.

*Plasma Volume Changes due to Exercise:* The effects of heat and exercise on blood volume are determined mainly by changes in the forces between absorption and filtration acting along the capillary beds (Harrison, 1986). Prolonged exercise in the heat is noted to cause a reduction in blood volume through plasma volume changes as a consequence of fluid shifts in the body (Senay, 1985). Plasma volume changes are affected by
three factors: exercise intensity, posture and the state of hydration of the body (Senay, 1985).

When measuring plasma volume it is necessary to understand the make up of the body, in particular the fluid component of the body. Research has shown that total body water content of men in their third decade is usually taken as 60% of total body weight and 50% for women (Senay, 1985). When applying this to older or younger persons slight modifications may be necessary. The different percentage between men and women is a simple function of body fat content. Adipose tissue contains little water and since the fat content of an average female is between 25 and 30% total body weight, the proportion of lean body mass to total body weight, is lower in women. The lean body mass for all persons is said to be 73% water, with the distribution of total body water much the same in both men and women (Guyton et al., 1975; Moore et al., 1963). The majority of the total body water is contained within the intracellular compartments with about one-third making up the extracellular fluid. The extracellular fluid is then subdivided into plasma water and interstitial water. Approximately 3 kg of the extracellular water is contained within the vascular volume as plasma water in an average male subject, while for the average female, plasma water would be about 2.4 kg (Senay 1985).

Plasma volume changes in exercise appear to be dependent upon the different types of exercise undertaken (Wells et al.,
1987; Senay, 1985; Harrison, 1985). The discrepancy in the findings over plasma volume changes across various exercise modes may merely highlight the transient nature of body fluids and the effects of intersubject variability when exercising (Harrison, 1985; Wells et al., 1987). The transient shifts of fluids in and out of the vascular spaces influences hemodilution, the progressive gain of interstitial fluid and hemoconcentration which is the progressive loss of plasma water (Harrison, 1985). The primary factors inducing the change in plasma volume are increased capillary and hydrostatic pressure which occurs when exercise is initiated (Convertino, 1987; Hahn, 1988; Harrison, 1985). Hemoconcentration or hemodilution is predominantly affected by the severity of the thermal strain the body is placed under (Harrison, 1985).

It is thought that a rise in core temperature stimulates vasodilation resulting in hemoconcentration. Vasodilation increases total capillary perfusion and hydrostatic pressure within the cutaneous circulation (Harrison, 1985; Harrison, et al., 1983). Less severe thermal stress influences venodilation but not vasodilation and as such leads to a drop in hydrostatic pressure and thus hemodilution results (Harrison, 1985). These body fluid shifts within the body occur very rapidly, and plasma volume is usually stabilized after 10 minutes of activity (Convertino, 1987; Harrison, 1985). The body implements several protective mechanisms to avoid continued
loss of plasma volume. Vasoconstriction of inactive tissues as noted by Rowell (1974) reduces capillary hydrostatic pressure and potentially increasing the amount of plasma proteins entering the vascular spaces (Harrison, 1985; Harrison, 1986).

A reduction in plasma volume results in a reduction of blood volume and therefore an increased demand being placed on cardiac output (Hahn, 1988). As earlier reported prolonged exercise in the heat, increases the demand on cardiac output leading to the eventual compromise of the thermoregulatory mechanisms in order to meet the increased exercise metabolic demands of the body (Rowell, 1969). Demands placed on the cardiac output will hamper the ability of the body to dissipate heat and delivery of sufficient oxygen to the working muscles (Harrison, 1985).

As previously stated posture will affect plasma volume changes, thus different exercise activities are likely to influence specific responses to plasma volume. In general, exercise performed in a supine or seated position, and without any fluid replacement, influences hemoconcentration. Cycling invariably is accompanied by a decrease in plasma volume up to 8 to 15%. Such decreases in plasma volume have been found to be directly proportional to exercise intensity within the range of 40 to 90% of maximum oxygen uptake (Harrison, 1985). Such a reduction in plasma volume would, therefore,
hamper thermoregulation and exercise performance (Wells et al., 1987).

Two variables which are used to measure plasma volume changes are hematocrit (percentage of packed red blood cells) and hemoglobin. The use of hematocrit and hemoglobin as means to calculate plasma volume changes is dependent on several factors: (1) that the volume of red corpuscles is constant; (2) the red blood cell size is constant; and (3) the ratio of hematocrit and whole body hematocrit remains unchanged (Costill and Fink, 1974; Harrison, 1985). However, it is believed that if water is lost from the red blood cells due to exercise, that hematocrit measurement may in fact underestimate plasma volume changes. It is, therefore, suggested that the use of both hemoglobin and hematocrit should be used to obtain accurate estimations of changes in plasma volume (Harrison, 1985).

Although it is generally accepted that women are as tolerant of the heat as men, it is not known, however, whether these similar responses described for the exercising adult are also found between the male and female younger age groups. The literature would seem to suggest that there are similarities between the younger male and female as the thermoregulatory and cardiovascular responses of these two groups are usually considered together, rather than performing an analysis between the two sexes.
CHAPTER III

METHODS
METHODS

Subjects

Twelve females (15±0.79 yrs old) and eleven male (15±0.94 yrs old) adolescent subjects volunteered to participate in the study. Subjects were all trained field hockey players from the Illawarra Sports Academy. Prior to participation, subjects (or guardians of the subjects) completed an informed voluntary consent form (Appendix A) and a medical history questionnaire (Appendix B). The study was approved by the University of Wollongong Ethics Committee and adhered to the guidelines presented in the Statement on Human Experimentation produced by the National Health and Medical Research Council (Appendix C)

Experimental protocol

Anthropometry: One week prior to the first testing day anthropometric measurements were taken of variables which were likely to affect temperature regulation. The body mass of each subject (in bathing suit) was measured on a precision balance scale and recorded to the nearest 20 grams (gms). The height of each subject was measured on a stadiometer and recorded to the nearest 0.1 centimeter (cm). Body surface area was calculated by the Dubois method where surface area (m²) = 0.00718.Weight⁰.⁴²⁵.Height⁰.⁷²⁵ (Martin, 1984). Skinfold
thickness was measured on seven sites in the females (triceps, subscapular, suprailiac, umbilical, biceps, thigh, medial mid-calf) and on eight sites in the males (triceps, subscapular, suprailiac, umbilical, biceps, thigh, medial mid-calf, axillary) using Harpenden calipers (Telford et al., 1984).

