THE EFFECT OF HEAT STRESS ON SALIVA

BY

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INTRODUCTION

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The human body is a complex and magnificent organism, that, among other things, is capable of adapting to a wide range of environmental conditions. It does, of course, have limits to its adaptability. Where that physiological adaptability ends, however, man is capable of altering the environment to bring it within his physiological adaptability range. This combination of physiological adaptability and alteration of the environment has made it possible for man to exist in virtually every natural environmental extreme found on earth: from the Arctic Circle to the Equator; from below sea level to the highlands of Tibet and South America. Environment can be, and is, altered in a very local sense, with clothing being an obvious example of this. Both the Eskimo and the desert Bedouin wear clothing which, in effect, creates a local environment favorable to his own survival, if not comfort as well.

As a by-product of civilization, however, man has succeeded in creating artificial environments hostile to himself. These also must be dealt with if he is to be able to continue living and functioning effectively in those environments. In certain industrial situations a hostile environment is integral to the specific industrial process. A foundry, steel mill, laundry, mine, glass factory, and many other such situations produce an environment which would very likely include such factors as high heat and high humidity, possibly combined with a contaminated atmosphere. It must be accepted that a high heat stress condition, possibly combined with a contaminated atmosphere, is at present a significant industrial problem.

The term "individual cooling" applies to a scientific and engineering area of interest oriented towards direct extraction of excess heat from the human body rather than the altering of the general environment. In addition to the applications of individual cooling in mundane industrial situations, it must be remembered that man has developed the technological capability of taking himself out of the natural environment of earth and into totally alien environments. Such is the case with man's exploration of outer space and, less spectacularly, inner space, by the astronauts and the aquanauts. Such programs have required the development of total integrated artificial environment systems for a man and have given considerable impetus to research in the area of individual cooling.

Individual cooling has been the subject of continuing research at Kansas State University in the past several years. This research has been particularly germane to possible industrial applications and has followed two general approaches: water cooling and air cooling. This thesis compares the effects of using air to locally cool two separate parts of the body, the torso and the head.

LITERATURE REVIEW

Physiology of Heat Stress

General. Heat stress and the reaction of the human body to it are discussed by Grollman (1969), Leithead and Lind (1964), Winslow and Herrington (1949), Folk (1966), Lee (1964), and many others. Specialized information on the subject is available from the articles referenced from the Handbook of Physiology.

Body heat exchange is expressed by:

$$M \pm C_d \pm C \pm R - E = \pm S$$

where

M = metabolic heat

C_d = conductive exchange (normally negligible)

C = convective exchange

R = radiation exchange

E = evaporative loss

S = incremental heat storage

The task of the body's thermoregulatory mechanism is to balance the above equation such that the incremental heat storage (S) remains essentially zero. In balancing that equation, it must ultimately depend on the physics of the relationship between the temperature and vapor pressure gradients of the body surface and that of the environment. The thermoregulatory mechanisms are oriented towards appropriate manipulation of the body's surface temperature and vapor pressure. The two physiological mechanisms that influence surface temperature and vapor pressure are the cardiovascular system and the sweating mechanism.

Cardiovascular system. Under heat stress the mechanism of vasodilation occurs. This increases blood flow to the skin and serves to transfer heat from body tissues to the skin where it is disposed of by radiation, convection, and evaporation. Various degrees of vasodilation are achieved by the body's ability to dilate the peripheral blood vessels and to regulate the blood flow through the arteriovenous anastomoses. These anastomoses, which abound in the skin, form a direct connection between the arteries and veins. Their function is to shunt blood directly from arterial to venous flow, thus drawing blood away from capillary circulation. In vasodilation these anastomoses are constricted, forcing blood to flow through the dilated peripheral vessels (Grollman, 1969).

An initial reaction to heat stress is a drop in blood pressure due to the dilated peripheral vessels, but a more protracted or severe heat stress results in increased systolic blood pressure due to the increased circulation demand (Bazett, 1968). This vasodilation obviously requires a greater volume of blood. On a temporary basis this increased blood volume is supplied by a decreased volume in internal areas.

Sweating. Evaporation of sweat provides the body's primary means of heat removal when the "critical atmospheric temperature", usually 88 F (31 C), is exceeded. The heat required to evaporate each gram of water is 0.58 kcal (2.3 BTUs), a fact that makes sweating quite a powerful heat removal mechanism. However, this mechanism is effective only if the sweat does evaporate. Eccrine glands, which cover most of the body, produce the clear aqueous sweat utilized for heat regulation. Even under basal conditions a person in a comfortable environment produces about 1 pint (0.5 liter) of insensible perspiration per day. This thin coating of moisture on the surface of the skin is continuously being secreted and evaporated.

Control of thermoregulatory mechanism. The hypothalamus of the brain is the primary control center for the thermoregulatory mechanism. It is apparently capable of reacting both to sensory input from various parts of the body as well as its own temperature (Leithead and Lind, 1964). The deep position of the hypothalamus, combined with a rich, well protected blood supply and high metabolism rate of the brain, make it relatively insensitive to local influences. However, brain temperature is relatively sensitive to heating of the extremities. Bazett (1968) cites evidence which shows that local heating of hands or feet will cause measurable change in brain temperature within three or four minutes while the rectal temperature would take eight to fifteen minutes to change.

The hypothalamus apparently integrates its various inputs in the performance of its temperature regulatory role and influences the various physiological mechanisms (heart rate, sweat rate, vasodilation or constriction) in response to that integrated input. Bazett (1968) points out that vasoconstriction initially results in a temporary rise in rectal temperature and probably brain temperature as well, but this does not reverse the vasoconstriction process. Byrne (1968) tested the theory that the hypothalamus integrates its various inputs with an experiment where the abdomen, scapula, or thighs were locally cooled. He found that sweat production caused by moderate heat stress was reduced by stimulating peripheral cold receptors and was probably further reduced by lowered activation of the warm receptors in the locally cooled areas. He concluded that integrated peripheral sensory inputs play a major role in the human temperature regulating mechanism.

The importance of local input in the body's thermoregulatory mechanism was further illustrated in a study reported by Wurster _et al_. (1969). Sweating normally begins at the lower body extremities and tends to progress upward. In this experiment a subject reclined in a split chamber, divided at the subject's waist. In this test chamber the subject's upper body (torso) was heated while his lower body was cooled, or vice versa. Results showed that heating the upper body would either greatly decrease the time for sweating to proceed from the bottom, or the order would be reversed, with sweating beginning on the upper body. The report concluded that skin temperature exercises a crucial influence on sweating.

Physiological effect of heat stress. For environmental temperatures under 88 F (31 C) the body is said to be under vasomotor control (Grollman, 1968), meaning that vasodilation or vasoconstriction are used to control heat flow from the inner tissues to the skin, and radiation and convection dissipate the heat. Under neutral conditions radiation accounts for about 60% of the total heat loss, while insensible sweat evaporation accounts for about 25%. Above 88 F (31 C), however, the body temperature regulating mechanism depends primarily upon sweat evaporation for heat removal. As heat stress is increased, vasodilation and sweating are increased and thermal equilibrium can be maintained over a wide range, while physiological cost, in terms of heart rate and sweat rate, increases for an increased heat stress.

Wyndham <u>et al</u>. (1965) reported an experiment which illustrates the body's capability to maintain thermal equilibrium over a range of thermal stress but at an increased physiological cost. The hypothesis was that miners, instead of working in a saturated 90 F (32 C) environment, would experience better body cooling if the wet bulb temperature were held at 90 F (32 C) and the dry bulb temperature were elevated. The net effect of the new situation is, of course, a higher ambient temperature but a lower relative humidity. The experimental results showed that the higher temperature with lowered relative humidity did not change the thermal equilibrium of the subjects but that it substantially increased the physiological cost to maintain the same essential heat balance.

