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THE EFFECTS OF HAND COOLING DURING
STRENUOUS EXERCISE ON METABOLIC
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THE EFFECTS OF HAND COOLING DURING STRENUOUS EXERCISE ON METABOLIC AND CARDIORESPIRATORY FUNCTION

By

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ABSTRACT

THE EFFECTS OF HAND COOLING DURING STRENUOUS EXERCISE ON METABOLIC AND CARDIORESPIRATORY FUNCTION

By

Jaci Lynn VanHeest

Cardiorespiratory and metabolic responses to hand cooling were investigated in nine male trained endurance runners. Subjects were exercised twice on a treadmill, each time for thirty minutes at 80-85% of maximal oxygen uptake and carrying room temperature hand held weights. At minutes ten and twenty of each run the room temperature weights were exchanged for either a second pair of room temperature weights or a set of cold (-1 - 2 degrees celcius) weights for two minutes. The results indicated that hand cooling had a significant ($p \leq .05$) effect on heart rate and respiratory exchange ratio but did not effect oxygen uptake, respiration rate, ventilatory equivalents, or blood lactate concentration. These data suggest that repeated utilization of ice packs during strenuous exercise may have negative effects on heart rate and respiratory exchange ratio. However, the lack of significant difference in oxygen uptake and ventilatory equivalent of oxygen suggest that a single bout of cold application has relatively nominal effects on overall performance.

This thesis is respectfully dedicated to my parents, Rev. and Mrs. Jack VanHeest, whose prayers and encouragement has aided in developing my eagerness to learn and whose sacrifices have enabled me to continue my education.

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CHAPTER I

INTRODUCTION

The risk of heat injury is a serious problem for distance runners. In an attempt to gain a more complete understanding of this problem, researchers have investigated thermal regulation from both a mechanistic and performance perspective. Studies involving heat acclimation, water ingestion, and hydration/dehydration are all prevalent in the current literature (13,32,34). However, one of the areas in thermoregulatory research which has been somewhat overlooked is the interaction between hand cooling and the body's response to an increased metabolic demand. With the recent availability of ice cubes at runner's aid stations to assist in providing relief from the heat and minimizing the risk of heat injury, the need to obtain a more complete understanding of this interaction is essential. The performance benefits of such practices are unknown and the literature related to cardiorespiratory and metabolic responses to external hand cooling techniques presents opposing viewpoints. In addition, the possibility that individuals predisposed to cardiovascular disease may experience myocardial hypoxia and angina pectoris when exercise and hand cooling are combined (11) creates a further need for investigations in this area, particularly as it relates to the increased participation of individuals in running road races in the heat. It was therefore, the purpose of this study to evaluate selected cardiorespiratory and metabolic effects of hand cooling during strenuous exercise.

Need for the Study

Holding ice cubes in the hand, has increased in the past several years as a possible means of providing relief from the heat during running events. Currently there exists few studies examining the interaction between hand cooling techniques of this nature and overall thermal regulation and that which does exist is controversial. The limited information regarding the use of hand cooling and its implications for exercise performance as well as the possible negative cardiovascular side effects associated with the use of cold demonstrate a need for this study. Cooling of the body alone or in combination with exercise has been shown to affect both cardiorespiratory and metabolic variables.

Research studies have shown that heart rate may increase (15,26,33), decrease (6,24,28,36,37), or show no change (17) during facial cooling. Mean arterial blood pressure may remain unchanged (17) or increase (33). Increases in either the systolic or diastolic components of blood pressure may also occur (15,26). In addition, angina pectoris in cardiac patients has also been demonstrated in conjunction with facial cooling (16,24,33,37,39). Inconsistency exists among the findings of many researchers.

Immersion of the hand or foot in water has been studied in both healthy individuals and those with cardiovascular disease. These procedures have elicited attacks of angina pectoris in cardiac patients both at rest and during exercise (16,26,33,39). In addition, the findings of Freedberg et al. (11) indicated that angina pectoris can be precipitated during exercise in a warm environment while holding an ice cube.

Although some literature in this area does exist, the cardiorespiratory and metabolic effects of hand cooling during strenuous exercise have not been clearly identified. What data is available clearly indicates a response in cardiac patients with precipitating angina pectoris. This suggests that there exists a possibility that individuals predisposed to cardiovascular disease may experience myocardial hypoxia and angina when exercise and hand cooling are combined. Running road races afford an opportunity for many individuals to engage in exercise. These events often provide both ice and ice water at water stops throughout the race. The combination of ice and strenuous exercise may cause negative effects on the performance of both healthy participants and participants with undiagnosed cardiovascular disease.

Further research is needed to clarify the effects of hand cooling on various physiological parameters during exercise.

Elucidation of the mechanisms involved may guide medical personnel in planning road race events.

Purpose of the Study

This study was designed to determine the effects of hand cooling on metabolic (blood lactate concentration) and cardiorespiratory (oxygen uptake, respiration rate, heart rate, respiratory exchange ratio, ventilatory equivalent of oxygen and carbon dioxide, and electrocardiograph) variables during strenuous exercise.

Research Hypotheses

The study was designed to test the following hypotheses:

1. There will be no significant difference in any of the metabolic (blood lactate concentration) and cardiorespiratory variables (heart rate, respiration rate, oxygen uptake, respiratory exchange ratio, ventilatory equivalent of oxygen and ventilatory equivalent of carbon dioxide) between bouts of strenuous exercise with and without hand cooling.

2. There will be no significant difference in any of the cardiorespiratory variables (heart rate, respiration rate, oxygen uptake, respiratory exchange ratio, ventilatory equivalent of oxygen and ventilatory equivalent of carbon dioxide) between individual bouts of hand cooling during strenuous exercise.

Rationale for the Research Plan

The research plan of the present study was constructed to simulate a ten kilometer road race and to observe the effects of repeated bouts of hand cooling on selected metabolic and cardiorespiratory variables. The study was designed to facilitate the examination of selected metabolic and cardiorespiratory parameters during a simulated popular running event. Hence, it examines both the physiological and performance implications of hand cooling during exercise.

Research Plan

The sample consisted of nine trained male distance runners with ten kilometer road race performance times under thirty-six minutes. The subjects ranged in age from nineteen to thirty-eight years and competed in ten kilometer and half-marathon road races. The subjects were tested under each of the following conditions:

1. maximal run to volitional exhaustion
2. thirty minute constant velocity run at a pre-determined pace without hand cooling (control run)
3. thirty minute constant velocity run at a pre-determined pace with two bouts of hand cooling at ten and twenty minutes (experimental run)

In all three runs expired gas was collected using the Douglas Bag method and analyzed for carbon dioxide (CO_2) and oxygen (O_2) content. Heart rate (HR), respiration rate (RR), and electrocardiograph (ECG) were measured at defined intervals throughout both the thirty minute runs and the maximal run to exhaustion. Hand weights were carried throughout both of the thirty minute constant velocity runs. The hand weights were exchanged at ten, twelve, twenty and twenty-four minutes into the run for another pair which were either cold (-1 - 2 degrees Celcius) hand weights (experimental run) or at room temperature (control run).

Cardiorespiratory data was initially analyzed to determine the need for the use of a covariate analysis. A one-way analysis of variance was used to analyze this parameter. Following this determination, a three-way analysis of variance (subject x treatment x time) was utilized for the cardiorespiratory variables. The minutes assessed were eight to fourteen and eighteen to twenty-four. A post hoc Tukey analysis was performed when significant differences were determined. A one-way analysis of variance was utilized for the metabolic variables. A significance level of $p \leq .05$ was chosen for use throughout the study.

Limitations

Three major limitations existed in association with the present study. First, conclusions made from the results obtained from this study can only be generalized to the specific sample population studied. Second, all physiological responses that occurred as a result of the hand cooling procedure were specific to the temperature range of the hand weights used in this study. Finally, the palmar surface area in contact with the hand weight could not be controlled between subjects or between runs.

CHAPTER II

REVIEW OF THE LITERATURE

Temperature regulation is a major physiological response of the body to increased physical activity and combines various bodily processes in a complex system. This review of literature will focus first on general cardiorespiratory and vascular adaptations of the body to physical activity and then give consideration to the thermoregulatory process as it relates to these variables and localized application of cold.

Literature related to this study has been divided into three major topical sections: (a) cardiorespiratory and vascular responses to physical activity, (b) thermoregulatory response to exercise and (c) physiological response to cold exposure. The latter section has been further subdivided into two areas; generalized cold exposure and localized cold exposure (cold air inhalation, facial/neck cooling, and limb cooling). Cardiorespiratory and metabolic responses will be the primary focus of this review relative to cold exposure.

Cardiorespiratory and Vascular Responses to Physical Activity

The following brief explanation of cardiorespiratory and vascular responses to physical activity has been included to identify some of the physiological variables which are altered during exercise and which may be further affected by changes in the thermal balance of the organism. Only those variables pertinent to this research study have been considered.

Physical activity causes changes in the resting homeostatic environment and results in the development of a new equilibrium state of many bodily systems. One of the means by which this is accomplished is through an increase in sympathetic nervous system activity. As can be seen in Figure 1, this increased activity is reflected in changes in both the cardiovascular and respiratory systems and has effects on the overall metabolic state of the body.

One of the most apparent effects of increased sympathetic nervous system activity is an increased demand for blood flow by various systems, including the contracting muscles and the cutaneous tissue (32). Although facilitated by an increased peripheral resistance and venous return, this increased demand for blood flow is in itself met by elevations in heart rate, stroke volume, cardiac output and blood pressure (11). Proportional increases in cardiac output and oxygen uptake have been described