**Maximal oxygen consumption:** All subjects performed a stepwise incremental test (Thoden et al., 1982) one week prior to the study in order to measure maximal oxygen consumption ($\dot{V}O_2$ max). Before the testing began, the subjects were familiarized with cycle ergometer exercise at a constant pedalling rate while breathing through the mouthpiece and the breathing valve used in the metabolic measurements. The $\dot{V}O_2$ max test, performed on a Monark cycle ergometer, consisted of a five minute warm-up at 30 Watts (W). The initial work load was then increased by 30 or 60 W (depending on heart rate), after which time each subsequent load was increased by 30 W every two minutes. Pedalling speed was constant at 60 rpm (Thoden et al., 1982). Verbal encouragement to attain maximal values was given to each subject. Attainment of $\dot{V}O_2$ max was based upon the following criteria: (1) a plateau or decrease of less than 150 ml-min$^{-1}$ in oxygen uptake, subsequent to an increase in workload; (2) the attainment of estimated maximum heart rate (220-age); and (3) a respiratory exchange ratio exceeding 1.0. From this volitional test oxygen consumption was then plotted against power output to determine the work rate at 50% $\dot{V}O_2$ max (the relative
intensity of the continuous test protocol) and at 30 and 70% \( \dot{V}O_2 \) max (the relative intensity of the intermittent test protocol) for each subject. This estimation was later confirmed by the measurement of \( \dot{V}O_2 \) at those workloads during the first 10 minutes of the exercise heat tolerance test.

All ventilatory measurements, taken every sixty seconds, were made by standard open circuit spirometry. Subjects wore noseclips and breathed through a Hans Rudolph low resistance, low deadspace valve (Model No. 2700). The volume of air inspired (VI) during measurement periods was measured by a turbine Ventilometer (Morgan Mark 2). All volumes were corrected to Standard Temperature Pressure Dry (STPD). Morgan carbon dioxide (infra-red Type 901 MK2) and oxygen (paramagnetic Model OA 500D) analyzers were used for the measurement of respiratory gases. Heart rate was recorded every minute from a Sports Tester PE3000.

Calibration of the gas analyzers, using certified gravimetric calibration gas provided by Commonwealth Industrial Gases (CIG), was conducted prior to each test. The Ventilometer was calibrated using a one litre syringe and the Monark Cycle Ergometer was calibrated with standard calibration weights.

Test Protocol: Each subject came to the laboratory for two trials, one week apart, and was tested at the same time of day. Prior instruction not to engage in any physical activity on the day of the test was given to all subjects. The protocols for
the testing days were identical with the exception of the exercise protocol. The first test consisted of a continuous cycle ergometer exercise for one hour at 50% \( \dot{VO}_2 \) max, while the second test consisted of an intermittent cycle ergometer exercise for one hour at 30 and 70% \( \dot{VO}_2 \) max. During both the intermittent and continuous exercise bouts the subjects cycled at 60 rpm. Total work performed during the two different exercise protocols was equated. Once the subjects reported to the laboratory (after at least a four hour fast), they consumed no food or beverage, with the exception of water, until the test was completed.

Each subject performed the two tests (on two separate occasions) in a hot humid environment: \((\text{Temperature}_{\text{dry bulb}}/\text{Temperature}_{\text{wet bulb}} = 31/27 \, ^\circ C; \text{relative humidity} = 73\%; \text{Wet Bulb Global Temperature} = 28.2 \, ^\circ C)\). This climate conformed to typical east coastal weather patterns of Australia (Bureau of Meteorology, 1988). A fan was used to generate a wind speed of 4 m.sec\(^{-1}\) which was confirmed by a wind speed hygrometer (Izuzu Aneometer). This wind speed encouraged the evaporation of sweat.

All subjects, upon entering the climate chamber, rested for a period of fifteen minutes prior to performing either the continuous or the intermittent cycle ergometer exercise. During the continuous exercise bout, pulmonary ventilation, oxygen uptake and carbon dioxide output were measured during the 4-5, 29-30 and the 59-60 minute by open circuit
spirometry. During the intermittent cycle ergometer exercise subjects cycled at 30% VO₂ max for the first five minutes, followed by 5 minutes of exercise at 70% VO₂ max. This protocol was repeated for the one hour duration of the cycle ergometer exercise test. During the intermittent exercise, pulmonary ventilation, oxygen uptake and carbon dioxide output were measured during the 4-5, 9-10, 29-30, 34-35, 54-55, and the 59-60 minute by open circuit spirometry. In both tests the volume of air inspired during the measurement periods was measured by a Morgan Ventilometer (Morgan Mark 2), with subjects breathing through a Hans Rudolph low resistance, respiratory valve. Expired air was collected in Ohmeda anti-static balloons, and oxygen and carbon dioxide concentrations were analyzed using a Morgan gas analysis system. Heart rate was monitored via the Sports Tester PE3000 and recorded every five minutes throughout both exercise protocols. Calibration of all the instruments was performed as mentioned previously. Subjects were dressed in bathings suits and wore running shoes throughout the entire test.

Thermoregulatory Protocol: After at least a four hour fast and one hour prior to the exercise heat tolerance test, all subjects drank approximately 500 ml of cold water to ensure that they were sufficiently hydrated. The subjects were then weighed on a precision balance scale (±20 gms) before entering the climate chamber and then again immediately following the exercise bout. Prior to entering the chamber, a Sports Tester
PE3000 and thermistors for measuring skin and core temperature were placed in position. The skin thermistors were placed on the outside of the middle upper arm, on the manubrium and mid thigh (Grucza, 1983) and secured with porous tape. All skin thermistors were then connected to a Yellow Springs Instrument (YSI) six channel telethermometer unit for recording temperature readings. The probes were calibrated prior to each testing session by immersing a certified mercury thermometer and the specified thermal recorder leads in a water bath. The water was continuously stirred to avoid differences in temperature readings throughout the bath. The temperatures recorded by the telethermometer unit were then compared with those of the certified thermometer at 30, 35 and 40 °C. An auditory thermistor, which was calibrated independently according to the same protocol mentioned above, was inserted into the external ear canal until the temperature rose above 36 °C or the subject indicated hearing a scratching sound (Benzinger, 1959). The ear canal was then sealed with wax. Skin and core temperature responses were recorded every five minutes prior to and during exercise. The auditory temperature when compared with the rectal temperature is a reliable measurement of core body temperature (Cork et al., 1983; Edwards et al., 1978).

**Hematological measurements:** Plasma volume changes throughout the exercise heat tolerance tests were estimated
by changes in hemoglobin and hematocrit concentrations (Dill and Costill, 1974). A microsample of blood from the finger was taken at rest and at the end of each exercise bout and analyzed using a Labco Hemoglobin Analyzer (Delphi Portable) and a Hematocrit centrifuge (Clements Australia).

**DATA ANALYSIS**

The physical characteristics of the adolescent subjects were analyzed using a one way analysis of variance (ANOVA). The mean values of age, height, weight, BSA, sum of skinfolds and maximum oxygen uptake between male and female subjects were compared.

The experimental data were statistically analyzed using both factorial and repeated measures two way analysis of variance. Energy expenditure and production, core and skin temperature, heart rate, sweat rate and blood plasma volume were compared across exercise (intermittent versus continuous) and sex (male versus female).