Part of the body's ability to accommodate heat stress depends upon its ability to store heat in body tissues when the heat stress precludes the dissipation of any additional heat. A sufficiently high level of heat stress, however, considered in terms of both intensity and duration, will override the body's regulatory mechanism and a heat disorder, such as heat stroke, heat exhaustion or heat syncope, will result (Leithead and Lind, 1964).

Effect of heat stress on human performance. A number of studies verify what is intuitively evident: higher levels of heat stress can be expected to produce a decrement in human performance. In addition to the representative work described below, studies on this matter have been reported by Bell (1967), Cooke *et al*. (1961), Crockford (1967), Snellen (1962), Davies *et al*. (1967), and others.

Wyndham and Strydom (1965) demonstrated a significant productivity decline in a manual work situation at Effective Temperatures from 81 to 86 F (27 to 30 C) as well as significant health hazards to unacclimatized men at Effective Temperatures in excess of 82 F (28 C). Wing (1965) studied the effect of Effective Temperature on mental performance and proposed a curve delineating the limit for unimpaired mental performance. Figure 1, adapted from Wing's article, includes the curves for mental performance, recommended physiological limit, and marginal physiological limit.

A useful device for assessing heat stress is the Heat Stress Index (HSI), (McKarns and Brief, 1966). This HSI is a ratio of the evaporation rate required to maintain an acceptable

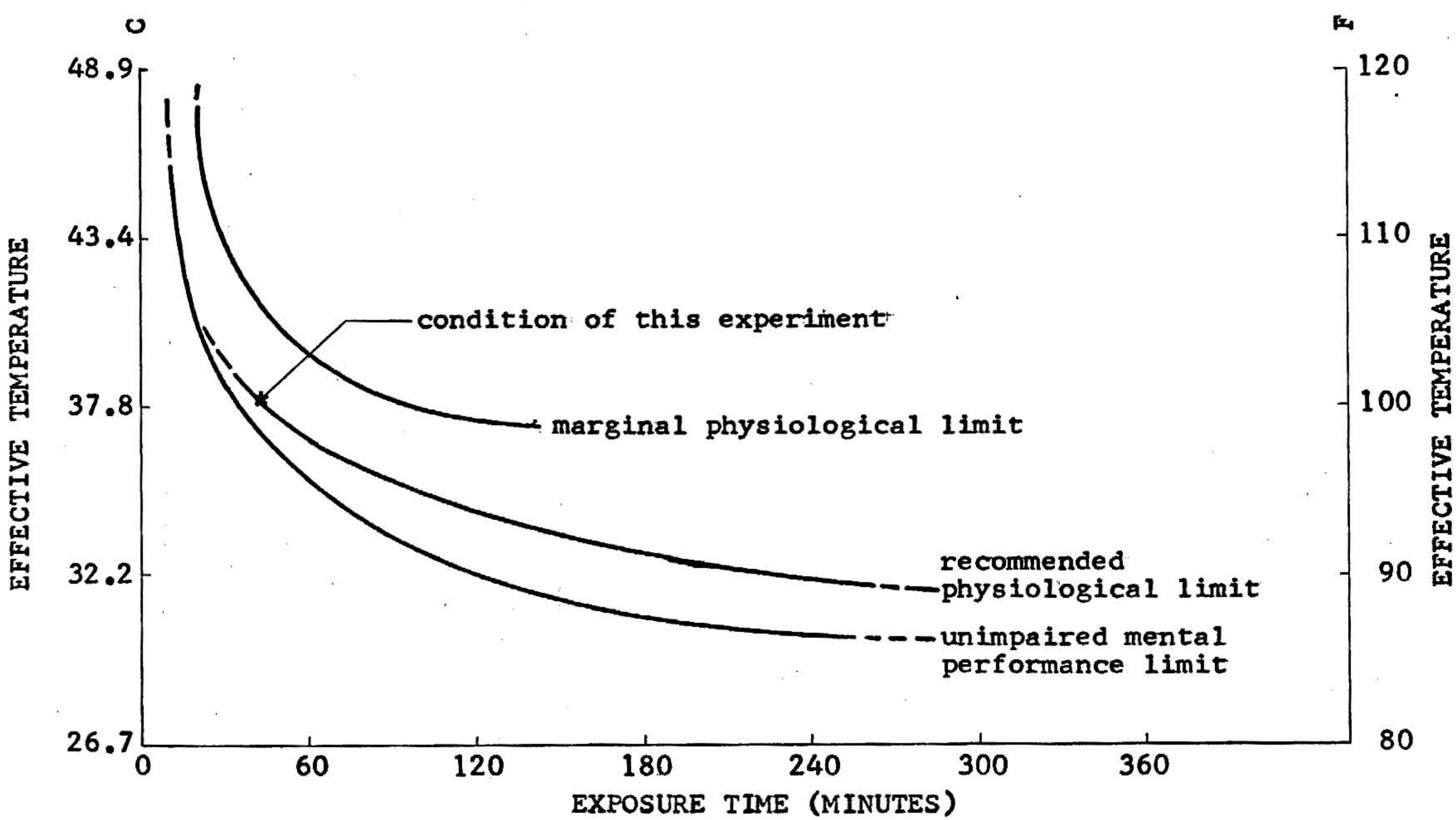

Figure 1. Human Performance Limits in Heat Stress (Wing, 1965).

thermal equilibrium and the maximum evaporative capacity of the hot environment. It considers energy expenditure as well as the various parameters of the environmental conditions. An HSI of 100 is considered to be the maximum that a healthy young adult male can tolerate for eight hours and remain effective. The experimental conditions for the experiment upon which this thesis is based, 110 F (43 C) and 60% RH, yielded an HSI of 1,300. The HSI Nomogram specified a 20 minute allowable exposure time for these conditions; exposure time for this experiment was 40 minutes.

Air Cooling

General. Circulating air is the oldest and probably still the most widely used means of reducing heat strain in industry. The effect of air velocity is illustrated by the Effective Temperature Scale (Leithead and Lind, 1964). In general, it can be said that an increase in air velocity at a given dry bulb temperature will reduce the Effective Temperature. Increased air velocity becomes less effective, however, as dry and wet bulb temperatures increase, and at about 100 F (38 C) at saturated humidity, air velocity has no effect on Effective Temperature. It can also be noted that for low humidity conditions, where there is a spread between dry bulb and wet bulb temperatures on the order of 60 F (33 C), an intermediate Effective Temperature remains relatively constant over a wide range of air velocities. For example, 30 F (-1 C) wet bulb and 92 F (33 C) dry bulb temperatures produce an Effective Temperature of 63 F (17 C) which is constant for air velocities from 0 to 700 feet (213 m) per minute. The Effective Temperature concept very impressively shows that humidity is the villain in many air cooling applications. It also illustrates the limitations of cooling by air circulation for higher level heat stresses.

Recognizing the limitations of simply circulating the air for higher level heat stress situations, numerous devices have been developed to cool the individual locally with ventilated clothing.

Ventilated devices. The concept of ventilated clothing is not new. A patent for a "Body Ventilating Apparatus" was issued in 1904 and others have been issued since (Fletcher *et al.*, 1949). Serious investigation and use of ventilated clothing seems not to have developed until the 1930's, however, possibly due to the rapidly increasing number of situations where such devices would be useful or necessary, as well as an increasing concern for the worker. Several representative examples of the more current work done in this field are reported here.

