

SELECTED PHYSIOLOGICAL AND PERCEPTUAL RESPONSES  
OF MALES DURING PROLONGED EXERCISE

by

Patricia Dean Wilson

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APPROVED:

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William G. Herbert

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George A. Clum

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Janet L. Walberg

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Blacksburg, Virginia

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(ABSTRACT)

Six males of similar body composition and aerobic physical fitness were tested to determine their perceptual responses to exercise and the relation of these perceptions to core temperature ( $T_{re}$ ) under three conditions of thermoregulatory stress. The experimental protocol consisted of 120 min of upright stationery cycling at 50%  $VO_2max$  under conditions of neutral (24°C, 50% RH/hydration (NH)), hot (35°C, 50% RH/hydration (HH)), and hot (35°, 50% RH/hypohydration (HP)). Perceptual responses were determined by Borg's 10-point category ratio scale (1980) and by a multi-dimensional symptom scale which contained six symptoms commonly associated with heat stress: weakness; fatigue; thirst; irritability; headache; and dizziness. Core temperature responses and perceptions were obtained throughout exercise in each condition. An analysis of variance was utilized to determine if significant differences existed between  $T_{re}$  responses, symptom scale responses and RPE responses in each condition. Analysis of variance revealed statistically significant ( $p < 0.05$ )

differences between  $T_{re}$  responses in the three conditions. Statistically significant ( $P < 0.05$ ) differences were also found for the symptom scale responses of thirst and weakness. Regression analysis within each condition was utilized to evaluate the relationship of  $T_{re}$  and RPE responses and of  $T_{re}$  and the combined scores of weakness, fatigue and thirst. The regression analysis revealed an  $R^2$  of .997 for prediction of  $T_{re}$  using RPE data in the HP trial; the  $R^2$  for  $T_{re}$  prediction from the symptom scale responses in HP was .992. The  $R^2$  values for prediction of  $T_{re}$  in the NH and HH conditions were .953 and .983, respectively. The  $R^2$  obtained in the HH and NH conditions were lower than those  $R^2$  obtained in the HP trials for both the RPE and symptom scale predictors. These data suggest that RPE is a meaningful predictor of  $T_{re}$  increases i.e., given a particular RPE, the model gives a meaningful estimate of  $T_{re}$  within the range of core temperatures that were observed.

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Chapter I  
INTRODUCTION

One of the most serious consequences of prolonged work in the heat is the possibility of heat injury. Recent attention has been directed to the type of heat illness that occurs in otherwise healthy individuals during intense physical activity (14,24,35). Heat exhaustion and related heat injuries are commonly evidenced in runners competing in long distance races. The incidence of heat injury in race participants is probably less than one percent, but at that rate, 50-200 heat casualties may occur in some large warm weather events (32,46). In the past, the majority of these injuries have occurred in warm weather; however, the increase in the number of participants in road races has resulted in episodes occurring in less extreme conditions (32). Novice runners in particular appear to be more prone to exertional hyperthermia when compared to runners with more experience (29). Also, increasing one's running pace and attempting to complete distances exceeding one's normal training level in attempts to finish a race may accentuate the possibility of heat injury (22).

The evaluation and management of heat illnesses has become a major medical concern and has prompted interested

researchers to develop guidelines which enable the race organizers to provide a safer racing environment (33). It is imperative that provisions be made for handling emergencies of varying severity. The most common type of heat illness experienced by runners is heat exhaustion, which is characterized by moderate to severe volume depletion and may be accompanied by headache, weakness, nausea and irritability. The treatment of heat exhaustion consists of administering either normal or isotonic glucose solution in accordance with the proportion of salt or water losses (27). The patient is usually discharged after adequate fluid replacement and return of orthostatic blood pressure to normal.

At the other extreme is heat stroke and although the least common, it is the most severe form of heat illness. It is a life-threatening emergency carrying an 80% mortality rate (27). Heatstroke is characterized by hyperthermia, altered cerebral function, and hypohidrosis (40). Rectal temperatures may range from 40.0 to 43.0°C, and may be used to differentiate heatstroke from other possible causes of mental aberrancies such as hypoglycemia or heat exhaustion (21). Initial treatment involves immediate cooling and fluid therapy. Complex hematologic and biochemical alterations may occur and the patient should be observed

closely for widespread complications including acute renal failure, myocardial infarction, thermal hepatitis, cerebral edema and rhamdomyolysis coagulations (21).

These occurrences require prompt medical treatment and it is essential that medical personnel and emergency transportation be available to handle such emergencies. These conditions are vital to race planning. Also, of extreme importance are preventive measures which include participant education. Information should be presented to the competitors advising them of the importance of prior training, heat acclimatization, fluid replacement, type of clothing to wear, environmental considerations, and running pace (1). Important to both race personnel and participants is the ability to recognize heat stress symptoms such as fatigue, dizziness, nausea, and irritability. The runner's ability to perceive the effort experienced during a run may be essential in preventing heat injuries.

Effective methods for evaluating perceived exertion during physical activity have evolved over the past two decades. Borg has devised several scales which have been useful in allowing individuals to estimate their feelings of stress, effort and fatigue (6,7,8). The results of his research have been applied to regulate intensity in clinical, exercise and sport situations.

In summary, individuals participating in prolonged activities in the heat may suffer from heat related injuries. Guidelines are presently available which provide suggestions for a safer exercise environment; however, competitors frequently ignore or are unaware of premonitory symptoms associated with heat exhaustion. They may continue to exercise, despite escalating heat stress, thereby enhancing the possibility of heat injury or possibly heat death.

#### Statement of the Problem

To minimize the occurrence of heat injuries experienced during prolonged work in the heat, more effective techniques for prevention are indicated. Perhaps by monitoring an individual's signs and symptoms experienced during heat stress a systematic method of predicting which preliminary sensations and physical manifestations are likely to forecast heat exhaustion can be developed. This study will investigate the rate of perceived exertion and appearance of untoward signs by experimentally manipulating core temperature by withholding fluids or manipulating external heat load.

### Research Hypotheses

1.  $H_0$ : The perception of effort in prolonged aerobic exercise performed at 50%  $\dot{V}O_2\text{max}$  on a bicycle ergometer does not differentiate the conditions under which exertional hyperthermia are likely to develop.
2.  $H_0$ : The signs and symptoms experienced during prolonged exercise at a workload of 50%  $\dot{V}O_2\text{max}$  on a bicycle ergometer does not differentiate the conditions under which exertional hyperthermia are likely to develop.

### Delimitations

The following delimitations were imposed:

1. Exercise was terminated when subject's core temperature reached 39.5°C;
2. Only six male participants served as subjects;
3. Selection of subjects was restricted to males aged 22 to 35 years and only subjects whose percent body fat was less than 16% and maximal oxygen uptake was at least 40  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$  were included. Moreover, participation was also restricted to subjects whose habitual level of training was equivalent to 10-15 miles per week;
4. The mode of physical activity was restricted to bicycle ergometry. In addition, the work intensity during the experimental trials was 50% of maximal  $\dot{V}O_2$  and cycle time was terminated at 120 minutes.

### Limitations

1. Due to the core temperature limitations imposed in this study, the findings are applicable to this particular sample of subjects;
2. Due to the small number of subjects in the study, the findings are applicable to this particular sample of subjects;
3. Due to certain characteristics related to these subjects, i.e., age, frequency of training, percent body fat, and  $\dot{V}O_2$ , the findings are applicable to this particular sample of subjects;
4. Due to the mode of physical activity, the intensity level and time restraint imposed upon the exercise, the findings are applicable only to this particular study.

### Definitions

1. Heat exhaustion: One of the most common forms of heat stress most often characterized by symptoms of fatigue, dizziness, headache, weakness, irritability, and thirst.
2. Heat stroke: The most severe but least common form of heat injury which is characterized by hyperthermia, hypohidrosis, and altered cerebral function (40).
3. Rate of perceived exertion: Rating scale developed by Borg which can be used to subjectively rate an individual's effort perceived during exercise (6).

4.  $\dot{V}O_2\text{max}$ : A person's peak rate of oxygen consumption achieved during maximal intensity exercise. The  $\dot{V}O_2$ , calculated in  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , expresses the capacity of the heart and lungs to deliver oxygen to active muscles (3).

#### Significance of the Study

Heat illnesses resulting from prolonged physical activity in high environmental temperature is not uncommon among runners in long distance races. The increase in the number of heat-related emergencies in recent years has prompted researchers to develop more effective evaluation, management and treatment techniques.

A majority of efforts are directed towards educating the runner about medical aspects of distance races. They are encouraged to recognize perceptual antecedents and signs accompanying intense physical activity in high environmental temperatures in themselves and fellow competitors.

If a systematic method of identifying the symptoms associated with heat exhaustion were available, runners and race organizers may recognize signs and symptoms more effectively and adjust their activity level accordingly so that heat stress might be avoided and the race completed safely.

## Chapter 2

### LITERATURE REVIEW

Recent literature has indicated that individuals who engage in strenuous prolonged activities under high environmental temperatures may be susceptible to heat injury. In this chapter, the various physiological and psychological responses which are associated with exercise-induced heat stress is discussed. The chapter is organized into the following sections: thermoregulation and fluid balance; signs and symptoms of heat stress; and perceptual responses to work in the heat. The first section contains a general review of various physiological responses occurring during strenuous activity in a hot environment. The second section includes the signs and symptoms associated with heat exhaustion and heat stroke. The final section emphasizes perceived exertion responses under conditions of work in the heat and includes a review of scales which have been previously employed for evaluating a subject's perceptions and feeling of effort during exercise.

#### Thermoregulation and Fluid Balance

Much study has been directed to understanding man's physiological responses to work in the heat (38). Under conditions of resting metabolism, the body maintains a

normal fluid balance and body temperature. However, during sustained exercise under conditions of environmental heat stress, progressive dehydration and hyperthermia occur. The temperature regulating system of the body can maintain these responses until the heat gain exceed the heat dissipation capabilities, and beyond this point, progressive dehydration contributes to further increases in body heat storage and resultant increases in core temperature. Strydom and Holdsworth (44) suggest that the more severe the level of dehydration under exercise conditions, the higher the body temperature. In addition, Costill and Sparks (3) have shown that dehydration of more than two percent water deficit can significantly impair performance. In a more recent study, Wyndham (52) found a linear increase in rectal temperature in subjects performing prolonged exercise, as soon as their dehydrative weights exceeded three percent. To combat the undesirable effects of dehydration, such as increased core and skin temperature and increased heart rate, researchers have suggested that runners should consume fluids while exercising to replace body water losses from sweating. Furthermore, Moroff and Bass (30) have shown that water administration in excess of need improves performance. In addition, research by Costill, Krammer and Fisher (12) indicates that fluid replacement should be provided in

regular fluid feedings during exercise and ideally should equal the body water lost through sweating.

Unfortunately, individuals are often reluctant to replace body water losses, especially those competing in athletic events. For example, the average runner may lose up to 1.5 to 2.5 l of water during each hour of active sweating and fluid intake by most runners seldom is adequate to replace even 50% of this loss (11). Still others may find themselves in a situation where the water supply is limited or unavailable. The performance of strenuous activity under these conditions has been notorious for heat injury as in the blacks in the South African mines (45). This problem of inadequate water supply also exists for military personnel, especially among recruits where the requirement of forced physical exercise often exceeds their tolerance.

Illness attributed to heat is a serious health hazard and has the propensity to occur in catastrophic numbers. Literature is available which sites incidents where hundreds of fatalities have occurred as a result of environmental heat stress. For example, the yearly pilgrimage to Mecca has resulted in large numbers of fatalities from heat illness (20). Large numbers of unacclimatized urban dwellers have suffered when urban areas have been involved

in heat waves (16,17,23). In fact, summer heat alone kills 4,000 or more people per year in cities and other humid areas of the United States (39). A number of factors predispose the risk of heat stress injury, i.e., alcoholism, heart disease, obesity, and incidental fever, and although 80% of deaths occur in people over 50, an appreciable mortality exists among healthy young people subjected to hard physical work in a hot environment (10).

As a result, much of the recent literature has been directed to the type of heat illness that occurs in physically conditioned young men. Heat illness is common among athletes competing in prolonged endurance activities. In runners alone, it has become a major medical concern with 50 to 100 heat-related incidents occurring in some large road race events (32,46). Heat illness can be classified into three conditions and it is of predominate importance that they be diagnosed correctly since the physiologic disturbance and management of each is different.

Heat cramps are the least serious of the three conditions. Early research dealing with heat cramps tend to refer to Talbott's article in which the clinical picture has been described as repeated and recurrent extremely painful muscle cramps occurring in conscious patients following exertion under heat stress (47). The paroxysms of painful

cramping tend to last no more than a few minutes and appear spontaneously. Most individuals who sustain heat cramps soon discover that ingestion of salt is successful in their prevention. In the event of severe and unrelenting cramps, oral or intravenous salt solutions rapidly relieve symptoms (27).

Another form of heat illness is heat exhaustion, which is the most common clinical disorder resulting from hard work in a hot environment. It differs from heat cramps in two respects: First, it is accompanied by systematic symptoms and, second, it tends to occur in unacclimatized individuals. Heat exhaustion is characterized by moderate to severe volume depletion and its symptoms often include headache, dizziness, nausea, irritability, fatigue, thirst and weakness. If left untreated or ignored, marked central nervous system dysfunction eventually becomes more prominent and may be manifested by hyperventilation, hysteria, muscular incoordination, and in some cases, frank psychosis (27). Terminally, patients demonstrate delirium, hyperthermia and coma, which may terminate in heat stroke.

Physical examination show rectal temperatures elevated to 39-40°C, but below 41°C. Circulatory status is characterized by a narrow pulse pressure and a rapid pulse averaging 120-140  $\text{bts}\cdot\text{min}^{-1}$ , however, bradycardia may be seen in highly conditioned runners (22).

The treatment of heat exhaustion consists of administering either normal or isotonic glucose solution in accordance with the proportion of salt or water losses (27). If there are no complications, the patient is usually discharged after adequate fluid replacement and return of orthostatic blood pressure to normal.

The third form of heat illness experienced by runners is heatstroke and although the least common, it is the most severe, carrying an 80% mortality rate (27). Heatstroke is characterized by hyperthermia, altered cerebral function, and hypohidrosis (40). It is evident that heat stroke can occur in persons who are perfectly healthy, highly conditioned and acclimatized when the means to dissipate heat is exceeded by endogenous heat production. Rectal temperatures during heat stroke may range from 40 to 43°C, and may be used to differentiate heat stroke from other possible causes of mental aberrancies such as heat exhaustion or hypoglycemia (21).

Loss of consciousness may also be used to distinguish heat stroke from heat exhaustion and may occur in some individuals with little warning. On the other hand, premonitory symptoms of headache, dizziness, weakness and mental confusion may precede collapse. Consciousness, may return early if cooling is instituted immediately (39).

Coma persisting as long as 24 hrs may be followed by recovery without evidence of mental or neurologic impairment. Unfortunately, there are cases, despite immediate vigorous treatment, in which a number of complications may occur as a result of thermal cellular injury and circulatory changes. Complications include widespread tissue injury to heart, liver, kidney and blood coagulation systems.

Survival from heat stroke depends largely upon maintenance of cardiac output sufficient to meet elevated circulatory demand. Acute circulatory failure has been observed to precede death in 80% of the cases (4,49). In addition, it has been observed that individuals with cardiovascular disease tolerate heat very poorly (27). O'Donnell and Clowes (36) observed eight marine recruits suffering from heat stroke and found victims' circulatory pattern resembles the previously defined low peripheral vascular resistance and high circulatory demand. Physical examination reveals initially a rapid pulse with a wide pulse pressure. Extreme tachycardia above 120 is common and rhythm disturbances may occur. The electrocardiogram may display flattened or inverted T waves and ST segment depression. Costrini et al. (14) observed marine recruits who had experienced heat stroke during basic training and

found ST segment depression compatible with anteriolateral ischemia in two patients. In six of twelve EKGs of heat stroke patients, borderline QT intervals were demonstrated. Myocardial damage is common in heatstroke and best reflected by elevated serum levels of cardiac specific enzymes. Subendocardial hemorrhages have been described and rupture of cardiac muscle fibers can further complicate condition.

Acid-base disturbances are also a common feature of heat stroke and in patients with heat stroke associated with exertion, metabolic acidosis may be profound and largely due to the accumulation of lactic acid (42). Also common to heat stroke are disturbances in blood coagulation. These disturbances may arise on the first day, but generally appear the second or third day of heat stroke. Manifestations include thrombocytopenia, prolongation of bleeding and clotting times, lowered plasma fibrinogen and prothrombin levels and increased fibrinolytic activity (50).

Evidence of kidney damage is very common in patients with acute heat stroke. In patients with heat illness induced by exertion, acute renal insufficiency occurs in approximately 25% of the cases (35). A large array of conditions exists that could conceivably contribute to the pathogenesis of acute renal failure. Thus, they may be partly dehydrated, excrete an acidic urine, and are often

hyperuricemic despite the excretion of larger quantities of uric acid than normal in their urine (27). Most patients apparently sustain no more than acute tubular necrosis and recover fully.

Heatstroke is also responsible for liver damage and skeletal muscle damage. Juandice occurs commonly in patients surviving more than two days, however, there is usually no residual impairment and complete recovery is possible.

Kew and co-workers (26) examined SGOT, SGPT, LDH, and CPK activities in 53 heat stroke patients and found substantial elevations in all. Their data suggest that SGOT levels of less than 1,000 units indicated a favorable outcome, whereas higher values were associated with severe complications and death.

The initial treatment of heatstroke involves two principle objectives. First, the immediate elimination of hyperpyrexia and then the support of vital organ systems. Wyndham (57) has shown that mortality rate increases significantly as cooling is delayed. Clothing should be removed and patient cooled by any means, but as soon as possible, put in an ice bath and massaged vigorously. This is the most effective means of rapid lowering of body temperature. The patient should be removed from the ice bath as soon as the core temperature reaches 38.3°C.

Although dehydration is not common in acute heatstroke, prolonged sweating may lead to severe dehydration in some cases and may be the primary cause of death. In such circumstances, Ringer's lactate is administered cautiously.

Fluid therapy should be guided by hourly urine output, serum electrolyte values, hematocrit and cardiovascular pressure. If acute renal failure is anticipated, mannitol may be given to increase urine flow. Heatstroke victims should be hospitalized for at least 36 hrs so that potential secondary complications can be identified (22).

Individuals vary in their ability to tolerate heat loads, but four principle factors exist which can affect the possibility of heat stroke: environment, including ambient temperature, humidity and wind velocity, isolation and clothing; water intake; previous recent acclimatization to heat; and speed and duration of run. Guidelines are available which currently suggest temperature limitations for conducting a race, however, these are not fool proof for injuries have occurred even in temperate climates. Loose clothing is suggested because impermeable clothing does not allow for heat dissipation and brings about increases in body temperature. Football players should be warned about these considerations for they often practice in full heavy gear. Water intake, as mentioned previously is recommended

prior to and during physical exertion. It has been found that when subjected to heat stress, man will not drink enough fluids and suffer from voluntary dehydration (2). Overhydration has, in fact, been found to be beneficial during physical exertion in the heat (30).

Acclimatization plays a major role in an individual's tolerance of heat load. During this period, changes in endocrinologic, renal, and circulatory mechanisms occur which enable one to tolerate the heat load more efficiently.

The speed and duration of a run should be carefully considered by an individual competing in a road race. Prior training level times should be evaluated before undertaking a race. Morgan and Pollock (29) suggest that the inexperienced runner may be more prone to heat injury because such runners may disassociate from the unpleasant symptoms of work and may not be as successful in adjusting pace and "reading body signals" when compared to the more experienced runner. In addition, they may ignore evolving symptoms of heat stress and increase their running pace to improve their race finish. Hanson and Zimmerman (22) observed that an increase in metabolic rate, even for a short period may essentially overwhelm the existing capacity of heat dissipation. They observed four cases of heat injury in inexperienced runners competing in road race

events of 10, 16, 32, and 42 km. Each attempted to increase his running pace by approximately  $1 \text{ min/km}^{-1}$  during the last 5 km of the race. Symptoms of heat stroke occurred within 5 to 10 min of the onset of increased effort.

### Perceptual Responses to Work

In an attempt to understand physical performance, one's psychological and physiological attributes should be considered. Perceptual cues serve as the primary information source and exert an important influence on physical performance. The perceived exertion ratings serve as an indication of the degree of physical strain encountered during work. The ratings of physical exertion have been useful in clinical, occupational and sport environments as an index for judging proper work intensity and as an indication of the degree of physical stress encountered during work.

The most widely used application of perceptual response data involves stress testing. Many laboratories use the Borg scale to monitor patients' feelings during a graded exercise test. These perceptions obtained during a stress test may further be used to control exercise intensity during training. Several cardiac programs are currently using RPE for controlling intensities, i.e., Gutman et al., (19) working in a cardiac program at Mt. Sinai Hospital in

Milwaukee observed patients during training following GXT's (graded exercise test) and found that self-selected intensities during training result in RPE comparable to those in GXT's at the same heart rate. In other words, RPE can be effectively used to control exercise intensity. Ratings of perceived exertion have also proved useful in clinical tests if there is some doubt when to interrupt the tests. For example, a particular heart rate is often used as a criterion for stress test termination; however, because of variability in maximal heart rate this level may be stressful for some subjects and only moderately stressful for others. In these cases, the ratings compliment the heart rate and give cues for interrupting tests and also for making changes in increasing the workloads (7,8,9).

Scales for rating perception during exercise have been devised in the past two decades in attempts to measure these perceptual intensities. One method is ratio-scaling in which subjects are asked to increase or decrease a certain variable stimulus until it is perceived to be a fraction of a standard stimulus.

A popular method of ratio-scaling is magnitude estimation (43). With this method subjects are presented with stimuli of different intensities and asked to assign numbers to them in such a manner that the numbers vary directly in proportion to subjective intensities.

One major draw back to ratio-scaling is that it does not provide distinct levels for interindividual comparisons which means in effect, that it is difficult to compare subjects with each other because subjects are asked to make only relative comparisons. To overcome these difficulties Borg (8) developed a 21-grade scale with verbal anchors. It is a category scale which allowed simple, direct estimation of subjective intensity. Another advantage was that it allowed interindividual comparisons. For example, if one subject rated an intensity as "light" it would seem relatively lighter to that person than to someone who says it is "heavy."

Borg (7) later developed a new category scale for ratings of perceived exertion which increased linearly with exercise intensity. In many studies, correlations of ratings and heart rate ranging from 0.80 to 0.90 have been found, but high correlations with other physiological variables have also been found. The scale values ranged from 6 to 20 and can be used to denote heart rates ranging from 60 to 200  $\text{bts}\cdot\text{min}^{-1}$  and was intended to make the scale easier to use because an RPE value of 6 would approximately match a heart rate of 60.

Recently Borg (6) developed a category scale with ratio properties. Like his previous scales, this one is easy for

the lay population to use and the numbers are once again anchored by verbal expressions. Recent studies of this scale have given psychophysical functions of about the same appearance as those obtained with magnitude estimation (6). In another study, close correlation between ratings according to this scale and blood and muscle lactate were obtained (34).

Influence of Environmental Heat on RPE. It is a well known fact that heat stress may be a serious threat to the health and safety of individuals during work and recreation. Even well-trained individuals, such as fire-fighters and those involved in military operations may overexert themselves in hot environments and collapse. A possible explanation for this is that heat stress somehow makes the individual unable to make an adequate judgement of the physiological load he encounters. For example, in training courses recommendations are given to fire-fighters which suggest they lie down and rest when they feel exerted. In spite of this, physically fit and trained individuals tend to overexert themselves.

Based on this assumption, Gamberale and Holmer (18) obtained data in two investigations. The first study was a simulated firedrill, in which 15 men were told to put out a fire and search for and rescue dolls. The duration of

activity was 35 min and air temperature varied between 150°F and 250°F. Heart rate, body temperature and RPE were obtained at various intervals.

The second study investigated 10 subjects who performed two types of exercise; (A) 15 min of work at 50 W on a bicycle ergometer, immediately followed by 15 min at 100 W and (B) a simulated gas accident practice which included running and working for 12 min in an unventilated gas protection suit. To serve as a control, bicycle ergometer exercise was performed without wearing suits. Heart rate, skin and core temperature and RPE were recorded at various intervals. A summary of the two investigations with regard to RPE and heart rate shows that with the exception of exercise on the bicycle ergometer at 50 W, where no appreciable increase in heart rate was attributable to "abnormal" heat storage, the values of RPE seem lower than would be expected if heart rate values were to be considered as representative of the rate of work. Results of this investigation imply that the strain induced by heat stress, which manifests itself in increased heart rate is not followed by an adequate increase in perceived exertion. Thus, the investigators suggest that heat load does not have a sufficient impact on the ratings of perceived exertion comparable to physiological strain it imposes which may

cause someone in a fire-fighting or similar situation of heat stress to overestimate their endurance and collapse.

An earlier study by Skinner, Hustler, Bergsteinova and Buskirk (41) also investigated perceptual responses in a hot environment. They observed eight lean and eight obese men in treadmill and bicycle exercise under different environmental conditions. Measurements of heart rate,  $\dot{V}O_2$ ,  $\dot{V}_e$ , and RPE were obtained at each workload. Their results suggested that subjects who performed aerobic exercise in a hot environment rated their perception of effort at a higher level than at the same workload in a cool environment.

Pandolf, and co-workers (37) also investigated RPE under different environmental conditions. In this study, 10 fit males were exposed to an experimental design that utilized heat to manipulate cardiac frequency. The five treatment conditions consisted of prolonged exercise of various workloads in neutral and hot-dry environments. Pandolf, et al. (37), found no significant differences in RPE during equal work load conditions even though heart rate had been significantly increased by environmental heat.