The 0.05 level of confidence was accepted as statistically significant for all statistical tests, except where otherwise mentioned. All values reported were means and standard deviations (x±SD).
CHAPTER IV

RESULTS
RESULTS

Physical Characteristics:

The physical characteristics selected to describe the subjects participating in the study are shown in Table 1a and 1b. No significant difference in age was observed between the adolescent males (15.09±0.94 years) and females (15.08±0.79 years) who took part in the study. The males (172.06±8.35 cm) were significantly (p<0.05) taller than the females (163.62±3.75 cm), with no significant differences observed between the two sexes in weight or BSA. The results also showed that the female subjects had a significantly (p<0.05) higher body fat content (106.65±25.93 mm) than the male subjects (66.76±18.63 mm), as illustrated by the sum of skinfolds. The mean maximal oxygen consumption levels of the sexes showed that the male adolescents had significantly (p<0.05) higher \( \dot{V}O_2 \) max values (53.45±4.87 ml·kg\(^{-1}\)·min\(^{-1}\)) than did the female adolescents (44.42±4.56 ml·kg\(^{-1}\)·min\(^{-1}\)).

Metabolism:

Energy expenditure: The mean workloads of the male and female adolescents, expressed as a percentage of maximum oxygen uptake, during continuous and intermittent exercise is
Table 1a

Physical characteristics of female subjects (n=12)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BSA (m²)</th>
<th>Sum of Skinfolds (mm)</th>
<th>VO₂ max (ml·kg⁻¹·min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>162.70</td>
<td>57.44</td>
<td>1.61</td>
<td>134.20</td>
<td>43.37</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>156.00</td>
<td>60.52</td>
<td>1.60</td>
<td>120.40</td>
<td>50.54</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>166.00</td>
<td>75.18</td>
<td>1.83</td>
<td>151.90</td>
<td>37.82</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>164.10</td>
<td>59.65</td>
<td>1.65</td>
<td>71.20</td>
<td>43.88</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>158.30</td>
<td>54.22</td>
<td>1.54</td>
<td>103.30</td>
<td>47.70</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>166.60</td>
<td>58.46</td>
<td>1.65</td>
<td>110.50</td>
<td>48.84</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>162.20</td>
<td>55.48</td>
<td>1.58</td>
<td>96.90</td>
<td>46.12</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>167.00</td>
<td>61.08</td>
<td>1.69</td>
<td>92.70</td>
<td>36.83</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
<td>162.30</td>
<td>62.96</td>
<td>1.67</td>
<td>134.40</td>
<td>46.45</td>
</tr>
<tr>
<td>10</td>
<td>14</td>
<td>169.70</td>
<td>55.64</td>
<td>1.64</td>
<td>80.00</td>
<td>39.36</td>
</tr>
<tr>
<td>11</td>
<td>14</td>
<td>164.00</td>
<td>52.60</td>
<td>1.56</td>
<td>70.60</td>
<td>49.22</td>
</tr>
<tr>
<td>12</td>
<td>14</td>
<td>164.50</td>
<td>58.16</td>
<td>1.63</td>
<td>113.70</td>
<td>49.22</td>
</tr>
</tbody>
</table>

| Mean    | 15.08 | 163.62 | 59.28 | 1.64 | 106.65 | 44.42 |
| S.D.    | 0.79  | 3.75   | 5.84  | 0.08 | 25.93  | 4.56  |
Table 1b

Physical characteristics of male subjects (n=11)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BSA (m²)</th>
<th>Sum of Skinfolds (mm)</th>
<th>VO₂ max (ml·kg⁻¹·min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>166.30</td>
<td>59.74</td>
<td>1.66</td>
<td>54.90</td>
<td>59.49</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>177.70</td>
<td>73.52</td>
<td>1.91</td>
<td>97.50</td>
<td>48.39</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>171.80</td>
<td>54.82</td>
<td>1.64</td>
<td>55.50</td>
<td>47.77</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>175.10</td>
<td>66.16</td>
<td>1.80</td>
<td>69.50</td>
<td>50.86</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>180.30</td>
<td>73.78</td>
<td>1.93</td>
<td>70.50</td>
<td>51.29</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>166.50</td>
<td>62.82</td>
<td>1.70</td>
<td>65.20</td>
<td>54.72</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>153.30</td>
<td>44.16</td>
<td>1.38</td>
<td>74.60</td>
<td>59.86</td>
</tr>
<tr>
<td>8</td>
<td>14</td>
<td>178.60</td>
<td>62.74</td>
<td>1.79</td>
<td>43.70</td>
<td>57.86</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>172.90</td>
<td>67.80</td>
<td>1.79</td>
<td>100.60</td>
<td>46.10</td>
</tr>
<tr>
<td>10</td>
<td>14</td>
<td>182.50</td>
<td>64.46</td>
<td>1.84</td>
<td>49.30</td>
<td>57.29</td>
</tr>
<tr>
<td>11</td>
<td>14</td>
<td>167.70</td>
<td>54.14</td>
<td>1.61</td>
<td>53.00</td>
<td>54.27</td>
</tr>
</tbody>
</table>

Mean 15.09 172.06 62.20 1.73 66.76 53.45
S.D. 0.94 8.35 8.75 0.16 18.63 4.87
shown in Figure 1. No significant difference was observed in the workload that the males (53.55±3.17%) and females (51.86±5.11%) cycled at during the continuous exercise bout (50% \( \dot{\text{VO}}_2 \) max). Similarly, there was no significant difference observed during the work phase of the intermittent exercise bout (70% \( \dot{\text{VO}}_2 \) max) between the males (73.57±4.13%) and females (76.43±6.19%). This non-significant difference was also observed during the active rest phase of the intermittent exercise (30% \( \dot{\text{VO}}_2 \) max) in the male (32.83±3.05%) and female (31.48±5.18%) adolescents.

When the workloads of the two exercise protocols were expressed in total energy expenditure (Figure 2), the results illustrated that the males expended significantly (\( p \leq 0.05 \)) more energy (232.31±19.42 kJ·m\(^{-2}\)·hr\(^{-1}\)) than the females (185.21±26.24 kJ·m\(^{-2}\)·hr\(^{-1}\)) during both continuous and intermittent exercise in a hot humid environment.

**Energy production:** The metabolic heat produced by the males and females during continuous exercise is shown in Figure 3. The results showed that the males produced significantly (\( p \leq 0.05 \)) more heat (1259.91±97.62 kJ·m\(^{-2}\)·hr\(^{-1}\)) than the females (1024.09±115.61 kJ·m\(^{-2}\)·hr\(^{-1}\)) during this exercise bout in the hot climatic conditions.