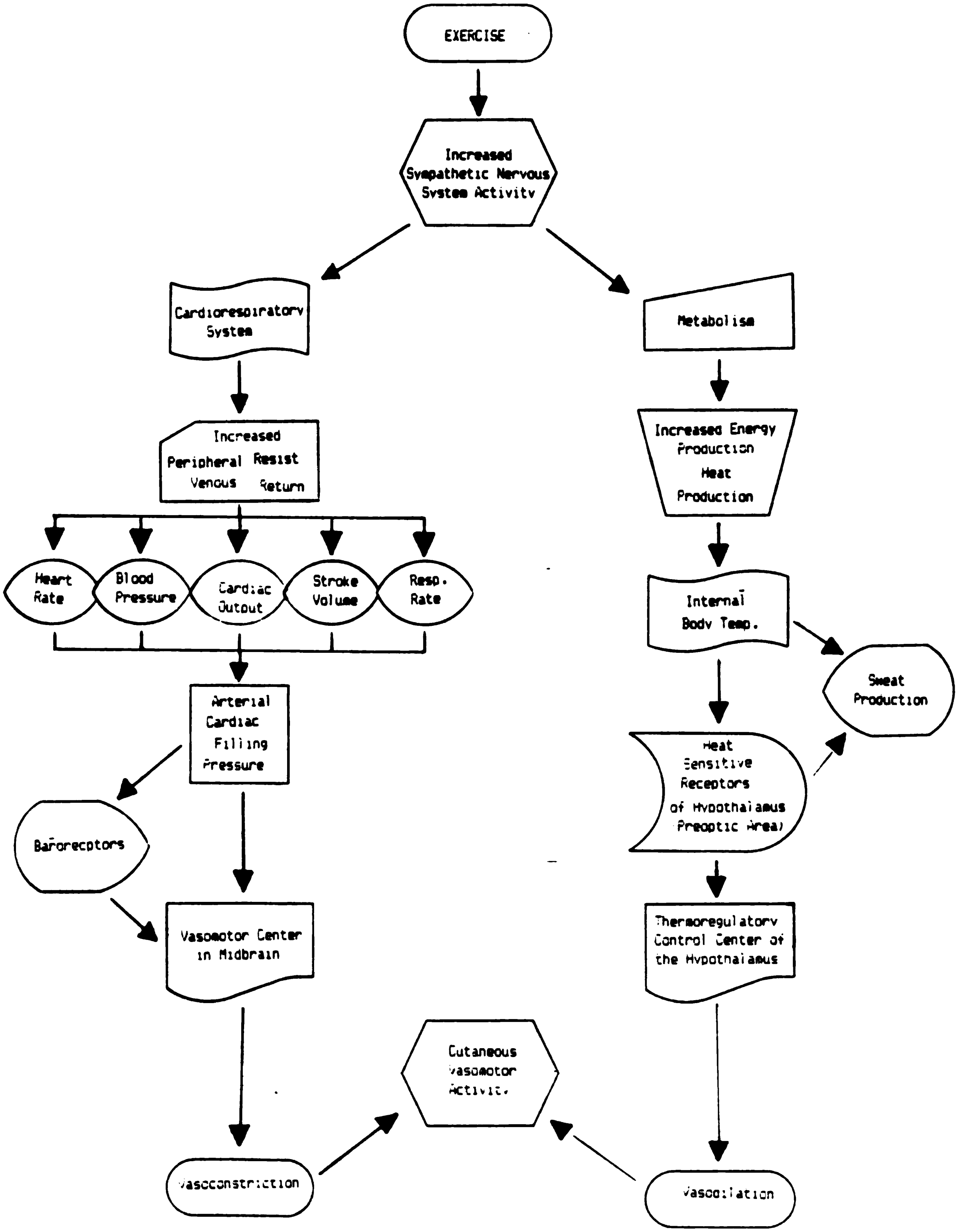


Figure 1. Cardiorespiratory and metabolic responses during exercise relative to thermal control.

in the literature (1) and the rate of blood flow to the muscles has been shown to correspond to elevations in cardiac output (40). Regulation of blood flow to the skin relative to increases in cardiac output and oxygen uptake have not however, been clearly defined.

The changes in heart rate and blood pressure which occur to assist in the development of an augmented blood flow also cause an increase in both the arterial and the cardiac filling pressures which, in turn, stimulate the vasomotor center located in the midbrain (42). Although, at the same time, baroreceptors sense the increased blood pressure and reflexively inhibit the vasomotor center, this effect is overridden and the overall result is a stimulation of the vasomotor center. The vasomotor center effects the cutaneous vasomotor activity by causing vasoconstriction of the cutaneous vessels. Vasoconstriction is a positive feedback to the vasomotor center and continues throughout exercise helping to enable appropriate redistribution of blood flow to the working muscles (32).

In addition to these changes at the cardiovascular level, the activity induced increased sympathetic nervous system activity also causes an increase in the cellular demands for energy (29). Since oxygen is a vital component to this long term energy production respiration rate is also increased to help meet the demands of an added workload on the body. The ventilatory control center in the lower brain stem controls these changes in respiration through a complex multi-feedback system (5,9).

Thermoregulatory Response to Exercise

In addition to precipitating changes in blood flow and respiration, increased sympathetic nervous system activity also causes an elevation in the rate of metabolic energy production in the early stages of exercise (Figure 1). This elevation in energy production triggers an increase in core body temperature due to some loss of energy in the form of heat and places new demands upon the body's thermoregulatory system (29).

The regulation of thermal balance occurs through involuntary processes which allow the organism to maintain a relatively constant internal temperature. Heat sensitive receptors of the hypothalamus respond to an activity-induced increase in core body temperature and send messages to the body's thermoregulatory control center which is located in the hypothalamus. In addition, various organs (smooth muscle, sweat glands) function as effector organs and are responsible for the vasomotor responses which aid in adjusting the internal temperature (4). Actual removal of internal body heat is facilitated by vasodilation of the cutaneous vessels.

A final important mechanism of heat loss which cannot be overlooked is that of sweat production. The thermoregulatory control center also stimulates sweat production which generates a negative feedback on internal body temperature (42). The evaporation of sweat is an extremely important mechanism of heat loss and thermal regulation during exercise. It is the only

mechanism available under conditions where the environmental temperature is greater than skin temperature (43).

This dual response of the sympathetic nervous system to physical activity facilitates the establishment of a new equilibrated state of the organism both from a cardiorespiratory and a thermoregulatory point of view. It must not be overlooked however, that this state can be easily modified by external factors such as generalized or localized cold application and tilt the thermal homeostatic scale to such a degree that further compensatory changes must occur to reestablish an equilibrated condition.

Physiological Response to Cold Exposure

Research which has investigated the various physiological responses to cold exposure will be reviewed according to the type of cold exposrue having been examined; generalized or localized. The effects of localized cold will be further subdivided into cold air inhalation, facial/neck cooling and limb cooling.

Generalized Cold Exposure

Several investigators have studied the effects of generalized cold exposure on cardiorespiratory and metabolic parameters at rest and/or during exercise. The methods of cold application used have involved either (a) spraying water on the entire body, (b) immersion of the body in water and/or (c) blowing cold air over the entire body surface.

Bassett et al. (2), Davies et al. (8) and Gisolfi and Copping (13) each utilized sponging or spraying water over the body as a cooling medium in their investigations. The temperature of the water used in each of these studies was related to the ambient temperature (28-30 degrees Celcius). No significant differences in heart rate and oxygen uptake were found between treadmill runs with or without skin wetting (2,8). However, when the use of water as a cooling agent was extended to total body immersion, such as in the studies by Holmer and Bergh (19) and Craig and Dvorak (7) which have assessed adaptations while swimming in varying water temperatures, increase in oxygen cost, both at rest and during submaximal work was found to occur as water temperature increased. Moreover, McArdle et al. (30) and Rennie et al. (35) found a decrease in heart rate and an increase in stroke volume to occur when subjects were exercised on a bicycle ergometer immersed in cold water (5-18 degrees Celcius). There was however, no significant difference between the cardiac output observed while exercising on land and that observed while exercising in cold water, suggesting that the significant bradycardia observed had been compensated for by changes in the stroke volume. It was postulated that the increase in stroke volume which occurred was due to changes in breathing mechanics and hydrostatic pressure was the cause of heightened venous return.

In addition to their assessment of the cardiorespiratory adaptations to total body immersion, Holmer and Bergh (19) also analyzed blood lactate concentrations. Significantly higher blood lactate values were observed when subjects worked submaximally in cold water (18 degrees Celcius) than when they exercised at the same intensity in warmer water (26 or 34 degrees Celcius).

In studies where air was used as the cooling element, subjects tested in an environmental chamber and air was blown, by fans, on various body segments (3,10,27,31). Epstein et al. (10) studied both healthy and coronary artery disease patients during rest and work under these conditions. No significant changes in heart rate, stroke volume or cardiac output were observed, findings which have also been supported by other investigators (27,31).

Significant increases in mean systemic arterial pressure, peripheral resistance and left ventricular minute work were also observed by Epstein et al. (10). These results occurred at rest and were magnified during exercise. It was postulated that these changes were a function of a concomitant sympathetic stimulatory effect on, and baroreceptor inhibition of, the sinus node. The overall net effect being an increased systemic pressure and an increased peripheral resistance with a subsequent increased myocardial oxygen requirement (3). Additional studies by Epstein et al. (10), Berman (3) and Wayne and Graybiel (41) have shown this consequent rise in myocardial oxygen demand to precipitate angina pectoris.

Localized Cold Exposure

Cold air inhalation, facial cooling, neck cooling and limb cooling have all been used to examine the effects of localized cold on physiological parameters during the resting condition or in combination with exercise.

Cold Air Inhalation

Studies investigating the effects of cold air inhalation on pulmonary mechanics, cardiovascular function and body metabolism have utilized a range of air temperatures from negative forty to negative twenty-four degrees Celcius. In addition, these studies have focused on the relationship between cold air inhalation and angina pectoris during both resting and exercising conditions.

Researchers have reported that cold air inhalation increases heart rate and systolic and diastolic blood pressure (15,16). The observed increase in diastolic blood pressure however, was inconsistent with the typical exercise response in which diastolic blood pressure remained stable or decreased.

The observations of Hartung et al. (15) indicated no significant changes in respiration rate, oxygen uptake and respiratory exchange ratio.

Angina pectoris was again linked to cold exposure as in previous studies. Hartung et al (15) and Hattenhauer and Neill (16) concluded that the changes in diastolic blood pressure partially explained the cold-induced angina pectoris in coronary artery disease patients. According to Hartung et al. (15) an increase in ventricular pressure increased the myocardial oxygen demand which precipitated angina pectoris. Hattenhauer and Neill (16) retested this mechanism and found conflicting results. Heart rate multiplied by systemic arterial pressure was used as a major determinant of myocardial oxygen consumption. Angina pectoris occurred at a particular value of this calculation (HR x SAP) under specific conditions for individual patients (38). Leon et al. (26) and Hattenhauer and Neill (16) observed that cold air inhalation increased the sum of heart rate times systemmic arterial pressure only slightly in those subjects who experienced angina pectoris. Leon et al. (26) speculated that the angina pectoris was mediated by an increased myocardial oxygen demand due to an increased cardiac contractile state, caused by cold induced sympathetic stimulation. These hypothesies have yet to be confirmed.

Facial/Neck Cooling

Cooling of the face without cold air inhalation has also been investigated. Facial immersion, cold air blowing on the face and cold pack application have been used with healthy individuals and coronary artery disease patients.

Frey et al. (12), Heistad et al. (18) and Kobayas and Ogawa (22) utilized facial immersion in cold water and observed a significant bradycardial response. Frey et al. (12) and Heistad et al. (18) reported a sixteen percent and twenty-three percent reduction in heart rate respectively, in healthy subjects. The degree of bradycardia was dependent on the water temperature with colder water producing greater reductions in heart rate (22).