Subjective Responses In the Heat. At the present time there are no scales which enable investigators to estimate how someone is feeling with respect to symptoms which are commonly associated with heat stress. Adolph and his

associates (2), however, observed and measured signs and symptoms during dehydration of men under desert conditions. By arranging these signs and changes on a scale representing the extent of dehydration, they were able to estimate roughly the body water deficit from the signs seen in a particular instance.

Dehydration was obtained by having men walk in the desert while they refrained from drinking. Observers noted the men's appearance, their remarks and their complaints at hourly intervals. When the men became unable to continue, the outstanding points of their remarks were recorded. The deficit of body weight for each sign and symptom was known and to summarize the observations they ascertained the smallest deficit at which the sign or symptom was recorded. They also developed a frequency distribution which showed the number of instances noted with each percent of dehydration.

In conclusion they found qualitative signs and symptoms become marked at 4 to 6% dehydration and thirst sensations are less distressing than headache, dyspnea and tingling. The information obtained may therefore be used to avoid dehydration or in its diagnosis or prognosis.

### Summary

The possibility of heat stress illnesses occurring during prolonged aerobic activities particularly in a warm environment should be evident. The preceding sections have included reviews of important literature in several research areas. In the initial section, the regulation of body temperature, including the importance of fluid intake during activity was reviewed. In the second section, the pathophysiology of heat cramps, heat exhaustion, and heat stroke were explored. In addition, those factors which may contribute to heat stress illness were covered. Thirdly, it was shown that perceptual responses contribute heavily to physical performance, thus establishing that subjective responses may play an important role in monitoring one's feeling of exertion during exercise.

Chapter III  
JOURNAL MANUSCRIPT

Prediction of Thermoregulatory Strain in Men  
During Prolonged Exercise From Perceptual Responses

Patricia D. Wilson and William G. Herbert  
George A. Clum and Janet L. Walberg

Patricia D. Wilson, William G. Herbert,  
George A. Clum and Janet L. Walberg  
Human Performance Laboratory  
Department of HPER  
VPI & SU  
Blacksburg, VA 24061  
703-961-6565

## ABSTRACT

Six males of similar body composition and aerobic physical fitness were tested to determine their perceptual responses to exercise and the relation of these perceptions to core temperature ( $T_{re}$ ) under three conditions of thermoregulatory stress. The experimental protocol consisted of 120 min of upright stationary cycling at 50%  $VO_2$ max under conditions of neutral (24°C, 50% RH/hydration (NH)), hot (35°C, 50% RH/hydration (HH)), and hot (35°, 50% RH/hypohydration (HP)). Perceptual responses were determined by Borg's 10-point category ratio scale (1980) and by a multi-dimensional symptom scale which contained six symptoms commonly associated with heat stress: weakness; fatigue; thirst; irritability; headache; and dizziness. Core temperature responses and perceptions were obtained throughout exercise in each condition. An analysis of variance was utilized to determine if significant differences existed between  $T_{re}$  responses, symptom scale responses and RPE responses in each condition. Analysis of variance revealed statistically significant ( $p < 0.05$ ) differences between  $T_{re}$  responses in the three conditions. Statistically significant ( $P < 0.05$ ) differences were also found for the symptom scale responses of thirst and weakness. Regression analysis within each condition was

utilized to evaluate the relationship of  $T_{re}$  and RPE responses and of  $T_{re}$  and the combined scores of weakness, fatigue and thirst. The regression analysis revealed an  $R^2$  of .997 for prediction of  $T_{re}$  using RPE data in the HP trial; the  $R^2$  for  $T_{re}$  prediction from the symptom scale responses in HP was .992. The  $R^2$  values for prediction of  $T_{re}$  in the NH and HH conditions were .953 and .983, respectively. The  $R^2$  obtained in the HH and NH conditions were lower than those  $R^2$  obtained in the HP trials for both the RPE and symptom scale predictors. These data suggest that RPE is a meaningful predictor of  $T_{re}$  increases i.e., given a particular RPE, the model gives a meaningful estimate of  $T_{re}$  within the range of core temperatures that were observed.

Index terms: RPE, symptom scale, thermoregulatory stress

The increase in the number of individuals competing in long-distance road races has resulted in an attendant increase in the number of related heat stress injuries. The possibility exists for heat cramps, heat exhaustion and heat stroke to occur, even in conditions of moderate environmental temperature and humidity. Poorly trained and acclimated participants are especially susceptible. To minimize chances of heat related problems, runners and race administrators need more effective techniques for forecasting and preventing these occurrences.

In recent years, much research has focused on the type of heat illness that occurs in otherwise healthy individuals during intense physical activity. A major concern has been the number of heat injuries that require medical attention. The incidence of heat injury in race participants is probably less than one percent, but with the high levels of participation, as many as 200 serious heat casualties may occur in the larger warm weather events.<sup>1,2</sup>

Researchers have investigated man's physiological responses to heat stress and furthermore, have identified a number of premonitory symptoms which are characteristic of heat related illnesses.<sup>3,4</sup> A runner's ability to perceive the effort level experienced during a prolonged run and the warning signals of advancing heat stress may be essential if an individual is to complete the activity safely.

This study was undertaken to determine if there is a relationship between core temperature ( $T_{re}$ ) and perceptual responses under conditions of prolonged exercise that would impose different degrees of body heating. It has been established that one's core temperature increases during prolonged aerobic activity, particularly in conditions of high environmental temperature and humidity. In fact, elevated core temperatures are associated with heat stress illnesses and are often used in clinical evaluation to differentiate between cases of heat exhaustion and heat stroke. It would be of utmost utility if one could monitor changes in perceptual responses and symptoms as a means of forecasting  $T_{re}$  rise.

The specific approach used in this study was to assess the relation between  $T_{re}$  and RPE during prolonged exercise under variable temperature conditions and states of hydration. The responses to a set of scales containing symptoms of weakness, irritability, headache, dizziness, fatigue and thirst were also investigated. Finally, the predictability of  $T_{re}$  from RPE and these symptom responses under the three experimental conditions was also evaluated.

## Methods

Six male volunteers of similar body composition and physical fitness were subjects (Table 1). Preliminary screening included hydrostatic weighing to determine percent body fat and determination of the maximal oxygen consumption ( $\dot{V}O_2\text{max}$ ) on a stationary bicycle ergometer. The  $\dot{V}O_2\text{max}$  test also provided a basis for calculation of constant workload used in the prolonged exercise bouts, i.e., 50%  $\dot{V}O_2\text{max}$ . Preliminary experimentation showed that this was the highest exercise intensity at which all subjects were able to complete the entire 2 hr of cycling in the warm test condition. These subjects had an habitual training level equivalent to running 10-20 miles $\cdot$ week $^{-1}$ , but none were highly trained or competitive cyclists. Each subject was required to participate in a pretrial consisting of 60 min of upright stationary cycling, the purpose of which was to minimize habituation effects. Subjects then performed three experimental trials each in different weeks and these consisted of 120 min of stationary cycling under cool/well-hydrated (NH), hot/well-hydrated (HH), and hot/hypohydrated (HP) conditions. The mean ( $\pm$ SD) temperature for the NE trials was  $24.2 \pm 2.0^\circ\text{C}$  and relative humidity averaged  $50.8 \pm 4.5\%$ . These values for the HH trials were  $35.4 \pm 0.2^\circ\text{C}$  and relative humidity averaged  $55.6 \pm 5.4\%$ . The temperature

conditions for the HP trials were  $35.4 \pm 0.6^{\circ}\text{C}$  and relative humidity averaged  $50.2 \pm 1.2\%$ . Each trial consisted of 30 min of sitting at rest prior to exercise in which baseline measurements were obtained followed by 120 min of stationary cycling and a 30 min recovery period in an upright position. Body water balance in the NH and HH conditions was maintained by having each subject drink a volume of tepid water equivalent to one percent of his body weight prior to exercise and an equivalent amount ad libitum during the exercise bout. To verify that hypohydration was prevented, each subject was weighed prior to and immediately following exercise. The average weight loss (%) in each condition is presented in Table 2.

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INSERT TABLES 1 and 2 ABOUT HERE.  
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The order of the experimental trials was randomized for each subject. All sessions were administered in a controlled environmental chamber and were conducted between mid-morning and mid-afternoon, as to reduce possible diurnal influences. The study was done in the cool months of spring to avoid heat acclimation effects and subjects were asked not to do recreational exercise during the warm hours of the day. During each trial the environmental conditions and

subject's  $VO_2$  responses were monitored and adjustments in heat, humidity and workload were made to hold these variables constant.

Prior to each trial the subject was fitted with eight thermocouples placed on sites recommended by Nadel.<sup>5</sup> Deep body temperature was monitored by a thermister inserted to a depth of 10-15 cm into the rectum. Body temperature changes were continuously monitored by a telethermometer (Yellow Springs Model TUC46) and recorded at 10 min intervals. Heart rate and blood pressure were also monitored throughout each trial.

Perceptual responses to exercise were determined by Borg's<sup>6</sup> 10-point category ratio scale. Borg's scales have been shown to be reliable and correlate highly with indicators of circulorespiratory and glycogenolytic demand in exercise. The scales have also been used widely in the past two decades in clinical exercise and sport situations for quantifying effort sense under varied conditions. In this investigation the Borg (1980) scale was easily understood by the subjects and each was therefore able to rate a wide range of perceptual intensities ranging from 0 to beyond 10, in increments of  $\pm 0.5$  scale units (Table 3).

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INSERT TABLE 3 ABOUT HERE.  
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The symptom scale consisted of a set of six symptoms which have been reported (3,4) as most commonly associated with heat stress; i.e., fatigue, weakness, thirst, irritability, headache, and dizziness. Under each scale were the numbers 0-6 and as with the Borg scale (1980), several of the numbers were anchored by verbal descriptors, which would aid the subject in rating his perceptions. The subject was asked to point to a number which best described how he was feeling at the particular time. Landy and Trumbo<sup>7</sup> suggest that reliable rating scales utilize between five and ten discriminative points. The perceptual responses were recorded at intervals corresponding with the physiological measurements. Verbal instructions describing the use of the scales were given prior to exercise to insure subject adherence to perceptual reporting (Table 4).

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INSERT TABLE 4 ABOUT HERE.  
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#### Statistical Analysis

The data were analyzed to determine to what extent selected subjective responses and core temperature of exercising males varied under conditions of different environmental conditions and states of hydration. Further

analysis was done to evaluate the relationship of RPE and  $T_{re}$  changes and also, symptom scale responses and  $T_{re}$  changes. An analysis of variance (ANOVA) was utilized to determine if significant differences existed between RPE responses in the three experimental conditions. ANOVA was also conducted on the data to determine if significant difference existed between  $T_{re}$  responses and symptom scale responses in each of the three conditions. In order to determine where the differences existed, a Duncan's Multiple Range Test was utilized.

To further analyze the RPE vs  $T_{re}$  relation and the symptom scale vs  $T_{re}$  relation a standard statistical analysis computer software package was utilized.<sup>8</sup> The average RPE and the average  $T_{re}$  for each time interval was calculated ( $\bar{X}$  of six subjects). A cubic regression model of average RPE and average  $T_{re}$  was constructed and the following formula was utilized.

$$T_{re} = RPE + (RPE)^2 + (RPE)^3$$

Improved  $R^2$  values and statistically significant coefficients for the quadratic and cubic terms of the model indicated that the above model be used. Using this least squares regression analysis, an estimated model of  $T_{re}$  was generated. To determine symptom scale responses vs  $T_{re}$  relation, the scores for the parameters of weakness, fatigue

and thirst were combined and averaged over subjects in order to obtain one score for each interval within a condition. Using this method a model was generated for each of the three experimental conditions.

### Results

Figure 1 depicts the changes in  $T_{re}$  under the three experimental conditions.  $T_{re}$  showed a gradual linear increase in all three conditions during the first 40 min of exercise. This increase continued thereafter only in the HP condition. Two subjects were however, unable to complete the entire 120 min of their HD trial due to  $T_{re}$  increase above the level accepted as safety criterion for test termination, i.e.,  $>39.5^{\circ}\text{C}$ .  $T_{re}$  was observed to vary significantly ( $p < 0.01$ ) as a function of treatment by time interaction ( $F = 5.72$ ,  $df = 22$ ). A summary of the ANOVA for core temperature, RPE, and symptom scale responses are presented in Tables 5 and 6. A Duncan's Multiple Range Test for detection of critical mean difference revealed statistically significant ( $p < 0.05$ ) differences between the HP and NH trials, but not between HP vs HH or HH vs NH.

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INSERT FIGURE 1 ABOUT HERE.  
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Figure 2 depicts the changes in RPE under the three experimental conditions. As with  $T_{re}$  analysis, the Duncan's Test revealed significant ( $p < 0.05$ ) differences between the HP and NH trials, but not between HP vs HH or HH vs NH condition.

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INSERT FIGURE 2 ABOUT HERE.  
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ANOVA was also conducted on the data for the six symptom scale responses. The results revealed statistically significant ( $p < 0.05$ ) differences in the thirst response ( $F = 21.82$ ,  $df = 2$ ) and the weakness response ( $F = 4.11$ ,  $df = 2$ ). The interpretation of these significant F-values were that there existed a statistically significant difference in these two perceptual response values due to the environmental treatment. The remaining symptoms of fatigue, headache, irritability and dizziness were not significantly ( $p > 0.05$ ) different. A Duncan's Multiple Range Test was used to determine which treatments resulted in the significant weakness and fatigue responses. Significant differences in regard to the weakness response were found between the HP and NH conditions and between the HH and NH, but not between HP and HH. As would be anticipated for the thirst variable, statistically significant differences were

found between HP vs HH, and HP vs NH, but not between HH vs NH.

Figure 3 depicts the relationship of  $T_{re}$  and RPE under the three experimental conditions. The average  $T_{re}$  and the average RPE for each interval was calculated ( $\bar{X}$  of six subjects) and a cubic regression model of average  $T_{re}$  was constructed. The regression analysis revealed an  $R^2$  of .997 in the HP condition and .953 and .983 in the HH and NH conditions, respectively.

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 INSERT FIGURE 3 ABOUT HERE.  
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Figure 4 graphically depicts the relationship of  $T_{re}$  and the combined symptom scale responses in each condition. The regression analysis of  $T_{re}$  on the combined responses of weakness, fatigue and thirst were also evaluated for the three different conditions. The analyses were also developed with quadratic and cubic terms to explain as much variance in  $T_{re}$  as might be attributed to these symptom factors. The analysis revealed an  $R^2$  of .992 in the HP condition and .940 and .951 in the HH and NH conditions, respectively.

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 INSERT FIGURE 4 ABOUT HERE.  
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## Discussion

This study investigated core temperature responses and perceptual responses to steady state exercise ( $50\% \dot{V}O_2\text{max}$ ) in three experimental conditions. The core temperature responses were then also evaluated in relation to RPE responses and selected perceptual responses of fatigue, weakness and thirst obtained from a specially designed symptom scale.

The changes in core temperature under the three experimental conditions revealed that core temperatures increased gradually during the first 40 min of exercise and was elevated in the HP condition. The ratings of perceived exertion were also elevated in the HP condition, but continued to increase gradually throughout the entire 120 min of exercise. Since oxygen consumption, ventilation and heart rate increase sharply with the onset of exercise and then level off once steady state is achieved, it would seem RPE would exhibit a similar pattern, provided that metabolic cost are important perceptual cues. The responses of perceived exertion in this investigation never reached a point of leveling off and are consistent with those results reported by Pandolf *et al.*<sup>9</sup> They reported that while oxygen consumption and ventilation demonstrated a steady state after 10 min of exercise at three submaximal bicycle

exercise intensities, perception of effort continued to increase over a 30 min period. Further investigations have observed responses of perceived exertion under neutral and heated conditions. The findings obtained by Skinner et al.<sup>10</sup> are similar to those seen in this study. They observed eight lean and eight obese individuals during aerobic, bicycle and treadmill exercise. The subjects who performed exercise in a hot environment rated their effort at a higher level than at the same workload in cool conditions.

This study also evaluated other perceptual variables by utilizing a symptomology scale which contained six symptoms most commonly associated with heat stress; weakness, fatigue, thirst, irritability, dizziness and headache. The results revealed statistically significant ( $p < 0.05$ ) differences in the responses of weakness and thirst between the three experimental conditions and the responses of weakness, fatigue and thirst were elevated in the HP condition. The three symptoms, irritability, headache and thirst showed no significant differences between the three experimental conditions.

Although based on a limited number of subjects, the regression analysis revealed a strong relationship between  $T_{re}$  changes and RPE responses in each of the three

experimental conditions. The overall  $T_{re}$  and the overall RPE responses represented an average value of the six subjects for each time interval. High  $R^2$  values were reported for each condition which implies that RPE is a good predictor of  $T_{re}$ ; i.e., given a particular RPE, the model gives a meaningful estimate of  $T_{re}$ . However it should be noted that the model may not be as accurate for  $T_{re}$  outside the range of those which were observed in this investigation. A  $T_{re}$  of  $39.5^{\circ}\text{C}$  was used as criterion for termination of exercise.

The influence of core temperature has been investigated previously by other investigators by comparing responses in neutral and heated conditions. Using a sample size identical to the one in this study ( $n = 6$ ) Pandolf, et al.,<sup>9</sup> found that while skin temperature and self reports of thermal sensations were significantly higher for 30 min of bicycle exercise in thermally hot conditions, perceived exertion was not influenced by the heat. However, both RPE and  $T_{re}$  were significantly elevated for the highest exercise intensity in neutral environment in comparison with other neutral and hot conditions. This is in contrast to data obtained in this study, which suggest that RPE may be a predictor of  $T_{re}$ . The discrepancy in results may be attributed to the intensity and duration of exercise imposed

in the two investigations, the subjects in Pandolf's et al., study cycled for a shorter duration (30 min) and at a lower intensity (40%  $\dot{V}O_2\text{max}$ ) which could influence the rise in  $T_{re}$  and RPE responses. Noble et al.<sup>11</sup> reported from the same data that rectal and skin temperature accounted for a greater proportion of perceptual variable in hot conditions compared with neutral environments. It is unfortunate that although RPE responses were reported to be higher in the hot environment in Skinner's et al., investigation,<sup>10</sup>  $T_{re}$  were not reported, so it is not known what effect, if any,  $T_{re}$  may have had on perceptual responses. Elevation of rectal temperature during high intensity exercise is paralleled by an increased in perceived effort, thus, during high intensity or prolonged exercise which provokes a rise in rectal temperature, the processes which regulate deep body temperature may provide sensory input for perception of effort.<sup>12</sup>

The study also investigated the relationship of  $T_{re}$  to combined responses obtained from the symptom scale. As with  $T_{re}$  and RPE, high  $R^2$  were reported for the three experimental conditions, the higher  $R^2$  being reported in the HP condition. These results indicate that perceptual responses such as these may be good predictors of  $T_{re}$ .

The results obtained in this investigation have beneficial implications for individuals engaged in or working with endurance activities such as road races. The possibility exists for using RPE and the combination of symptoms associated with heat stress for evaluating one's feelings of exertion during exercise. The RPE and the symptom scale appear to be good predictors of  $T_{re}$  and therefore, may be advantageous in managing heat stress. The RPE scale may be easier to use in a race situation since only one value is needed to predict individual's level of effort experienced during exercise. However, the symptom scale may be more practical and more easily understood by the runner since perceptions of weakness, thirst, and fatigue are commonly experienced symptoms.

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Table 1. Subject Characteristics

| Age<br>yr | Height<br>cm | Weight<br>kg | Body Fat<br>% | VO <sub>2</sub> max<br>ml•kg <sup>-1</sup> •min <sup>-1</sup> | Body<br>Surface<br>Area |
|-----------|--------------|--------------|---------------|---|-------------------------|
| 26.5      | 183.5        | 80.1         | 12.8          | 48.5  | 2.0                     |
| 4.5       | 6.0          | 13.5         | 3.4           | 8.0   | .152                    |

Values are means  $\pm$ SD, N=6. VO<sub>2</sub>max, maximal oxygen consumption.

Table 2. Weight Loss (%)

|           | Trial |      |      |
|-----------|-------|------|------|
|           | NH    | HH   | HP   |
| $\bar{X}$ | 0.5   | 1.5  | 2.6  |
| SD        | .371  | .943 | .645 |

$\bar{X}$  = Mean

SD = Standard Deviation

Table 3. 10-Point RPE Scale\*

---

|     |                   |                   |
|-----|-------------------|-------------------|
| 0   | NOTHING AT ALL    |                   |
| 0.5 | VERY, VERY WEAK   | (JUST NOTICEABLE) |
| 1   | VERY WEAK         |                   |
| 2   | WEAK              |                   |
| 3   | MODERATE          |                   |
| 4   | SOMEHWAT STRONG   |                   |
| 5   | STRONG            | (HEAVY)           |
| 7   | VERY STRONG       |                   |
| 8   |                   |                   |
| 9   |                   |                   |
| 10  | VERY, VERY STRONG | (ALMOST MAX)      |
| •   | MAXIMAL           |                   |

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\*Borg Category - Ratio Scale

Table 4. Symptom Scale

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|                        |                     |
|------------------------|---------------------|
| <u>Fatigue</u>         | <u>Irritability</u> |
| 0 very refreshed       | 0 very calm         |
| 1                      | 1                   |
| 2 somewhat refreshed   | 2 somewhat calm     |
| 3                      | 3                   |
| 4 tired                | 4 irritable         |
| 5                      | 5                   |
| 6 very tired           | 6 very irritable    |
|                        |                     |
| <u>Dizziness</u>       | <u>Headache</u>     |
| 0 very clearheaded     | 0 no headache       |
| 1                      | 1                   |
| 2 somewhat clearheaded | 2 slight headache   |
| 3                      | 3                   |
| 4 dizzy                | 4 headache          |
| 5                      | 5                   |
| 6 very dizzy           | 6 severe headache   |
|                        |                     |
| <u>Thirst</u>          | <u>Weakness</u>     |
| 0 not thirsty          | 0 very strong       |
| 1                      | 1                   |
| 2 slightly thirsty     | 2 somewhat strong   |
| 3                      | 3                   |
| 4 thirsty              | 4 weak              |
| 5                      | 5                   |
| 6 very thirsty         | 6 very weak         |

---

Table 5. Summary of Analysis of Variance

| Source              | Core Temp |      |          | RPE |        |         | Weakness |        |         | Fatigue |        |         |
|---------------------|-----------|------|----------|-----|--------|---------|----------|--------|---------|---------|--------|---------|
|                     | df        | MS   | F        | df  | MS     | F       | df       | MF     | F       | df      | MS     | F       |
| Treatment           | 2         | 3.49 | 4.92*    | 2   | 28.63  | 3.55    | 2        | 13.58  | 4.11**  | 2       | 10.37  | 3.18    |
| Time                | 11        | 8.23 | 59.54**  | 11  | 272.86 | 28.10** | 11       | 167.07 | 47.99** | 11      | 155.23 | 31.72** |
| Subject             | 5         | 9.03 | 134.36** | 5   | 9.41   | 5.68**  | 5        | 11.92  | 18.89** | 5       | 13.57  | 16.55** |
| Treatment X Time    | 22        | 1.98 | 6.72**   | 22  | 18.96  | 2.60**  | 22       | 5.93   | 2.28**  | 22      | 6.36   | 1.76*   |
| Treatment X Subject | 10        | 3.55 | 26.39**  | 10  | 40.37  | 12.19** | 10       | 16.62  | 14.03** | 10      | 16.31  | 9.95**  |
| Subject X Time      | 55        | 0.69 | 0.94     | 55  | 48.57  | 2.66**  | 55       | 17.40  | 2.67**  | 55      | 24.47  | 2.71**  |

Treatment tested by Treatment X Subject  
 Time tested by Subject X Treatment  
 Subject tested by Treatment X Subject X Time  
 Treatment X Time tested by Treatment X Subject X Time  
 Treatment X Subject tested by Treatment X Subject X Time  
 Subject X Time tested by Treatment X Subject X Time

df = degrees of freedom  
 ms = mean squares  
 \* = p < 0.05  
 \*\* = p < 0.01

Table 6. Summary of Analysis of Variance

| Source              | Thirst |        |         | Dizziness |       |         | Headache |       |         | Irritability |        |          |
|---------------------|--------|--------|---------|-----------|-------|---------|----------|-------|---------|--------------|--------|----------|
|                     | df     | MS     | F       | df        | MS    | F       | df       | MF    | F       | df           | MS     | F        |
| Treatment           | 2      | 110.01 | 21.82** | 2         | 11.22 | 1.53    | 2        | 2.04  | 0.41    | 2            | 3.22   | 0.70     |
| Time                | 11     | 64.17  | 19.80** | 11        | 11.47 | 2.90**  | 11       | 4.67  | 2.15*   | 11           | 17.59  | 2.86**   |
| Subject             | 5      | 49.19  | 50.28** | 5         | 39.85 | 53.88** | 5        | 11.99 | 13.35** | 5            | 117.56 | 144.27** |
| Treatment X Time    | 22     | 43.42  | 10.09** | 22        | 5.34  | 1.64    | 22       | 3.22  | 0.81    | 22           | 2.44   | 0.68*    |
| Treatment X Subject | 10     | 25.71  | 12.89** | 10        | 36.62 | 24.75** | 10       | 25.10 | 13.97** | 10           | 23.07  | 14.16**  |
| Subject X Time      | 55     | 16.20  | 1.51**  | 55        | 19.77 | 2.43**  | 55       | 10.88 | 1.10    | 55           | 30.78  | 3.43**   |

Treatment tested by Treatment X Subject  
 Time tested by Subject X Treatment  
 Subject tested by Treatment X Subject X Time  
 Treatment X Time tested by Treatment X Subject X Time  
 Treatment X Subject tested by Treatment X Subject X Time  
 Subject X Time tested by Treatment X Subject X Time

df = degrees of freedom  
 ms = mean squares  
 \* = p < 0.05  
 \*\* = p < 0.01

## Figure Legends

- FIG. 1. Core temperature ( $^{\circ}\text{C}$ ) changes before, during and after 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in three experimental conditions, neutral ( $24^{\circ}\text{C}$ , 50%RH)/hydration, NH; hot ( $35^{\circ}\text{C}$ , 50% RH)/hydration, HH; and hot/hypohydration ( $35^{\circ}\text{C}$ , 50% RH), HP.
- FIG. 2. Rate of perceived exertion responses during 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in the three experimental conditions.
- FIG. 3. Relationship of core temperature ( $^{\circ}\text{C}$ ) responses and rate of perceived exertion (RPE) responses during 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in the three experimental conditions.
- FIG. 4. Relationship of core temperature ( $^{\circ}\text{C}$ ) responses and combined (comb) symptom scale responses (weakness, fatigue and thirst) during 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in three environmental conditions.