As illustrated in Figure 3 there was a significant difference (\( p \leq 0.05 \)) between the total heat production during intermittent exercise in a hot humid environment between the males
Figure 1. Mean workloads of males (n=11) and females (n=12) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment.
* $p < 0.05$ males vs females (continuous and intermittent)

**Figure 2.** Energy expenditure (kJ·m$^{-2}$·hr$^{-1}$) of male (n=11) and female (n=12) adolescents following 60 minutes of continuous and intermittent exercise in a hot humid environment.
* $p < 0.05$ male vs female (continuous)

+ $p < 0.05$ male vs female (intermittent)

Figure 3. Metabolic heat production (kJ·m$^{-2}$·hr$^{-1}$) of male ($n=11$) and female ($n=12$) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment.
(1256.06±106.98 kJ·m⁻²·hr⁻¹) and females (1082.85±107.98 kJ·m⁻²·hr⁻¹). During the active rest portion of intermittent exercise the males produced 30.6% (383.87±46.41 kJ·m⁻²·hr⁻¹) of their total metabolic heat compared to 28.5% (308.83±46.35 kJ·m⁻²·hr⁻¹) produced by the females. The work phase of the intermittent exercise produced the other 69.4% (872.19±69.87 kJ·m⁻²·hr⁻¹) and 71.5% (774.02±80.68 kJ·m⁻²·hr⁻¹) of metabolic heat, respectively (Figure 4).

The metabolic heat produced during intermittent exercise (active rest and work) versus continuous exercise is shown in Figure 3. No significant difference was observed between the two exercise protocols in either the male or female adolescents. There was, however, a significant difference (p<0.05) observed between the sexes during both continuous and intermittent exercise in the heat. The results illustrated that the males had a greater heat production (1259.91±97.62 kJ·m⁻²·hr⁻¹ in continuous exercise; 1256.06±106.98 kJ·m⁻²·hr⁻¹ in intermittent exercise) than the female adolescents (1024.09±115.61 kJ·m⁻²·hr⁻¹ in continuous exercise; 1082.85±107.98 kJ·m⁻²·hr⁻¹ in intermittent exercise).

Thermoregulatory Responses:

Core Temperature: The mean core temperature responses during continuous exercise of the males and females participating in the study are shown in Figure 5. The core
* p < 0.05 males vs females (intermittent and continuous)

Figure 4. Metabolic heat production (kJ·m⁻²·hr⁻¹) of male (n=11) and female (n=12) adolescents during 60 minutes of continuous and intermittent exercise in a hot humid environment.
Figure 5. Core temperature responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of continuous exercise in a hot humid environment.

* p < 0.05 males vs females (continuous)
temperature of the males increased significantly \( (p \leq 0.05) \) from rest \( (37.16 \pm 0.28 \, ^{\circ}C) \) in the hot humid environment to cessation of exercise \( (37.72 \pm 0.31 \, ^{\circ}C) \). The core temperature of the female adolescents during continuous work also increased significantly \( (p \leq 0.05) \) from rest \( (37.41 \pm 0.14 \, ^{\circ}C) \) to the end of continuous exercise \( (37.75 \pm 0.27 \, ^{\circ}C) \). A significant difference \( (p \leq 0.05) \) was also observed between the males the females at rest \( (37.16 \pm 0.28 \) and \( 37.41 \pm 0.14 \, ^{\circ}C \) respectively) and at five minutes into the exercise bout \( (37.17 \pm 0.29 \) and \( 37.43 \pm 0.14 \, ^{\circ}C \) respectively), with all other core temperature measurements showing no significant difference between the sexes.

The core temperature responses of the males and females during intermittent exercise are shown in Figure 6. The core temperature of the males increased significantly \( (p \leq 0.05) \) from rest in the hot humid environment \( (37.27 \pm 0.22 \, ^{\circ}C) \) to the end of intermittent exercise \( (37.77 \pm 0.32 \, ^{\circ}C) \). The core temperature of the female adolescents also increased significantly \( (p \leq 0.05) \) during rest prior to intermittent exercise \( (37.37 \pm 0.30 \, ^{\circ}C) \) until cessation of the work bout \( (37.74 \pm 0.26 \, ^{\circ}C) \). No significant difference was observed in the core temperature between the males and females during intermittent exercise in the hot humid environment.

The temperature responses of the male and female subjects observed during continuous and intermittent exercise are shown in Figures 7 and 8. No significant difference was observed in the core temperature of either males or females.
Figure 6. Core temperature responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of intermittent exercise in a hot humid environment.
Figure 7. Core temperature responses of male (n=11) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
Figure 8. Core temperature responses of female (n=12) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
performing a continuous cycling task versus an intermittent cycling task in the hot humid environment.

**Mean Skin Temperature:** The mean skin temperature responses of the males and females during continuous exercise in a hot wet environment are shown in Figure 9. The skin temperature of the males increased significantly ($p \leq 0.05$) from rest (34.11±0.68 °C) to cessation of exercise (35.26±0.38 °C). The skin temperature of the female adolescent subjects during continuous work also increased significantly ($p \leq 0.05$) from rest (34.55±0.57 °C) to the end of continuous exercise (35.12±0.37 °C). No significant difference was observed between the sexes either at rest or following the continuous exercise bout in the hot humid environment.

The male and female skin temperature responses to intermittent exercise in the hot humid climate are shown in Figure 10. There was a significant difference ($p \leq 0.05$) observed in the males from rest (34.42±0.72 °C) to the cessation of the intermittent cycling (35.03±0.25 °C). The females also demonstrated a significant increase in skin temperature from rest (34.39±0.53 °C) to the end of exercise (34.84±0.36 °C) while working intermittently in the heat.

The skin temperature responses of the male and female adolescents exercising continuously versus intermittently in the hot humid environment are shown in Figures 11 and 12. Significant differences ($p \leq 0.05$) in the males' mean
Figure 9. Skin temperature responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of continuous exercise in a hot humid environment.
Figure 10. Skin temperature responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of intermittent exercise in a hot humid environment.
* p < 0.05 continuous vs intermittent (males)

Figure 11. Skin temperature responses of male (n=11) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
Figure 12. Skin temperature responses of female (n=12) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
skin temperature responses were observed between continuous and intermittent exercise at the 45th and 55th minute, however, all other comparisons between the two exercise protocols showed no significant differences. No significant differences were observed in the females mean skin temperature responses between the continuous and intermittent exercise protocols in the hot humid environment. It should be noted, however, that in both sexes the trend was for the skin temperature during continuous exercise to be slightly higher than that observed during the intermittent exercise bouts.