Bradycardia was evidenced in response to cold air blown on the face (6,21,23,24,28,36,37). LeBlanc et al. (23) proposed an explanation for this response and suggested that temperature and wind speed are synergistic elements. LeBlanc et al. (24), in a latter study, manipulated these variables and the results indicated the greatest magnitude of change at a temperature of ten degrees Celcius and a wind speed of 6.7 meters per second.

LeBlanc et al. (25) reported that the response shown in heart rate paralleled that observed for skin temperature. Subsequent to these findings a highly intricate interrelationship between these two parameters was proposed and it was postulated that the observed bradycardia was triggered by a vagal reflex initiated by stimulation of the trigeminal nerve due to a decrease in skin temperature. A linear relationship existed between these two variables for skin temperatures ranging from twenty-three to thirty-five degree Celcius. At twenty-three degrees, the heart rate had reached its maximum reduction and further decreases in skin temperature caused little reciprocal changes in heart rate. For skin temperatures below twenty-three degree Celcius (10 - 23 degrees Celcius), a relationship between these two variables was not found to exist.

In contrast, Cabanac and Caputa (6) postulated that the cause of the bradycardia was a function of changes in brain, not core temperature. Subjects exercised while exposed to facial cooling and temperature measurements were made of the tympanic membrane and the esophagus. The tympanic membrane temperature was used as a measure of brain temperature while esophogeal temperature was used to indicate the core temperature. A correlation between heart rate and temperature of the tympanic membrane was indicated but not between heart rate and esophgeal temperature. These findings suggest that heart rate was controlled by brain temperature and not by core temperature. Additional studies by Kissen et al. (21) support such a hypothesis. Air cooling of the head and face of subjects exposed to hyperthermic conditions was shown to reduce the change in heart rate by half of that observed for the same trunk temperature under non-localized cooled conditions. Such a response once again indicated a relationship between brain temperature and heart rate irrespective of core temperature.

Only one investigation has examined the effects of cold air blown on the face and blood lactate levels during exercise. Riggs et al. (37) showed blood lactate concentration to be increased significantly in healthy subjects exposed to ten degree Celcius wind while exercising.

The effects of application of ice packs on the head and neck have been investigated by Neill et al. (33) and Leon et al. (26) using individuals with a history of coronary artery disease. Heart rate was found to be significantly increased in these individuals when ice was applied. In Mannino and Washburn's (28) review of the relevant literature, however, it becomes apparent that controversy exists both in the cardiorespiratory results themselves and the interpretation of these results.

<u>Limb Cooling</u>

Research examining changes in cardiopulmonary parameters due to cooling of the limbs is limited. Of the studies undertaken, most focus on immersion of the hand or foot in cold water (4 - 5 degrees Celcius) and have examined primarily, changes in heart rate and blood pressure.

Studies under resting conditions have shown increases in systolic and diastolic blood pressure after immersion of a hand or foot in cold water for periods of time ranging from one to six minutes (12,14,20,25). These changes have been shown to occur rapidly and return to resting levels after five minutes (14). In addition, Frey et al. (12) noted a larger response in males than in females in blood pressure change. In addition, LeBlanc et al. (25) found a significantly greater range in initiation and duration of response in females. Attempts at correlation of blood pressure response (systolic) with $\dot{V}O_{2max}$ have indicated a negative relationship between these two parameters with subjects whose $\dot{V}O_{2max}$ ranged from 26-75 ml/kg/min (25).

Patterns in heart rate response have been shown to be similar to those of blood pressure (12,14,20,25), although differences between the sexes are not as apparent.

Extension of the research scope to include individuals with angina pectoris has indicated a variety of negative cardiovascular responses when such persons are exposed to conditions of exercise in a cold environment. Freedberg et al. (11) assessed work tolerance in such individuals under four conditions; (a) in a cold room (45-55 degrees Fahrenheit), (b) in a warm room (72-75 degrees Fahrenheit), (c) in a cold room with a hand in 110 degrees Fahrenheit water and (d) in a warm room holding ice cubes. Work tolerance, as measured on a step test, was improved in the warm environment. Heat application aided in increasing work tolerance in the cold room although not to the level of a warm environment alone. Negative effects occurred when a combination of ice cubes and exercise in a warm room was evaluated. Ninety-five percent of the subjects experienced angina pectoris under these conditions. Most subjects experienced discomfort within ten seconds of ice application with a maximum effect occurring within thirty and forty seconds of application. Although documented occurrences of angina pectoris were reported, no significant changes in blood pressure or heart rate were evident under this condition.

Many investigators have suggested that the mechanism for these rapid responses may be reflex in nature (11,12,25). It is thought that the vasomotor changes in the coronary arteries may in fact be caused by a reflexive response which has been triggered by adrenal medullary catecholamines (14). However, conclusive evidence supportive of this mechanism has yet to be determined.

An overview of the literature indicates various areas where discrepancies exist in the cardiorespiratory parameters evaluated. Metabolic parameters have not been investigated in most studies involving cold exposure. Further research in the area of cooling, especially limb cooling, is necessary to clarify the inconsistencies and increase the knowledge base regarding metabolic response to cold application.

CHAPTER III

RESEARCH METHODS

This study was designed to evaluate the metabolic and cardiorespiratory responses to hand cooling during strenuous exercise. Trained male runners performed one maximal exercise bout and two thirty minute constant velocity runs on a treadmill. Cold hand weights were carried at predetermined intervals throughout one of the two thirty minute runs. Selected cardiorespiratory and metabolic parameters were assessed and compared during the treadmill runs.

Subjects

Nine male runners between the ages of nineteen and thirty-eight volunteered to be subjects in this study. A criterion for inclusion in the study was a ten kilometer performance time under thirty-six minutes. All subjects were well trained and continued to follow their individual training program throughout the study.

An explanation of the procedures, purpose and risks associated with the study was given to each subject prior to their signing an informed consent form approved by Michigan State University's Human Subject Committee (Appendix A).

Research Design

Each subject performed a total of three runs on the treadmill. Treadmill runs were seperated by one week intervals. All testing was done after 12:00 noon to avoid possible confounding diurnal factors. A maximal run to exhaustion was the first run for each subject. Data from this run was used to determine the treadmill velocity for the thirty minute constant velocity runs.

The subjects served as their own control for the two thirty minute constant velocity runs. Treatment order was randomized between subjects as well as within each subject for the thirty minute constant velocity runs. Test order was also randomized throughout the study.

Two groups of physiological parameters were assessed during the study and served as dependent variables. These included cardiorespiratory variables (heart rate, oxygen uptake, respiratory rate, respiratory exchange ratio, ventilatory equivalent of oxygen and ventilatory equivalent of carbon dioxide) and a metabolic variable (blood lactic acid concentration). The independent variables were: subject, time, and treatment.

Experimental Procedures

Data collection was performed at Michigan State University in the Center for the Study of Human Performance. Experimental procedures consisted of each subject running three runs on a treadmill as well as assessment of anthropometric parameters (height, weight, and body composition as explained in Appendix B).

Subject Preparation

For each of the treadmill run test sessions, the subject was weighed while dressed in running clothes and shoes. Stretching was performed by each subject according to his own routine. Following stretching, electrodes were applied to the subject's chest to monitor the CM5 lead.

Following a five to ten minute period of sitting quietly, resting measurements (blood pressure, heart rate, ECG, blood lactate) for each subject were taken. Subjects warmed up running on the treadmill prior to the designated treadmill run.

Protocols

Two treadmill protocols (ramp run to exhaustion and thirty minute constant velocity run), each serving a different purpose and containing different methodological components, were used in this study. The protocols differed in (a) the use or non use of hand weights, (b) the intensity or the speed of the treadmill at which the subjects ran, (c) the duration of the run and (d) the intervals used for data collection.

Ramp Run Protocol

The ramp protocol consisted of a warm-up run at six miles per hour and zero percent grade to allow for subject accomodation and physiological adaptations. Duration of the warm-up was dependent upon the accomodation of individual subjects. The ramp began at a speed of 5.1 miles per hour and increased 0.3 miles per hour every minute. The incline of the treadmill was maintained at zero percent throughout the run. The test was terminated upon volitional exhaustion of the subject.

Expired gases were collected using a two-way Daniels respiratory valve (RPel Company, Los Altos, CA) connected to a four-way automated switching valve (VanHuss/Wells Automated Switching Valve) by two feet of corrugated tubing with a 1.25 inch internal diameter. The expired gases were then collected in neoprene weather balloons in thirty second intervals using the open circuit Douglas bag method.

Collected gases were pumped through a DTM-115 (Applied Electrochemistry Inc., Sunnyvale, CA) dry gas meter at a rate of fifty liters per minute to determine gas volume. The O_2 and CO_2 percentage for each bag was determined using an infrared CO_2 analyzer (Applied Electrochemistry CD-3A, American Meter Co., Singer) and an electrochemical O_2 analyzer (Applied

Electrochemistry S-3A, American Meter Co., Singer). The analyzers were zeroed using helium and then calibrated using a verified standard gas sample prior to each run. The standard gas sample was verified for O_2 and CO_2 with a Haldane Chemical Analyzer (Arthur H. Thomas Co., Philadelphia, PA).

Respiration rate was measured using a thermister mounted on the Daniel's valve apparatus. The rate was measured in thirty second intervals throughout the run. Heart rate was monitored with the CM5 lead and was recorded at thirty second intervals. An electrocardiogram was recorded every five minutes, at peak work, and immediately following termination of the test. A fingerstick blood sample was taken prior to beginning the run and two minutes following termination of the test. Lactate concentration in the blood samples was determined using an enzymatic-amperometric measurement with the Roche Model 640 Lactate Analyzer (Roche Bio-Electronics, Basal, Switzerland).

<u>Thirty Minute Constant Velocity Run Protocol</u>

Max $\dot{V}_{O2}$ was determined from an oxygen uptake vs. treadmill velocity graph. The running speed used for the thirty minute constant velocity runs was determined as calculated from the oxygen uptake versus velocity graph (Appendix C). Eighty and eighty-five percent of maximal oxygen uptake were calculated and plotted on this graph. From each of these points, running speed was determined using a line drawn from the point of oxygen consumption vertically to the abscissa where it intersected with a velocity value. These values were then averaged to determine the speed for the thirty minute runs. This procedure was standard for all nine subjects.

Hand weights of varying temperatures were carried throughout the constant velocity runs. The temperature of the hand weights denoted the difference between runs; control (room temperature) and experimental (cold: -1 - 2 degrees Celcius) run.

Both the control and experimental runs began with room temperature weights and consisted of four exchanges of hand weights. Hand weights were carried throughout the entire test. The subject exchanged the set of weights for another set at ten, twelve, twenty and twenty-two minutes into the run. During the experimental run, the hand weights given at minutes ten and twenty were cold followed by room temperature weights at minutes twelve and twenty-two. Conversely, the control run consisted of room temperature hand weights throughout although exchanges still occurred at the predetermined intervals.