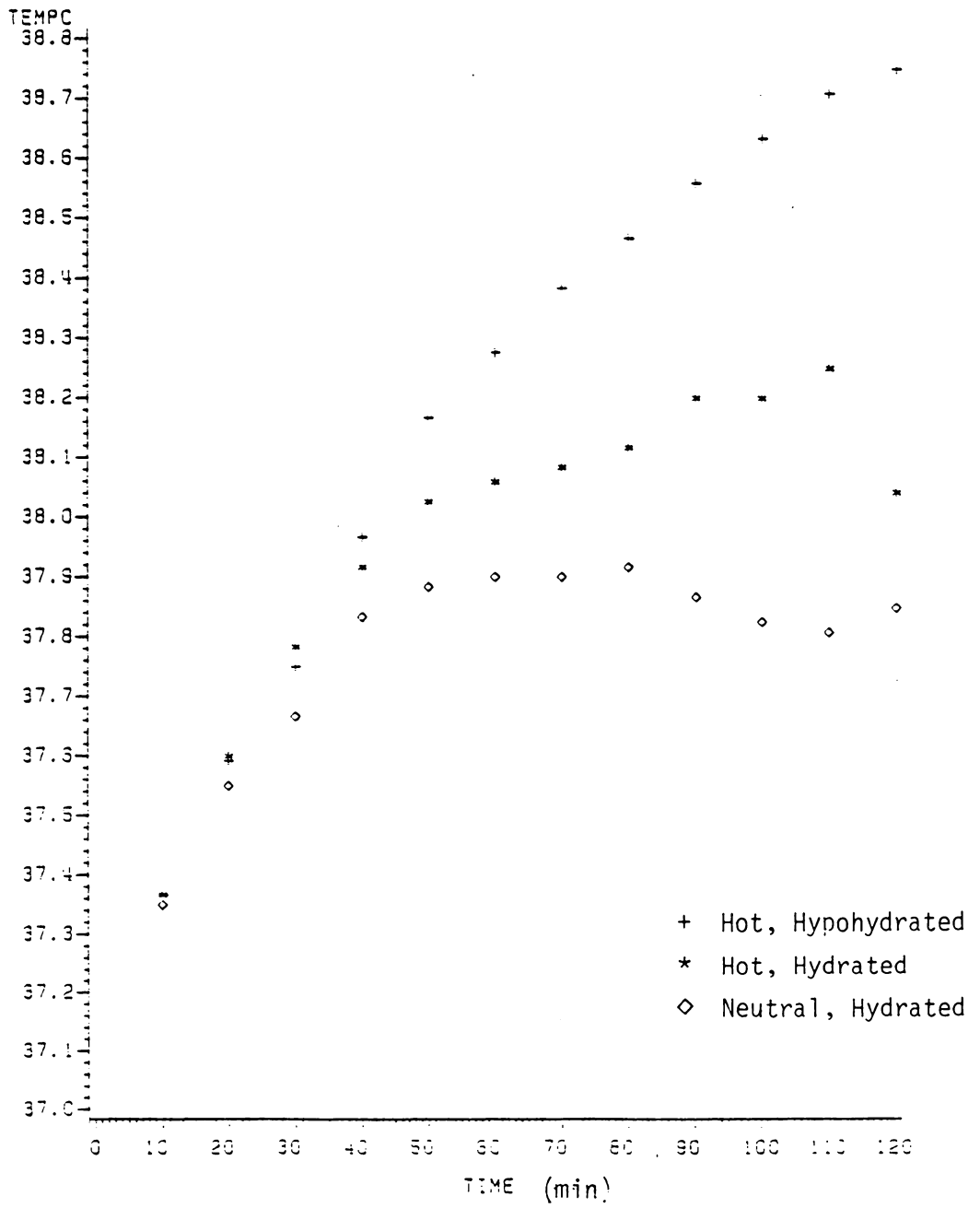


FIGURE 1.

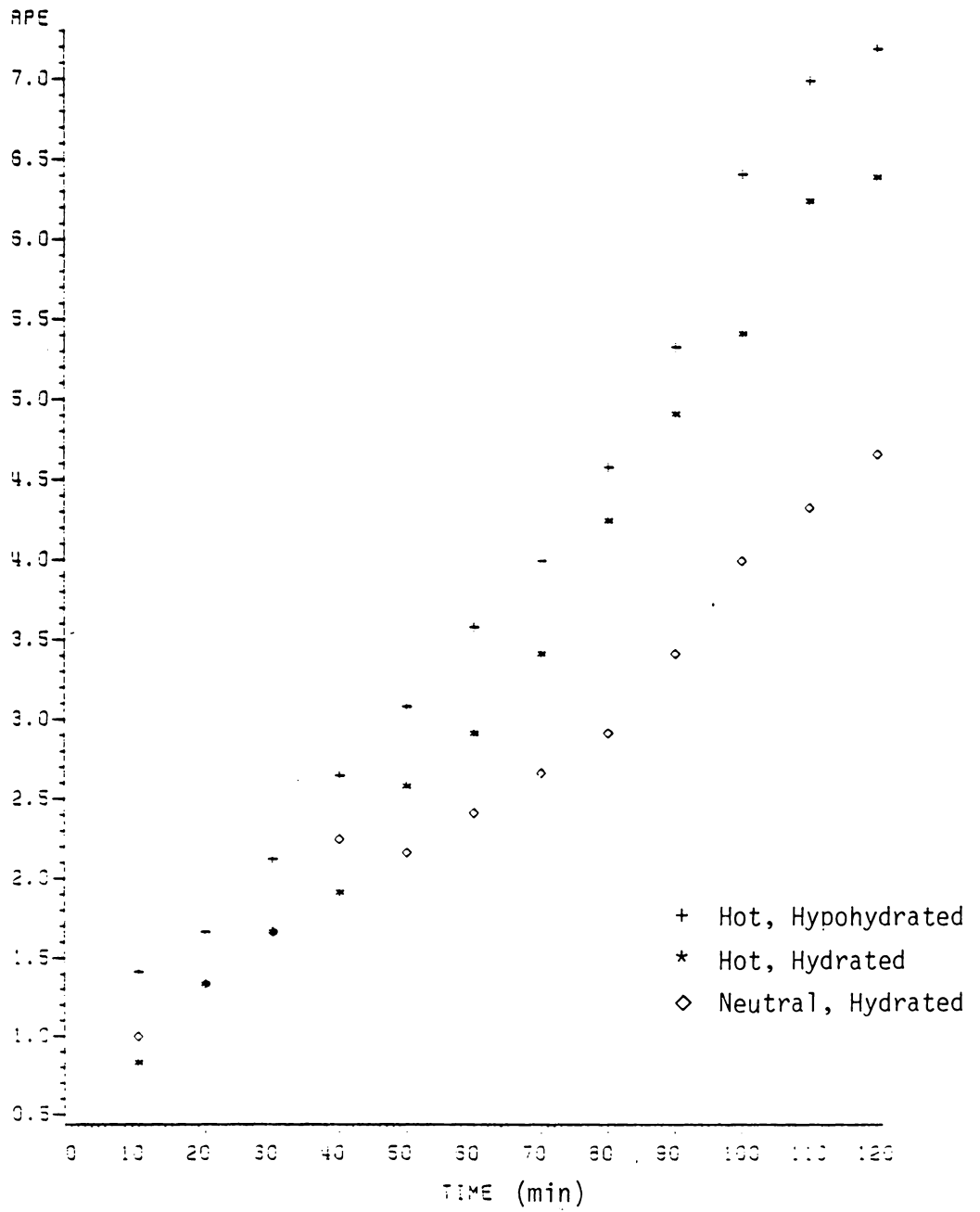


FIGURE 2.

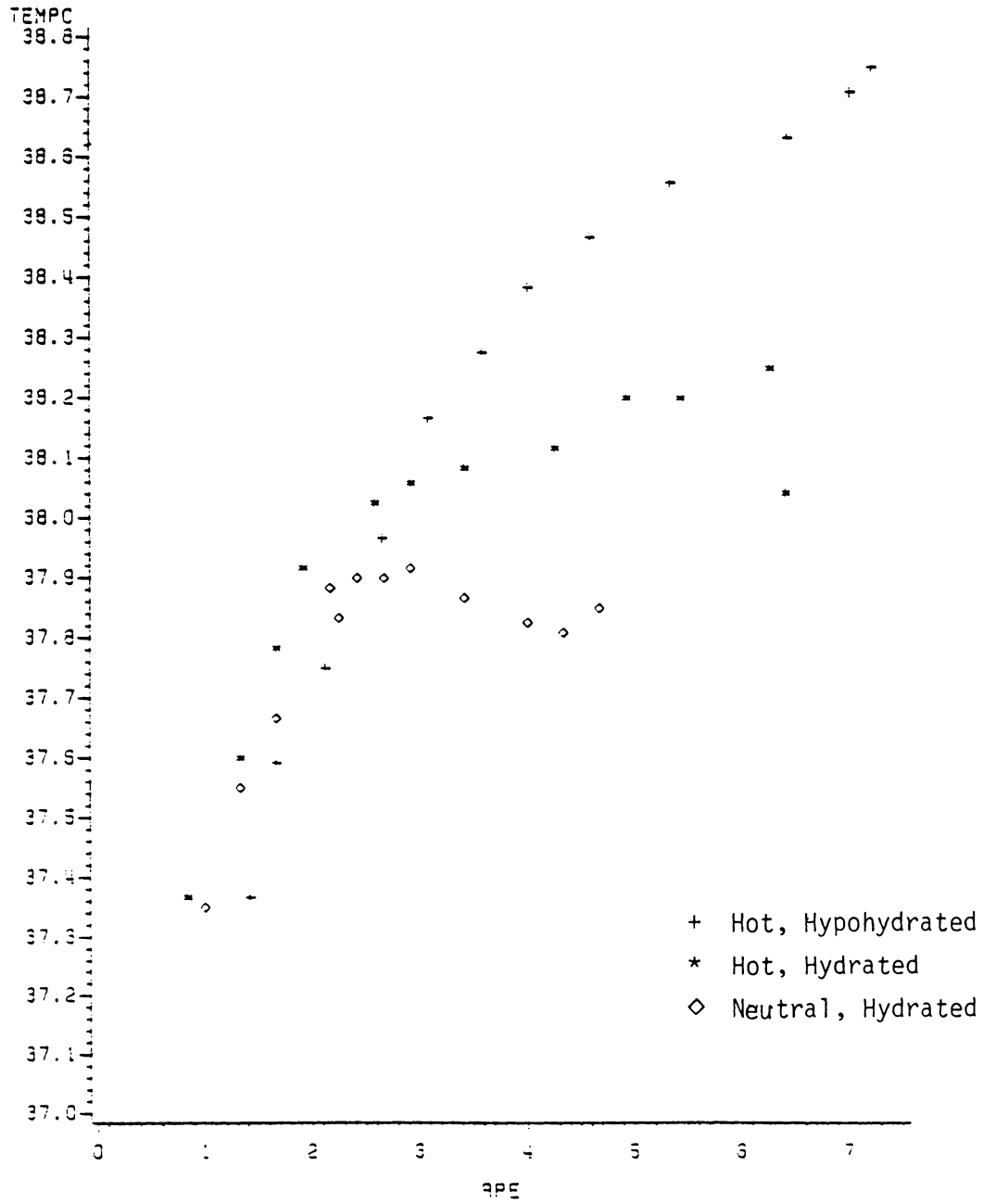


FIGURE 3.

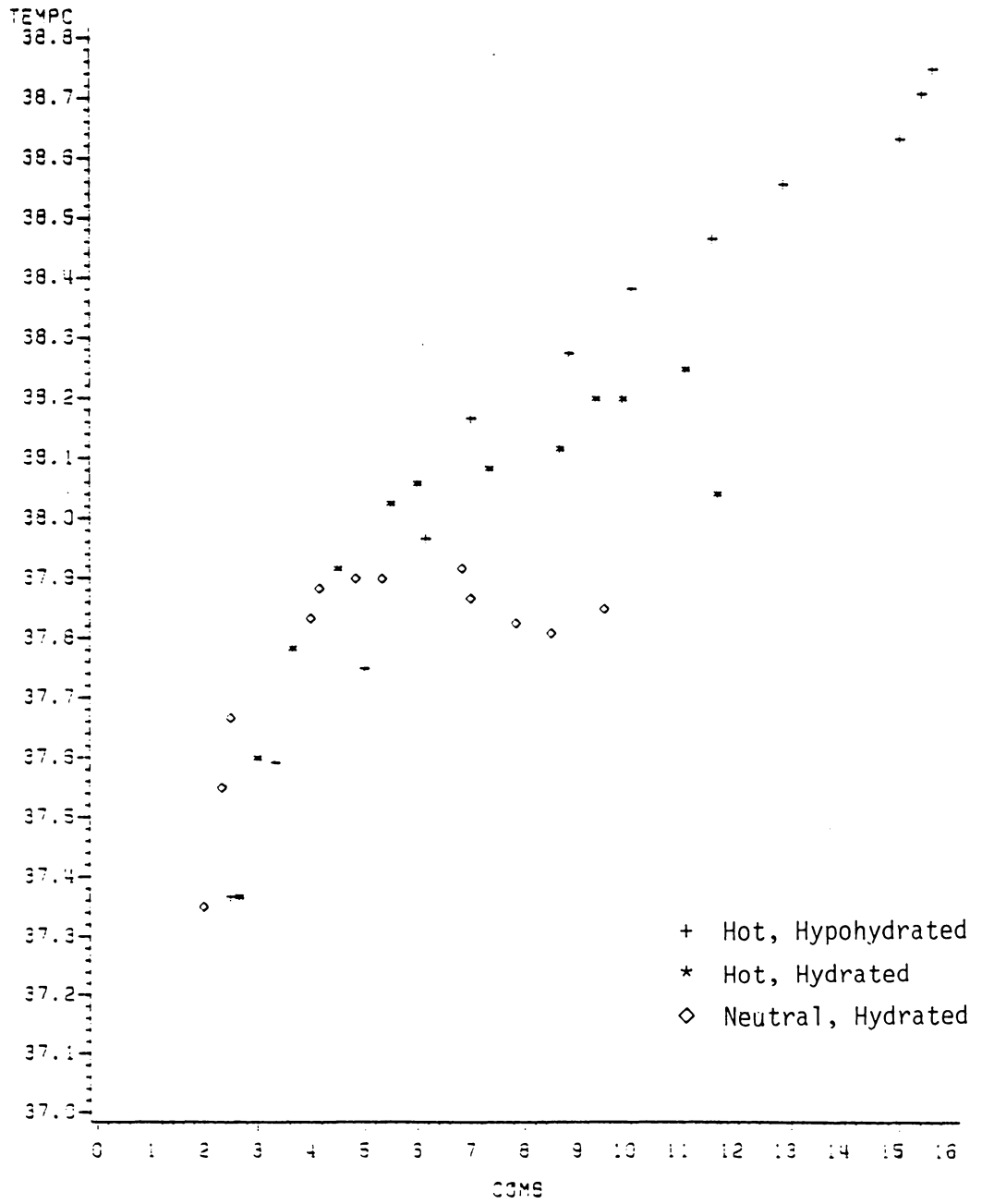


FIGURE 4.

## Chapter. 4

### SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

#### Summary

The increased incidence of heat stress illnesses in prolonged endurance events, such as road races has prompted interested researchers to investigate more effective techniques for prevention, evaluation and management of heat stress. Injuries associated with heat stress were once thought to occur only in hot climates, but published clinical reports have demonstrated that such cases may develop even in moderate climatic conditions and in otherwise healthy individuals (32). Road races, in particular, have become a major medical concern with 50 to 100 heat-related incidents occurring in some large road race events (32, 46). The heat illnesses most often associated with endurance activities can be classified into three conditions; heat cramps, heat exhaustion and heat stroke, and it is of predominant importance that these be diagnosed correctly since the physiologic disturbance and management of each is different.

The least serious of the three conditions is the heat cramp syndrome. The runner suffering from this condition may experience painful recurring muscle cramps. These cramps generally follow exertion under heat stress, and can

usually be prevented by ingesting sufficient amounts of water to assure adequate hydration and increasing the daily intake of salt several days prior to competition in a heat stress situation. Another form of heat illness is heat exhaustion, which is the most common clinical disorder resulting from hard work in a hot environment. Heat exhaustion is characterized by headache, dizziness, thirst, irritability, weakness and fatigue. If left untreated or ignored, marked central nervous system dysfunction becomes more prominent and may be manifested by hyperventilation, hysteria, muscular incoordination, and frank psychosis (27). The treatment of heat exhaustion consists of administering either normal or isotonic glucose solution in accordance with the proportion of salt or water losses (26). The patient is usually discharged after adequate fluid replacement and return of orthostatic blood pressure to normal. The most severe form of heat illness is heat stroke, which is characterized by hyperthermia, altered cerebral function, and hypohydrosis (40). Rectal temperatures may range from 40°C to 43°C, and may be used to differentiate heat stroke from other mental aberrancies such as heat exhaustion or hypoglycemia (21). Initial treatment involves prompt cooling of the individual usually by means of an ice bath. Unfortunately, there are cases, despite

immediate vigorous treatment, in which a number of complications may occur as a result of thermal cellular injury and circulatory changes.

Individuals vary in their ability to tolerate heat stress but four principle factors exist which an affect the risk of heat illness: environmental factors; including ambient temperature and humidity, wind (convection), isolation and clothing; body water balance; recent acclimatization to heat; and intensity and duration of the run. Guidelines are available which offer suggestions for conducting and completing a race safely; however, despite these recommendations, injuries still occur in significant numbers, which suggest the need for additional techniques for preventing heat-related illnesses. No doubt there are many more who suffer temporary ill effects of heat stress but seek no on-site assistance during or after the race.

Based on this concern, this study was undertaken to investigate additional means for identifying premonitory symptoms of potential heat stress injuries in individuals engaged in endurance events. Such early identifiers can then be used in the prevention and management techniques in activities such as road races. Six adult males of similar physical fitness levels; volunteered and served as subjects for this study. Three trials consisting of 120 min of

upright stationary cycling, 50%  $VO_2$ max, were administered. One trial was performed under neutral (24°C, 50% RH)/hydration condition (NH). Additional trials were administered in two specified heat stress conditions. In one of the hyperthermic trials, fluids were administered (HH). In the remaining condition, (HP), no fluids were administered.

The results of this investigation showed that RPE and symptom scale responses in the HP condition differed significantly ( $p < 0.05$ ) from the NH condition. However, there was no significant difference ( $p > 0.05$ ) in the HP and HH conditions. Statistically significant differences ( $p < 0.05$ ) in rectal temperatures ( $T_{re}$ ) were found between each of the three experimental conditions.

Further analysis were applied to quantify the relation between  $T_{re}$  and RPE responses as well as the  $T_{re}$  and symptom scale responses. Results indicate that RPE and the combined responses to a particular subset of symptoms were meaningful predictors of  $T_{re}$ . The symptom scale consisted of six symptoms characteristic of heat stress; fatigue, weakness, thirst, headache, irritability, and dizziness; however the scores of only three symptoms (fatigue, weakness and thirst) were utilized in this regression analysis. These symptoms were utilized because an ANOVA revealed that these symptoms

showed statistically significant differences ( $p < 0.05$ ) between each of the three conditions or more nearly approached this level of significance than the remaining three symptoms of headache, irritability and dizziness. The highest  $R^2$  for the RPe and  $T_{re}$  data as well as the combined symptom scale and  $T_{re}$  data was reported in the hot environment dehydration condition. The ratings of perceived exertion elicited a slightly higher  $R^2$  than the symptom scale; however, the results indicate that these responses are meaningful predictors of  $T_{re}$ . The proposed models may only be effective within the range of RPE and  $T_{re}$  that were observed in this investigation. The range of  $T_{re}$  observed in this study was 36.7 to 39.5°C and the rating of perceived exertion ranged from "very, very easy" to that of "very, very hard."

#### Recommendations for Future Research

The results of this investigation indicate a variety of approaches for future research. If a follow-up study is to be utilized, there are several recommendations to be made: a) use of a larger sample; b) use of a treadmill as mode of exercise; c) allow subjects to vary the speed of the treadmill in accordance with their desire to optimize performance (fastest time for a particular distance).

Due to the small number of subjects and variability of individual responses, the larger sample size would provide more specific results. Furthermore, the use of a treadmill as mode of exercise is suggested because the treadmill more closely resembles conditions experienced during a 10 km race. The RPE scale utilized in this investigation was one which represented an overall (general) feeling of exertion; however, since the bicycle was utilized in this study, it is subject to question how much leg fatigue or local factors weighed in one's perception of effort or feelings of exertion. It would be interesting to see if a treadmill was utilized if the perceptions of effort would resemble those utilized on the bicycle. These recommendations may elicit emergence of signs and symptoms associated with heat stress, and only then can more effective techniques be developed.

Allowing subjects to manipulate the speed of the treadmill in their desire to optimize performance would more closely resemble actual race conditions, since runners in a race are free to set their own pace. The subjects in this study, cycled at a constant 50%  $\dot{V}O_2\text{max}$ , if allowed to vary the speed, a subject's perceptions may be somewhat different, and in addition, his  $T^{\text{re}}$  may follow a different pattern.

Appendix A  
DETAILED METHODOLOGY

## METHODOLOGY

### Introduction

The individuals who served as subjects in this study were medically and functionally screened prior to any testing. They first participated in a preliminary test before taking part in the three experimental trials. The nature of this investigation was such that it required measuring and recording of numerous variables; therefore, the coordination of the experimentors and their testing procedures were extremely important. To insure the effectiveness of the experimental procedures a pilot investigation was first conducted on two individuals.

### Subject Screening and Selection

The subjects who participated in this investigation were selected from a pool of volunteers. The six males ranged in age from 22 to 34 years and approval to conduct the studies was secured from the University Board for the Protection of Human Subjects. Prior to participation, each subject was required to sign an informed consent which contained information as to the nature of the tests and any risks involved and benefits to be expected (Appendix C). Initially, each subject was screened by skilled technicians for potential cardiovascular problems using a 12-lead

electrocardiogram, and blood pressure; these measurements provided a basis for determination of subject suitability for participation. Each was also required to meet the following criteria for inclusion in the study: (1) A  $\dot{V}O_2$ max of 40-60 ml $\cdot$ kg $^{-1}\cdot$ min $^{-1}$ ; (2) a body fat content of 10-16%; (3) a habitual training level equivalent to running 10-20 mile $\cdot$ wk $^{-1}$ . The data on individual physical characteristics are provided in Appendix B.

#### Preliminary Exercise Testing

Each subject was required to perform a maximal oxygen uptake test on a Monark bicycle ergometer. The maximal physiological values were used to predict subject suitability for participation. For those who qualified, the  $VO_2$ max data also provided a basis for describing the exercise tolerance of subjects and determination of the workload prescription to be utilized during the experimental trials. Prior to exercise, each subject was asked to adjust the height of the seat to a position where his legs were just slightly bent. At this time, resting heart rate and blood pressure measurements were obtained. Each was then asked to freewheel for 1 min at 50 rpm. To help the subject maintain cadence, a metronome, calibrated to 50 bts $\cdot$ min $^{-1}$  was employed. Following the freewheel period, 1 kg of resistance was applied every 2 min for the first 4-8 min of

exercise. After this, the resistance was increased with 0.5 kg loads until the subject reached exhaustion. The oxygen content of the expired air was determined using the Applied Electrochemistry Oxygen Analyzer (Model 1-3A) and the carbon dioxide content of the gas was determined using the Applied Electrochemistry Carbon Dioxide Analyzer (Model CD-3A). For determination of the expired ventilation rates a Hewlett Packard Pneumotach (Model A7303 A) was employed. Oxygen uptakes were then calculated using the formula for open circuit spirometry. Heart rates were determined by auscultation every 2 min to insure attainment of maximal level of exertion. Maximum oxygen uptake was accepted as the highest oxygen uptake obtained and a regression analysis was used on the data points in the linear portion of the oxygen uptake vs. work rate to determine the workload necessary to elicit a 50%  $\dot{V}O_2$ max.

Due to the nature of this investigation, it was desirable that the subjects have similar physical characteristics, e.g., approximately the same percentage of body fat and body surface area. Therefore, each subject's body composition was estimated by utilizing the hydrostatic weighing technique. Each was asked to shower thoroughly and eliminate bodily waste, which might otherwise have contributed to experimental error in estimating body

density. The subject then entered the under water weighting tank which was filled with warm water (30-33°C). The recorder was calibrated previously with a known weight.

Following detailed instructions, weights were placed on the individual's chest and attached to his ankles in order to reduce the buoyancy of the body. A noseclip was then placed on the subject's nose and he was asked to assume a supine position, expel as much air as possible and then remain motionless for about 10 sec. Any excess movement resulted in artifact noise on the recorder. Due to the learning effect involved, the subject was asked to repeat the procedure a minimum of seven times. As the subject became more relaxed and familiar with the procedures, the more air he was able to expel resulting in a more accurate estimation of underwater weight.