**Cardiovascular Responses:**

*Heart Rate:* The heart rate responses at rest and during continuous exercise of the males and females participating in the study are shown in Figure 13. During continuous exercise the males' heart rate increased significantly \((p<0.05)\) from rest in the hot humid environment \((88.46\pm8.87 \text{ bpm})\) to cessation of exercise \((159.64\pm11.14 \text{ bpm})\). The heart rate of the female adolescents during continuous work also increased significantly \((p<0.05)\) from rest \((89.25\pm10.81 \text{ bpm})\) to the end of continuous exercise \((163.08\pm8.69 \text{ bpm})\). No significant difference was observed in heart rates between the sexes either at rest or following continuous exercise in the hot humid environment. When the heart rate responses were
Figure 13. Heart rate responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of continuous exercise in a hot humid environment.
averaged over the 60 minutes of continuous exercise, there was no significant difference observed between the male (146.62±18.46 bpm) and female (147.49±18.63 bpm) adolescents.

The heart rate responses of the males and females during intermittent exercise are shown in Figure 14. The heart rate response of the males increased significantly \((p<0.05)\) from rest in the hot climate \((88.91±9.56\) bpm) to the end of intermittent exercise \((183.27±10.14\) bpm). The heart rate of the female adolescents also increased significantly \((p<0.05)\) during intermittent exercise \((88.42±13.14\) bpm) to cessation of exercise \((188.83±7.23\) bpm). No significant difference was observed in the heart rates between the males and females during intermittent exercise in the hot humid environment. When the heart rate responses were averaged over the 60 minutes of intermittent exercise, there was no significant difference observed between the male \((148.62±32.1\) bpm) and female \((150.96±34.31\) bpm) adolescents.

The heart rate responses of the male and female subjects observed during continuous versus intermittent exercise are shown in Figures 15 and 16. No significant difference was observed in the resting heart rates prior to beginning either the continuous or intermittent work bouts in either the male (Figure 15) or the female (Figure 16) subjects. Throughout the exercise there was a significant difference \((p<0.05)\) observed
Figure 14. Heart rate responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of intermittent exercise in a hot humid environment.
Figure 15. Heart rate responses of male (n=11) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
Figure 16. Heart rate responses of female (n=12) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
in the heart rate responses of the two sexes between continuous and intermittent exercise. However, when the heart rates of the two sexes were averaged over the 60 minutes of exercise there was no significant difference observed between the continuous or intermittent exercise in either the male (146.62±18.46 bpm during continuous; 148.62±32.1 bpm during intermittent) or female (147.49±18.63 bpm during continuous; 150.96±34.31 bpm during intermittent) adolescents. Following cessation of continuous exercise the heart rate response of the males (159.64±11.14 bpm) was significantly (p≤0.05) lower than the heart rate following cessation of intermittent exercise (183.23±10.14 bpm). The females' heart rate response following cessation of continuous exercise (163.08±8.69 bpm) was also significantly (p≤0.05) lower than the heart rate following cessation of intermittent exercise (188.83±7.23 bpm).

Evaporation:

As illustrated in Figure 17, the mean sweat rate was significantly (p≤0.05) higher in males than females under both the continuous (410.42±86.60 g·m⁻²·hr⁻¹ in males; 286.18±41.69 g·m⁻²·hr⁻¹ in females) and intermittent (459.51±123.66 g·m⁻²·hr⁻¹ in males; 330.80±101.23 g·m⁻²·hr⁻¹ in females) exercise conditions. A significant difference (p≤0.05) in the sweat rate was also observed between the
+ p < 0.05  male vs female (continuous)

x p < 0.05  male vs female (intermittent)

* p < 0.05 Continuous vs intermittent (female)

Figure 17. Sweat rate (g·m⁻²·hr⁻¹) responses of male (n=11) and female (n=12) adolescents at rest and during 60 minutes of continuous and intermittent exercise in a hot humid environment.
continuous (286.18±41.69 g·m⁻²·hr⁻¹) and intermittent (330.80±101.23 g·m⁻²·hr⁻¹) exercise in females. Although there was no significant difference found between the two exercise protocols in the male subjects the sweat rate during the intermittent exercise bout (410.42±86.60 g·m⁻²·hr⁻¹) was higher than continuous exercise (459.51±123.66 g·m⁻²·hr⁻¹).

Plasma Volume:

Figure 18 illustrates the percent change in plasma volume in both sexes following the two exercise protocols. There was no significant difference observed between males and females exercising continuously or intermittently. There was, however, a significant difference (p≤0.10) observed in between the continuous and intermittent exercise protocols both sexes (0.92±8.20 and -7.01±10.81, respectively in males; -0.25±9.95 and -6.95±6.53, respectively in females).
* $p < 0.10$ intermittent vs. continuous in both sexes

**Figure 18.** Percent change in plasma volume of males ($n=11$) and females ($n=12$) after 60 minutes of continuous and intermittent exercise in a hot humid environment.
CHAPTER V

DISCUSSION
DISCUSSION

The present study has shown that there are several significant thermoregulatory and cardiovascular changes that occur to male and female adolescents when exercising in a hot humid environment as suggested by the National Health and Medical Research Council (1989). The present data have also highlighted differences in the thermoregulatory responses when subjects perform continuous versus intermittent exercise.

The age of the male and female adolescent subjects in this study fall within the range of that particular group which the National Health and Medical Research Council (1989) suggests may be at risk to serious illness or injury when predisposed to a hot environment during sport. The anthropometric data of the males and females in the present study support earlier cross sectional data of that individual age group (Tanner, 1978). The height and body mass of the male subjects were in 75th percentile, while the height and body mass of the female subjects fell within the 60th and 70th percentile, respectively (Tanner, 1978). The sum of skinfolds of both males (66.76±18.63 mm) and females (106.65±25.93 mm) indicate that they are of "normal" body composition, although the females had a significantly (37%) higher body fat content than did the males. The mean maximal oxygen consumption of the
males and females reflects the high fitness levels of the subjects (Haywood, 1986) and confirms that the subjects were trained sports persons. The male maximum oxygen consumption values were significantly higher than the females, which supports the literature reported on this age group (Shvartz and Reibold, 1988).

Comparisons of previous findings on the thermoregulatory and cardiovascular responses during intermittent and continuous work with the present study are complicated by the variability of exercise tasks and differences in experimental design. In the present study, the intermittent exercise consisted of work and active rest periods, whereas in earlier studies the exercise protocols consisted of work and non-active rest phases (Drinkwater, 1976; Ekblom et al., 1971; Nielsen, 1968 and Lind, 1963). Since research has shown that an active rest phase of approximately 30% of maximal oxygen uptake hastens the removal of accumulated lactic acid from the blood, the earlier protocols using non-active rest periods may not represent in full the typical responses one would expect in a adolescent competitive sporting situation. Furthermore, it should be noted that comparisons across the literature are also difficult due to the differences in environmental conditions used in the various studies. Earlier research has concentrated on neutral ambient conditions (Christensen et al., 1960) or on neutral dry climates (Ekblom et al., 1971) in comparison to the present study which incorporated a hot,
humid environment, similar to that experienced on the Eastern seaboard of Australia (Bureau of Meteorology, 1988)