Crockford and Hellon (1964) reported on ventilated suits designed to be used as hot entry suits for furnace wrecking. A permeable suit was developed and compared with three different insulated but non-permeable suits. The unique feature of the permeable suit was that the air would exhaust radially from the body through the fabric, creating the effect known as dynamic insulation. The suits were compared in an environment of 190 C

(374 F) radiant temperature and 72 C (162 F) air temperature. The permeable suit showed superior insulative qualities capable of limiting heat flow into the suit in proportion to the air flow to the suit, while air flow in the impermeable suits had no effect on heat flow into the suit. While all the suits tested demonstrated considerable effectiveness in reducing heat strain, the permeable suit was superior under the high radiant heat conditions of the test.

Crockford and Lee (1967) tested the cooling effectiveness of dry and humid ventilating air when used in an air cooled jacket. Various combinations of flow rate from 15 to 60 cfm (424 to 1690 l./min.) and air temperatures from 59 to 86 F (15 to 30 C) were translated into cooling capacity which was used as the comparative criterion. For cooling capacities over 4.5 kcal (17.8 BTU) per minute, humid air was equivalent to dry air in the capability of bringing a subject into thermal equilibrium.

Following earlier work on individual cooling at the du Pont Savannah River Plant reported by Butler and Van Wyck (1960), Croley (1969) reported on an impermeable ventilated suit used to protect personnel from radioactive and chemical contamination. Ventilation extended wearing time of the protective clothing by providing cool, pure breathing air and reducing heat strain. Several methods had been used for supplying air but had proven to be undesirable. Cool air supplied from a central system was excessively heated during distribution. Compressed air was undesirable since it was supplied at ambient temperatures and selfcontained liquid air cooling packs were expensive, dangerous, and subject to contamination. Therefore a modified vortex tube was developed which supplied air at 16 to 18 cfm (453 to 510 l./min.) at 50 to 60 F (10 to 16 C) lower than the inlet temperature. Croley reported that this arrangement proved to be effective for a variety of environmental conditions.

Sharma (1970) tested a ventilated helmet supplied with 6.4 cfm (183 l./min.) of 70 F (21 C) air from a vortex tube. The test was performed with eight male subjects in a heat stress environment of 112 F (44 C) and 60% RH. The subjects were exposed twice with the helmet and twice without the helmet for 45 minutes per trial while walking at 2 - 2.5 miles (3.2 - 4 km) per hour. Rectal and head temperatures of the helmet were found to be significantly lower and the helmet reduced heat storage by 25 kcal (9.9 BTU) per hour. Mean heart rate was lower but not significantly so. There was a nonsignificant decrease in salivary creatinine.

Gandhok (1970) evaluated an air cooled jacket, supplied by vortex tube cooled air, in a heat stress environment of 112 F (44 C) and 60% RH. Two male subjects were used for the evaluation, each being exposed six times for 45 minutes each trial, three times while wearing the helmet, with a different flow rate for each trial, and three times without the helmet. The subjects walked at 2 miles (3.2 km) per hour during exposure. The jacket was found to be most effective at the maximum flow rate used, 6.8 cfm (192 l./min.) and 68 F (20 C). Mean skin temperature under the jacket, head temperature, rectal temperature, and heart rate were all found to be significantly reduced by the jacket. Gandhok also reported that creatinine concentration in saliva tended to decrease during heat stress.

The experiments of Sharma and Gandhok are of particular interest as the devices they tested separately are directly compared in this thesis.

Saliva

General. The effects of heat stress on saliva are of significant interest in this thesis. The following literature survey will serve as a basis for analyzing the saliva component changes observed in this experiment.

Saliva secretion and salt balance. According to Campbell *et al.* (1968), saliva is secreted from the acinar cells of the parotid, submandibular, sublingual, and buccal glands of the oral cavity. Secretions of these glands have different compositions and the saliva collected from the oral cavity is a mixture of the secretions of all the salivary glands (Grollman, 1969).

Parotid saliva is of particular interest. It is an albuminous, watery liquid, containing high concentrations of salts and digestive compounds. The submandibular, sublingual, and buccal glands contribute mainly mucin to the saliva mixture (Grollman, 1969). The parotid saliva is acted upon by aldosterone during secretion to conserve body sodium. Aldosterone is secreted by the adrenal cortex of the kidneys and has a powerful body salt regulating function (Strauss, 1957). Aldosterone removes sodium from the saliva while adding potassium. An increase in aldosterone secretion will intensify that process, causing a reduction in the sodium to potassium ratio of the parotid saliva fluid. Aldosterone secretion has been shown to increase due to physiological heat strain (Leithead and Lind, 1964). Thus a decrease in the salivary sodium to potassium ratio is indicative of increased aldosterone secretion and hence of physiological heat strain.

A change in saliva flow rate also causes a change in the salt balance of the saliva. As the parotid saliva secretion rate increases, its sodium concentration and acidity increase while potassium concentration falls (Burgen and Emmelin, 1961). This is probably due to the overriding of the salt balancing mechanism by the lymph fluid.

Since exercise was a factor in this experiment as well as heat stress, the influence of exercise on the saliva is also important. Shannon (1966) found that exercise alone did not alter the salivary sodium to potassium ratio or the adrenal cortical function. This is a useful finding in this experiment since any changes in the sodium to potassium ratio can be reasonably attributed to heat stress.

<u>Creatinine</u>. According to Grollman (1969), creatinine is the end product of creatine metabolism. The excretion rate of this substance by the kidneys is quite constant in a healthy per-

son (Strauss, 1957). Since the excretion rate is essentially constant, a change in concentration would be indicative of a change of saliva flow.

Amylase. This substance is the major protein component secreted by the parotid gland and has a carbohydrate digestive function. The digestive function is minor, however; stomach acids neutralize amylase, allowing it to act on food only before it reaches the stomach. The parotid gland has no provision for storing amylase and it is simply secreted as it is produced. The secretion rate of amylase is possibly related to blood flow: the higher the blood flow to the parotid gland, the greater the secretion rate of amylase (Osbaldiston, 1969). Relative to heat stress, it might be expected that amylase secretion would increase simply by virtue of the higher blood circulation elicited by heat stress.

THE PROBLEM

Gandhok (1970) evaluated an air cooled jacket and Sharma (1970) an air cooled helmet. Both devices reduced the physiological strain imposed by heat stress. However, the vortex tube cool air source limited cooling air volume to approximately 6 cfm (170 l./min.) which was only marginally effective. This experiment directly compares the two devices, but with a flow rate of 35 cfm (990 l./min.).

Another consideration was to examine some of the biochemical changes in the saliva resulting from heat stress.

METHOD

Apparatus

Test facility. The environmental test chamber at the Institute for Environmental Research, Kansas State University, was used for the experiment. It is described in detail by Nevins, Rohles, Springer, and Feyerherm (1966). The test chamber is a room 12' by 24' by 8' in which temperature, humidity, and air velocity can be maintained at predetermined values. See Figure 2 for the organizational layout of the test facility for this experiment.

The control room adjacent to the test chamber was used to house the monitoring instruments and equipment as well as the air conditioner assembly which provided the cool air source to the subjects.

Adjacent to the control room was a pre-test room where the subjects prepared for and recovered from the trials. This room provided the "neutral" environment for basal and recovery monitoring. Since the control and pre-test rooms acted as the heat sink for the air conditioner, however, the temperature in these rooms ranged from 80 to 85 F (27 to 29 C).