Prior to the calculation of body density, which is expressed as mass per unit volume, the total body volume was corrected for residual gas volume in the lungs and gas in the intestinal tract. Wilmore (47) suggested that there is very close agreement between the actual values for density, percent fat and lean body weight, and those obtained through either an estimated or a constant residual volume. This investigation assumed lung residual volume to be a constant 1300 ml and volume of gas in the gastrointestinal tract a

constant 100 ml. After body density was determined, the percent of body fat was then estimated. Each subject's height (cm) and body mass (kg) were determined so that body surface area could be estimated. DuBois (17) nomogram was then used to make these calculations.

### Experimental Trials

Upon completion of medical and functional screening processes, the subjects chosen to participate in the study were required to perform a preliminary test, the purpose of which was to alleviate any anxiety and to minimize any learning effects that might affect the physiological responses. The procedures were similar to those utilized in the experimental trials with the exception that the duration was reduced and blood sampling was not done. The subject cycle at 50% of his  $\dot{V}O_2$ max for 1 hr in a thermoneutral environment.

The experimental tests consisted of three trials performed in a controlled environmental chamber. The condition of each trial were as follows:

1. Neutral/Hydration: consisted of an average temperature of 24.2°C and 50.8% relative humidity. Each subject drank an amount of water at room temperature equal to 1.0% of his body weight prior to the pretrial rest period and the equivalent amount, ad libitum, during exercise. The

fluid had to be consumed prior to the end of the exercise bout. Thus, the total amount was 2.0% of his body weight.

2. Hot/Hydration: consisted of an average ambient temperature of 35.4° with 55.6% relative humidity. The hydration procedures were identical to those mentioned above.

3. Hot/Hypohydration: consisted of an average temperature of 35.4°C with relative humidity equal to 50.2%. No fluids were consumed prior to or during this test.

To insure consistency of the environmental conditions, the temperature and relative humidity were assessed and recorded at 15 min intervals and the necessary adjustments made to maintain a constant environment. Detailed data on the environmental conditions may be found in Appendix B.

All experimental tests were conducted at approximately the same time of day with at least 1 wk separating trials for each of the subjects. As soon as the subject entered the lab, the preparatory phase of the trial began. The subject, clad in gym shorts and tennis shoes was fitted with eight thermocouples and a rectal probe. The subject was weighed at this time and then given water at room temperature if indicated according to the procedure described earlier in this Appendix. Shortly thereafter, the subject entered the environmental chamber and rested quietly

for 30 min in an upright position. Physiological measures were obtained at -30 and 0 min relative to the start of the exercise. Next, the subject began cycling at a workload equivalent to 50% of his  $\dot{V}O_{2\max}$ . To insure the subject maintained this workload, oxygen uptake measures were assessed and recorded at 15 min intervals with gas analyzers and pneumotach calibrated prior to each measurement. If necessary, adjustments were then made on the bicycle ergometer by either increasing or decreasing the workload in order to elicit the desired  $VO_2$ . A metronome set at 50  $bt \cdot min^{-1}$  was utilized to help subject maintain cadence.

The exercise was terminated at 120 min or upon attainment of body temperature of  $39.5^{\circ}C$  or when signs or symptoms of intolerance appeared. This was incorporated in order to protect subject against heat illness. Physiological responses and measures of psychological demand were obtained at various time intervals. following completion of the exercise bout, the subject was weighed and then remained in an upright position in the environmental chamber for a 30 min recovery phase. Physiological data were obtained at termination and at 15 and 30 min post-exercise.

Description and Instrumentation of  
Dependent Measures.

Skin temperature and core temperature were monitored continuously and recorded at 10 min intervals. Body surface temperature was assessed by thermocouples placed on the sites recommended by Nadel (31). They were placed on the face, chest, upper arm and leg, lower arm and leg and the abdomen. Mean skin temperature was calculated using the weighted coefficients suggested by Nadel, et al. (31).

Circulatory Variables. Heart rate was measured every 5 min by palpating for 10 sec at the radial artery. Blood pressure was obtained at 10 min intervals using auscultation. It was measured in the subject's left arm, which was supported at heart level by the technician.

Symptomatology Variables. The rating of perceived exertion was determined using Borg's scale (6) and recorded at 10 min intervals. Scales developed by Borg have been used successfully over the past two decades in clinical, sport and exercise settings for measuring exercise intensity and in determining exercise prescriptions. The scale utilized in this investigation allowed for simple direct estimation of subjective intensity, and also allowed the subject to rate his effort level on a scale which provided a reasonably good range of intensities. Other subjective

responses were determined by a symptom scale which contained a set of symptoms that are most commonly associated with heat stress; fatigue, weakness, irritability, headache, thirst, and dizziness. The subject was asked to rate his perceptions to each symptom on a scale from 0-6, at 10 min intervals. Landy and Trumbo (25) suggest that reliable rating scales contain between five and ten discriminative points. Several of the numbers were anchored by verbal expressions to aid the subject in his perceptual responses. The subject was also watched for other signs of heat stress, i.e., pilo erection, pallor of the skin and flush face. The time at which these appeared were recorded by the investigator. A copy of the scales utilized in the investigation is presented on pages 51 and 52 of Chapter III.

#### Subject Instructions

Prior to exercise, the subject was given a verbal explanation which instructed him how to interpret the two scales. The following instructions were read to the subject:

You will now be taking part in an experiment involving cycling in a warm/cool environment. We will be measuring various physiological functions and feelings of effort during the test. We will be showing you two charts - the first of which is a perceived exertion scale. We would like you to rate the degree of exertion you feel; that is, how hard you feel the work is. By perceived exertion,

we mean the total of all sensations and feelings of stress, effort and fatigue. Do not focus on one aspect, such as leg fatigue or shortness of breath, but try to concentrate on the sum total of all your feelings of exertion. The numbers on the chart are anchored by verbal expressions and should be an indication of how hard you feel the work is. You are permitted to rate perceptions beyond 0.5 and 10 and to use decimals in your ratings.

The second scale you will be shown contains several descriptive terms. Under each term are the numbers 0 through 6, several of which are anchored by verbal expressions. We will ask you to point to a number, 0-6, which best reflects the way you are feeling.

It is important that your responses to both scales are made as accurately and as honestly as possible. Also, under fatiguing exercise, some subjects may have the tendency to become unreliable in their perceptual reporting, please try to avoid this and respond accurately throughout the entire experiment.

During the entire experiment, subjects were prevented from having access to information about their physiological responses such as heart rate, core temperature and blood pressure. They were also forewarned about the tendency of some persons becoming unreliable in their perceptual reporting under fatiguing conditions, and asked to avoid this tendency. The investigator's perception of the subject's compliance to the required procedure of reporting perceptions was also recorded.

### Statistical Analysis of Dependent Variables

The data were analyzed to determine to what extent selected subjective responses and core temperature of exercising males varied under conditions of different environmental temperatures and states of hydration. Further analysis was done to evaluate the relationship of RPE and core temperature ( $T_{re}$ ) changes and also, symptom scale responses and  $T_{re}$  changes.

The design of this study was such that each of the six subjects participated in three experimental trials. In each of the trials, the subjects were asked to rate their perceptions of exertion and their responses to a set of symptom scales at 10 min intervals. In addition, physiological responses of heart rate, core temperature and blood pressure were concurrently recorded in each of the three experimental conditions throughout the exercise bout. An analysis of variance was utilized to determine if significant differences existed between RPE responses in the three experimental conditions. An analysis of variance was also used to determine if significant difference existed between  $T_{re}$  responses and symptom scale responses in each of the conditions. In order to determine where the differences existed, a Duncan's Multiple Range Test was utilized.

To further analyze the RPE vs  $T_{re}$  relation a standard statistical analysis computer software package was utilized (5). The average RPE and the average  $T_{re}$  for each time interval was calculated ( $\bar{X}$  of six subjects). A cubic regression model of average RPE and average  $T_{re}$  was constructed and the following formula was utilized.

$$T_{re} = RPE + (RPE)^2 + (RPE)^3.$$

Improved  $R^2$  values and statistically significant coefficients for the quadratic and cubic terms of the model indicated that the above model be used. Also figures 3 and 4 reveal that the data does not follow a strictly linear relationship (27). Using this least squares regression analysis, an estimated model of  $T_{re}$  was generated.

To analyze the possible relation between the various symptoms and  $T_{re}$  a regression analysis was utilized (5). The scores for the parameters of weakness, fatigue and thirst were combined and averaged over subjects in order to obtain one score for each interval within a condition. Using this method, a model was generated for each of the three experimental conditions.

Finally, the investigator's observation of signs and symptoms were evaluated. The observer recorded any signs or symptoms which were communicated, verbal or non-verbal, by the subject. The subject was watched in particular for

signs of leg fatigue, pallor of the skin, flushed face, or pilo erection. Leg fatigue and flush faced were the signs most commonly observed and related to the investigator. The earliest point which these were noticed was recorded. The times were then added and divided by the frequency of times the response was noted. This, in effect, would give an indication as to the signs and symptoms which may appear in a particular environmental condition. In addition, it may suggest that HP conditions may elicit heat stress signs and symptoms at an earlier point in time as compared to a NH or HH condition.

Appendix B  
DATA TABLES

Table 7. Individual Subject Characteristics

| Subject        | Height<br>cm | Weight<br>kg | Body Fat<br>% | $\dot{V}O_2\text{max}$<br>$\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ | Body<br>Surface<br>Area ( $\text{M}^2$ ) |
|----------------|--------------|--------------|---------------|--|--|
| 1              | 185.4        | 86.7         | 15.5          | 41.0   | 2.10                                     |
| 2              | 176.5        | 82.7         | 17.8          | 46.0   | 1.98                                     |
| 3              | 182.9        | 56.3         | 10.5          | 51.4   | 1.72                                     |
| 4              | 177.8        | 70.8         | 10.4          | 39.0   | 1.86                                     |
| 5              | 193.0        | 85.2         | 13.0          | 60.4   | 2.14                                     |
| 6              | 185.4        | 89.5         | 9.1           | 52.9   | 2.12                                     |
| $\bar{X}$      | 183.5        | 80.1         | 12.8          | 48.5   | 2.0                                      |
| $\pm\text{SD}$ | $\pm 6.0$    | $\pm 13.5$   | $\pm 3.4$     | $\pm 8.0$  | $\pm 0.152$                              |

Table 8. Individual Weight Loss (%)

| Subject   | Trial |      |      |
|-----------|-------|------|------|
|           | NH    | HH   | HP   |
| 1         | 0.7   | 1.0  | 2.7  |
| 2         | 0.8   | 0.0  | 2.2  |
| 3         | 0.0   | 2.1  | 2.7  |
| 4         | 0.0   | 0.9  | 2.1  |
| 5         | 0.7   | 1.9  | 3.8  |
| 6         | 0.9   | 2.9  | 1.8  |
| $\bar{X}$ | 0.5   | 1.5  | 2.6  |
| SD        | .371  | .943 | .645 |

N = 6

Table 9. Environmental Conditions of Neutral Hydration Trials

| Subject               | Ambient<br>Dry Temperature ( $^{\circ}\text{C}$ ) | Relative<br>Humidity (%) |
|-----------------------|---|--------------------------|
| 1                     | 23.90   | 49.0                     |
| 2                     | 21.52   | 51.9                     |
| 3                     | 22.52   | 56.1                     |
| 4                     | 27.10   | 45.4                     |
| 5                     | 25.00   | 47.0                     |
| 6                     | 25.10   | 55.6                     |
| $\bar{X}\pm\text{SD}$ | 24.2 $\pm$ 1.9                                    | 40.8 $\pm$ 4.5           |

Values represent a mean of 12 observations taken per subject trial.

Table 10. Environmental Conditions of Hot Hydration Trials

| Subject               | Ambient<br>Dry Temperature ( $^{\circ}\text{C}$ ) | Relative<br>Humidity (%) |
|-----------------------|---|--------------------------|
| 1                     | 35.49   | 49.9                     |
| 2                     | 35.62   | 61.4                     |
| 3                     | 35.50   | 46.5                     |
| 4                     | 35.50   | 47.5                     |
| 5                     | 33.38   | 49.2                     |
| 6                     | 33.05   | 49.0                     |
| $\bar{X}\pm\text{SD}$ | 35.4 $\pm$ 0.2                                    | 55.6 $\pm$ 5.4           |

Values represent a mean of 12 observations taken per subject trial.

Table 11. Environmental Conditions of Hot Hypohydration Trials

| Subject               | Ambient<br>Dry Temperature ( $^{\circ}\text{C}$ ) | Relative<br>Humidity (%) |
|-----------------------|---|--------------------------|
| 1                     | 36.33   | 50.7                     |
| 2                     | 35.89   | 48.6                     |
| 3                     | 35.00   | 49.0                     |
| 4                     | 35.18   | 51.6                     |
| 5                     | 35.10   | 50.3                     |
| 6                     | 34.70   | 51.0                     |
| $\bar{X}\pm\text{SD}$ | 35.4 $\pm$ 0.6                                    | 50.2 $\pm$ 1.2           |

Values represent a mean of 12 observations taken per subject trial.

Table 12. Core Temperature Changes ( C) During Neutral Environment (35 C, 50% RH)/Hydration Conditions

| Subject   | Time (min) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-----------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | -30        | 0     | 10    | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   | 110   | 120   | +15   | +30   |
| 1         | 37.20      | 37.40 | 37.50 | 37.80 | 37.80 | 37.90 | 37.90 | 37.80 | 37.80 | 37.80 | 37.70 | 37.60 | 37.60 | 37.60 | 37.60 | 37.40 |
| 2         | 37.40      | 37.70 | 37.30 | 37.60 | 37.60 | 37.70 | 37.70 | 37.70 | 37.70 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.70 | 37.60 |
| 3         | 37.40      | 37.40 | 37.40 | 37.40 | 37.50 | 37.60 | 37.70 | 37.80 | 37.80 | 37.80 | 37.70 | 37.60 | 37.55 | 37.60 | 37.35 | 37.25 |
| 4         | 36.70      | 37.20 | 37.30 | 37.50 | 37.80 | 38.00 | 38.10 | 38.10 | 38.20 | 38.20 | 38.10 | 38.10 | 38.10 | 38.10 | 37.40 | 37.40 |
| 5         | 37.10      | 36.60 | 37.40 | 37.60 | 37.80 | 37.90 | 38.00 | 38.20 | 38.10 | 38.20 | 38.20 | 38.15 | 38.20 | 38.20 | 37.20 | 37.90 |
| 6         | 37.60      | 37.10 | 37.20 | 37.40 | 37.50 | 37.90 | 37.90 | 37.80 | 37.80 | 37.80 | 37.90 | 37.90 | 37.90 | 37.80 | 37.40 | 37.20 |
| $\bar{X}$ | 37.17      | 37.23 | 37.35 | 37.55 | 37.66 | 37.83 | 37.88 | 37.90 | 37.90 | 37.91 | 37.86 | 37.82 | 37.80 | 37.85 | 37.44 | 37.29 |
| SD        | 0.30       | 0.40  | 0.10  | 0.10  | 0.10  | 0.10  | 0.10  | 0.20  | 0.20  | 0.20  | 0.20  | 0.20  | 0.20  | 0.20  | 0.20  | 0.20  |

$\bar{X}$  = Mean  
SD = Standard Deviation

Table 13. Core Temperature Changes ( C) During Hot Environment (35 C, 50% RH)/Hydration Conditions

| Subject   | Time (min) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-----------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | -30        | 0     | 10    | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   | 110   | 120   | +15   | +30   |
| 1         | 37.60      | 37.70 | 37.20 | 37.70 | 38.00 | 38.10 | 38.20 | 38.20 | 38.20 | 38.20 | 38.30 | 38.30 | 38.40 | 38.20 | 38.20 | 38.00 |
| 2         | 37.80      | 37.80 | 37.00 | 37.20 | 37.30 | 37.40 | 37.55 | 37.55 | 37.60 | 37.70 | 37.70 | 37.70 | 37.70 | 38.00 | 38.60 | 38.40 |
| 3         | 37.20      | 37.20 | 37.40 | 37.60 | 37.90 | 38.00 | 38.20 | 38.30 | 38.40 | 38.40 | 38.00 | 38.60 | 38.70 | 37.20 | 38.80 | 37.80 |
| 4         | 36.90      | 36.90 | 37.80 | 38.00 | 38.10 | 38.30 | 38.40 | 38.50 | 38.50 | 38.60 | 38.70 | 38.70 | 38.70 | 38.80 | 37.60 | 37.40 |
| 5         | 37.20      | 37.20 | 37.90 | 38.10 | 38.20 | 38.40 | 38.40 | 38.40 | 38.40 | 38.30 | 38.40 | 38.40 | 38.40 | 38.40 | 38.40 | 37.90 |
| 6         | 36.70      | 36.60 | 36.90 | 37.00 | 37.20 | 37.30 | 37.40 | 37.40 | 37.40 | 37.50 | 37.50 | 37.50 | 37.60 | 37.65 | 37.60 | 37.40 |
| $\bar{X}$ | 37.23      | 37.23 | 37.36 | 37.60 | 37.78 | 37.91 | 38.02 | 38.05 | 38.08 | 38.11 | 38.20 | 38.20 | 38.25 | 38.04 | 38.07 | 37.82 |
| SD        | 0.40       | 0.50  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.50  | 0.40  | 0.40  |

$\bar{X}$  = Mean  
SD = Standard Deviation

Table 14. Core Temperature Changes ( C) During Hot Environment (35 C, 50% RH)/Hypohydration Conditions

| Subject   | Time (min) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-----------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | -30        | 0     | 10    | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   | 110   | 120   | +15   | +30   |
| 1         | 37.40      | 37.50 | 37.50 | 37.60 | 37.80 | 38.00 | 38.10 | 38.20 | 38.30 | 38.40 | 38.50 | 38.50 | 38.50 | 38.60 | 38.40 | 38.20 |
| 2         | 37.40      | 37.50 | 37.20 | 37.40 | 37.60 | 37.80 | 37.80 | 37.95 | 38.00 | 38.00 | 38.05 | 38.10 | 38.20 | 38.30 | 39.60 | 39.10 |
| 3         | 37.20      | 37.30 | 37.40 | 37.65 | 37.80 | 38.10 | 38.50 | 38.60 | 38.80 | 39.00 | 39.10 | 39.20 | 39.40 | 39.40 | 38.40 | 38.00 |
| 4         | 36.90      | 37.10 | 37.40 | 37.80 | 37.90 | 38.10 | 38.20 | 38.30 | 38.40 | 38.50 | 38.60 | 38.60 | 38.70 | 38.70 | 38.10 | 38.00 |
| 5         | 37.10      | 37.20 | 37.80 | 38.00 | 38.20 | 38.40 | 38.90 | 39.00 | 39.10 | 39.10 | 39.20 | 39.40 | 39.50 | 39.50 | 39.00 | 38.45 |
| 6         | 36.80      | 36.80 | 36.90 | 37.00 | 37.20 | 37.40 | 37.50 | 37.60 | 37.70 | 37.80 | 37.90 | 38.00 | 37.95 | 38.00 | 38.00 | 37.70 |
| $\bar{X}$ | 37.13      | 37.25 | 37.36 | 37.59 | 37.75 | 37.96 | 38.16 | 38.27 | 38.38 | 38.46 | 38.55 | 38.63 | 38.70 | 38.75 | 38.58 | 38.24 |
| SD        | 0.30       | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  | 0.40  | 0.40  | 0.50  | 0.50  | 0.50  | 0.50  | 0.60  | 0.40  | 0.50  | 0.50  |

$\bar{X}$  = Mean  
SD = Standard Deviation

Table 15. Ratings of Perceived exertion During Neutral Environment (25 C, 50% RH)/ Hydration Condtions

| Subject   | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  | 120  |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1         | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 2.50 | 4.00 | 4.00 |
| 2         | 1.00 | 1.00 | 1.50 | 1.50 | 2.00 | 2.50 | 2.50 | 3.50 | 5.00 | 6.00 | 6.00 | 8.00 |
| 3         | 3.00 | 3.00 | 3.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| 4         | 0.50 | 1.00 | 1.00 | 2.00 | 2.00 | 2.00 | 2.00 | 3.00 | 3.00 | 3.50 | 4.00 | 4.00 |
| 5         | 0.00 | 1.00 | 1.50 | 2.00 | 1.00 | 2.00 | 2.00 | 2.00 | 2.00 | 3.00 | 3.00 | 3.00 |
| 6         | 0.50 | 1.00 | 2.00 | 3.00 | 3.00 | 3.00 | 4.50 | 4.00 | 4.50 | 5.00 | 5.00 | 5.00 |
| $\bar{X}$ | 1.00 | 1.33 | 1.66 | 2.25 | 2.16 | 2.41 | 2.66 | 2.91 | 3.41 | 4.00 | 4.33 | 4.66 |
| SD        | 1.00 | 0.80 | 0.70 | 1.10 | 1.00 | 1.10 | 1.30 | 1.20 | 1.20 | 1.30 | 1.00 | 1.70 |

$\bar{X}$  = Mean  
SD = Standard Deviation

Table 16. Ratings of Perceived Exertion During Hot Environment (35 C, 50% RH)/  
Hydration Conditions

| Subject   | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110   | 120  |
|-----------|------|------|------|------|------|------|------|------|------|------|-------|------|
| 1         | 0.00 | 2.00 | 2.50 | 2.00 | 3.00 | 2.50 | 3.50 | 4.50 | 5.00 | 6.00 | 7.00  | 8.50 |
| 2         | 0.50 | 0.50 | 1.00 | 2.00 | 3.00 | 3.00 | 3.50 | 5.50 | 5.50 | 5.00 | 6.00  | 6.50 |
| 3         | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.50 | 5.50 | 5.50 | 5.00 | 6.00  | 6.50 |
| 4         | 0.00 | 0.50 | 0.50 | 0.50 | 1.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 4.50  | 6.00 |
| 5         | 0.50 | 1.00 | 1.00 | 1.00 | 2.00 | 2.50 | 3.00 | 4.00 | 4.50 | 5.00 | 6.00  | 7.00 |
| 6         | 1.00 | 1.00 | 2.00 | 3.00 | 3.50 | 4.00 | 4.00 | 4.50 | 7.00 | 7.00 | 10.00 | ---  |
| $\bar{X}$ | 0.83 | 1.33 | 1.66 | 1.71 | 2.58 | 2.91 | 3.41 | 4.25 | 4.91 | 5.41 | 6.25  | 6.40 |
| SD        | 1.20 | 0.90 | 0.90 | 1.00 | 0.90 | 0.50 | 0.30 | 0.70 | 1.20 | 0.9  | 2.1   | 1.6  |

$\bar{X}$  = Mean  
SD = Standard Deviation

**Table 17. Ratings of Perceived Exertion During Hot Environment (35 C, 50% RH)/  
Hypohydration Condition**

| Subject   | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  | 120   |
|-----------|------|------|------|------|------|------|------|------|------|------|------|-------|
| 1         | 2.00 | 3.00 | 3.50 | 4.00 | 4.00 | 4.50 | 4.5  | 5.00 | 6.00 | 8.00 | 9.50 | 10.00 |
| 2         | 1.00 | 1.00 | 1.50 | 2.50 | 3.50 | 3.50 | 4.00 | 4.50 | 5.00 | 6.50 | 7.00 | 7.00  |
| 3         | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 4.00 | 4.00 | 4.00  |
| 4         | 0.50 | 0.50 | 0.75 | 2.00 | 2.00 | 3.00 | 3.50 | 5.00 | 6.00 | 7.00 | 9.50 | 10.00 |
| 5         | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 | ---  | ---   |
| 6         | 1.00 | 1.00 | 2.00 | 2.00 | 3.00 | 3.50 | 4.00 | 4.00 | 5.00 | 5.00 | 5.00 | 5.00  |
| $\bar{X}$ | 1.41 | 1.66 | 2.12 | 2.65 | 3.08 | 3.58 | 4.00 | 4.58 | 5.33 | 6.41 | 7.00 | 7.20  |
| SD        | 0.90 | 1.00 | 0.90 | 0.70 | 0.60 | 0.50 | 0.70 | 1.00 | 1.30 | 1.60 | 2.50 | 2.70  |

$\bar{X}$  = Mean  
SD = Standard Deviation

Table 18. Mean Responses of Fatigue, Thirst and Irritability During 120 Minutes of Stationary Cycling in Different Environments and States of Hydration

|              |    | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  | 120  |
|--------------|----|------|------|------|------|------|------|------|------|------|------|------|------|
| Fatigue      | NE | 1.00 | 1.16 | 1.00 | 1.66 | 1.83 | 2.00 | 2.33 | 3.00 | 3.00 | 3.50 | 3.66 | 3.83 |
|              |    | 1.00 | 0.90 | 0.80 | 0.80 | 0.70 | 0.80 | 0.80 | 0.80 | 1.00 | 0.80 | 0.80 | 0.70 |
|              | HE | 1.00 | 1.50 | 1.66 | 2.00 | 2.50 | 2.66 | 3.33 | 3.66 | 3.83 | 4.16 | 4.66 | 5.20 |
|              |    | 1.50 | 1.30 | 1.20 | 0.80 | 0.80 | 0.50 | 0.80 | 0.50 | 0.70 | 0.90 | 0.50 | 0.80 |
|              | HD | 0.83 | 1.16 | 1.83 | 2.00 | 2.33 | 2.66 | 3.16 | 3.83 | 3.83 | 5.00 | 5.00 | 5.00 |
|              |    | 0.70 | 0.70 | 0.90 | 0.60 | 0.80 | 0.80 | 0.70 | 0.90 | 0.70 | 0.80 | 1.00 | 1.00 |
| Thirst       | NE | 0.33 | 0.33 | 0.50 | 0.66 | 0.83 | 1.00 | 0.66 | 1.00 | 1.16 | 1.16 | 1.33 | 1.83 |
|              |    | 0.50 | 0.50 | 0.50 | 0.80 | 0.70 | 1.20 | 0.80 | 0.80 | 0.70 | 0.90 | 1.00 | 0.70 |
|              | HE | 0.83 | 0.66 | 1.00 | 1.00 | 1.00 | 1.00 | 1.33 | 1.66 | 1.66 | 1.83 | 1.83 | 1.60 |
|              |    | 0.70 | 0.80 | 0.70 | 1.20 | 1.20 | 1.20 | 1.20 | 1.70 | 1.80 | 1.80 | 2.10 | 2.50 |
|              | HD | 0.66 | 1.00 | 1.50 | 2.00 | 2.33 | 3.16 | 3.50 | 4.00 | 4.66 | 5.16 | 5.40 | 5.60 |
|              |    | 0.80 | 0.80 | 1.20 | 0.80 | 1.20 | 0.70 | 1.00 | 0.60 | 0.50 | 0.70 | 0.50 | 0.50 |
| Irritability | NE | 0.50 | 0.66 | 0.83 | 1.00 | 1.00 | 0.83 | 1.00 | 1.16 | 1.33 | 1.50 | 1.50 | 1.50 |
|              |    | 0.50 | 0.70 | 0.80 | 0.80 | 0.90 | 0.90 | 0.80 | 1.10 | 1.50 | 1.60 | 1.60 | 1.60 |
|              | HE | 0.83 | 0.83 | 1.00 | 1.00 | 1.16 | 1.66 | 1.66 | 1.83 | 1.83 | 1.83 | 2.00 | 2.40 |
|              |    | 1.10 | 1.10 | 1.20 | 1.20 | 1.40 | 1.20 | 1.20 | 1.40 | 1.70 | 1.70 | 1.80 | 2.80 |
|              | HD | 0.33 | 0.66 | 1.00 | 1.33 | 1.16 | 1.16 | 1.16 | 1.16 | 1.50 | 1.83 | 2.00 | 2.00 |
|              |    | 0.80 | 0.80 | 1.20 | 1.50 | 1.30 | 1.30 | 1.30 | 1.30 | 1.60 | 2.00 | 2.50 | 2.50 |

Values are means + SD: Time is in minutes with reference to exercise period.