In the present study, since the intensity levels during the continuous and intermittent work and active rest periods were different, it is assumed that the neuromuscular conditions in these three exercise situations at the same metabolic energy production (oxygen uptake) would also be very different (Nielsen, 1968). During the work phase of intermittent exercise the work load was 40.74% (males) and 44.95% (females) higher than that observed during the active rest phase and 20.02% (males) and 24.57% (females) higher than that observed during continuous work. It therefore, may be suggested that the mechanical tensions produced in the muscles, and the traffic of afferent and efferent nerve impulses in the work phase must have been much higher as compared to continuous work and the active rest phase of the intermittent exercise (Nielsen 1968). Furthermore, the lactic acid accumulation would be expected to be greater at the higher intensity level (ie. 70% $\dot{V}O_2$ max) than during the continuous exercise at 50% $\dot{V}O_2$ max or during the active rest phase at 30% $\dot{V}O_2$ max. In spite of these different exercise conditions, however, the increase in core temperature in the present study was almost equal for the same metabolic rate in both the continuous and intermittent exercise protocols (Figure 7 and 8). Nielsen (1968) observed similar core temperature responses during a continuous exercise protocol.
of 60 minutes versus an intermittent type exercise of 30 sec work/30 sec rest for 60 minutes. It, therefore, appears that the thermoregulatory responses observed during exercise do not seem to be influenced by the neuromuscular events occurring during the exercise.

Although the present study, along with earlier research (Nielsen 1968), found no significant difference in core temperature response between continuous and intermittent exercise, Ekblom et al., (1971) found when he compared these two exercise protocols there was a 0.35 °C increase in core temperature during intermittent exercise. Ekblom et al. (1971) stated that it was not necessary to postulate the existence of a mechanism that responds to proprioceptor and/or mechanoreceptor afferent stimuli of increased intensity that acts directly in controlling the equilibrium level of core temperature hypothesized by Nielsen (1968). Ekblom et al. (1971) suggested that this is because the average afferent stimulation was the same during intermittent and continuous exercise since during intermittent exercise, although the work load was approximately double, the work time was half due to the equal work-rest cycles. In the present study, since total work and exercise time was equated between the two exercise protocols, it may also be assumed that the percentage of afferent stimulation from the active rest and the work cycles during intermittent exercise would equate favorably with the continuous afferent stimulation.
Ekblom et al. (1971) postulated that the increase in core temperature during intermittent exercise was due to the reduction in evaporative heat loss. This was not the case in the present study where there was a significant increase in sweat rate during intermittent exercise in females and a non significant increase in males. The greater sweat rate and enhanced evaporation during intermittent exercise in the present study led to a decrease in skin temperature, which would be expected since evaporation is an effective means by which to lose body heat (Haymes and Wells, 1986). It should be noted, however that the decrease in skin temperature did not reach significant levels within the females and only in two recordings in the males. It may be that during continuous exercise the work intensity in the hot humid environment was severe enough that even with the fan air (4 m·sec⁻¹) the body became saturated with moisture decreasing the ability of the body to effectively evaporate the excess sweat. This appears to be the case particularly within the male adolescents who showed signs of a fluctuating skin temperature from the 35th minute to cessation of exercise. This fluctuation in skin temperature led to a significant difference at the 45th and 55th minute. It would seem that during the active rest phase of the intermittent exercise skin temperature decreases, possibly as a result of a decrease in metabolic energy. The moisture on the skin is, therefore, given time to evaporate allowing an increase in sweat production and a decrease in skin temperature. The differences in sweat rate and core
temperature reported in the literature (Ekblom et al., 1971; Nielsen, 1968) may also be the result of different intermittent protocols used in these studies. Both Ekblom et al. (1971) and Nielsen (1968) used 30 second intervals of work/rest. It is possible that the 30 second rest time was not long enough for the skin to gain the reduced metabolic heat benefit, and thus become less saturated. This decreased skin temperature response, however, was only observed in the male subjects. It should be noted that, although the skin temperature responses of the female subjects did not reach significance levels during continuous and intermittent exercise, there was a trend showing slightly reduced skin temperature in the adolescent females during intermittent exercise. This may be due to the reduced sweating capacity of females (Frye & Kamon, 1981; Hortsman & Christensen, 1982).

Research has shown that peripheral vasoconstriction occurs at the beginning of relatively heavy exercise (Bishop et al. 1957, Christensen et al. 1942). This could impede heat dissipation, thus causing a rise in core temperature as illustrated by Ekblom et al. (1971). In the present study since the work phase only demanded 70% of maximal oxygen uptake, in comparison to the 115% of maximal oxygen uptake demanded in the study of Ekblom et al. (1971), the peripheral vasoconstriction at the onset of exercise in the present study may not have been as severe as that reported by Ekblom et al. (1971). This reduced peripheral vasoconstriction would
increase heat dissipation to the periphery of the body surface allowing the body to dissipate internal heat rather than having to store any increase in metabolic heat. This would, therefore, explain the differences observed in core temperature between the Ekblom et al. (1971) and the present study. Furthermore, the use of an active rest period (30% max $\dot{V}O_2$) in the present study, which would help with hastening the removal of accumulated lactic acid from the blood (Belcastro 1975), could also account for the differences in core temperature observed between the present study and in the findings of Ekblom et al. (1971). The increased time of the work and rest components (5 min/5 min) used in the present study versus the 30 seconds work phase, followed by a non-active rest phase of 30 seconds by Ekblom et al. (1971), could further explain the core temperature differences observed between the studies. In other words, any build up of metabolic heat during the work period may not have been registered by an increase in core temperature but rather was dissipated during the active rest phase via peripheral vasodilation. This would, therefore, stimulate the sweat mechanism and explain the increase in sweat rate observed during intermittent work as well as the decrease in skin temperature during the active rest phase in the present study. During the active rest period it is assumed that vasodilation has occurred thus allowing the blood to freely flow to the peripheral blood vessels. This in turn allows the heat to be dispersed through the increased sweating response which cools the skin. This may be evident in the
present study where skin temperatures decreased in the latter part of the active rest phase during intermittent exercise. The increased sweat rate responses observed during intermittent exercise in the present study could also be the result of an increased metabolic heat production during the work phase of intermittent exercise. This may cause the warmer blood to be shunted to the periphery resulting in an increased skin temperature and possibly stimulate an increase in the sweat mechanism.

In the present study, since total heat production was essentially the same between continuous and intermittent exercise, but sweat rate higher during the intermittent exercise bout, it is possible that during intermittent work the level at which body temperature is regulated is non-linearly related to total work rate. Exercise without the necessary thermoregulatory adjustments to dissipate heat would cause large increases in body temperature and possibly other factors. The thermoregulatory adjustment that was observed during the intermittent exercise in the present study was an increased sweat rate. Although this is an important avenue for heat dissipation, there is, however, an increased danger of dehydration unless fluid intake is increased. This is particularly a concern when dealing with this specific age group since research has shown that this target group do not instinctively drink enough fluid to replenish what is lost during prolonged exercise and, therefore, they are especially
prone to dehydration (American Academy of Pediatrics, 1982). This is particularly concerning as mild dehydration, equivalent to as little as 2% of body weight can reduce cardiovascular capacity, while dehydration in excess of 5% of body weight can precipitate physical collapse and heat stroke (Astrand and Saltin, 1964; Saltin, 1964).