The hand weights used throughout the study were called Handteens (Rainbow Racing Systems, San Diego, CA). These plastic containers are generally used for carrying fluids during long duration activity. Room temperature containers contained styrofoam and dried peas. The cold containers were filled with ice and styrofoam. All containers were weighed prior to each testing session and calibrated to be 244.4 ± 0.05 grams.

During each testing session, the temperature of the hand weights was closely monitored. Room temperature weights were kept in the laboratory for three to three and one half hours prior to each testing session to allow for temperature adjustment. Similiarly, the cold hand weights were placed in an ice chest filled with thirty-six pounds of ice plus two liters of water for three to three and one half hours prior to each testing session and remained in the ice chest throughout the entire testing sessions. This procedure was utilized to maintain a temperature near zero degrees Celcius (-1 - 2 deg.C.). The cold hand weights were kept frozen in a conventional refrigerator freezer between testing days.

The temperature of the cold hand weights was measured prior to and following each exchange. Two sets of hand weights were utilized for each temperature to allow consistancy of temperature during each run. This procedure was standardized during the entire study.

Each subject was allowed a five minute warm-up (6 mph - 0% grade) on the treadmill following standard resting measurements. Similiar to the warm-up in the ramp protocol, accomodation to the treadmill as well as physiological adaptations were elicited during this period. Each subject ran for thirty-minutes at the predetermined velocity. Expired gases were collected using the instrumentation previously described. Thirty second bags were collected throughout the thirty minute run except during minutes ten through twelve and minutes twenty through twenty-two at which time intervals of fifteen seconds were used for gas collection. This procedure was used to gain a more detailed analysis of time course changes which occurred during the concurrent cold application. Respiration rate and heart rate were measured throughout the test at the same intervals as gas collection. An electrocardiogram was recorded at minute ten, minute eleven, minute twenty, minute twenty-one and immediately following termination of the test. A venous fingerstick blood sample was taken post warm-up and two minutes post exercise for the determination of blood lactate.

Statistical Analysis

The cardiorespiratory data was analyzed to determine the effectiveness of a covariate analysis. A one-way analysis of variance was utilized to assess for this parameter. Subsequently, a three-way analysis of variance (subject x treatment x time) was performed on the cardiorespiratory variables. The data from minutes eight to fourteen and eighteen through twenty-four were analyzed. A post hoc Tukey analysis was performed when significance was determined. A one-way analysis of variance was utilized to assess the metabolic data. A significance level of $p \leq 0.05$ was used for all analyses.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to determine the effects of hand cooling on cardiorespiratory and metabolic variables during strenuous exercise in trained male runners. The data are presented graphically or in tables and discussed as to the findings of statistical significance. The results are divided into three parts: (1) the descriptive data on individual subjects and parameters relating to environmental conditions during the study, (2) the findings from the cardiorespiratory variables, and (3) the metabolic variable results.

Methodology Overview

After determination of maximum oxygen consumption using a maximal run to exhaustion, subjects were tested on two subsequent occassions to assess the effects of hand cooling on metabolic (blood lactate concentration) and cardiorespiratory (heart rate, respiration rate, ventilatory equivalent of oxygen and carbon dioxide, oxygen uptake and respiratory exchange ratio) variables.

Each subject ran three runs on a treadmill. The first run was a maximal run to exhaustion which was used to determine the speed of the treadmill for the remaining runs. Each of the control and experimental runs were thirty minutes in duration and were run at a constant velocity. Hand weights were carried throughout all thirty minute runs. The hand weights were exchanged at minutes ten, twelve, twenty, and twenty-two for another set of hand weights. The temperature of the hand weights at minutes ten and twenty was determined by the run type; control (room temperature) and experimental (-1 - 2 degrees Celcius). Both control and experimental runs were at the speed which corresponded to eighty to eighty-five percent of each subject's maximal oxygen uptake. Data obtained were analyzed to determine whether any treatment (cold or room temperature hand weights) effects existed.

Results

Part I: Descriptive and Environmental Condition Data

Nine subjects between the ages of nineteen and thirty-eight (mean 24.67 $\pm$ 5.25) were used for this study. Physiological characteristics of these subjects are given in Table 1. All subjects were well trained distance runners and continued to train throughout the duration of the study.

TABLE 1

Physiological Characteristics

	Age yr	Height cm	Weight kg	Body Fat % *	V_{O2max} ml/kg/min
Mean	24.7	176.9	67.1	10.9	68.3
± SD	5.3	9.3	6.7	3.5	6.5

* Hydrostatic weighing method, technique Appendix B.

The average running speed for the thirty minute constant velocity runs was 9.81 ± 0.83 mph. This value corresponded to an average work intensity of 80.0 ± 1.41% of oxygen uptake for all subjects combined.

Due to the interaction of environmental conditions with the thermoregulatory responses of the body during strenuous exercise it was necessary to measure room temperature, humidity and barometric pressure at the onset of each testing session. As can be seen from the data presented in Table 2, these environmental conditions remained relatively constant and were not significantly different between testing sessions.

TABLE 2

Environmental Conditon Data

	Barometric Pressure mmHg	Room Temp. deg.C.	Humidity %	Temperature Ice Packs deg.C.
Control:				
Mean	738.6	23.8	22.11	**
± SD	5.07	0.49	1.76	**
Experimental:				
Mean	739.3	24.0	23.60	1.28
± SD	5.62	0.46	1.59	0.05
Combined Runs:				
Mean	738.9	23.9	22.80	**
± SD	5.21	0.48	1.79	**

** Not applicable for this treatment.

Part II: Cardiorespiratory Results

Differences were assessed in cardiorespiratory parameters between subjects and between treatments (control or experimental). Variability between individual subjects, observed in many parameters, is not unusual. Therefore, between subject differences will not be discussed in depth and the primary focus will be on between treatment differences which were evaluated to determine the validity of the proposed hypotheses.

Data was collected at numerous predetermined time intervals throughout the treatment runs but only minutes eight through fourteen and eighteen through twenty-four were analyzed. Such an analysis enabled the evaluation of three critical periods for each cold application bout. These were: (a) the two minutes prior to hand cooling (minutes 8-10 and 18-20), (b) the two minutes of hand cooling (minutes 10-12 and 20-22) and (c) the two minutes following cooling (minutes 12-14 and 22-24). The intervals analyzed allowed assessment of; a general baseline level for each variable, any pattern associated with the application of cold and any return to a baseline level.

The cardiorespiratory variables examined were heart rate, respiration rate, oxygen uptake, ventilatory equivalent of oxygen, ventilatory equivalent of carbon dioxide and respiratory exchange ratio. These variables will be discussed in the order stated above.

The mean values for heart rate at time intervals eight through fourteen and eighteen through twenty-four minutes are shown in Figure 2. Heart rate increased throughout both the control and experimental runs (control: 162-172 bpm; experimental: 167-175 bpm). Average peak heart rate assessed for both treatments was 177 beats per minute and was attained at twenty-one minutes of the experimental run. Heart rate was observed to be significantly different both between subjects (minutes 10-14 and 18-24) and between the two treatment runs (minutes 18, 20 and 21). The average heart rate for all subjects attained in the experimental run was significantly higher than that attained in the control run at minutes eighteen, twenty and twenty-one.

The heart rate data showed a pattern specific to the application of cold indicating an initial increase in heart rate with cold application followed by a subsequent depression in heart rate. Although there is a pattern suggesting an initial increase in heart rate with cold application, this was not found to be statistically significant.

Further evaluation of the heart rate data suggested a general trend in this parameter over the time course of the run. A line of best fit was drawn through the mean heart rate data for both control and experimental treatments. The slopes for the two lines were 0.27 for the control run and 0.59 for the experimental run. These values were not significant at the $p \leq .05$ level.

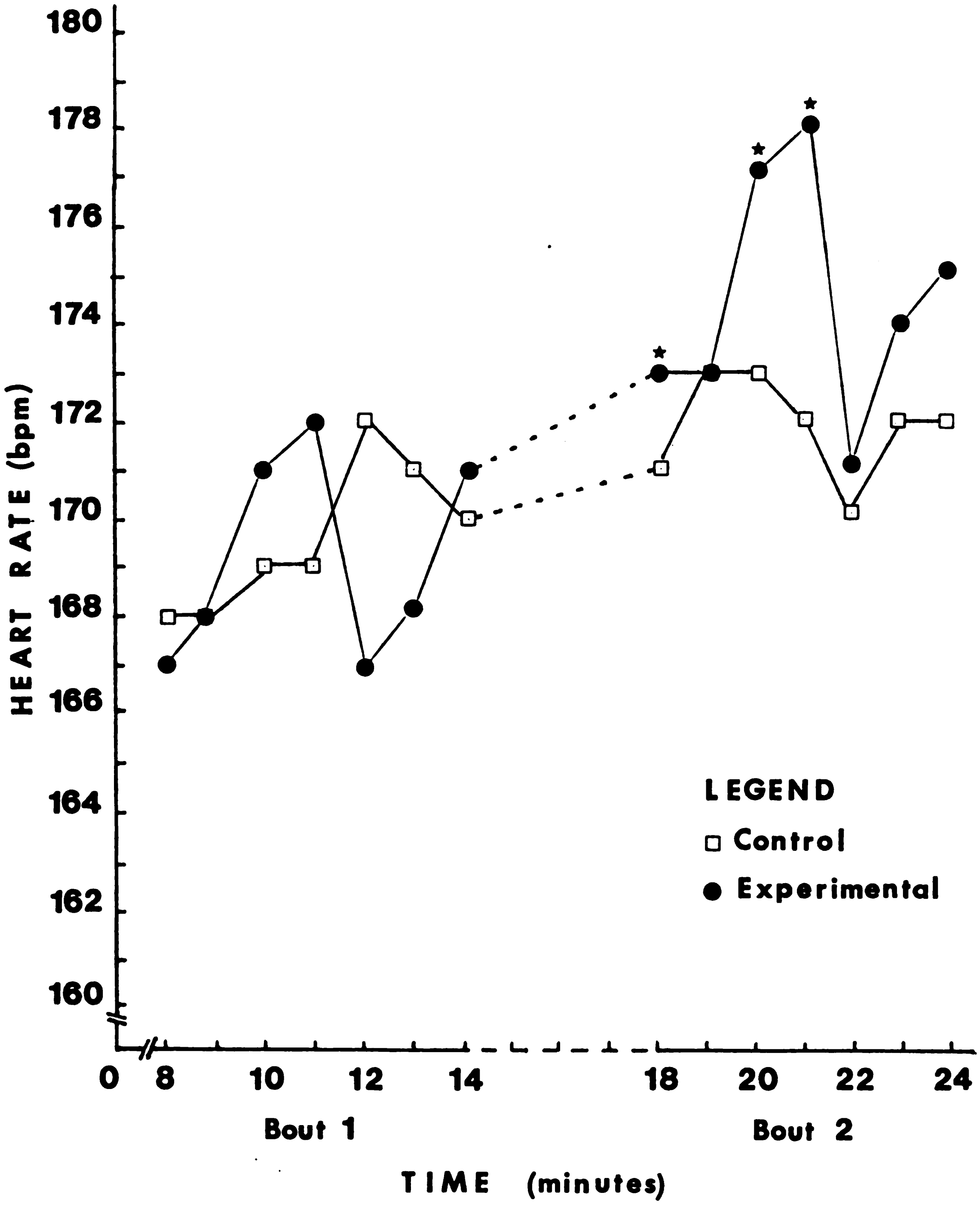


Figure 2. The effect of intermittant hand cooling on heart rate response during a thirty minute constant velocity run. Values expressed are mean data (± SD in Appendix E). ★ $p \leq .05$.