Table 19. Mean Responses of Weakness, Headache and Dizziness During 120 Minutes of Stationary Cycling in Different Environments and States of Hydration

|           |    | 10           | 20           | 30           | 40           | 50           | 60           | 70           | 80           | 90           | 100          | 110          | 120          |
|-----------|----|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Weakness  | NE | 0.83<br>0.80 | 0.83<br>0.70 | 1.16<br>0.80 | 1.50<br>0.80 | 2.00<br>0.50 | 2.33<br>0.90 | 3.00<br>0.80 | 3.66<br>0.70 | 3.83<br>1.10 | 3.83<br>0.70 | 4.50<br>0.50 | 4.80<br>0.70 |
|           | HE | 0.66<br>0.70 | 0.83<br>0.70 | 1.00<br>0.70 | 1.66<br>0.50 | 1.50<br>0.60 | 1.83<br>0.80 | 2.33<br>0.60 | 2.83<br>0.50 | 3.16<br>0.70 | 3.16<br>0.70 | 3.50<br>0.50 | 3.83<br>0.80 |
|           | HD | 0.16<br>0.80 | 1.16<br>0.70 | 1.66<br>1.00 | 2.16<br>0.70 | 2.33<br>0.80 | 3.00<br>0.60 | 3.33<br>0.80 | 3.66<br>1.00 | 4.33<br>0.80 | 4.83<br>1.10 | 5.00<br>1.10 | 5.00<br>1.00 |
|           | NE | 0.16<br>0.40 | 0.16<br>0.40 | 0.16<br>0.40 | 0.16<br>0.40 | 0.16<br>0.50 | 0.33<br>0.50 | 0.33<br>0.50 | 0.83<br>0.50 | 0.83<br>0.50 | 0.33<br>0.50 | 0.83<br>0.50 | 0.60<br>0.50 |
|           | HE | 0.16<br>0.40 | 0.16<br>0.40 | 0.16<br>0.40 | 0.16<br>0.40 | 0.33<br>0.80 | 0.33<br>0.80 | 0.33<br>0.50 | 0.33<br>0.90 | 0.33<br>1.30 | 0.33<br>0.80 | 0.33<br>0.90 | 0.33<br>0.80 |
|           | HD | 0.16<br>0.40 | 0.16<br>0.40 | 0.33<br>0.80 | 0.33<br>0.80 | 0.50<br>0.80 | 0.50<br>0.80 | 0.66<br>1.20 | 0.66<br>1.20 | 0.66<br>1.20 | 1.00<br>1.60 | 1.00<br>1.40 | 1.60<br>2.60 |
| Dizziness | NE | 0.33<br>0.00 | 0.33<br>0.00 | 0.33<br>0.00 | 0.50<br>0.40 | 0.66<br>0.40 | 0.50<br>0.80 | 0.66<br>0.40 | 0.83<br>0.40 | 0.66<br>0.40 | 0.83<br>0.40 | 1.16<br>0.50 | 1.20<br>0.80 |
|           | HE | 0.00<br>0.50 | 0.00<br>0.50 | 0.00<br>0.50 | 0.16<br>0.80 | 0.16<br>1.00 | 0.33<br>0.80 | 0.16<br>1.00 | 0.16<br>1.30 | 0.16<br>1.00 | 0.50<br>1.30 | 0.33<br>1.60 | 0.50<br>2.10 |
|           | HD | 0.00<br>0.00 | 0.16<br>0.40 | 0.16<br>0.40 | 0.66<br>0.80 | 1.00<br>1.20 | 1.00<br>1.20 | 1.33<br>1.60 | 1.33<br>1.60 | 1.50<br>1.70 | 1.83<br>2.20 | 1.40<br>2.10 | 1.80<br>2.40 |

Values are means + SD; Time is in minutes with references to exercise period.

Appendix C  
INFORMED CONSENT

## LABORATORY FOR EXERCISE AND WORK PHYSIOLOGY

Division of Health Physical Education and Recreation  
College of Education  
Virginia Tech  
Blacksburg, VA 24061

INFORMED CONSENT

I, \_\_\_\_\_, do hereby voluntarily agree and consent to participate in a testing program conducted by the personnel of the Human Performance Laboratory of the Division of Health, Physical Education and Recreation at Virginia Tech.

Title of Study: Effects of Endogenous B-endorphin and Hydration State on Thermoregulatory Mechanisms During Prolonged Exercise in the Heat.

The purposes of this experiment include: 1) to establish a comprehensive model of thermoregulation in man during prolonged work in the heat, integrating the time course changes in body fluids, hemodynamics and heat dissipation, 2) to determine the possible role of the hormone b-endorphin on exercise thermoregulation, 3) to investigate the possible effects of B-endorphin on body fluid balance during prolonged exercise in the heat.

I voluntarily agree to participate in this testing program. It is my understanding that my participation will include:

1. medical screening to determine my suitability for participation in this study,
2. a brief interview concerning my habitual activity,
3. maximal oxygen uptake test performed on a bicycle ergometer,
4. anthropometric measures including percent fat, (underwater weighing) height and weight,
5. a maximum of four trials of prolonged cycling at a workload equivalent to 50% of my maximal oxygen uptake. These exercise sessions will continue for a maximum of 120 minutes. I understand that I am encouraged to exercise to the end of each trial or to the point of exhaustion.

- a. the first trial will be an orientation trial in order to acquaint me with the experimental protocol. It will take place in a cool environment (25°C, 50% relative humidity) and last 60 min.
- b. A trial (120 min duration) will also take place in a cool environment (25°C, 50% relative humidity). Sweat losses will be replaced with water at 15 minute intervals.
- c. Another trial (120 min duration) will take place in a hot environment (35°C, 50% relative humidity). Sweat losses will be replaced with water at 15 minute intervals.
- d. The last type of trial (120 min duration) will take place in a hot environment (35°C, 50% relative humidity). Sweat losses will not be replaced. In addition, I understand that I may be assigned to a special testing situation involving the injection of Naloxone prior to the onset of exercise. A physician will administer the injection and supervise this trial.

Note: The order of trials will be randomized.

6. During each of the aforementioned trials the following measures will be taken at periodic intervals.
  - a. cardiac output: This will involve the rebreathing of a gas mixture containing a small amount of carbon dioxide in oxygen for a period not to exceed 15 seconds.
  - b. blood pressure will be measured indirectly via the placement of a cuff on the upper arm.
  - c. heart rate: Electrocardiographically determined from a series of 3 electrodes placed upon the chest.
  - d. core temperature: Determined by a rectal thermocouple self inserted to a depth of approximately 10cm.
  - e. perceived exertion: Subject reporting of the perception of effort based upon the Borg Relative Perceived Exertion Scale.

- f. blood samples: obtained from a catheter placed in the forearm by a registered nurse.
- g. skin temperature patterns: obtained from video camera recordings of infra red radiation emitted from the body, and eight skin thermocouples taped on the body at various anatomical locations.
- h. injection of naloxone prior to one of the exercise trials.

I understand that participation in this experiment may produce certain discomforts and risks. I understand that with any extended aerobic activity I will probably experience a general feeling of fatigue. In addition, due to the exercise mode (cycling), leg fatigue and leg cramps may occur. Residual muscular soreness may be present following the trials and may persist for several days. During the exercise tests, especially the exhaustive bouts, I understand that there is a remote chance of dizziness and nausea. It is also understood that the region surrounding the catheter insertion site may develop a sub-dermal hematoma (slight swelling due to fluid moving out of the vein into the surrounding area).

Certain personal benefits may be expected from participation in this experiment. As a participant in the subject selection process, I will be informed of the results of the medical screening. If cleared to continue in this endeavor, I will be informed of my body composition and physical work capacity, i.e., fitness level. Additionally, at the completion of the study I will have gained knowledge relative to my capacity to perform extended work in normal and heat stressful surroundings.

I understand that any data of a personal nature will be held confidential and will be used for research purposes only. I also understand that these data may only be used when not identifiable with me.

I understand that I may abstain from participation in any part of the experiment or withdraw from the experiment should I feel the activities might be injurious to my health. The experimenter may also terminate my participation should he feel the activities might be injurious to my health.

I understand that it is my personal responsibility to advise the researchers of any pre-existing medical problem that may

affect my participation or of any medical problems that might arise in the course of the experiment and that no medical treatment or compensation is available if injury is suffered as a result of this research. A telephone is available which would be used to call the community rescue squad for emergency service. A trained team of exercise technologists will administer each test. A registered nurse will be responsible for all blood sampling procedures and a physician will supervise the Naloxone trials.

I have read the above statements and have had the opportunity to ask questions. I understand that the researchers will, at any time, answer my inquiries concerning the procedures used in this experiment.

Scientific inquiry is indispensable to the advancement of knowledge. Your participation in this experiment provides the investigator the opportunity to conduct meaningful scientific observations designed to improve the safety of exercise and physical work in the heat.

If you would like to receive the results of this investigation, please indicate this choice by marking in the appropriate space provided below. A copy will then be distributed to you as soon as the results are made available by the investigator. Thank you for making this important contribution.

\_\_\_\_\_ I request a copy of the results of this study.

Date \_\_\_\_\_ Time \_\_\_\_\_ a.m./p.m.

Participant Signature \_\_\_\_\_

Witness \_\_\_\_\_  
HPL Personnel

Project Director Dr. William Herbert Telephone 961-6565

HPER Human Subjects Chairman Dr. Don Sebolt Telephone 961-5104

Charles Waring, Chairman, Institutional Review Board for Research Involving Human Subjects. Phone 961-5283.

Appendix D  
INDIVIDUAL GRAPHS

## Figure Legends

- FIG. 5-10: Individual core temperature ( $^{\circ}\text{C}$ ) changes for six subjects, before, during and after 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in three experimental conditions, neutral ( $24^{\circ}\text{C}$ , 50%RH)/hydration, NH; hot ( $35^{\circ}\text{C}$ , 50%RH)/hydration, HH; and hot ( $35^{\circ}\text{C}$ , 50%RH)/hypohydration, HP.
- FIG. 11-16: Individual ratings of perceived exertion responses during 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in the three experimental conditions.
- FIG. 17-22: Relationship of individual core temperature ( $^{\circ}\text{C}$ ) responses and rate of perceived exertion (RPE) responses during 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in the three experimental conditions.
- FIG. 23-28: Relationship of individual core temperature ( $^{\circ}\text{C}$ ) responses and combined (comb) symptom scale responses (weakness, fatigue and thirst) during 120 min of cycle ergometry at 50%  $\dot{V}\text{O}_2\text{max}$  in three environmental conditions.

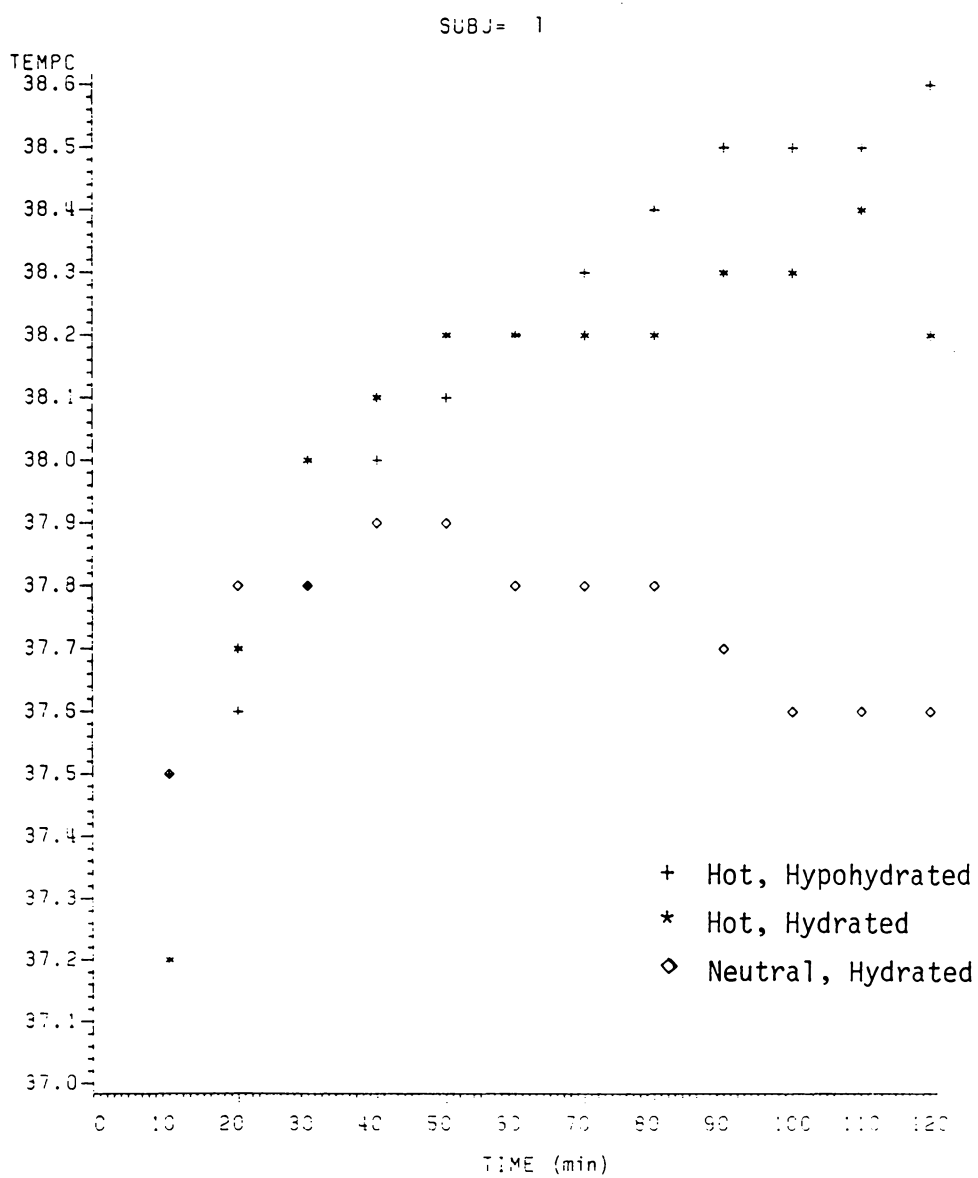


FIGURE 5.

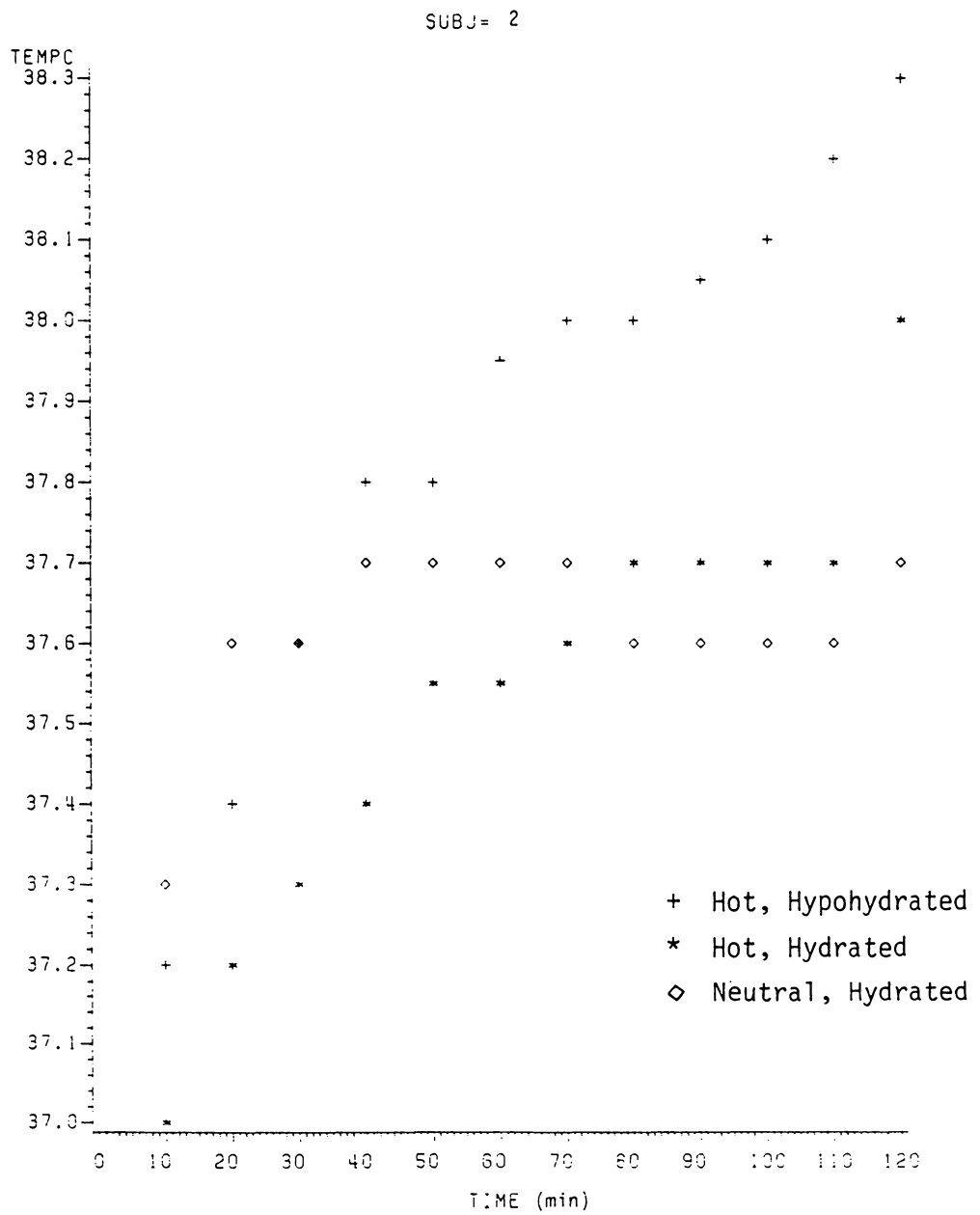


FIGURE 6.

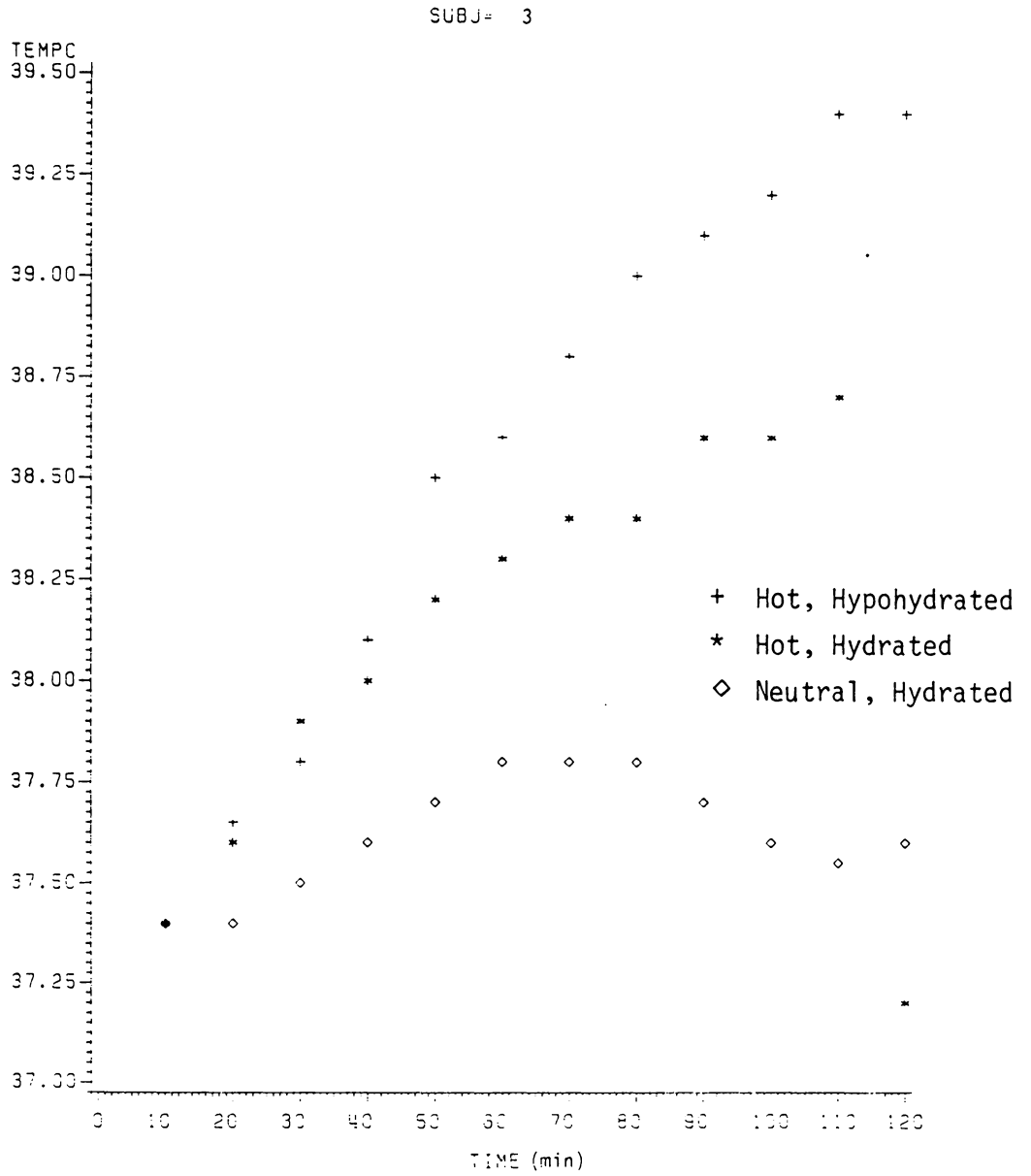


FIGURE 7.