Although the results from the present study suggest a non-linearity between body temperature regulation and total heat production during continuous and intermittent exercise, earlier studies found that sweat rate held the same correlation to total heat production for both the intermittent and continuous exercise protocols (Nielsen, 1968; Nielsen and Nielsen, 1965; and Nielsen, 1966). This difference may be due to the varying protocols and environmental conditions used in the different studies. The exercise and active rest periods in the present study were longer in duration and conducted under hot, humid environmental conditions whereas the earlier studies (Nielsen, 1968; Nielsen and Nielsen, 1965; and Nielsen, 1966) were performed in a cooler climate and incorporated much shorter work and rest periods.

In the present study the addition of an environmental heat load to the metabolic requirements of prolonged exercise increases the total heat load on the body. When this load becomes severe, apart from the thermoregulatory responses which occur, marked alterations in the cardiovascular responses also occur in an attempt to balance heat gain and heat loss (Rowell,
The cardiovascular responses observed in the present study concur with earlier findings which showed that moderate to heavy exercise in hot environments causes marked elevation in heart rates (Rowell, 1974). The increase in heart rates observed during both exercise protocols in the present study illustrated that, regardless of whether the exercise was continuous or intermittent in nature, there was a cardiovascular strain imposed upon the adolescent male and female subjects. It is interesting to note, however, that when the heart rate responses were averaged throughout both exercise protocols, the cardiovascular strain observed during intermittent exercise (active rest+work) was similar to that observed during the continuous exercise bout. This suggests that the cardiovascular strain of performing exercise at the same absolute work rate in a hot humid environment is independent of whether this exercise is performed in a continuous or intermittent manner. Since the intermittent work obviously yielded periods of greater physiological strain than those observed during continuous exercise, these were offset by the lower strain exhibited during the intervening active-rest periods. This could, therefore, account for the similar cardiovascular strain observed between the two exercise protocols.

In comparing the cardiovascular and thermoregulatory responses of adolescent males and females, working at the
same percent of VO$_2$ max, the present study showed that there was no significant difference between the heart rate, core temperature, or skin temperature responses of the males and females performing either continuous or intermittent exercise in a hot humid environment. The literature suggests that women would be expected to perform as well, if not better, than men in these environmental conditions because they have a larger BSA/wt ratio and sweat rate is not a limiting factor (Haymes, 1984). Although Avellini et al. (1980), Shapiro et al. (1980) and Paolone et al. (1978) found that women did have lower heart rates and core temperatures than men when exercising in hot, humid environments this was most probably due to the difference in BSA/wt ratio of the males and females used in these studies. Shapiro et al. (1980) found that when the men and women were matched for BSA/wt ratio no significant differences existed in core temperature or heart rates between the sexes. Results from the present study support this finding that cardiovascular and thermoregulatory response, observed during exercise in hot humid condition, are similar between the two sexes, when male and female adolescent subjects are matched in their BSA/wt ratios.

Sweat rate and metabolic heat production were the two areas where the male and female adolescents showed significant differences. The increased sweat rate of the males in the present study is supported by the findings of Avellini et al. (1980), Shapiro et al. (1980), and Weinman et al. (1967).
Wyndham et al. (1965) refers to the male as a "wasteful, prolific sweater," while he describes the female as able to adjust her "sweat rate better to the required heat loss". This was reflected in the present study where no significant differences were observed in the core and skin temperatures between the sexes in the two exercise protocols. The males, however, showed a significant increase in sweat rate. This may be due, in part, to the higher oxygen uptake of the males and, therefore, a higher work load.

The difference in heat production between the male and female adolescents may be due to the higher oxygen uptake values observed in the males even though both sexes were of a high fitness standard for their age group (Haywood, 1986).

Aside from the increased sweat rate observed between the continuous and intermittent exercise there was also a significant difference \( p \leq 0.10 \) in the percent change blood plasma volume. This may be due to the fact that the work in the present study was performed on a cycle ergometer which may induce hemoconcentration (Harrison, 1985; Edwards et al. 1983; Greenleaf et al. 1979), although this is not always the case (Novosadova, 1977). In the present study only the females demonstrated hemoconcentration during the continuous exercise, with the males showing a slight hemodilution. In the intermittent exercise both male and female subjects demonstrated hemoconcentration. Research has shown that generally the magnitude of cycling induced
hemoconcentration is directly proportional to the intensity of exercise (Beaumont et al. 1981, Nadel et al. 1979). It should be noted that in the present study there was a difference in the exercise intensities between continuous (50% \( \dot{V}O_2 \) max) and intermittent (30 and 70% \( \dot{V}O_2 \) max) work. When total work output was equated, however, the results showed that both continuous and intermittent exercise required equal energy expenditure and produced almost identical metabolic heat production. Therefore, it may be that the difference in percent change blood plasma volume between the continuous and intermittent exercise was not due to the form of exercise utilized (cycle ergometer), but the type of exercise being performed. It may be that hemoconcentration occurred due to the blood sample being taken immediately after the high intensity workload of 70% \( \dot{V}O_2 \) max. It remains to be seen, however, whether a 20% increase in work load would cause such an increase in hemoconcentration given that the blood sample taken during continuous exercise was also taken after 60 minutes of cycling at 50% \( \dot{V}O_2 \) max and that during the intermittent exercise there were the active rest phases to help alleviate the stress and any build up of hemoconcentration. It is, therefore, concluded that hemoconcentration, possibly due to higher intravascular, intramuscular and blood pressures, during intermittent exercise further demonstrates the extra strain caused by the intermittent exercise compared to the continuous exercise in the present study.
The current findings may be of practical importance in the prevention of heat illness in male and female adolescents. Due to the paucity of data available on adolescents exercising in the heat, the present study adds to the body of knowledge regarding the thermoregulatory and cardiovascular responses observed between these younger age groups. Furthermore, the findings provide additional information governing the participation of adolescents in continuous versus intermittent exercise. Results showed that male and female adolescents respond in a similar physiological manner to the stresses of a hot humid environment. The present study also demonstrated that male and female adolescents when exercising intermittently in a hot humid environment were placed under a greater thermoregulatory strain than when exercising continuously in the same environment. It may, therefore, be necessary to place a greater emphasis on fluid replacement when male and female adolescents are participating in a sport of an intermittent nature.
CHAPTER VI

REFERENCES
REFERENCES


Noble, B.J. (1986). *Physiology of Exercise and Sport*. Mosby College Publishers, USA.