Cool air supply. A modified Fedders 23,000 BTU window type air conditioner provided cool air to the two cooling devices used in the experiment. The air conditioner was located in the control room and unfortunately, as was mentioned, the control room acted as the heat sink for the device. The cooled

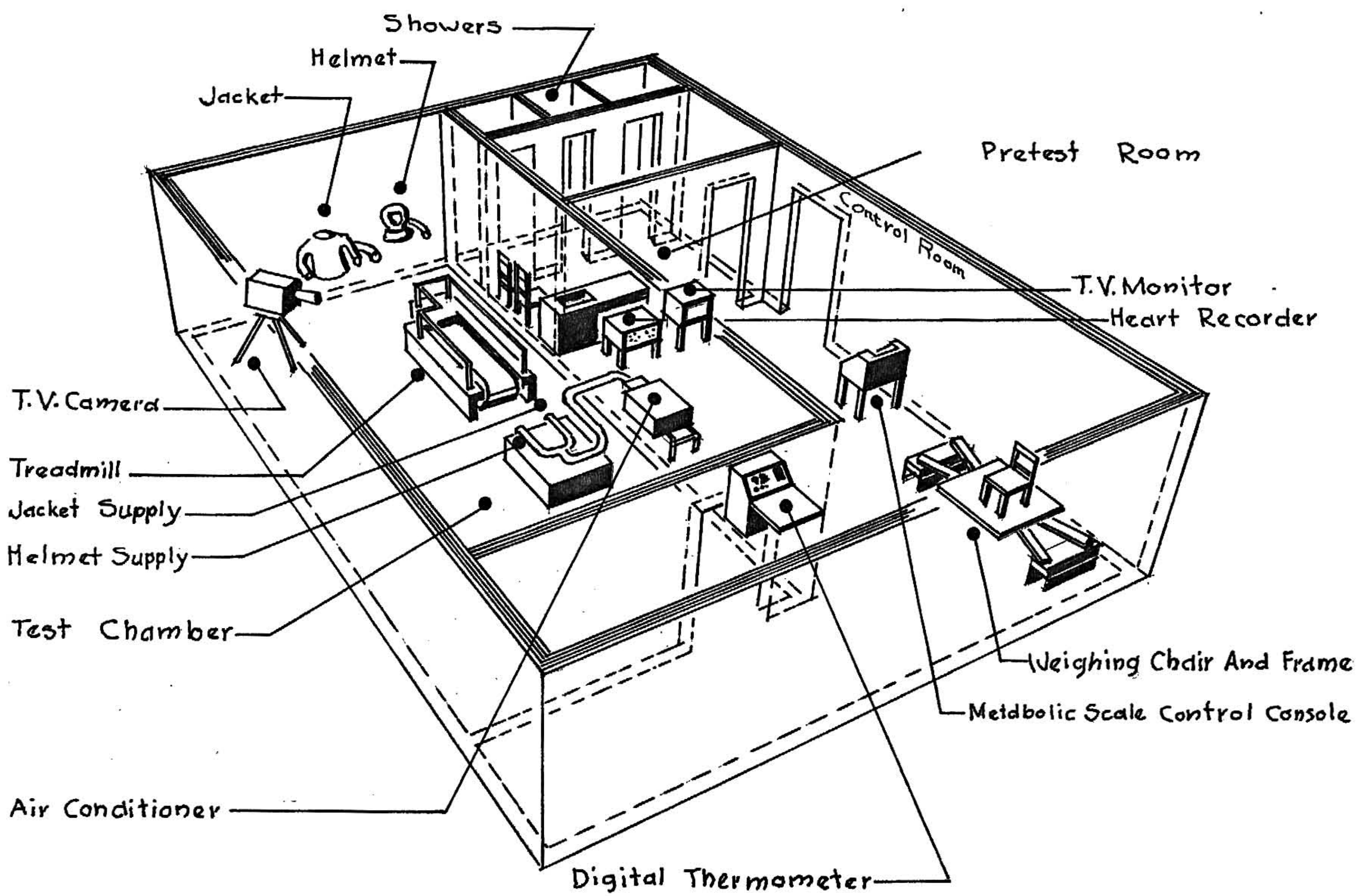

FIGURE 2. SCHEMATIC LAYOUT OF TEST FACILITY AND COOLING SYSTEM

air was manifolded into a 4 inch (10 cm) inside diameter polyvinyl pipe with 1/8 inch (0.3 cm) wall thickness and was ducted into the test chamber. This pipe was wrapped with 3 inch thick fiberglass insulation. Due to high pressure and velocity losses in the ducting, a 1/30 HP cage blower fan was inserted into the line to increase the air volume flow.

In the test chamber the main air supply line was split by a U-shaped duct to feed the two cooling devices. The legs of this U-shaped duct were 30 inches (76 cm) long and had a 1.5 inch (3.8 cm) diameter port, 4 inches (10 cm) from the end of each leg. These ports were used to provide access for air velocity measurement.

The U-duct was fabricated from 4 inch (10 cm) diameter metal clothes dryer duct pipe and elbows, and was insulated with 1 inch (2.5 cm) of fiberglass insulation. Six feet (1.8 m) of flexible uninsulated 4 inch (10 cm) diameter fabric and wire coil clothes dryer ducting was used to connect the cooling devices with the U-duct and allowed sufficient mobility for the subjects to accomplish their task.

<u>Cool air supply measurements</u>. Air velocity was measured directly with an Alnor Velometer, Type 3002, with jet 2220. Access for the pitot probe of this instrument was provided by the ports in the U-duct. Effects of static pressure in the air duct were eliminated by connecting the exhaust of the Velometer to a static port in the U-duct. Accuracy of this system was

verified with an Anemostat Corporation of America Anemotherm Air Meter, Model 60.

Dew point temperature was measured by a Cambridge System Dew Point Hygrometer, Model 990. This instrument sampled directly from the air conditioner manifold.

Temperature of the cooling air was sensed by a Yellow Springs Instrument thermistor, Model 409, suspended directly in the center of the 2 inch (5 cm) inside diameter inlet tube at a distance of 4 inches (10 cm) from the end of the nozzle on both the helmet and the jacket.

The system provided 35 cfm (990 l./min.) for each device at a dew point temperature of 32 F (0 C) and 70 F (21 C) inlet temperature. Based upon calculations from the <u>ASHRAE Handbook of Fundamentals</u>, the 32 F (0 C) dew point converts to a relative humidity of 25% at 70 F (21 C). Note that the ventilating air underwent considerable heating between the air conditioner and the cooling devices. The air left the air conditioner at 40 F (4 C) and was heated to 70 F (21 C) en route. Prevention of this heating presents a substantial problem when cool air must be transported an appreciable distance.

<u>Heart rate monitoring</u>. Three E & M Instrument Company surface electrodes were attached to the chest of each subject and connected into a junction box worn on a belt around the subject's waist. The junction box was directly connected by a shielded cable to one of the two channels on a Beckman Type RS

Dynograph strip chart recorder. In accordance with the uniform experimental procedure, the helmet subject was connected to the left channel while the jacket subject was connected to the right channel. Heart rate recordings were then taken simultaneously through their respective channels. An E & M Instrument Company Telemetry Unit consisting of Transmitter FM-1100-E2 and Receiver FM-1100-6 provided a backup system and was used on two of the trials when a junction box shorted due to moisture. Manual pulse reading was used as a final backup.

Subject weight. Subjects were weighed to the nearest gram on a Brookline Instrument Company Metabolic Scale. This scale is considered accurate to one gram.

Temperature monitoring.

Skin temperature. Skin temperature was sensed by Yellow Springs Instrument Model 409 thermistors. Seven of these thermistors were attached to each subject by duct tape. For consistency, all instrumentation was attached to the left side of the body. Seven skin temperatures were taken: sensors were placed on the forehead, on the hollow of the cheek, on the front-left of the neck, on the triceps muscle of the arm, on the back immediately below the ribs, on the abdomen, and on the rectus muscle at the front of the thigh.