However, to further investigate this trend, the heart rate data was projected over a second time course similar to the one analyzed in this study (Figure 3). The projections were calculated using the slope determined from the line of best fit drawn for both treatments. The peak heart rate for the projected control run was 177 beats per minute and the projected experimental value was 185 beats per minute. The difference in the average heart rate calculated from the projected graphs was statistically significant ($p \leqslant .05$).

Analysis of respiration rate indicated significant differences ($p \leqslant .05$) between subjects at all minutes analyzed except minutes twelve and fourteen (Table 3). No significant differences were noted however, between the two treatments at any of the time periods analyzed.

Mean oxygen uptake values are displayed in Figure 4. Oxygen uptake was significantly different ($p \leqslant .05$) between subjects at minutes nine, twelve, fourteen and eighteen and between treatments at minute nine. Both the control and experimental runs demonstrated a relatively stable oxygen uptake over the time course of the run. Although not significantly different, oxygen consumption during the experimental run was lower than that which occurred during the control run in every minute analyzed except minute twenty. A peak in oxygen uptake occurred at minute twenty

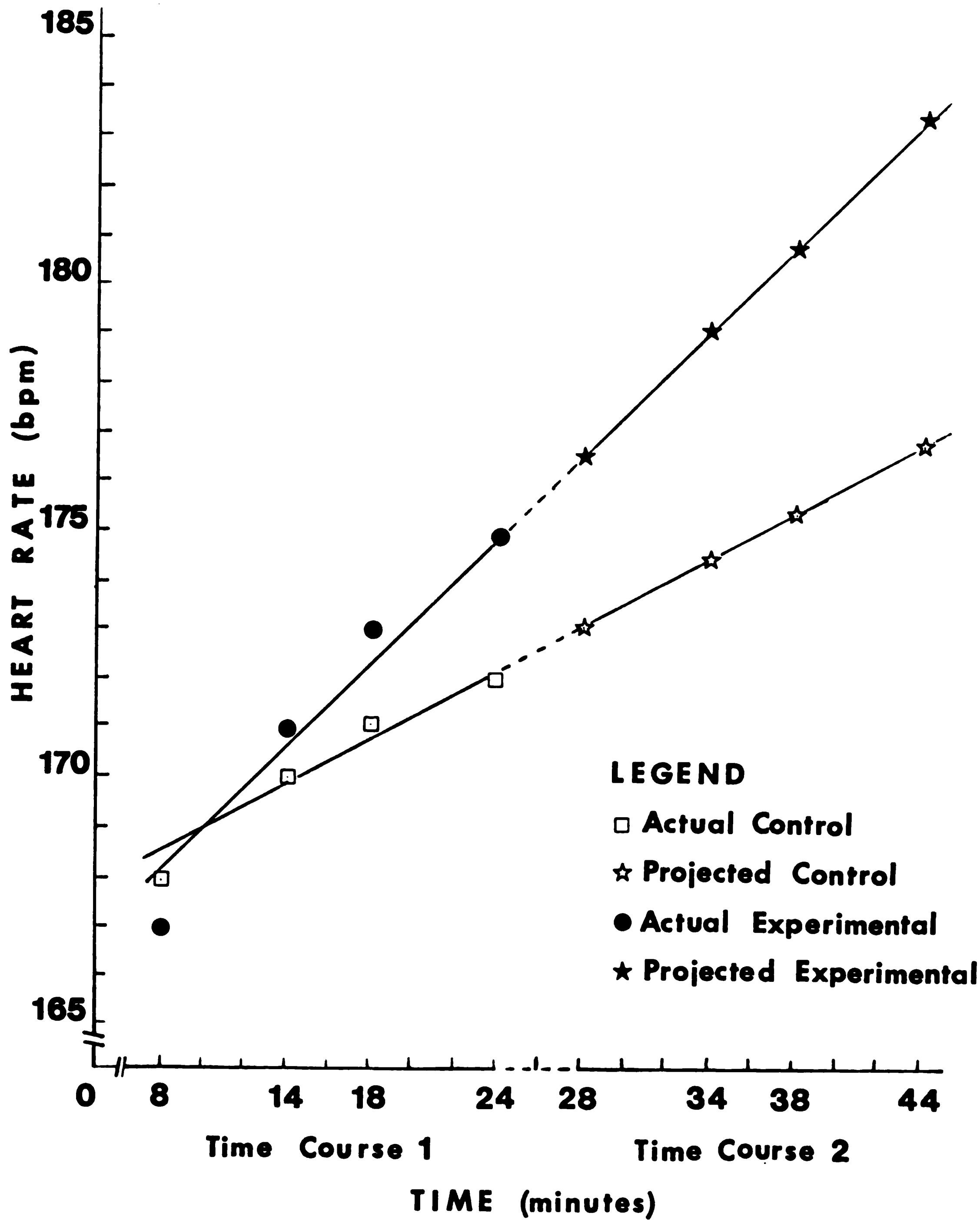


Figure 3. Linear representation of the heart rate response for two fourteen minute time courses: mean assessed and projected values.

TABLE 3

Mean Respiration Rate Measures

Time (minute)	Condition #	
	Control	Experimental
8	43.11 $\pm$ 4.3	41.30 $\pm$ 6.5 *
9	43.11 $\pm$ 3.5	41.56 $\pm$ 6.8 *
10 @	45.22 $\pm$ 5.1	42.67 $\pm$ 7.3 *
11 @	44.00 $\pm$ 5.8	43.00 $\pm$ 7.5 *
12	46.22 $\pm$ 6.0	43.67 $\pm$ 8.1
13	49.30 $\pm$ 6.3	43.44 $\pm$ 6.3 *
14	44.20 $\pm$ 5.1	42.30 $\pm$ 8.1
18	44.89 $\pm$ 6.0	45.10 $\pm$ 5.6 *
19	45.89 $\pm$ 6.8	44.70 $\pm$ 5.5 *
20 @	46.78 $\pm$ 5.5	45.50 $\pm$ 5.9 *
21 @	47.67 $\pm$ 6.4	44.70 $\pm$ 5.8 *
22	47.59 $\pm$ 6.5	45.70 $\pm$ 5.9 *
23	47.50 $\pm$ 6.8	45.20 $\pm$ 5.7 *
24	47.00 $\pm$ 7.1	45.40 $\pm$ 6.8 *

@ Minutes with cold application.
\# Values measured in breaths per minute.
* Significant between subjects ($p \leq .05$).

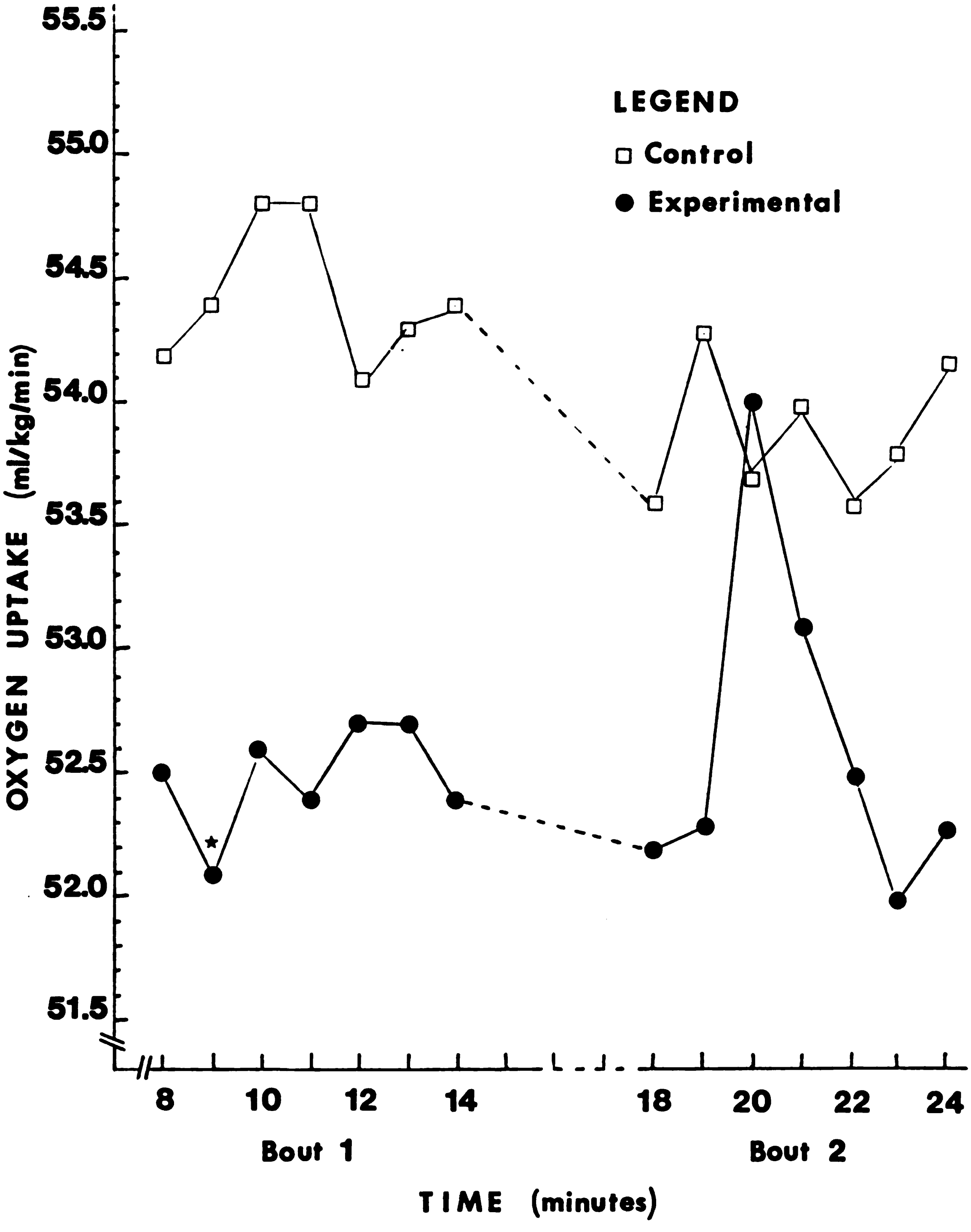


Figure 4. The effect of intermittant hand cooling on oxygen uptake response during a thirty minute constant velocity run. Values expressed are mean data ($\pm$ SD in Appendix E). ★ $p \leqslant .05$.

into the experimental run which corresponded to initiation of the second bout of cold application.