APPENDIX A

INFORMED VOLUNTARY CONSENT
INFORMED CONSENT FOR VOLUNTARY PARTICIPATION
IN
HEAT STRESS STUDY

1. **Explanation of the Exercise Test**

   A. You will first perform an exercise test on a bicycle. The exercise intensity will begin at a level you can easily accomplish and will be advanced in stages, depending on your fitness level. We may stop the test at any time because of signs of fatigue or you may stop when you wish because of personal feeling of fatigue or discomfort.

   B. You will then perform two exercise tests on a bicycle ergometer in a hot-wet environment on two separate occasions. One test will involve a continuous cycle at 50% of your maximum capacity for a duration of 60 minutes. The other test will involve an intermittent cycle ride at 70% of your maximum capacity, interspersed with active recovery periods at approximately 30% of your maximum capacity. During the tests we will monitor your body temperature through the use of three skin thermisters taped on your skin and by a tiny thermister placed in the external ear canal. No discomfort will be felt. Heart and respiratory rate will be monitored throughout the test. We will also take a small finger tip sample of blood before and immediately following the test.

2. **Risks and Discomforts**

   While it is highly unlikely that you will be injured or taken ill during a test or training session, laboratory personnel are trained in emergency procedures. Should symptoms of heat illness such as rapid pulse (>90% HRmax), high body temperature (>39.0°C), dizziness, headache or nausea be observed or reported by yourself, the test will be stopped.
3. **Benefits to be Expected**
With your help in participating in this study, the results from the test will be used to prevent heat illness in people of your age group.

4. **Inquiries**
Any questions about the procedures used in the test are encouraged. If you have any doubts or questions, please ask us for further explanations.

5. **Freedom of Consent**
Your permission to partake in this project is voluntary. You are free to deny consent if you so desire.

I have read this form and I understand the test procedures that I will perform. I consent to participate in this project.

_____________________________________________________________________

Signature of Subject
(or guardian if subject is less than 16 yrs of age)

_____________________________________________________________________

Witness Date
APPENDIX B

MEDICAL HISTORY QUESTIONNAIRE
MEDICAL HISTORY QUESTIONNAIRE

SURNAME__________________________
GIVEN NAMES__________________________
DATE OF BIRTH__________________________
SEX: M/F
ADDRESS________________________________

HOME PHONE NO____________ WORK PHONE NO____________
HEIGHT________cm. WEIGHT________kg.

1. When was the last time you had a physical examination?

2. If you are allergic to any medication, food or other substances, please name them.

3. If you have been told that you have any chronic or serious illness, please list them.

4. Have you been hospitalized in the last three years? Please give details.

5. During the last twelve months:
   a) Has a physician prescribed any form of medication for you? Y/N
   b) Has your weight fluctuated more than a few kilos? Y/N
   c) Did you attempt to bring about this weight change through diet and/or exercise? Y/N
   d) Have you experienced any faintness, lightheadedness, blackouts? Y/N
   e) Have you occasionally had trouble sleeping? Y/N
   f) Have you had any severe headaches? Y/N
g) Have you experienced unusual heartbeats such as skipped beats or palpitations? Y/N

h) Have you experienced periods in which you heart felt as though it were racing for no apparent reason? Y/N

6. At present:
   a) Do you experience shortness of breath or loss of breath while walking? Y/N

   b) Do you experience sudden tingling, numbness, or loss of feeling in your arms, hands, legs, feet or face? Y/N

   c) Do you experience swelling of your feet and ankles? Y/N

   d) Do you get pains or cramps in your legs? Y/N

   e) Do you experience any pain or discomfort in your chest? Y/N

   f) Do you experience any pressure or heaviness in your chest? Y/N

7. Have you ever been told that your blood pressure was abnormal? Y/N

8. Have you ever been told that your serum cholesterol or triglyceride level was high? Y/N

9. Do you have diabetes? Y/N
   If yes, how is it controlled:
   dietary means ___ insulin injection ___
   oral medication ___ unconcontrolled ___

10. How often would you characterize your stress level as being high?
    occasionally___ frequently___ constantly___
11. Have you ever been told that you have any of the following illnesses:

heart disease____  heart block____  aneurysm____  
rheumatic heart____  heart murmur____  angina____

12. Has any member of your immediate family been treated or suspected to have had any of the following conditions? Please identify their relationship to you (father, mother, etc.):

diabetes____________________
heart disease________________
stroke_______________________
high blood pressure_____________

___________________________  ______________________
Signature                                      Date
APPENDIX C

NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL
The collection of data from planned experimentation on human beings is necessary for the improvement of human health. Experiments range from those undertaken as a part of patient care to those undertaken either on patients or on healthy subjects for the purpose of contributing to knowledge, and include investigations on human behaviour. Investigators have ethical and legal responsibilities toward their subjects and should therefore observe the following principles:

(1) The research must conform to generally accepted moral and scientific principles. To this end institutions in which human experimentation is undertaken should have a committee concerned with ethical aspects and all projects involving human experimentation should be submitted for approval by such a committee.

(2) Protocols of proposed projects should contain a statement by the investigator of the ethical considerations involved.

(3) The investigator after careful consideration and appropriate consultation must be satisfied that the possible advantage to be gained from the work justifies any discomfort or risks involved.

(4) The research protocol should demonstrate knowledge of the relevant literature and wherever possible be based on prior laboratory and animal experiments.

(5) In the conduct of research, the investigator must at all times respect the personality, rights, wishes, beliefs, consent and freedom of the individual subject.

(6) Research should be conducted only by suitably qualified persons with appropriate competence, having facilities for the proper conduct of the work; clinical research requires not only clinical competence but also facilities for dealing with any contingencies that may arise.
(7) New therapeutic or experimental procedures which are at the stage of early evaluation and which may have long-term effects should not be undertaken unless appropriate provision has been made for long-term care, observation and maintenance of records.

(8) Before research is undertaken the free consent of the subject should be obtained. To this end the investigator is responsible for providing the subject at his or her level of comprehension with sufficient information about the purpose, methods, demands, risks, inconvenience and discomforts of the study. Consent should be obtained in writing unless there are good reasons to the contrary. If consent is not obtained in writing, the circumstances under which it is obtained should be recorded.

(9) The subject must be free at any time to withdraw consent to further participate.

(10) Special care must be taken in relation to consent and to safeguarding individual rights and welfare where the research involves children, the mentally ill and those in dependant relationships or comparable situations.

(11) The investigator must stop or modify the research program or experiment if it becomes apparent during the course of it that continuation may be harmful.

(12) Subject to maintenance of confidentiality in respect of individual patients, all members of research groups should be fully informed about projects on which they are working.

(13) Volunteers may be paid for inconvenience and time spent, but such payment should not be so large as to be an inducement to participate.