Rectal temperature. A Yellow Springs Instrument Model 401 thermistor was inserted 6 inches (15 cm) into the subject's anal canal to sense rectal temperature. A tape collar on this thermistor limited insertion depth.

Ear canal temperature. Ear canal temperature was monitored by a sensor assembly based upon a Yellow Springs Instrument Model 423 thermistor. The 0.08 inch diameter thermistor protruded 0.5 inch beyond a piece of 5/16 inch outside diameter tubing through which it was inserted and was securely taped in position. This assembly was inserted through an earmuff, then a 1.75 inch thick tapered foam pad and thence into the ear canal to a depth of 0.5 inch. Penetration was limited to only 0.5 inch to preclude injury to the tympanic membrane in case the probe were accidentally shifted after insertion.

Instrumentation harnesses. The thermistors were arranged into subject harness assemblies and each thermistor was labeled. This arrangement greatly assisted in instrumenting the subjects quickly and efficiently.

Temperature recording system. All thermistors were connected to a 20 position junction box and the junction box was connected by cable to a United Systems Corporation Digital Thermometer, Model 500. The digital thermometer had the capability of displaying individual thermistor temperature outputs from 59 to 122 F (15 to 50 C), to the nearest 0.1 F. A print out capability was provided by a United Systems Corporation Manual Identification Unit, Model 651. The unit had a total of eight information columns available: columns one and two were used to record the sequential trial number; three and four were used to record the thermistor number being recorded, and the remaining four columns recorded the thermistor temperature sensing to the nearest 0.1 F.

Treadmill. A Collins Treadmill was adjusted to a 5% slope and a speed of 2 miles (3.2 km) per hour.

Cooling devices. The two cooling devices were essentially the same as the helmet tested by Sharma (1970) and the jacket tested by Gandhok (1970). It should be kept in mind that these devices are not necessarily practical in their present form but were principally intended to investigate the concepts of air cooling the head versus air cooling the torso.

Air cooled helmet. This device was described by Sharma (1970). The helmet is commercially available from Rite Hardware Manufacturing Company of Glendale, California, under the trade name of the Whitecap Helmet. It is a combination safety (hard hat) helmet and breathing device. It is constructed with an inner and an outer fiberglass shell with an intervening space for air distribution. Air enters that space through an orifice at the bottom rear of the helmet and is blown primarily down over the face from a series of holes and slots in the inner shell. An adjustable suspension webbing seats the helmet on the head. A clear plastic visor allows for visibility and a plastic shroud draped over the shoulders from the helmet insured air flow to the bottom of the neck.

Air cooled jacket. Except for one major modification, the jacket was the same used by Gandhok (1970). The jacket was a waist length, pull-over parka type garment with draw strings at the neck, wrists, and waist for controlling air flow, and was made from 0.005 inch polyvinyl chloride. The one modification in this jacket was that a 1.5 inch (3.8 cm) inside diameter plastic plumbing "T" was fitted at the bottom rear of the jacket to serve as the air inlet. The vertical stem of the "T" served as the inlet connection on the outside of the jacket and on the inside the cross bar expelled air to the right and left and holes drilled in the top directed some air vertically. In practice this system provided good circulation within the jacket while it did not cause the subject discomfort by blowing air directly on his skin.

Closed circuit television monitor. A Sony Video Camera, Model VCK-2100A, was mounted in the test chamber and was connected to a Sony Videocorder, Model CV-2100, and a Sony TV Monitor, Model CVM-180U, both located in the control room.

Task

The subjects alternately walked on the treadmill and rested during a 10 minute cycle, 5 minutes walking, 5 minutes resting in a standing position. This was intended to simulate an overall condition of light work with an energy expenditure on the order of 200 kcal (800 BTU). The subjects alternated in the task: while one walked, the other rested. For consistency, the helmet subject took the first walking tour in each trial.

Every 5 minutes, during the changeover between resting and walking, both subjects would stand still for approximately 20 seconds while temperature and heart measurements were taken.

<u>Subjects</u>

Six Kansas State University male students were paid $10 each for this experiment. All were Americans except for subject "E", an Indian graduate student, who had been in the United States for 18 months and was considered to be acclimatized. Physical characteristics of the subjects are summarized in Table 1. The subjects wore only cotton socks and bermuda length shorts during the trials.

<u>Procedure</u>

<u>Schedules</u>. The schedule for each trial is outlined in Table 2 and the testing schedule is given in Table 3. Note in the testing schedule that the two treatments (helmet and jacket) were balanced within subjects as well as among subjects. As an aid to organizational uniformity, it can be noted that the helmet subject was always placed to the left of the jacket subject when relative position was involved, and the helmet was likewise placed first when sequence was involved.

<u>Subject control</u>. Upon arrival the subjects were sent to the pre-test room and were confined there for both preparation and recovery. They were allowed to enter the control room only to be weighed and while en route to or returning from the test chamber. Subjects were trained to assist in instrumenting them-

EXPLANATION OF PLATE I

Fig. 3. Picture of subjects in the environmental chamber.