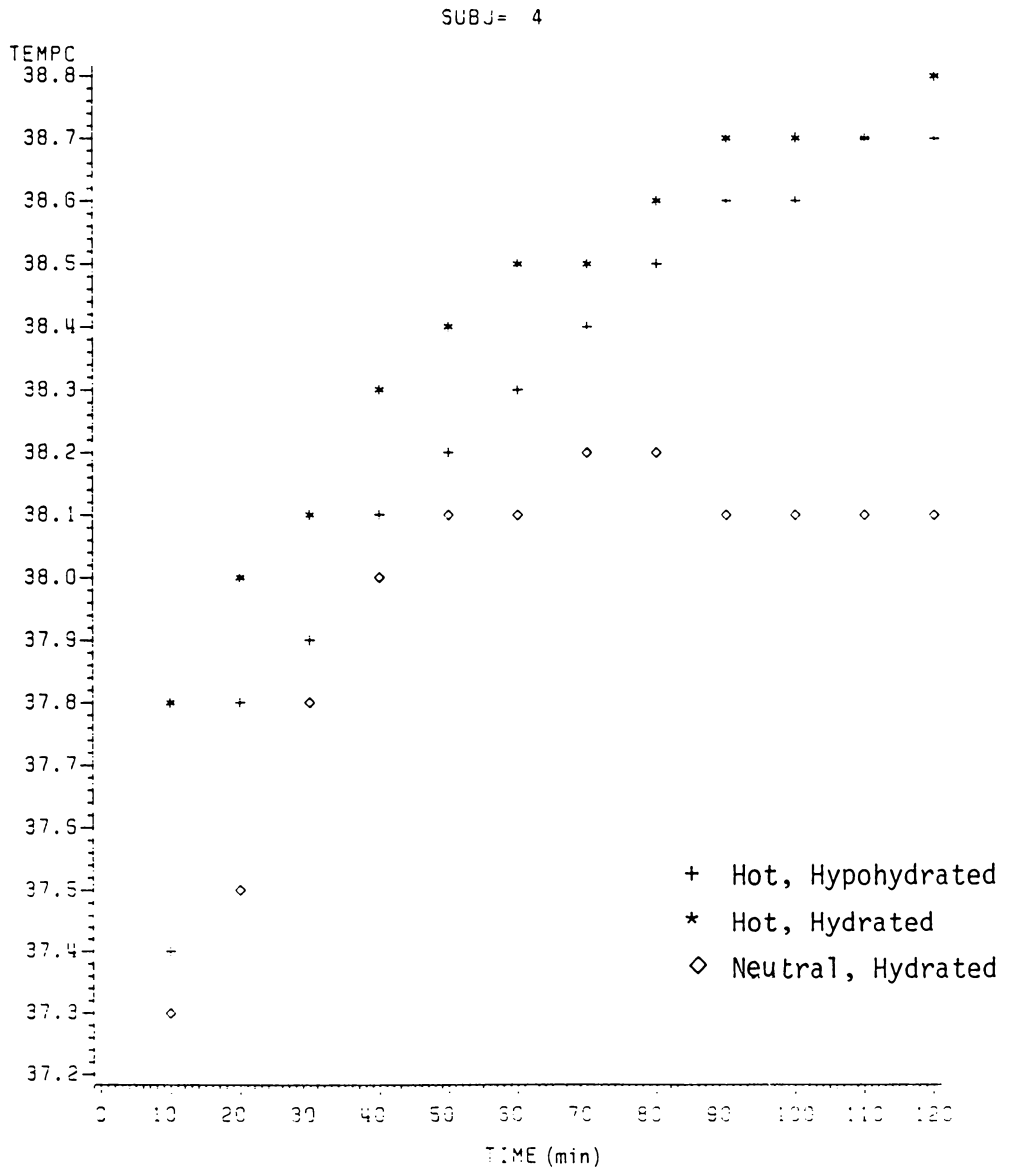


FIGURE 8.

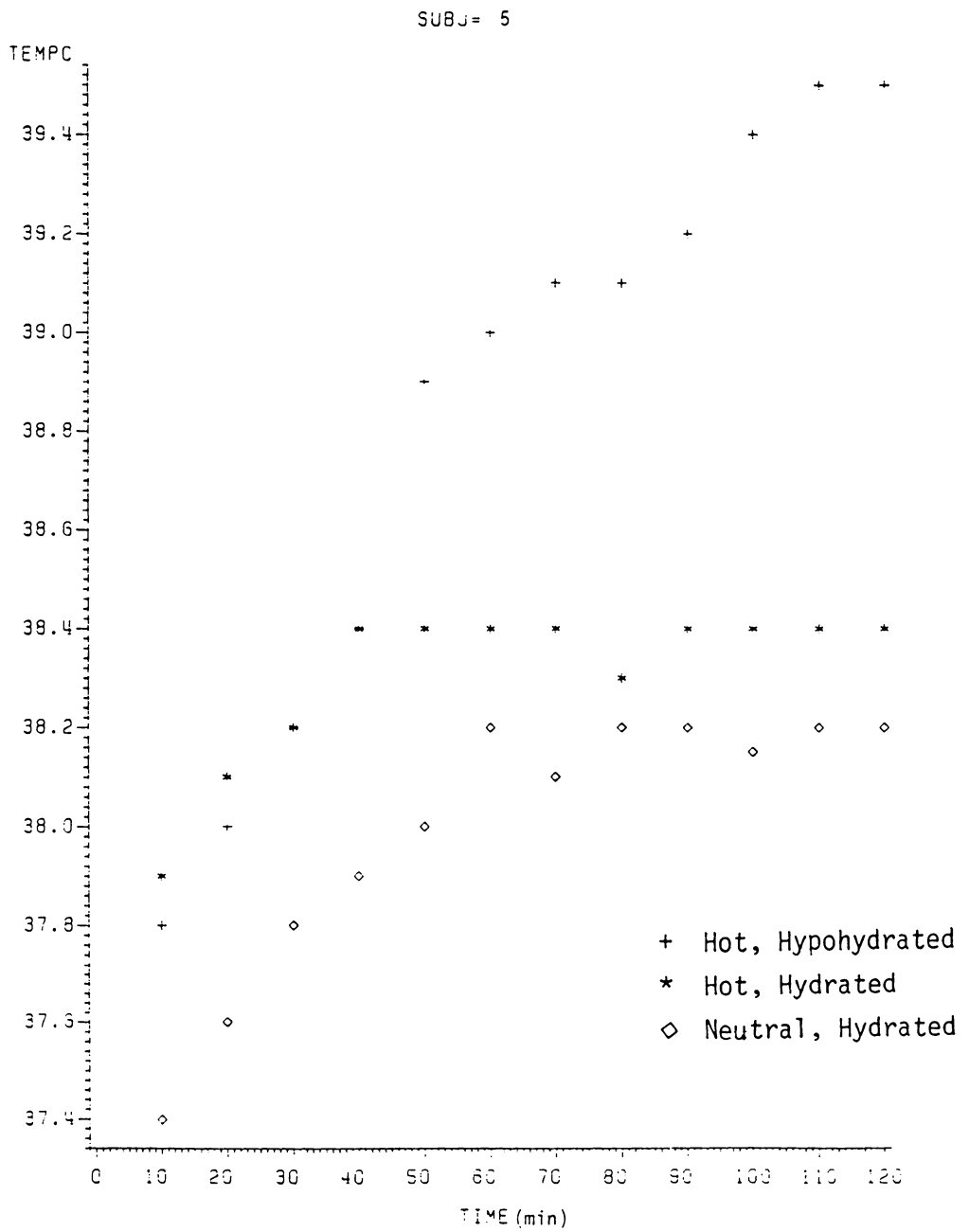


FIGURE 9.

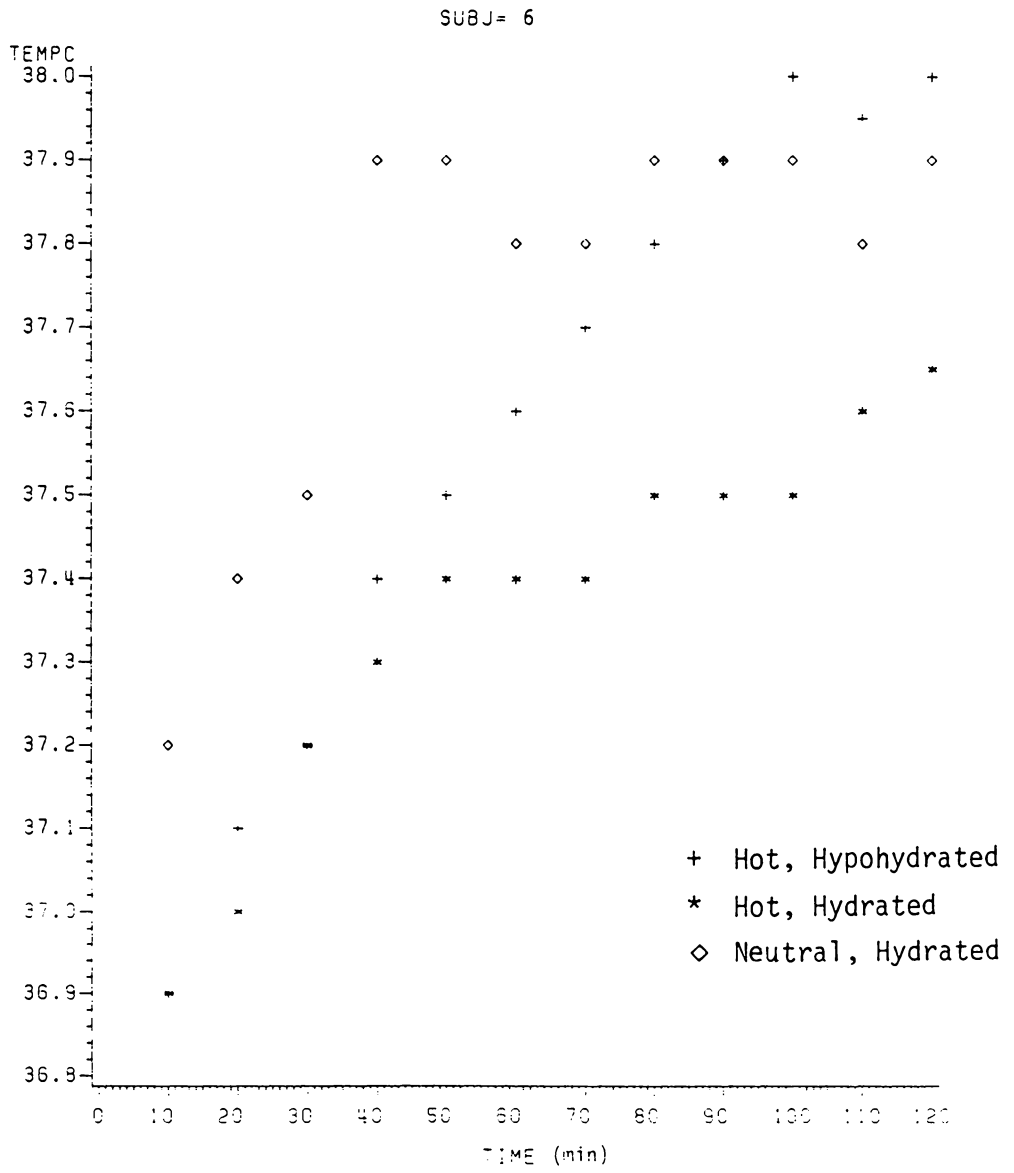


FIGURE 10.

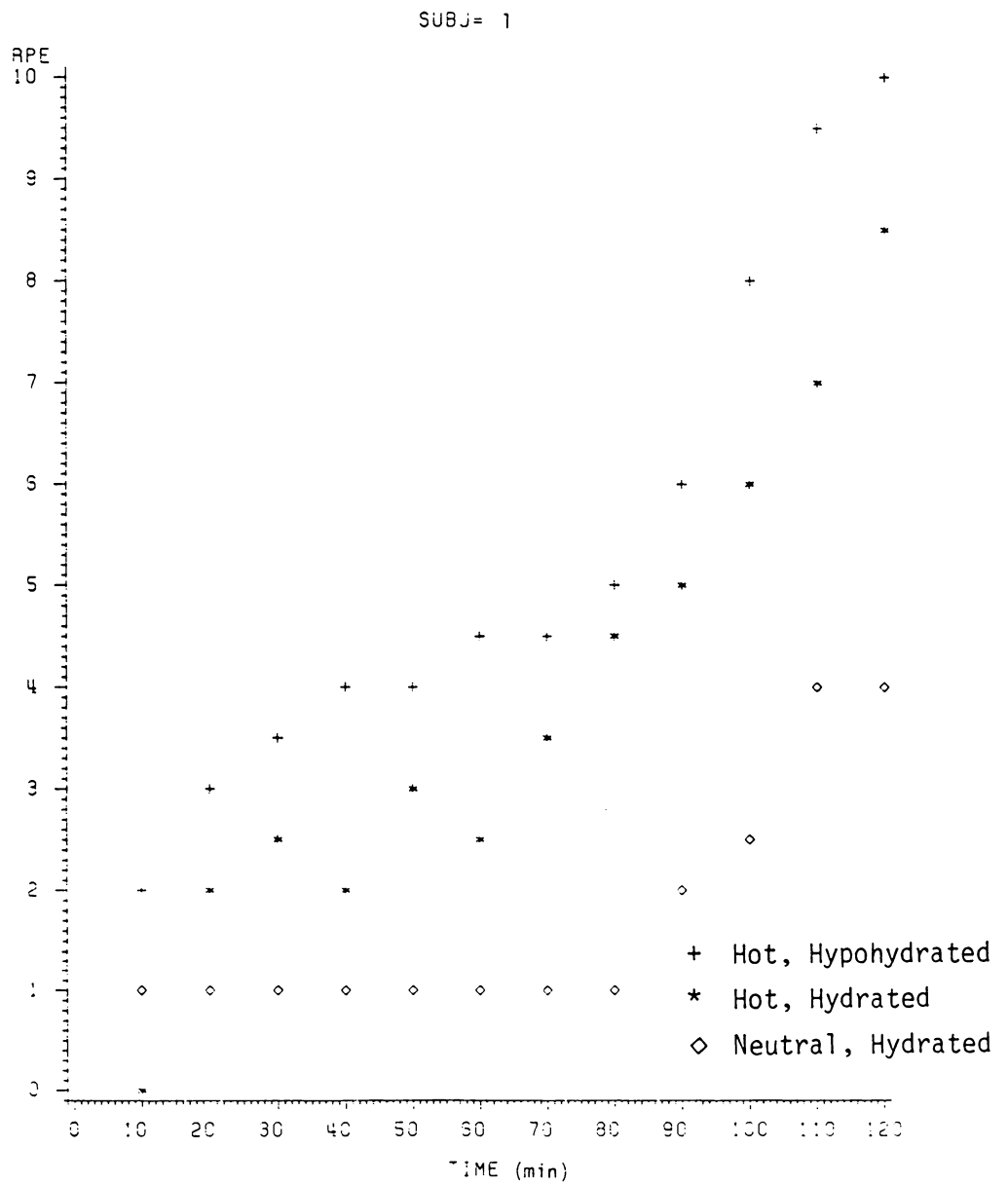


FIGURE 11.

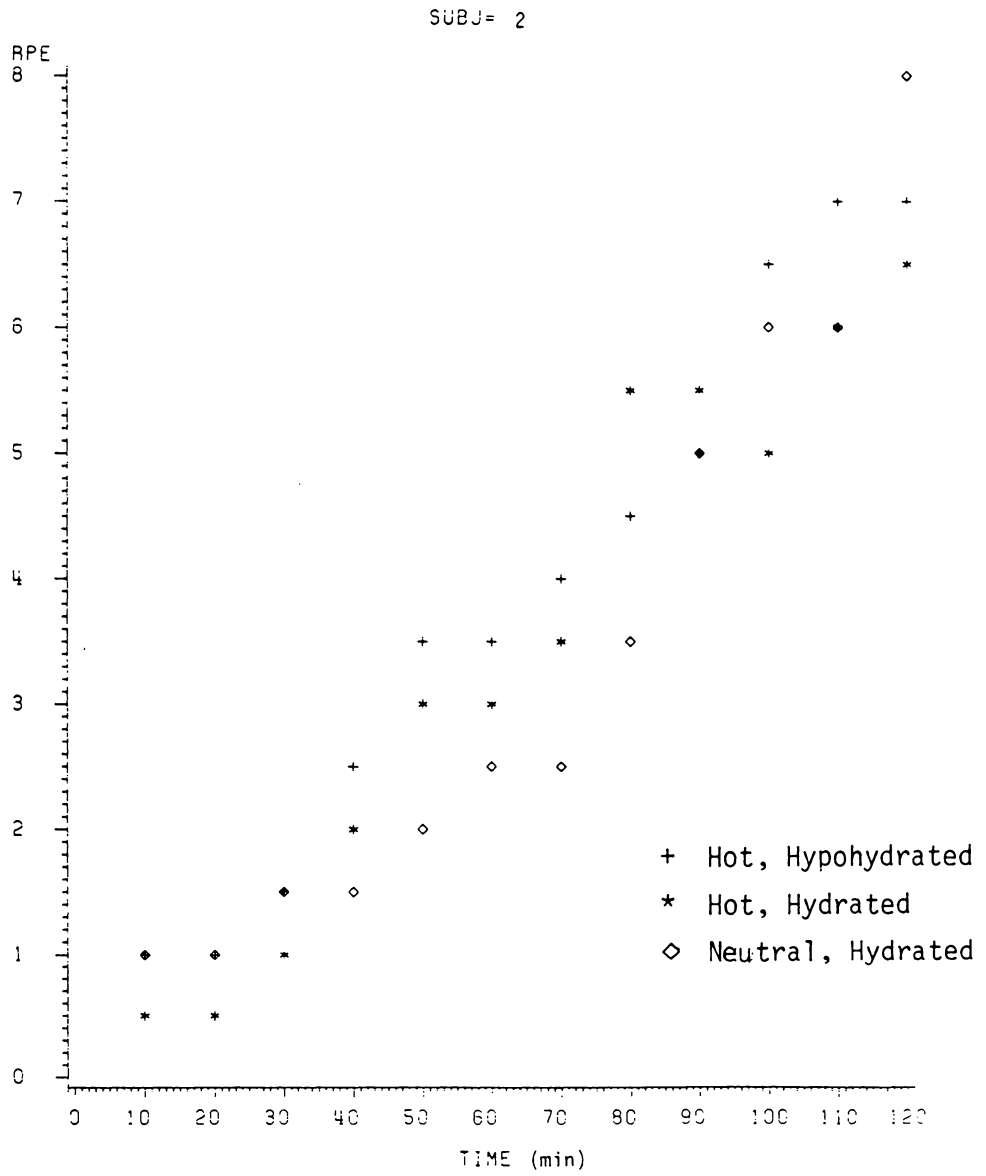


FIGURE 12.

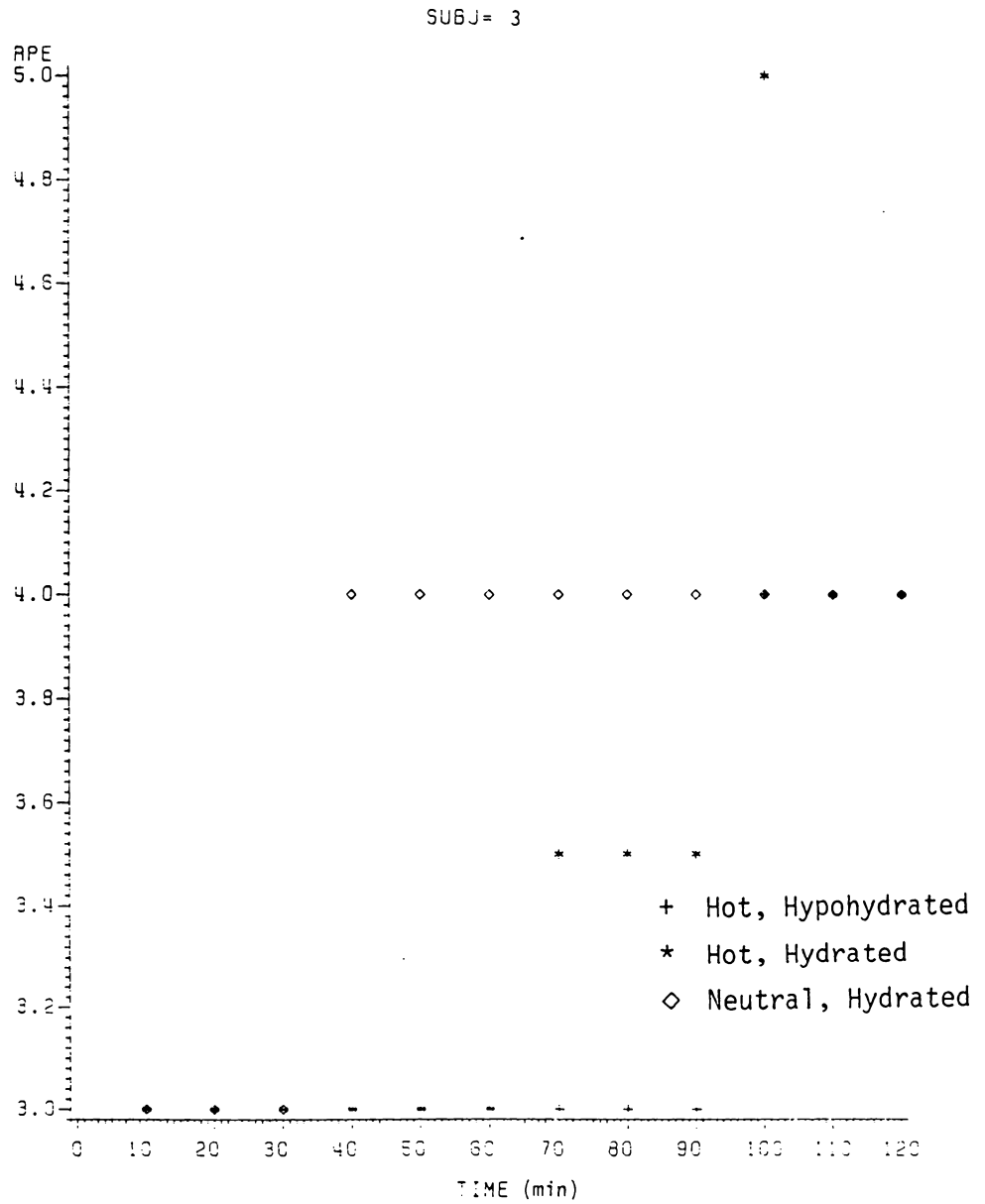


FIGURE 13.

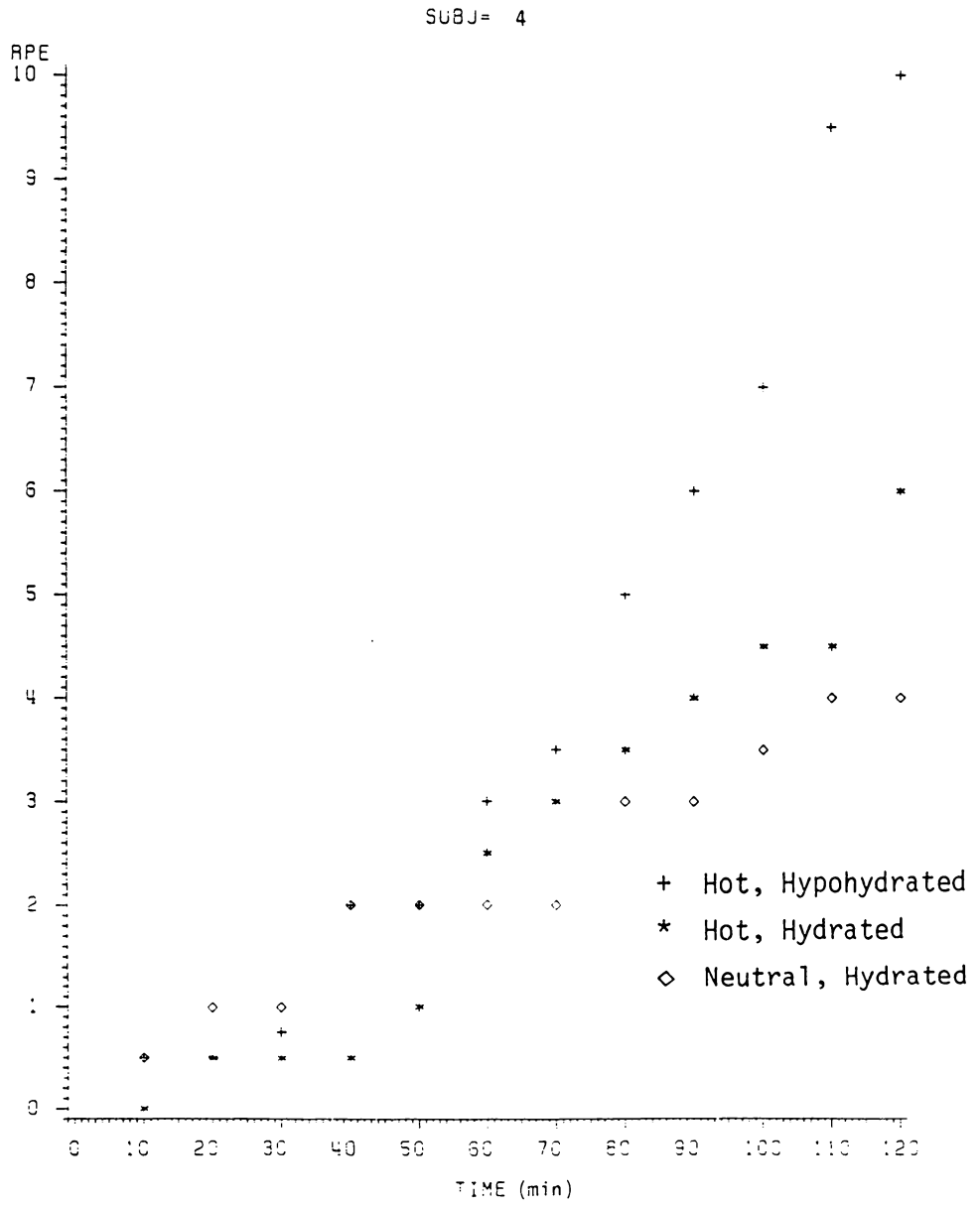


FIGURE 14.