Average ventilatory equivalent data for both oxygen ($\dot{V}_E/\dot{V}_{O2}$) and carbon dioxide ($\dot{V}_E/\dot{V}_{CO2}$) at minutes eight through fourteen and eighteen through twenty-four are shown in; Table 4 and Table 5 respectively.

The ventilatory equivalent of oxygen ($\dot{V}_E/\dot{V}_{O2}$) indicated significant differences ($p \leq .05$) between subjects at all minutes except minutes twenty-one and twenty-two (Table 4). No between treatment significant differences were found to occur at any of the minutes analyzed.

As is indicated in Table 5, $\dot{V}_E/\dot{V}_{CO2}$ was significantly different between subjects at all minutes analyzed except minute twenty-one. There was no significant difference between the control and experimental runs for this variable.

The response of the respiratory exchange ratio to the application of cold was distinct in pattern. Significant differences were shown both between subjects (minute fourteen) and between treatments (minutes twenty and twenty-one) and are displayed in Figure 5. Respiratory exchange ratio was elevated from 0.86-0.87 to 0.89 upon application of cold during both periods (10-12, 20-22 minutes) and returned to a baseline level following removal of the cold hand weights. In addition, a depression of respiratory exchange ratio occurred during the first minute following removal of the hand weights after both bouts of cold application.

TABLE 4

Mean Ventilatory Equivalent of Oxygen Measures

Time (minute)	Condition	
	Control L/(L/min)	Experimental L/(L/min)
8	21.72 ± 1.4	21.76 ± 1.9 *
9	21.87 ± 1.4	22.02 ± 4.8 *
10 @	22.53 ± 1.2	22.41 ± 1.6 *
11 @	22.53 ± 1.4	22.19 ± 2.0 *
12	22.40 ± 1.1	22.40 ± 1.7 *
13	22.27 ± 1.3	22.18 ± 1.7 *
14	22.03 ± 1.4	24.42 ± 1.5 *
18	22.23 ± 1.8	23.13 ± 1.6 *
19	23.17 ± 1.7	23.24 ± 1.5 *
20 @	23.66 ± 1.8	23.57 ± 1.5 *
21 @	23.83 ± 2.0	23.39 ± 1.1
22	23.90 ± 1.9	23.79 ± 1.8
23	23.08 ± 1.8	23.46 ± 1.6 *
24	22.84 ± 2.0	23.56 ± 1.7 *

@ Minutes with cold application.
* Significant between subjects ($p \leq .05$).

TABLE 5

Mean Ventilatory Equivalent of Carbon Dioxide Measures

Time (minute)	Condition	
	Control L/(L/min)	Experimental L/(L/min)
8	25.20 ± 1.6	25.27 ± 1.6 *
9	25.32 ± 1.3	25.47 ± 1.6 *
10 @	25.78 ± 1.1	25.68 ± 1.3 *
11 @	25.80 ± 1.3	25.39 ± 1.3 *
12	25.66 ± 1.1	25.58 ± 1.2 *
13	25.61 ± 1.1	25.60 ± 1.4 *
14	25.43 ± 1.3	25.70 ± 1.4 *
18	25.62 ± 1.6	26.61 ± 1.5 *
19	26.63 ± 1.6	26.68 ± 1.3 *
20 @	26.99 ± 1.7	26.94 ± 1.4 *
21 @	27.11 ± 1.8	26.57 ± 0.9
22	27.33 ± 1.8	26.94 ± 1.4 *
23	26.85 ± 1.8	27.00 ± 1.4 *
24	26.76 ± 2.1	27.18 ± 1.5 *

@ Minutes with cold application.
* Significant between subjects ($p \leq .05$).

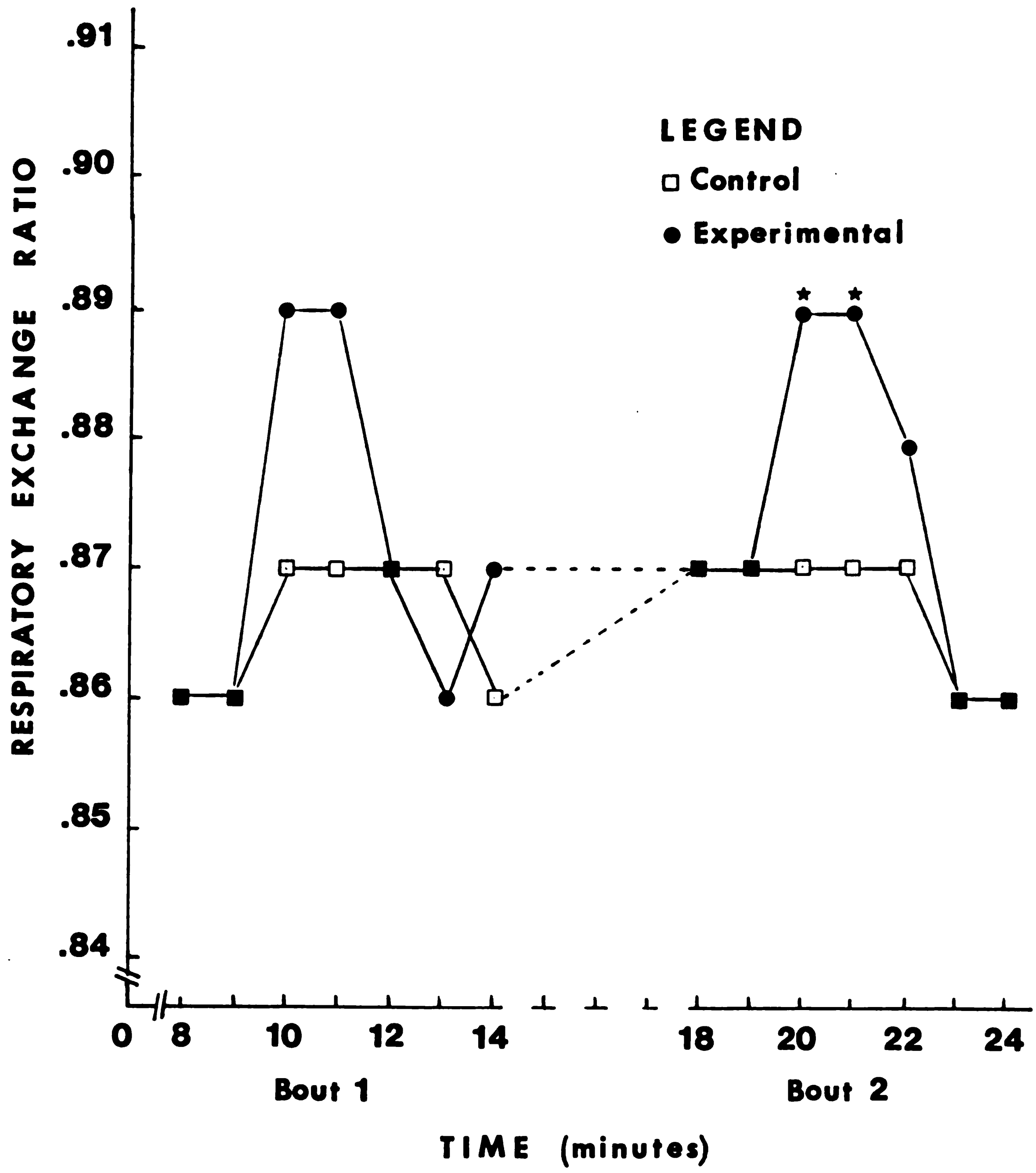


Figure 5. The effect of intermittant hand cooling on respiratory exchange ratio response during a thirty minute constant velocity run. Values expressed as mean data (± SD in Appendix E).
★ p ≤ .05.

Electrocardiographic results were analyzed using standard ECG interpretation and the graphs were assessed for any cardiac arrhythmias. Major abnormalities like premature atrial contractions, premature ventricular contractions or missing beats were documented.

Only one subject showed abnormalities in his electrocardiograph related to the cold application. Electrocardiographic data from this subject is given in Appendix F. He exhibited one unifocal premature ventricular contraction at minute eleven and minute twenty-one (Figure 6). It is interesting to note that his medical history reported mitral valve stenosis. However, no conclusions can be drawn from these results regarding a correlative relationship between his medical condition and his response to cold application. All other subjects demonstrated no significant cardiac abnormalities associated with application of the cold hand weights or throughout any other portion of their runs.

Part III: Metabolic Data

Mean values for blood lactic acid concentration were assessed in two ways. First, the absolute difference was calculated by subtracting the post exercise value from the post warm-up value. Second, the absolute value was computed as a percentage of the