PLATE I

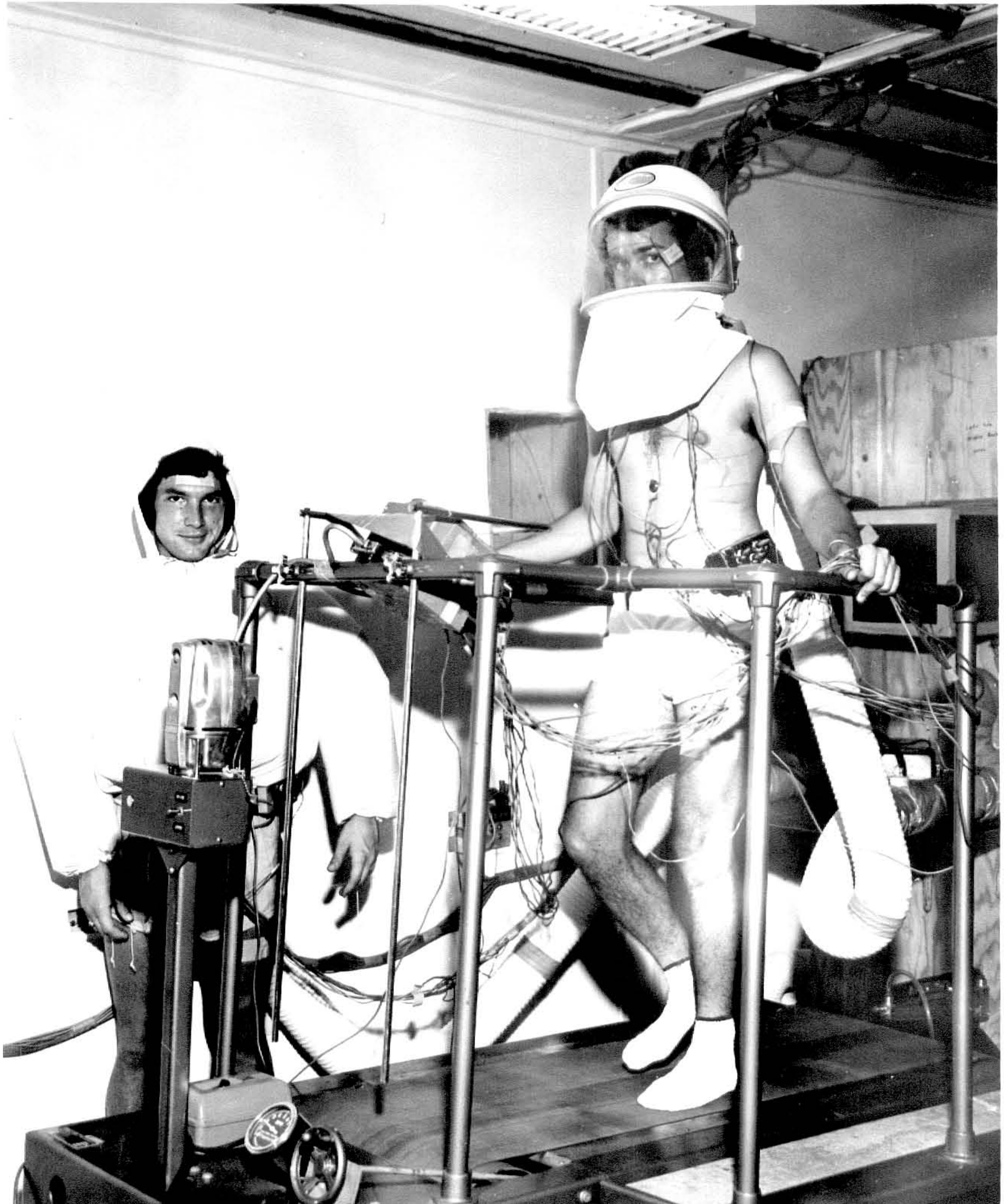

Table 1

Characteristics of the Subjects

Subject	Age, years	Weight, pounds	Height, nearest ½ inch	Dubois Body Area, meters^2
A	22	151	67.0	1.80
B	21	135	67.5	1.73
C	22	153	69.0	1.86
D	19	136	68.0	1.73
E	24	129	68.0	1.70
F	19	141	72.5	1.86
Mean	21	141	69.0	1.78
		(63.9 kg)	(175 cm)	

Table 2

Schedule For Each Trial

Minutes From Beginning	Event
0 - 20	1. Take saliva sample #1 during first 5 minutes 2. Remove clothing; weigh on metabolic scale 3. Attach instrumentation 4. Subject seated; relax prior to basal recording
20 - 30	1. Basal recordings made with subjects seated 2. Saliva sample #2 taken during final 5 minutes
30 - 40	1. Subjects don and adjust helmet and jacket in pretest room 2. Enter test chamber 3. Connect air ducts and test equipment 4. Check coolant velocity and adjust test devices for equal air flow
40 - 80	Test Period
80 - 95	1. Remove subjects from test chamber 2. Remove helmet and jacket 3. Take saliva sample #3 in first 5 minutes after removal of devices 4. Recovery recording
95 - 120	1. Remove instrumentation 2. Weigh on metabolic scale 3. Subjects prepare to depart 4. Take saliva sample #4 in last five minutes prior to departure

Table 3

Schedule of Conditions

Day	Trial	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F	Time
1st	1	H	J					2:30 - 4:30 P.M.
	2			H	J			4:30 - 6:30 P.M.
	3					H	J	7:00 - 9:00 P.M.
2nd	4	J	H					2:30 - 4:30 P.M.
	5			J	H			4:30 - 6:30 P.M.
	6					J	H	7:00 - 9:00 P.M.
3rd	7	J	H					2:30 - 4:30 P.M.
	8			J	H			4:30 - 6:30 P.M.
	9					J	H	7:00 - 9:00 P.M.
4th	10	H	J					2:30 - 4:30 P.M.
	11			H	J			4:30 - 6:30 P.M.
	12					H	J	7:00 - 9:00 P.M.

H = Helmet

J = Jacket

selves which substantially reduced preparation time.

Saliva samples. Four unstimulated saliva samples were taken as indicated in Table 2. The two samples taken prior to exposure were intended to establish a basal condition while the two post-exposure samples were expected to demonstrate a heat stress change. Graduated centrifuge tubes were prepared and coded prior to each day's runs. The tubes were individually sealed after the collection of each sample and the day's samples were delivered to the Clinical Chemistry Laboratory, College of Veterinary Medicine, Kansas State University, each morning to be analyzed for sodium, potassium, creatinine, and amylase concentrations. Sample volumes varied from 100 to 250 ml.

Measurements

Sweat loss. The difference in body weight occurring between the pre-exposure and post-exposure weighings was taken to be the weight of sweat loss during exposure. Although subjects were discouraged from drinking water between weighings, subject E, during his last trial, asked for and was given a drink. In this case he was given a measured amount of water and that weight was added to his weight difference to obtain sweat loss.

Body temperatures. All body temperatures were taken at 5 minute intervals during the subject change over between resting and walking.

Heart rate. Heart recordings were made of each subject for approximately 15 seconds immediately after the walking subject had dismounted from the treadmill. Both channels of the Beckman Recorder were employed for this purpose, allowing both subjects to be recorded simultaneously.

Saliva. The saliva was analyzed for sodium, potassium, and creatinine for all four days of the experiment. Half way through the experiment, it was decided to check for any effect on the amylase concentration as well, and reports on this substance were included for the final two days. This analysis work was by no means routine for the laboratory and the various techniques and methods used, such as methods of mixing and analyzing, measures to reduce contamination etc., were varied or changed several times during the experiment. The process of attempting to optimize analysis procedure and technique is believed to have contributed to some variation in the data. Experimental design tended to reduce the impact of this variability, however, since samples #1 and #2 were considered to represent the same physiological situation, that is, a basal condition, and samples #3 and #4 were considered to represent post heat stress. This arrangement gave some basis for eliminating outliers in the data, while averaging the before and after readings further reduced the impact of the several sources of variation. All things considered, it is believed that the final processed data represent a valid and useful picture of the heat stress chemistry of the saliva.

Ventilating air. It was desired to keep equal the air flow and air temperature to each device. This was achieved by adjusting the draw string closures of the jacket until equal air flows to each device were achieved. Since the air duct branches were physically balanced with equal length, equal insulation, and equal dimensions, the equal flow rate insured an equal outlet temperature as well as the converse. The equalization point was consistently at a velocity of 400 feet (122 m) per minute or 35 cfm (990 l./min.) at 70 F (21 C). Activity in the test chamber tended to loosen the jacket, causing an increased air flow to the jacket which was immediately detected on the digital thermometer as an inlet temperature drop for the jacket and a concurrent temperature rise for the helmet. A temperature differential of 1 F was indicative of 20 feet (6 m) per minute velocity differential and an on-the-spot correction was made for any temperature spread in excess of that value by adjusting the jacket closures. For analysis purposes, then, the 35 cfm (990 l./min.) at 70 F (21 C) is the constant ventilating volume of each device.

RESULTS

Detailed planning and preparation and capable assistance, plus excellent support from personnel of the Institute for Environmental Research paid off with a smooth, virtually routine experiment. As can be expected with electronic equipment, there were several minor malfunctions during the course of the experiment, specifically with the heart rate recording apparatus. Such minor difficulties only served to illustrate that the country doctor method of taking a pulse reading is still probably the most reliable in a pinch, even if not the most convenient.

Data Analysis

The results were tested for significance with the Wilcoxon Signed-Ranks Test. For the heart rate and temperatures, significance was tested both by:

Method 1: Between treatments, helmet versus jacket, paired by subject. Table 4 is an example of this method.

Method 2: Between treatments, paired for each of the eight readings made during the 40 minute exposure, each reading being averaged across all subjects for a given treatment. Table 5 is an example of method 2.

In each case where significance was found in one case, a corresponding significance was found in the other case as well. It is felt that the net effect of this procedure was to provide an unusually powerful test, reinforcing the validity of the inferences drawn. Additionally, method #2 provided the basis for sequentially plotting the average five minute readings, thus graphically illustrating the physiological trends during exposure for each treatment. Finally, agreement of the grand means of each of the two tests for a given criterion verified the accuracy of the computations.