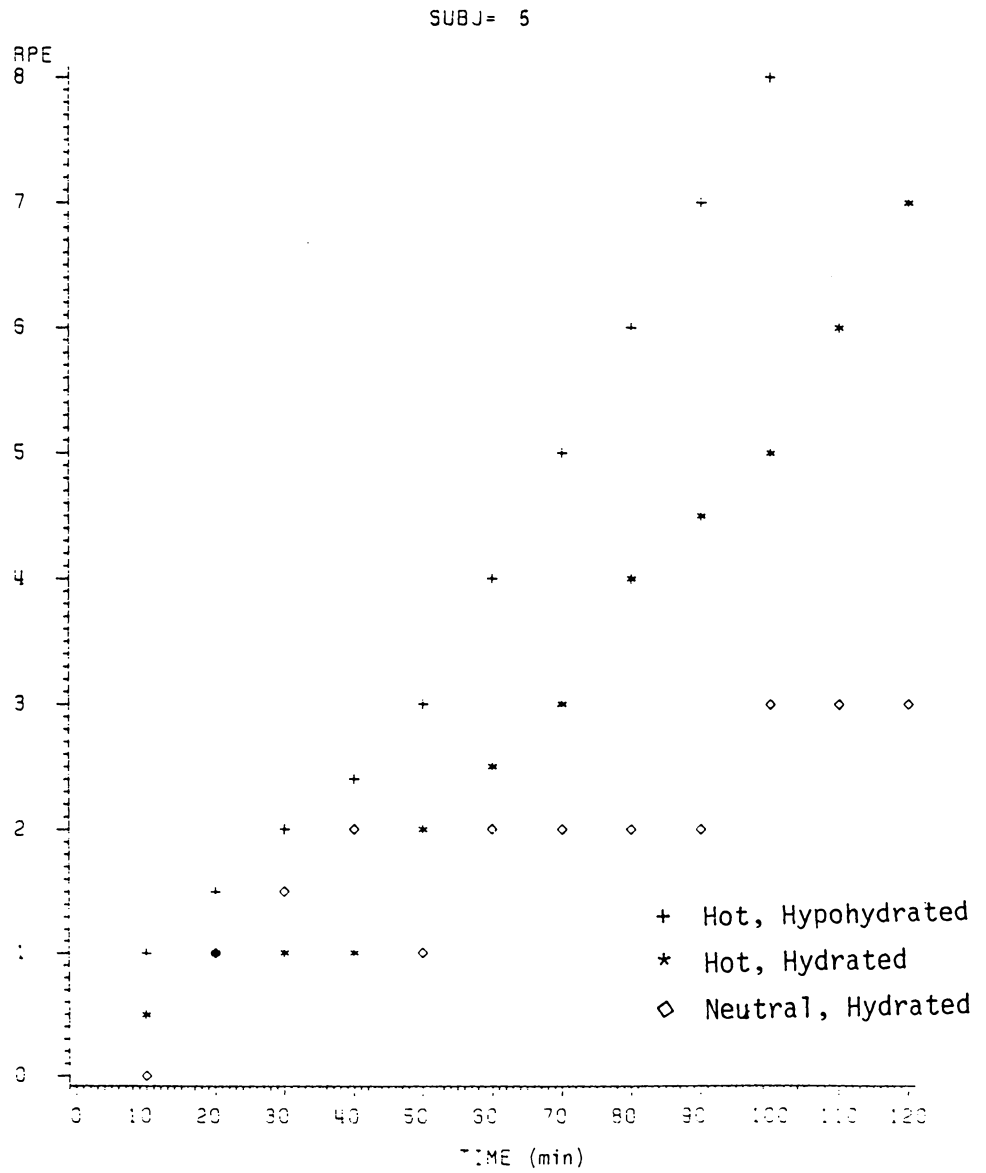


FIGURE 15.

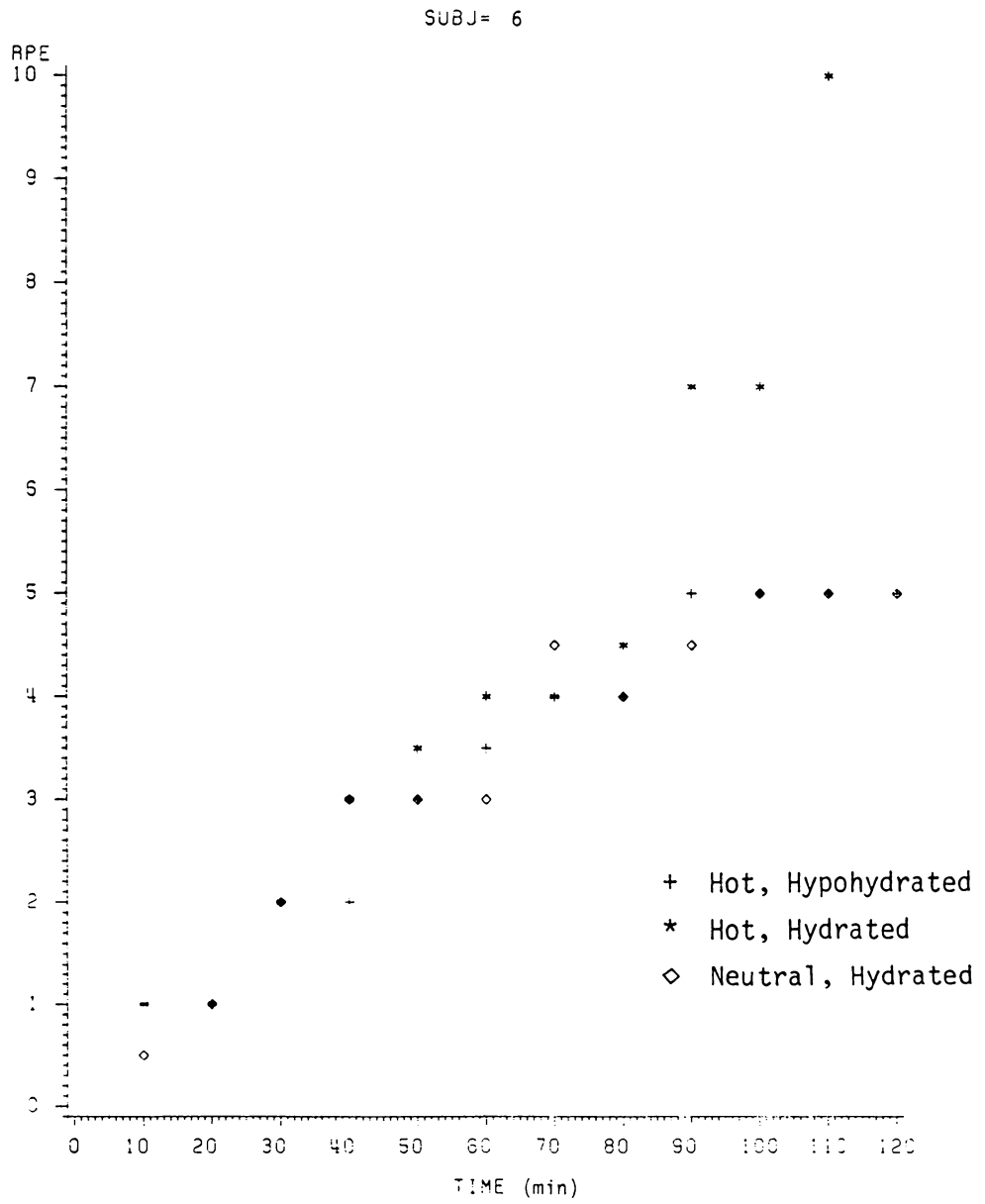


FIGURE 16.

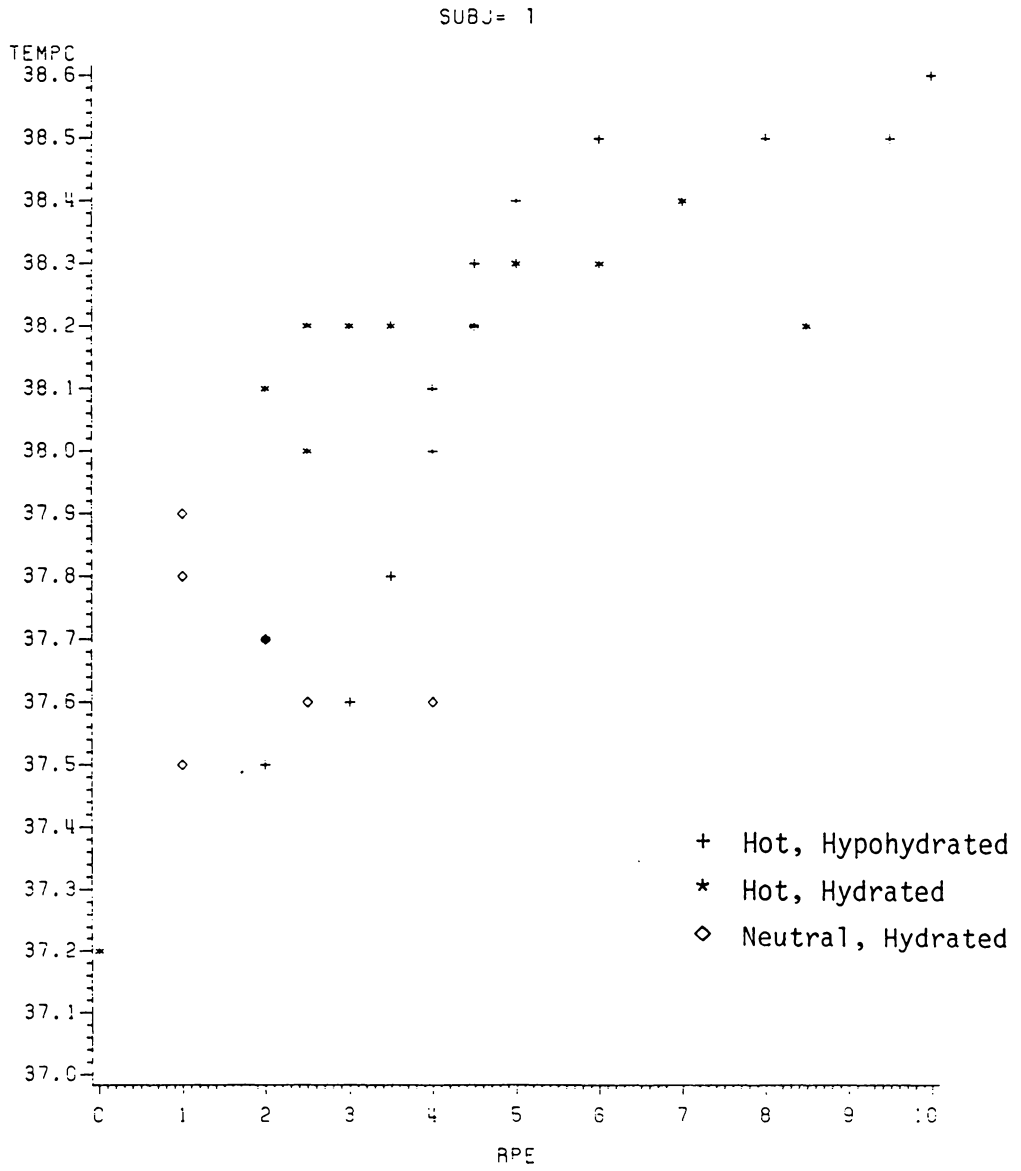


FIGURE 17.

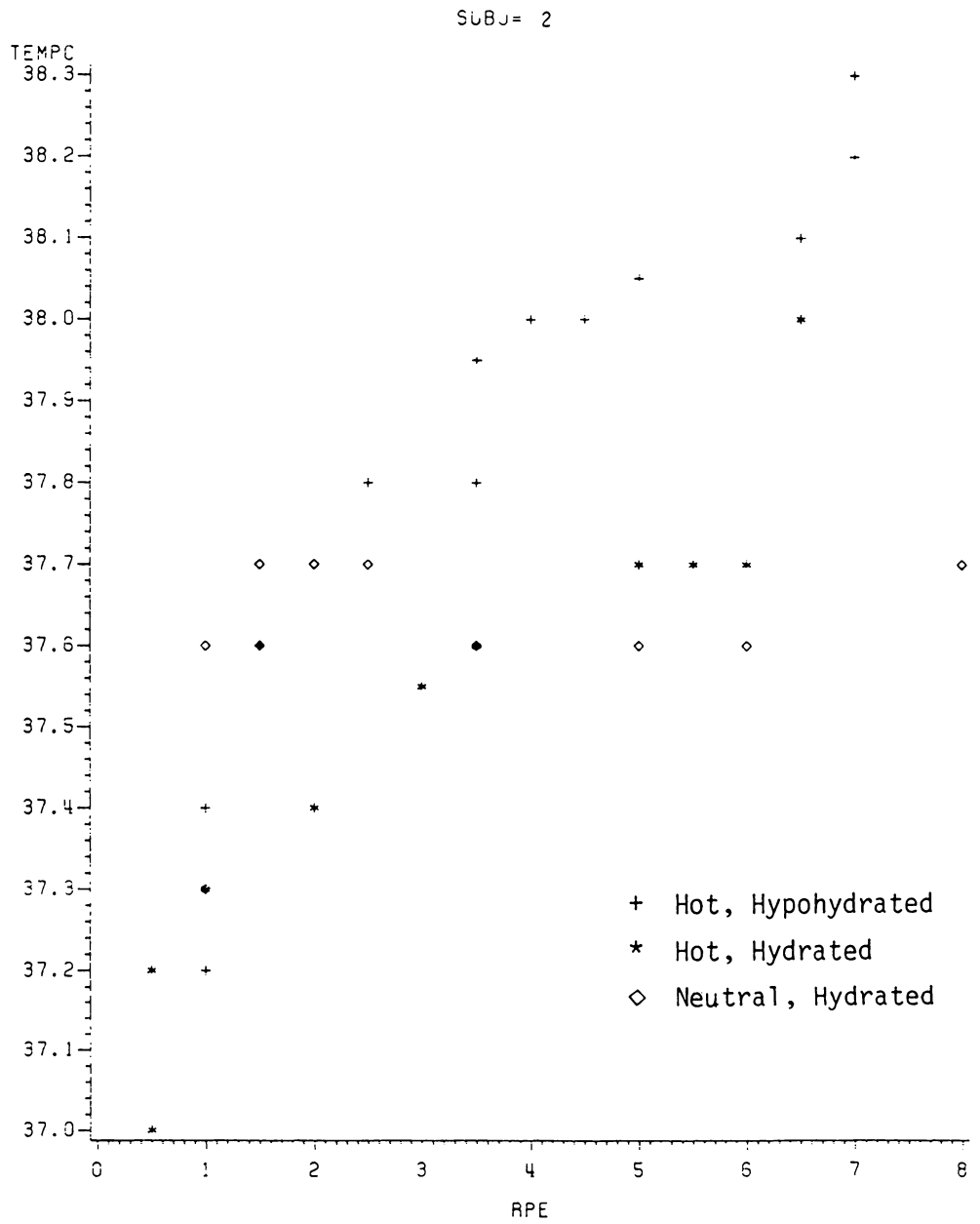


FIGURE 18.

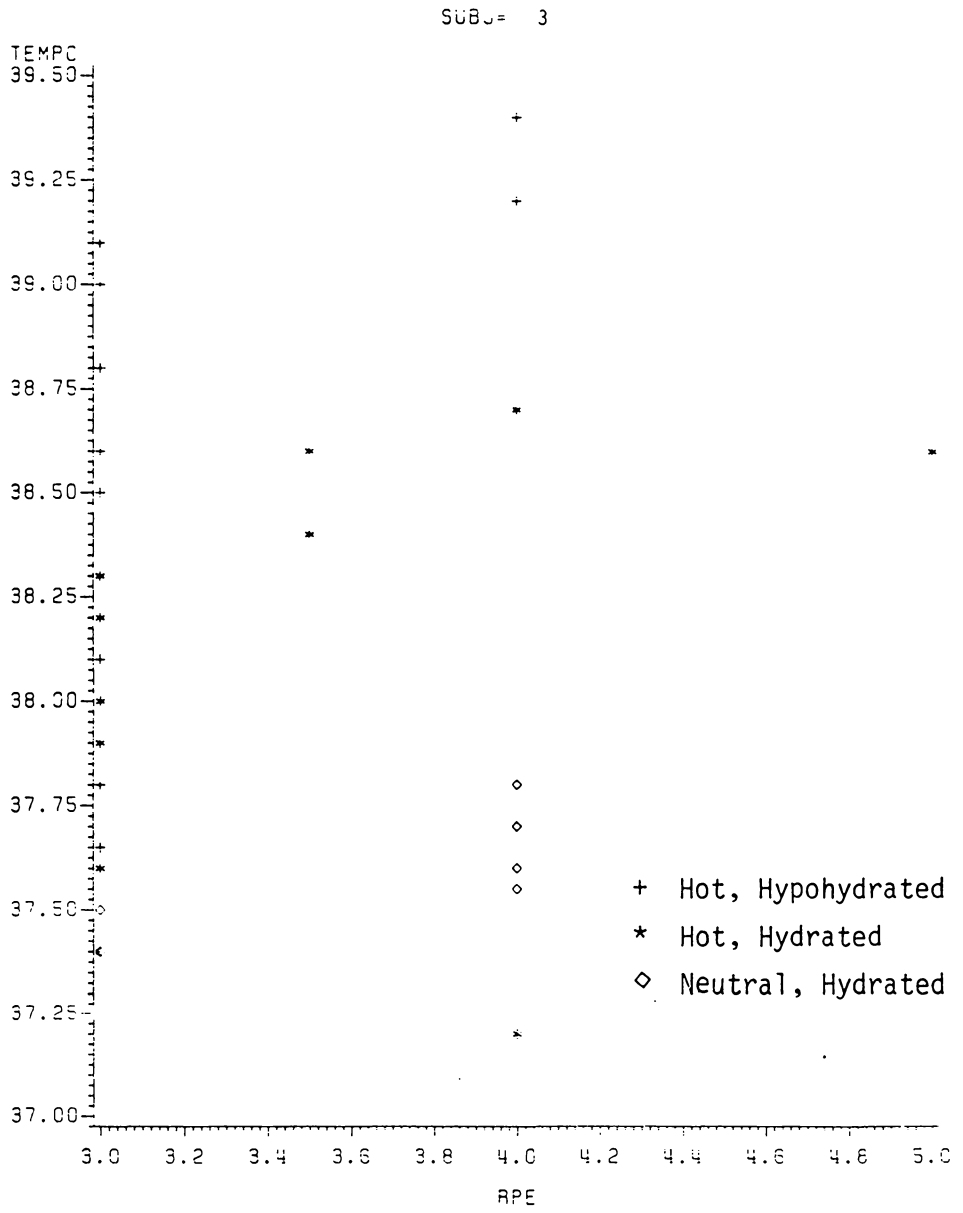


FIGURE 19.

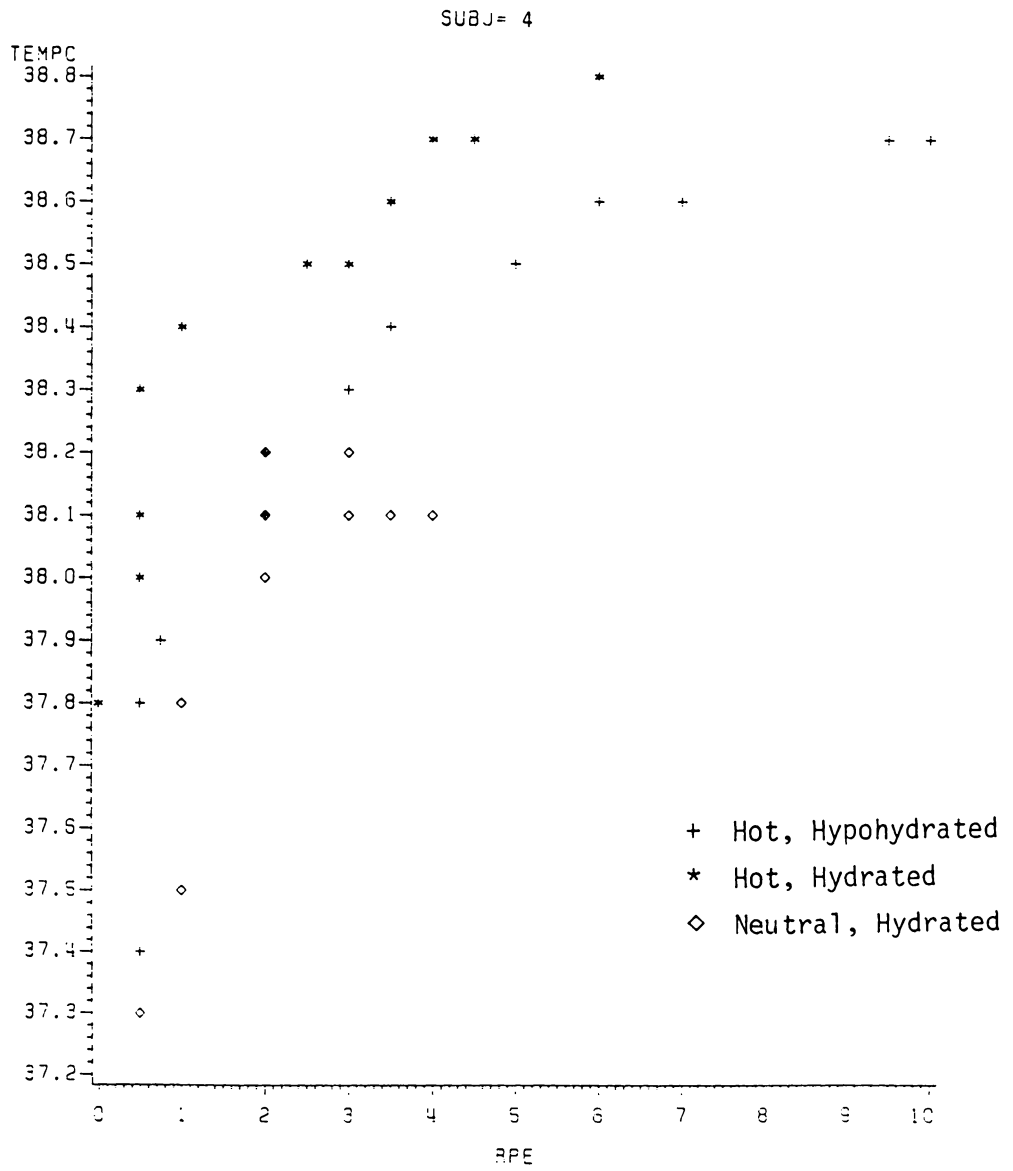


FIGURE 20.

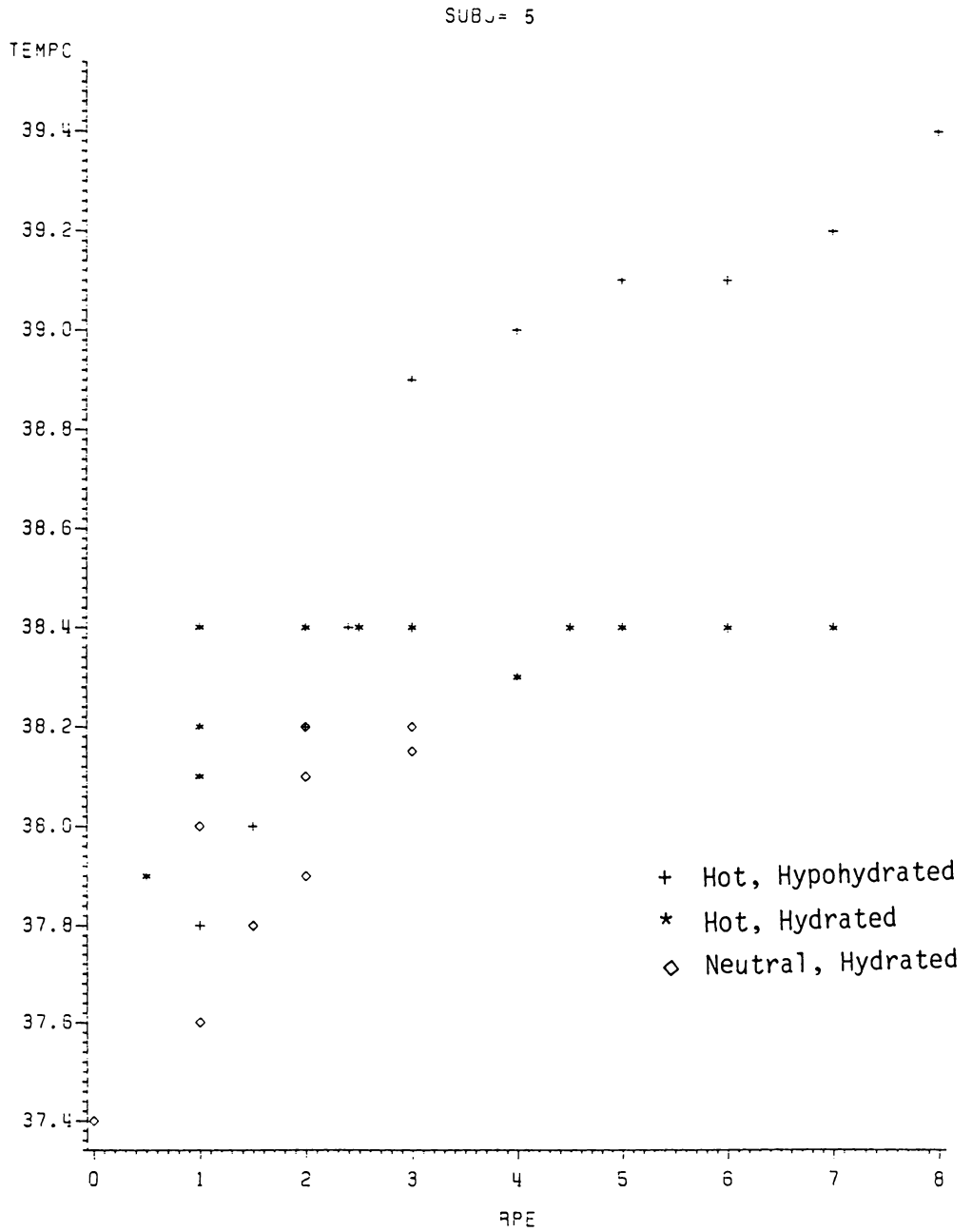


FIGURE 21.