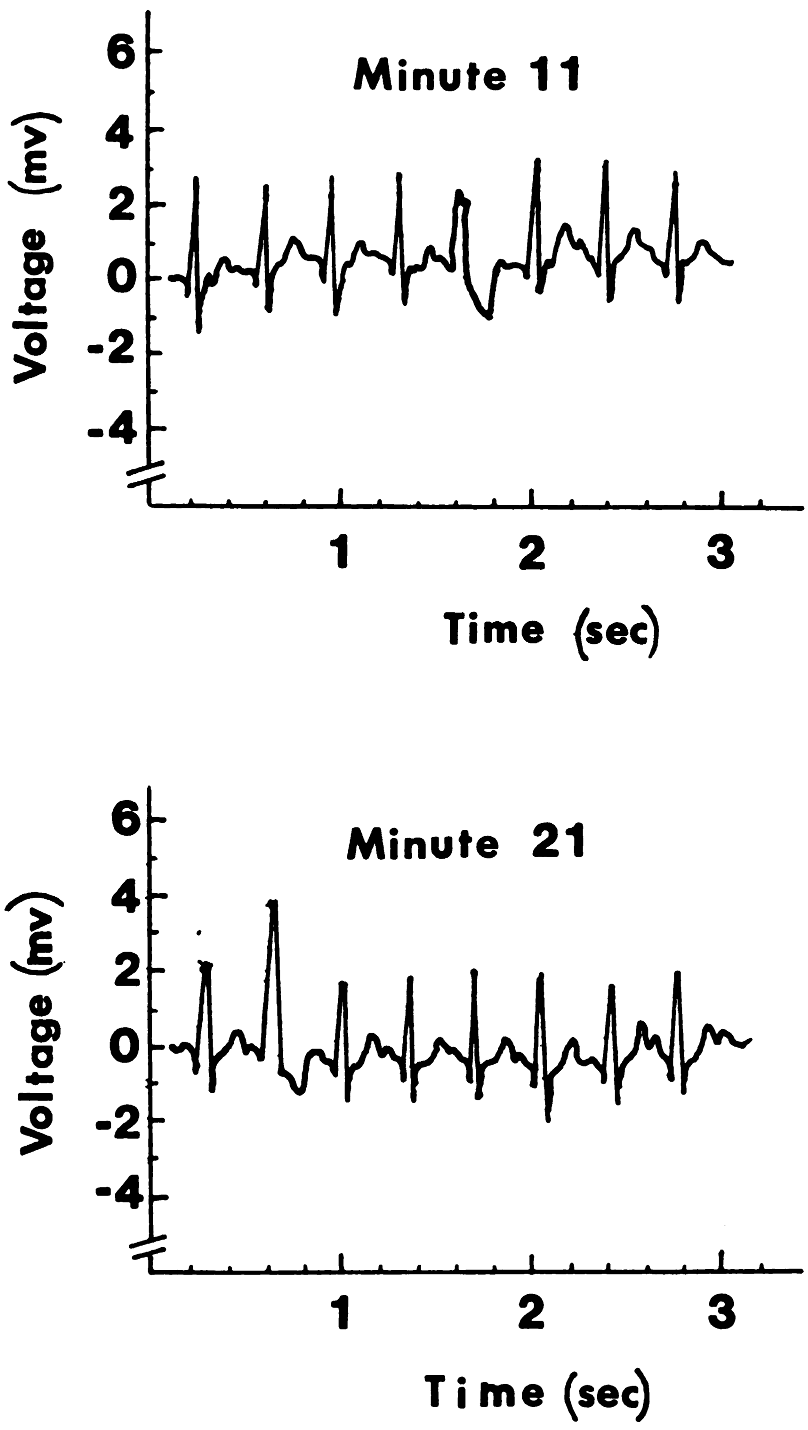


Figure 6. Electrocardiographs from subject with mitral valve stenosis for minutes eleven and twenty-one.

post warm-up value. The mean absolute value for the control and experimental runs were 2.05 ± 1.45 mMol and 2.03 ± 1.60 mMol of blood lactate respectively. When measuring lactate as a percentage of the post warm-up value, the mean value for the control run was determined to be 1.07 ± 0.91% and for the experimental run it was 1.11 ± 0.90%. In both instances of computation, no significant differences were obtained between the two treatment values.

DISCUSSION

Research investigating the effect of hand cooling during strenuous exercise is limited. This lack of information provided a need for further research in this area. The complexities in thermal and circulatory regulation during exercise are clearly evident and afford many possible interactive effects with various methods of cooling the body.

Discussion of the data will follow the three major divisions utilized in the presentation of the results: (1) descriptive and environmental condition data, (2) cardiorespiratory data and (3) metabolic data.

Part I: Descriptive and Environmental Data

The subjects in this study were trained male distance runners. Their physiological characteristics were similar and they were a relatively homogeneous group. The results indicated a profile typical of trained distance runners. The magnitude of physiological response to cold application by this group of trained subjects supports the findings of LeBlanc et al. (25) in which the degree of response was negatively related with fitness level.

The environmental parameters assessed did not afford additional uncontrollable variability due to the stability of these elements over the course of the study. Therefore, these parameters cannot be considered as potential causes for the variations assessed.

Part II: Cardiorespiratory Data

Heart rate response during both constant velocity runs were shown to increase over time. The response during the control run demonstrated a plateau effect beginning at approximately fifteen minutes and continuing for the duration of the run. The small increases in heart rate during the control run are nominal following the initiation of the plateau.

Unlike the findings during the control run, heart rate continued to elevate over time at a more rapid rate in the experimental run. Although the elevation in heart rate during the first bout of cold was not significantly different from the control run, it was maintained following removal of the ice and subsequently allowed for higher elevations in heart rate throughout the experimental run. Additionally, a heart rate pattern which consisted of an elevation upon intiation of cold followed by a slight depression with the release of the cold hand weights was shown to occur in the present study. These results support the findings of Frey et.al. (12), and LeBlanc et.al. (25) relative to heart rate response patterns with localized cold application. The rapid rate at which this response to cold application occurred supports the findings of Riggs et.al. (37) and would be in line with their hypothesis that the probable mechanism for this variation is neurogenic in nature.

Analysis of Figure 2 showed that the changes that occurred in heart rate over time are distinct. Heart rate following removal of the cold hand weights was higher than prior to application and this new heart rate value was the starting point for a continued increase in the heart rate. If one projects this linear trend for both runs, control and experimental, for another fourteen minutes further discrepancies are evident in heart rate between runs (Figure 3). Should this phenomenon indeed exist and be maintained over time, the negative effect of repeated bouts of hand cooling on performance would be clearly evident.

The response in respiration rate was not inconsistent with the physiological adaptations associated with an increase in workload. The subjects, as a group, did not adjust their respiration pattern due to the cold. Previous investigations indicated individual alterations due to cold which were evident in these findings as well (15).

Oxygen uptake for both treatment runs indicated that a steady-state level was achieved. The peak in oxygen consumption during the experimental run at the initiation of the second bout of cold may suggest that a critical level in some physiological parameter must be achieved prior to a cold induced response in oxygen uptake. This critical level may be related either to heart rate or body temperature but no conclusive evidence exists in the present results. Speculation based on the pertinant literature coupled with the present findings suggests that heart rate levels may be the mediating factor in overall response. More pronounced physiological variations occurred due to the cold application during the second bout of cold exposure than in the first bout of cold. A third bout of cold application may have aided in determining the existance of this critical level phenomenon and its mechanism of action.

Although the oxygen consumption data suggests that a steady-state level had been achieved during both treatment runs, analysis of the $\dot{V}_E/\dot{V}_{O2}$ and $\dot{V}_E/\dot{V}_{CO2}$ data is inconsistent with this finding. Both the $\dot{V}_E/\dot{V}_{O2}$ and $\dot{V}_E/\dot{V}_{CO2}$ continued to rise throughout both of the treatment runs suggesting that the subjects were beginning to fatigue. A probable cause for this finding has yet to be determined.

Significant changes in respiratory exchange ratio due to cold application were indicated. The significant differences associated with the second bout of cold application again suggested that a critical level must be achieved in some parameter prior to the initiation of a significant response in respiratory exchange ratio. As previously stated, heart rate was indicted as this factor. Although the first bout of cold did not induce a significant change in respiratory exchange ratio, a clear trend in the data existed. Increased variability in the early stages of the runs may be the cause for this lack of significance.

The electrocardiographic abnormalities in the subject with mitral valve stenosis, as stated previously, are inconclusive. A relationship between cardiovascular function and the cold has been investigated by many authors (6,10,11,12,26,37). Changes in the electrocardiogram of diagnosed cardiac patients has been documented, by these researchers, as it relates to cold exposure. Angina pectoris is a common result when a cold environment and exercise are combined in cardiac patients. Thus, the problem of ice and ice water use during running road races becomes one of individual differences. Trained individuals with no history of cardiovascular abnormalities seem to be protected from any potential negative effects of the cold application.

Part III: Metabolic Data

Blood lactate values determined in the present study are not supportive of earlier finding by Riggs et.al. (37) and Holmer and Bergh (19) which indicated a rise in blood lactate associated with cold application. Significant differences in this parameter between cold exposure and ambient temperature has been clearly documented in these earlier works. A possible explanation for the discrepancy is the fact that the previous authors used a different cooling medium, cooled wind and cold water immersion, respectively.

Finally, it should be noted that a psychological component may be involved in the subjective interpretation of the cold for individual subjects. Verbal responses following the experimental runs suggested a positive reaction from most subjects to the cold treatment. This parameter was not assessed objectively but may aid in the understanding of the use of cold by road race participants.

The results in this study would suggest that the changes in cardiorespiratory and metabolic parameters which occur are not sufficient to positively or negatively effect performance. However, speculation based on the trends in heart rate indicated possible negative performance effects if the present patterns continued over time. The fluctuations in heart rate, oxygen uptake and respiratory exchange ratio associated with cold application indicate that physiological adjustments occurred due to the cold. The magnitude of these responses, which has been linked with levels of fitness, was minimal and therefore may suggest that a higher level of fitness may be a protective factor from cold induced physiological variations.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The purpose of the present study was to determine the effects of hand cooling on metabolic and cardiorespiratory variables during strenuous exercise. The subjects for the study included nine actively training male runners aged nineteen to thirty-eight (mean 24.7 $\pm$ 5.3 years). Each subject served as his own control and ran three runs on the treadmill. The first run for each subject was a maximal run to exhaustion. The data from this run was used to determine the pace for the following two thirty minute constant velocity runs. A work intensity of 80-85% $\dot{V}_{O2max}$ was determined for each subject and this pace was maintained throughout both thirty minute runs. Subjects carried hand weights of either room temperature or cold (-1 - 2 degrees Celcius) temperature during the constant velocity runs. The hand weights were changed for another set at minutes ten, twelve, twenty and twenty-two for both runs. The temperature of the weights at minutes ten and twenty was dependent upon the run type, control or experimental, with room temperature weights being applied at minutes twelve and twenty-two reguardless of the nature of the run.

Collection of expired air, heart rate, respiration rate, EKG, and blood lactate data was performed during all runs. These parameters were analyzed and oxygen uptake, respiratory rate, heart rate, ventilatory equivalents and respiratory equivalent ratios were calculated.

Analysis of variance results for minutes eight to fourteen and eighteen to twenty-four indicated significant treatment effects in heart rate, oxygen uptake and respiratory exchange ratio. Graphical presentations of the heart rate and respiratory exchange ratio showed a distinct pattern for both parameters although not all mean values were significantly different. Between subject differences were found to exist for mean heart rate, respiratory exchange ratio, respiration rate, oxygen uptake and ventilatory equivalents.

CONCLUSIONS

Application of ice packs on the palmer surface of the hand during a bout of strenuous exercise was shown to significantly effect heart rate and respiratory exchange ratio upon repeated localized cold application. No significant effects of this treatment were found to exist for blood lactate concentration, oxygen uptake, ventilatory equivalent of oxygen and carbon dioxide or respiration rate.

Analysis of the present results suggests that the repeated utilization of ice packs during strenuous exercise by trained males may have negative effects on heart rate and respiratory exchange ratio. It should be noted however, that the magnitude of response, in these parameters, was minimal although a pattern of increasing response with repeated bouts of cold may exist. The electrocardiographic abnormalities evidenced by the subject with mitral valve stenosis suggests that individuals predisposed to cardiorespiratory abnormalities might be cautioned as to the use of ice or ice water but the results are inconclusive. The lack of significant difference in specific performance parameters such as oxygen uptake and ventilatory equivalent of oxygen suggest that a single bout of cold application has relatively nominal negative effects on performance. However, conclusions regarding the effects of multiple bouts of localized cold application on performance cannot be made until a more extensive exercise time course is assessed.