The saliva and the sweat loss data were taken only before and after the exposures and were analyzed only by method #1. Method #2 was applied to confirm the accuracy of the computations, but was of no value for analysis purposes. Each saliva value given in the tables is a mean of two samples: "before stress" values are the average of samples #1 and #2 and "after stress" values are the mean of samples #3 and #4.

Due to the experimental design, one subject walked while the other rested, causing an alternating fluctuation of heart rate, and to a smaller extent, temperatures. Good representation of this data was obtained by using the heart rate and temperature changes from the basal condition, subsequently referred to as "incremental heart beats" or "incremental temperature". These incremental values were averaged for all eight exposure readings in the case of analysis method #1, and for each of the eight readings of a specific treatment, averaged across all subjects, in the case of method #2. The methods utilized all exposure data and the system proved to be a sensitive and well suited analysis approach. It must be remembered, however, that the value yielded by method #1 represents the cumulative effect on a subject but is useful for comparative purposes only. Actual physiological trends during exposure may be implied from the results of method #2. Since neither the environment nor the work stress could be considered extreme and since both subjects in each trial were given a degree of protection by either the helmet or the jacket, it was necessary to discriminate between some rather small physiological differences. The results indicate that this was done satisfactorily. The basal value for heart rate and temperatures was defined as the mean of the three readings taken prior to each exposure. Heart rates and temperatures are all expressed as deviations from that basal value and the term "incremental" is used to express that deviation.

Heart Rate

Comparison by subject between treatments. Table 4 compares the mean incremental heart rate between the helmet and jacket treatments by subjects. Method #1 analysis of the 12 pairs was based upon a comparison of corresponding replications of the wearings of each device. That is, a subject's first trial wearing of the helmet is compared with his first trial wearing of the jacket and similarly for the second wearing of each device. The 19 beats/minute increase for the jacket was significantly ($\alpha<0.01$) lower than the 29 beats/minute increase for the helmet.

Comparison by reading, averaged for all subjects. This comparison (see Table 5 and Figure 4) provided the most impressive comparison of the two treatments. A special modification of

Table 4

Mean Incremental Heart Rate For Each Subject

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	13	35	24	10	7	9
B	26	20	23	17	20	18
C	39	30	35	17	22	20
D	14	19	17	17	16	16
E	44	42	43	21	22	22
F	31	35	33	32	29	30
Mean			29			19

29 for the Helmet is significantly ($\alpha<0.01$) greater than 19 for the Jacket.

Table 5

Mean Incremental Heart Rate For All Subjects For Each Exposure Reading

Minutes of Exposure	Helmet		Jacket		Average before and after work	
	after rest	after work	after rest	after work	Helmet	Jacket
5		26.6	11.6			
					20.8	17.0
10	14.9			22.4		
					25.6	17.4
15		36.3	12.3			
					26.2	20.6
20	16.0			28.8		
					29.1	20.0
25		42.1	11.1			
					31.8	18.4
30	21.5			25.6		
					31.1	18.9
35		40.6	12.1			
					36.1	20.1
40	31.6	___	___	28.1	___	___
Mean	21.0	36.4	11.8	26.2	28.7	18.9

28.7 for the Helmet is significantly ($\alpha<0.02$) greater than 18.9 for the Jacket.

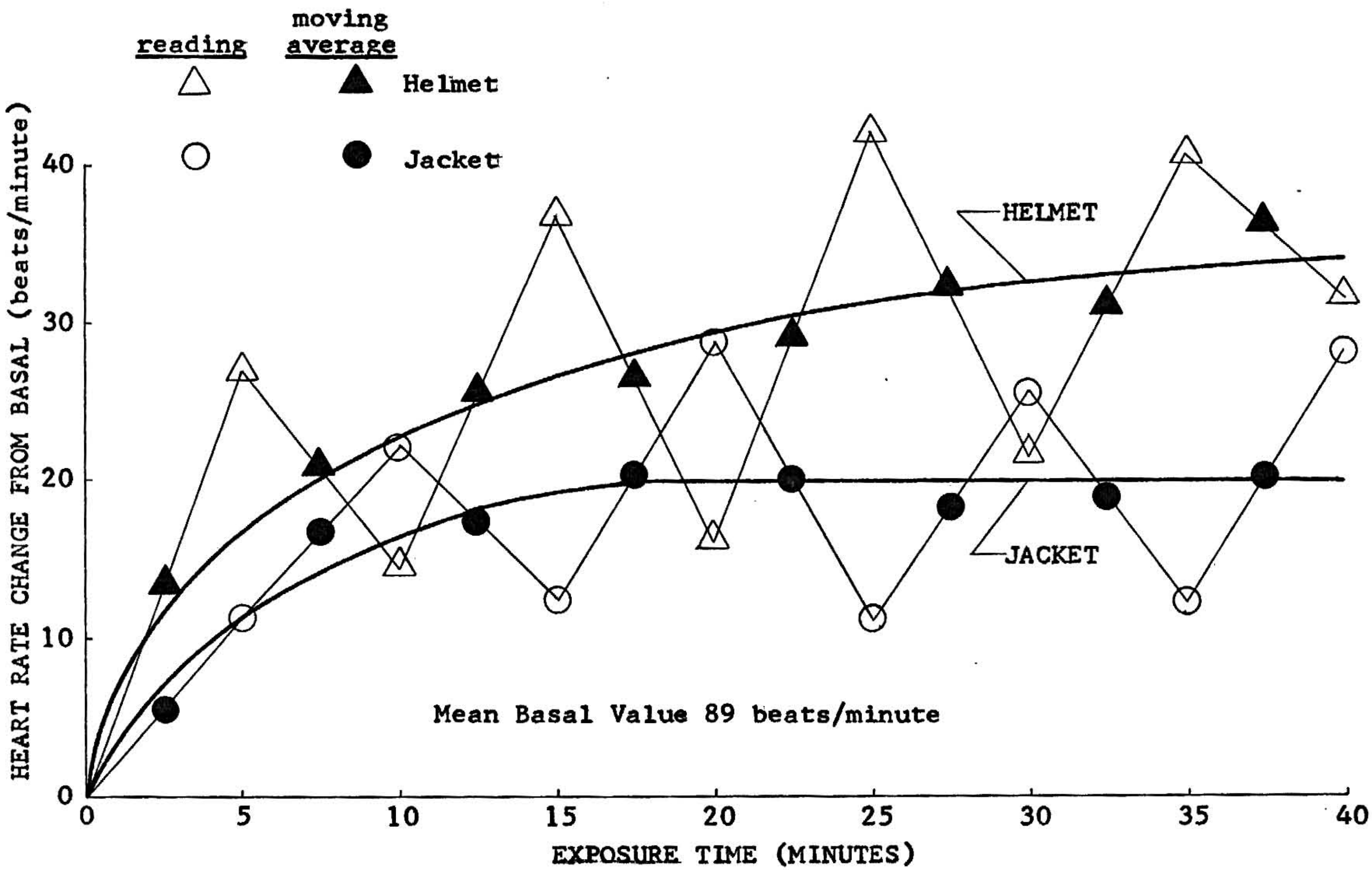

Figure 4. Mean Change in Heart Rate During Exposure.

analysis method #2 was used for this comparison. Individual readings could not be directly compared because, for each reading, one treatment, helmet or jacket, had just completed a five minute walking cycle while the other had just completed a five minute resting cycle. The odd numbered readings reflect the situation immediately following a five minute period when the helmet subject was walking on the treadmill and the jacket subject rested. The reverse was, of course, the case for the even numbered readings. Taking the averages between successive readings within a given treatment produced a series of values representing the average between the after work and after rest situations. These values were then compared between treatments, helmet versus jacket, in a significance test. They also provided the basis for a graphical illustration of the heart rate trend, shown in Figure 4.