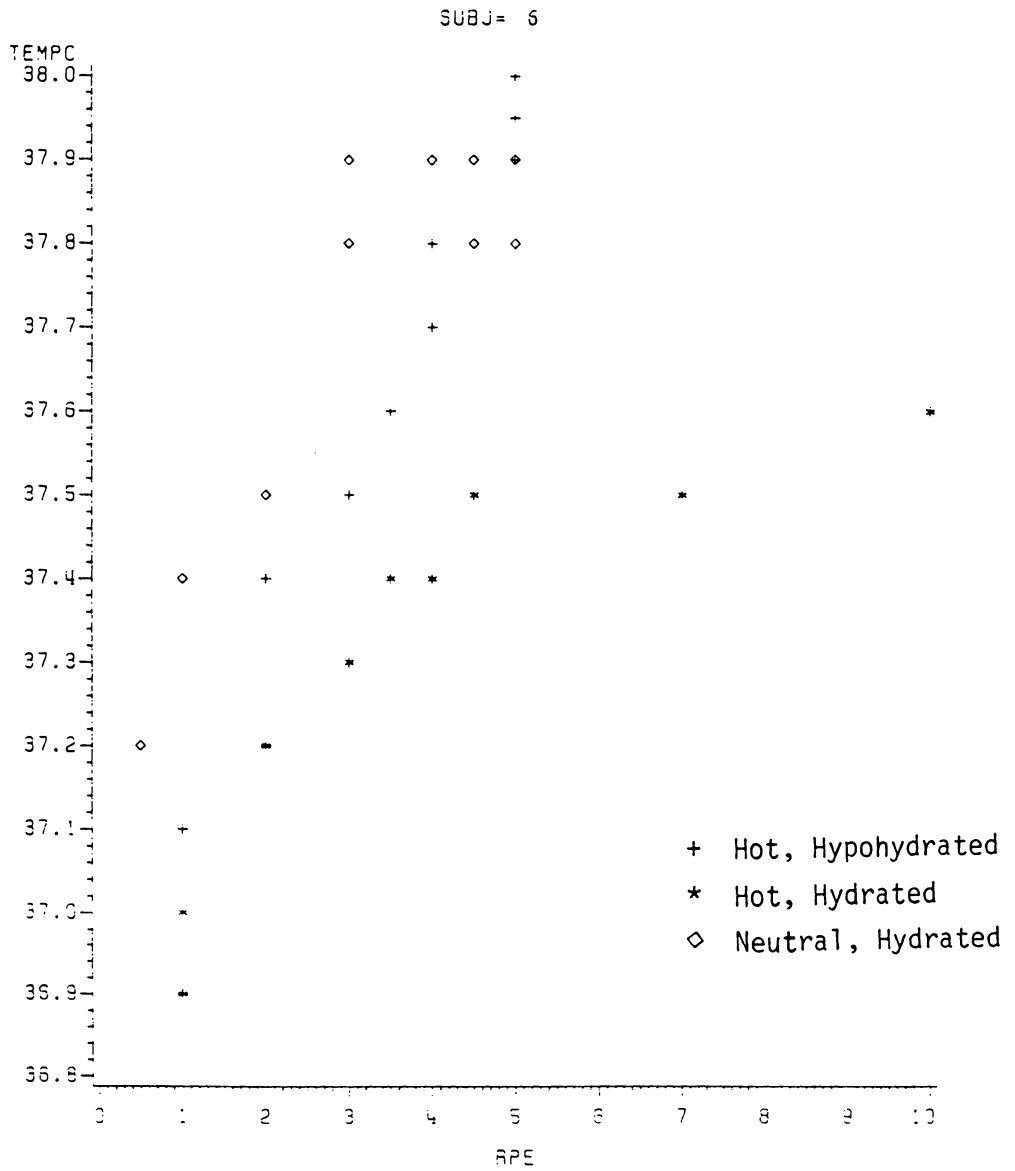


FIGURE 22.

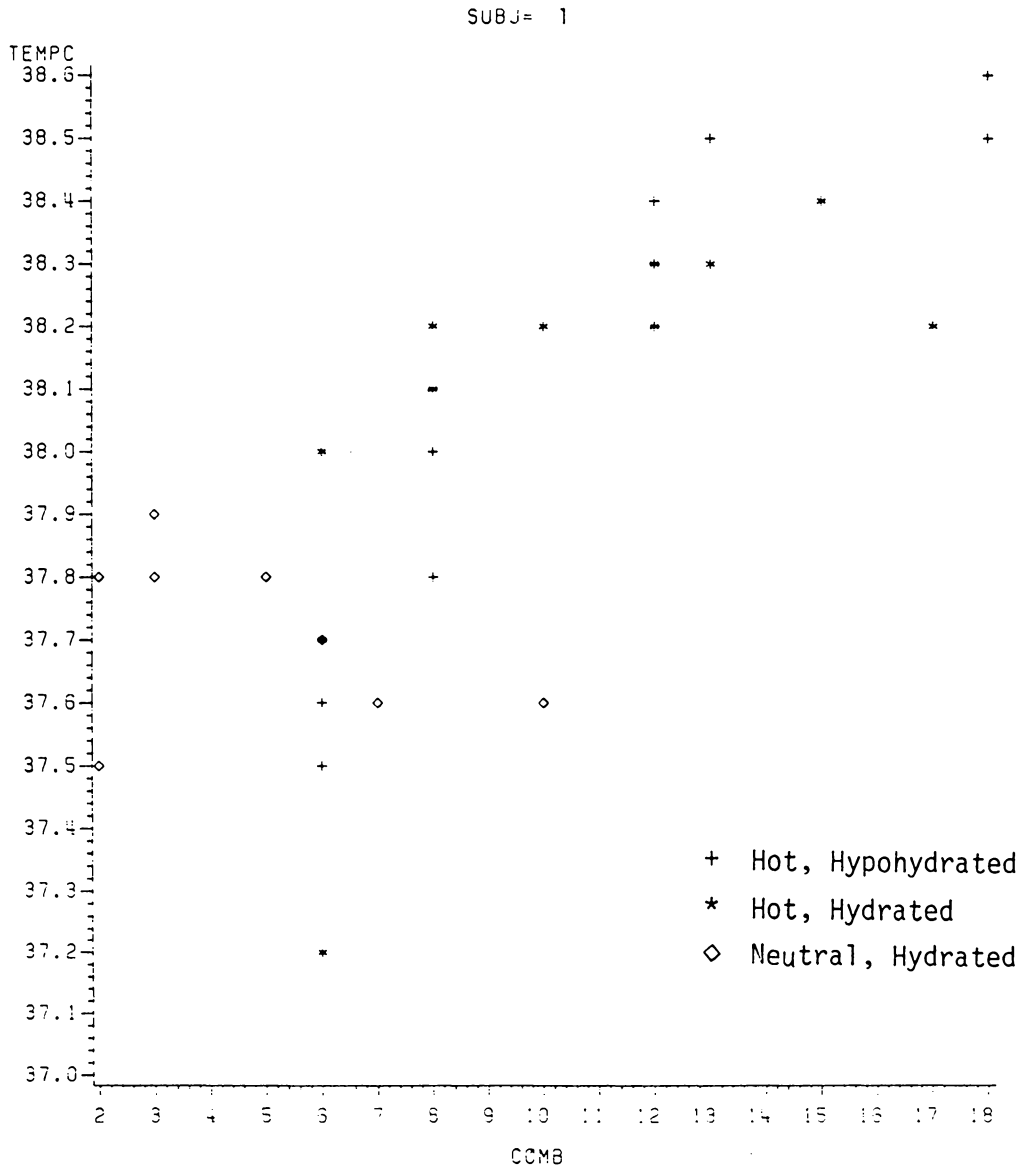


FIGURE 23.

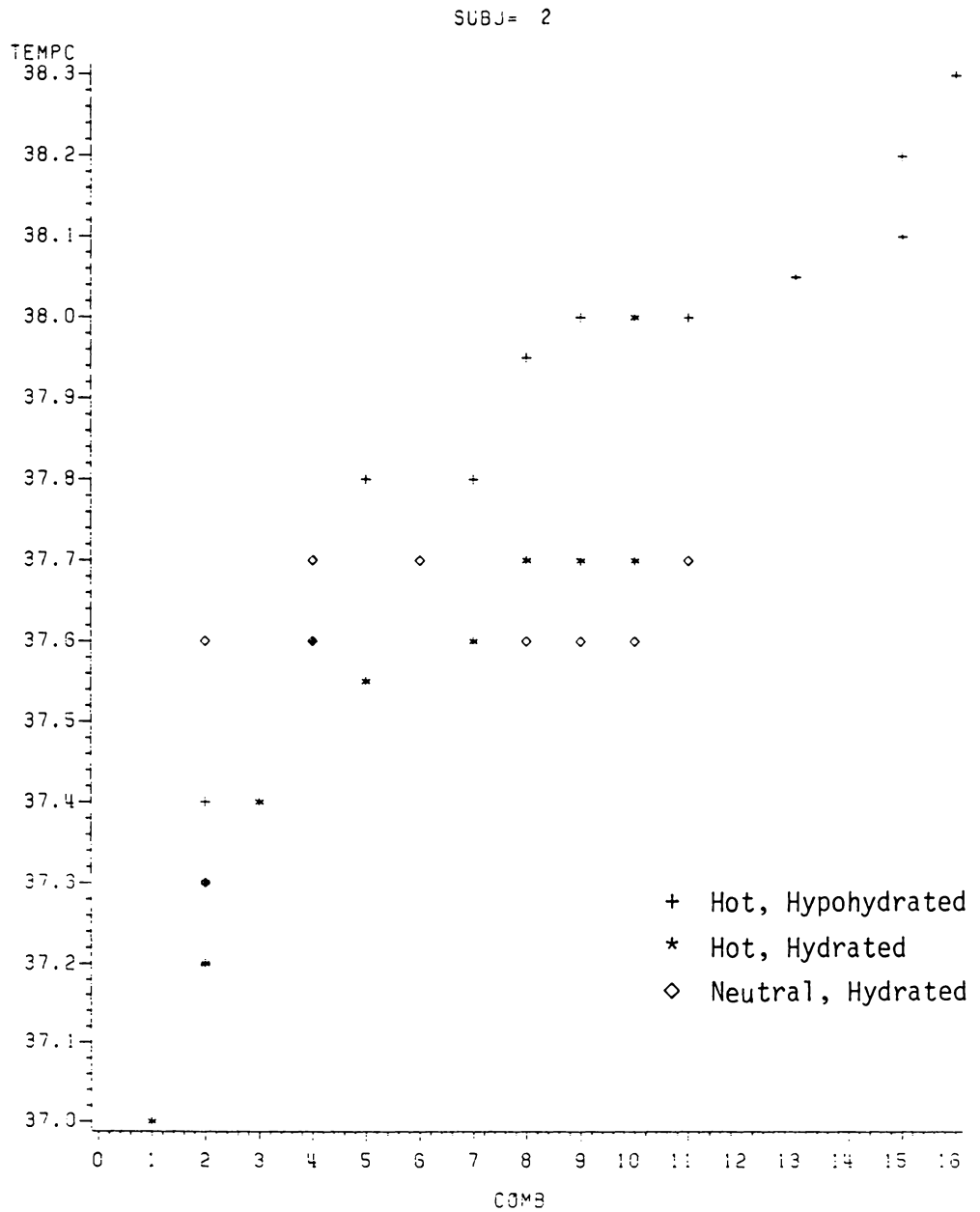


FIGURE 24.

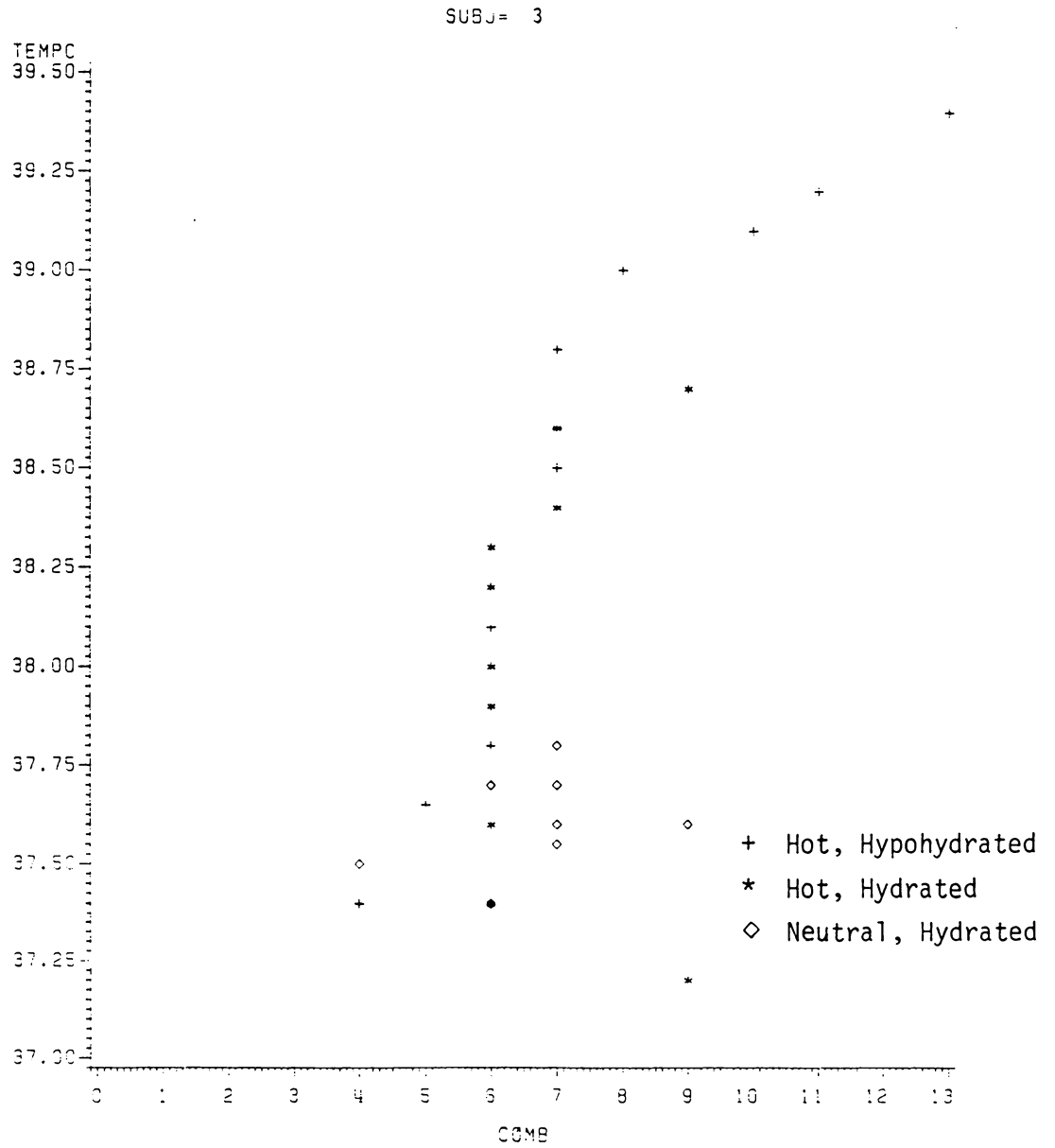


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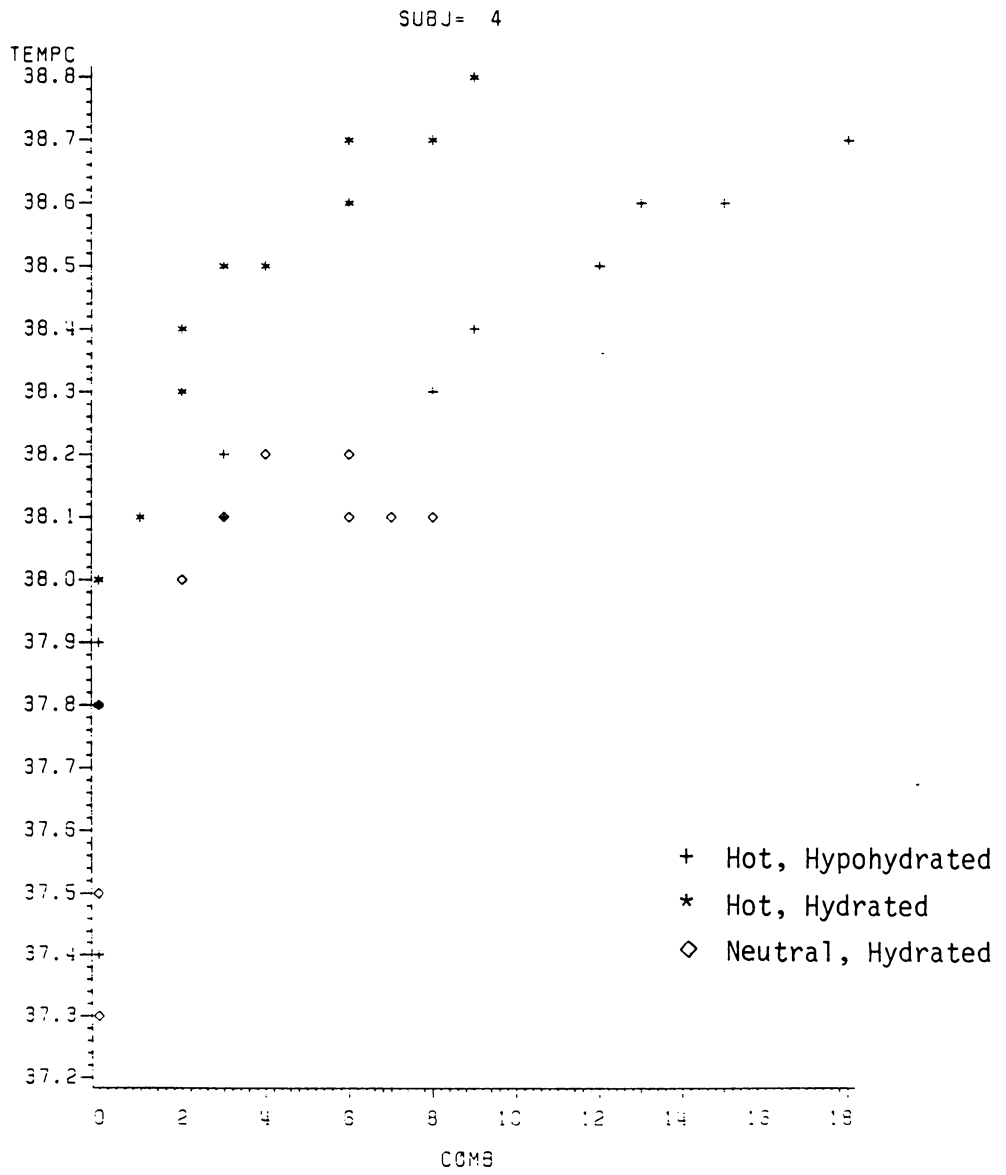


FIGURE 26.

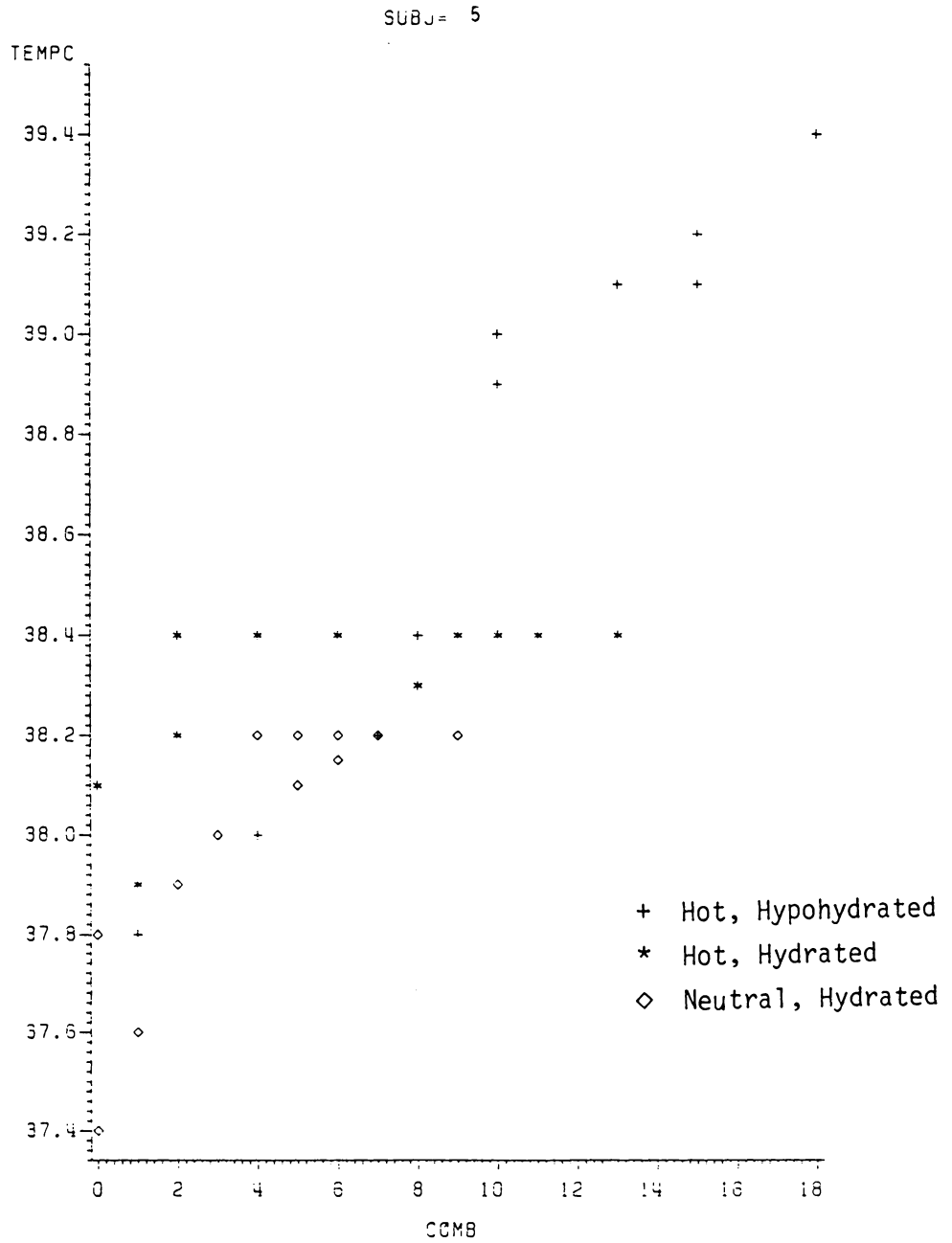


FIGURE 27.

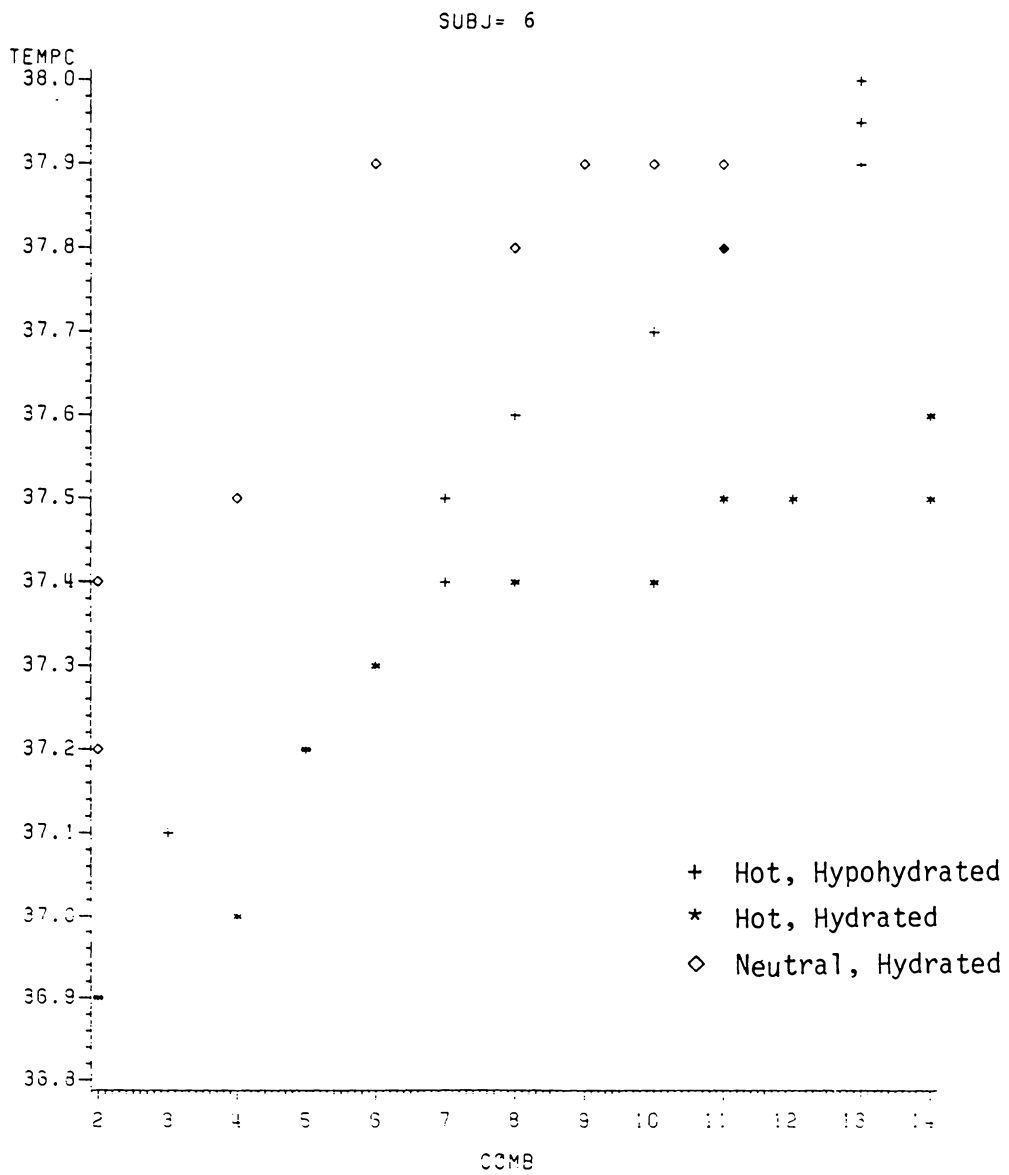


FIGURE 28.

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