RECOMMENDATIONS

Because of the practical implication relative to the use of ice or ice water during exercise, investigation in this area must be continued. Further studies of this nature should investigate multiple bouts of ice application over a longer exercise time course to determine if the linear trend in heart rate continues and subsequent negative effects in performance parameters are noted.

Further investigations should also monitor blood pressure response, temperature of the palmer surface and sympathetic nervous system activity throughout the study. Research should be initiated using both male and female subjects to further examine any gender linked responses to the application of cold. Various levels of fitness should also be examined further to allow for a larger population to whom the results can be generalized.

APPENDICES

APPENDIX A

INFORMED CONSENT FORM

MICHIGAN STATE UNIVERSITY

CENTER FOR THE STUDY OF HUMAN PERFORMANCE

Informed Consent

The exercise test(s) and measurement procedure(s) to be used in the study of Jaci VanHeest have been explained to me. I agree to serve voluntarily as a subject in the research described. I understand that this research is being undertaken to further knowledge concerning the responses of individuals to exercise regimens.

I understand that some physical discomfort may be experienced and that no beneficial effects are guaranteed. I further understand that certain inherent risks are associated with any test of physical capacity. These risks include, but are not limited to, orthopedic injuries, abnormal blood pressure, fainting, disorders of heart beat, and very rare instances of heart attack. I understand every reasonable effort will be made to minimize these risks and that emergency procedures and trained personnel are available to deal with unusual situations that may arise.

I have had an opportunity to ask questions regarding the test(s) and procedure(s) to be used. Furthermore, I have been informed that I am free to withdraw my consent and to discontinue my participation at any time.

I understand that group results may be used in scientific publication(s) with my anonymity assured, that the data of individuals will be treated in strict confidence, and that my results will be made available to me upon my request.

I understand that if I am injured as a result of my participation in this research project, Michigan State University will provide emergency medical care, if necessary, but these and any other medical expenses must be paid from my own health insurance program.

______________________________ Subject Signature

______________________________ Investigator Signature

__________________ Date

__________________ Date

APPENDIX B

HYDROSTATIC WEIGHING TECHNIQUE

The hydrostatic weighing technique used at Michigan State University's Center for the Study of Human Performance determines underwater lung volume using an adaptation of the closed-circiut nitrogen dilution method of Lundsgaard and VanSlyke. Body density is then calculated by the Buskirk formula. An estimate of intestinal gas in milliliters is made by multiplying the body weight in kilograms by 1.4. Percent body fat is then calculated using the Siri formula (44).

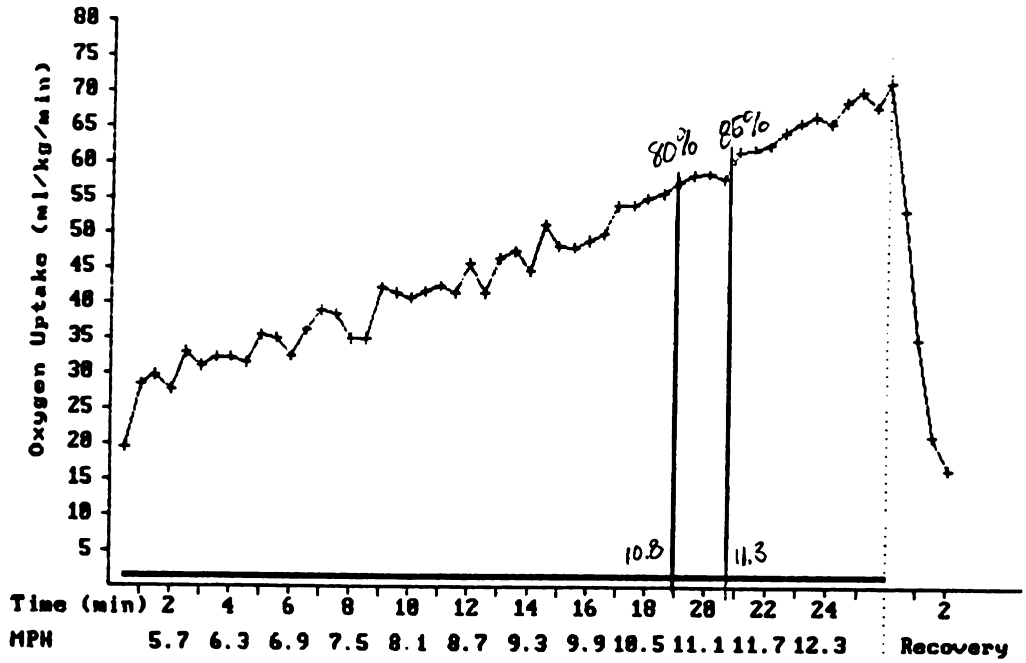
Subjects were weighed in their bathing suit following land weight measurement. Each subject repeated the procedure three times and the average body density and body fat percentrage values were determined. Body composition was assessed during the second testing session for all subjects.

APPENDIX C

METHODOLOGY FOR THE DETERMINATION OF RUNNING VELOCITY FOR THE THIRTY MINUTE CONSTANT VELOCITY RUNS

Data from Subject EP:

Maximal Oxygen Uptake:	73.3 ml/kg/min
85% Max. Oxygen Uptake:	62.3 ml/kg/min
80% Max. Oxygen Uptake:	58.6 ml/kg/min
Velocity at 85%:	11.3 mph
Velocity at 80%:	10.8 mph
Running speed:	11.0 mph



APPENDIX D

DATA FROM COVARIATE ANALYSIS

Variable	Control	Experimental
Heart Rate	166 ± 11.79	167 ± 12.76
Respiration Rate	44 ± 5.48	43 ± 7.09
Oxygen Uptake	54.3 ± 3.19	52.5 ± 3.76
Respiratory Exchange Ratio	0.86 ± .02	0.86 ± .03
Ventilatory Equivalent of Oxygen	21.5 ± 1.19	21.6 ± 1.40
Ventilatory Equivalent of Carbon Dioxide	25.12 ± 1.56	25.24 ± 1.41

- Values compared were taken from raw data at minute seven into the thirty minute runs.
- No significance was attained at ($p < .05$).

APPENDIX E

RAW DATA FROM HEART RATE, OXYGEN UPTAKE AND RESPIRATORY EXCHANGE RATIO

HEART RATE DATA:

Minute	Control	Experimental
8	168 ±17	167 ±11
9	168 ±11	168 ±10
10	169 ±10	171 ±11
11	169 ±10	172 ±10
12	172 ±9	167 ±9
13	171 ±11	168 ±11
14	170 ±11	171 ±10
18	171 ±11	173 ±10
19	173 ±12	173 ±9
20	173 ±13	177 ±8
21	172 ±10	178 ±9
22	170 ±9	171 ±9
23	172 ±11	174 ±9
24	172 ±12	175 ±9

OXYGEN UPTAKE DATA:

Minute	Control	Experimental
8	54.22 ±2.44	52.48 ±2.89
9	54.38 ±2.60	52.14 ±3.04
10	54.79 ±3.29	52.62 ±3.27
11	54.79 ±3.10	52.41 ±2.97
12	54.05 ±3.61	52.73 ±2.55
13	54.26 ±2.33	52.72 ±2.79
14	54.35 ±3.49	52.41 ±2.61
18	53.55 ±2.83	52.15 ±2.97
19	54.34 ±2.53	52.26 ±3.52
20	53.67 ±3.08	53.59 ±2.82
21	53.96 ±3.57	53.06 ±1.88
22	53.57 ±3.00	52.46 ±4.00
23	53.78 ±3.38	52.02 ±2.78
24	54.22 ±2.80	52.28 ±2.80

RESPIRATORY EXCHANGE RATIO DATA:

Minute	Control	Experimental
8	0.86 ±.02	0.86 ±.03
9	0.86 ±.03	0.86 ±.03
10	0.87 ±.03	0.89 ±.02
11	0.87 ±.03	0.89 ±.03
12	0.87 ±.02	0.87 ±.03
13	0.87 ±.02	0.86 ±.02
14	0.86 ±.02	0.87 ±.02
18	0.87 ±.03	0.87 ±.02
19	0.87 ±.02	0.87 ±.02
20	0.87 ±.03	0.89 ±.02
21	0.87 ±.02	0.89 ±.02
22	0.87 ±.02	0.88 ±.03
23	0.86 ±.03	0.86 ±.03
24	0.86 ±.02	0.86 ±.02

APPENDIX F

ELECTROCARDIOGRAPHS FROM SUBJECT WITH MITRAL VALVE STENOSIS

Physiological Characterists of the Subject:

Subject Number Five: JH

Age: 38

Height: 176.6 cm

Weight: 77.90 kg

Body Fat Percentage: 17.56%

Maximal Oxygen Uptake: 61.0 ml/kg/min

Resting Heart Rate: 54 bpm

Maximal Heart Rate: 184 bpm

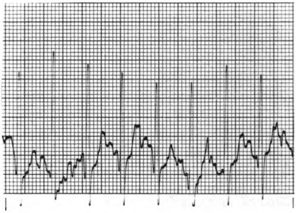
PRE-EXERCISE: Seated

CONTROL

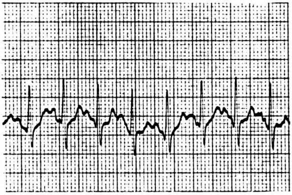
EXPERIMENTAL

MINUTE 10:

CONTROL

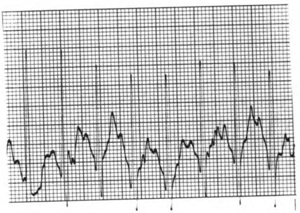


EXPERIMENTAL



MINUTE 11:

CONTROL



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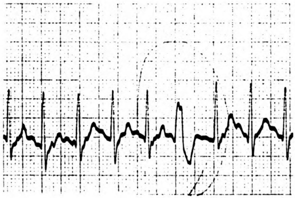

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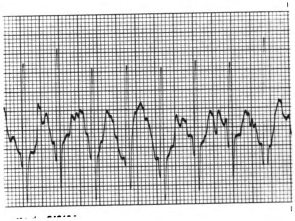
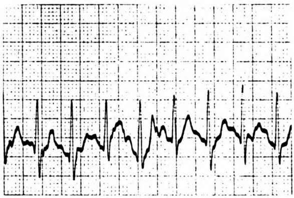


EXPERIMENTAL



MINUTE 21:

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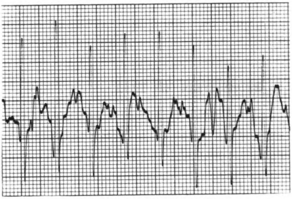

EXPERIMENTAL

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