Smooth trend curves were drawn by eye through the average after rest - after work values and serve to illustrate the trend. Note that the incremental heart rate for the jacket treatment stabilized after 20 minutes of exposure at 20 beats per minute, while the rate for the helmet treatment had reached 34 beats per minute at the end of the 40 minute exposure and appeared to be still increasing.

<u>Sweat Loss</u>

Sweat loss (Table 6) for the helmet treatment proved to be significantly ($\alpha<0.01$) higher than for the jacket treatment.

Table 6

Sweat Loss (grams/meter^2) During Exposure

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	406	432	419	203	243	223
B	208	260	234	227	195	211
C	349	383	366	282	287	285
D	228	234	231	218	223	221
E	290	301	296	189	216	203
F	337	379	358	206	277	242
Mean			317			231

317 for the Helmet is significantly ($\alpha<0.01$) greater than 231 for the Jacket.

The mean sweat loss for the helmet treatment, 317 grams per square meter of body area, was 37% higher than the 231 g/m^2 for the jacket treatment.

Ear Canal Temperature

This criterion was analyzed by both methods, #1 and #2, in Tables 7 and 8 respectively. Figure 5 is a graphical illustration of the method #2 analysis. Interpolation of the trend lines drawn by eye through the data indicate a 1.4 F (0.8 C) lower temperature for the helmet treatment after 40 minutes of exposure. Inferences from ear canal temperature must be drawn with caution: it was intended to give an indication of deep head temperature and, for comparative purposes, it does give the desired indication. However, the sensor was placed to avoid any possibility of contact with the tympanic membrane, penetration being limited to 0.5 inch (1.3 cm), and configuration of the sensor suspended it in the ear canal such that it sensed air temperature rather than tissue temperature. Also, the possibility must be allowed that the foam ear seal and insulation might not have been 100% effective and ambient air may have influenced some readings. These and other influences not withstanding, however, it would be reasonable to say that ear canal temperature is a better indication of deep head temperature than skin temperature. Deep head temperature and hence hypothalamus temperature were apparently somewhat lower for the helmet treatment.

Table 7

Mean Incremental Ear Canal Temperature (F)

For Each Subject

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	0.21	0.66	0.44	1.01	0.63	0.82
B	- 0.04	- 0.38	- 0.21	1.13	0.63	0.88
C	0.69	- 0.38	0.16	0.70	0.63	0.67
D	- 0.74	- 0.09	- 0.42	1.89	0.59	1.24
E	- 0.45	- 0.66	- 0.56	- 0.73	1.44	0.36
F	- 0.58	- 0.01	- 0.30	1.50	0.15	0.83
Mean			- 0.15			0.80

- 0.15 for the Helmet is significantly ($\alpha<0.01$) less than 0.80 for the Jacket.

Table 8

Mean Incremental Ear Canal Temperature (F)
For All Subjects For Each Exposure Reading

Minutes of Exposure	Helmet	Jacket
5	0.15	0.50
10	0.08	0.61
15	- 0.02	0.60
20	- 0.22	0.77
25	- 0.20	0.89
30	- 0.31	0.95
35	- 0.34	1.02
40	- 0.35	1.08
Mean	- 0.15	0.80

- 0.15 for the Helmet is significantly ($\alpha<0.01$) lower than 0.80 for the Jacket.

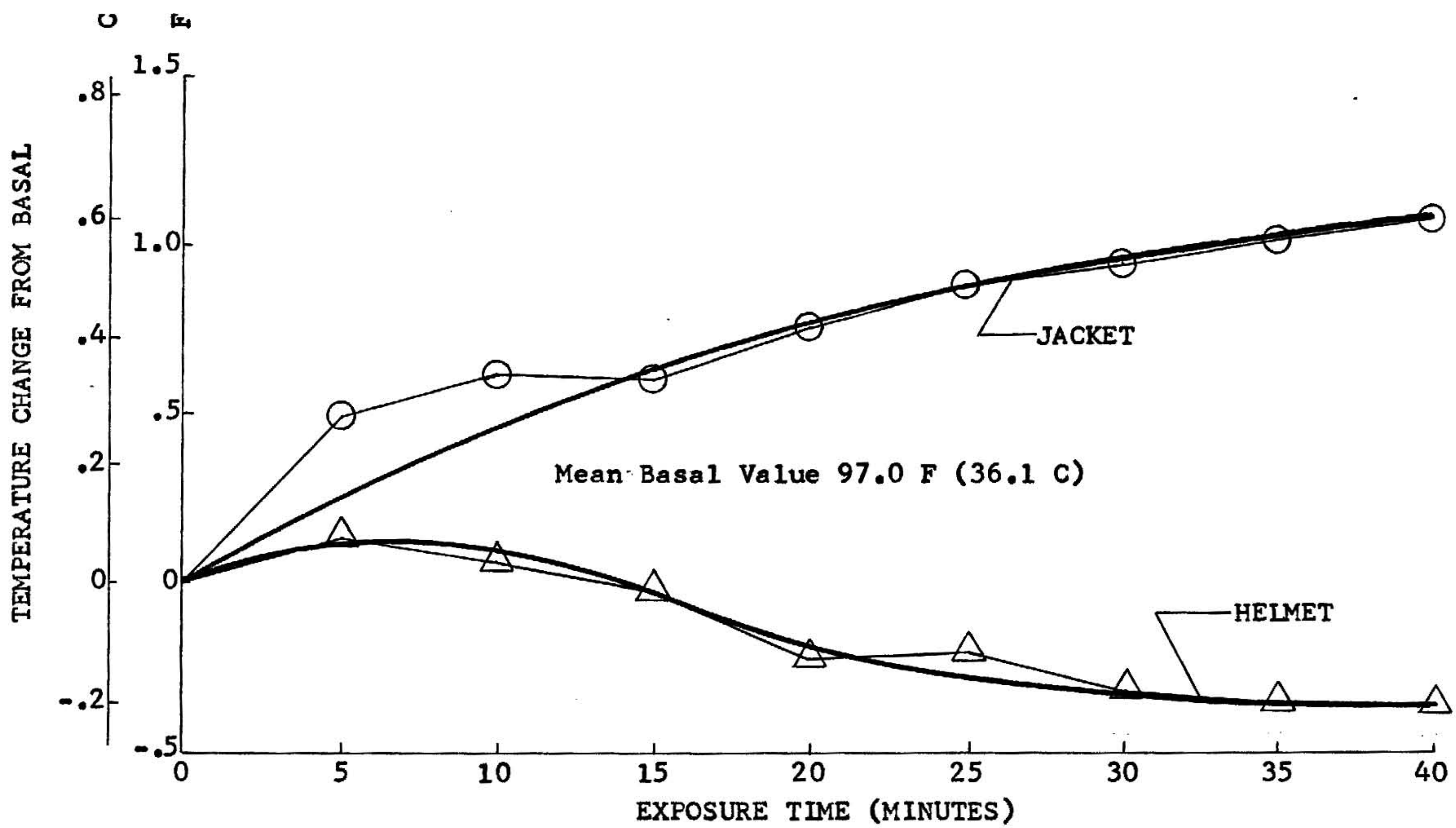

Figure 5. Mean Change in Ear Canal Temperature During Exposure.

Head Skin Temperature

Values for this criterion are equally weighted averages of temperatures for the brow, the cheek, and the neck. This average is indicative of the direct influence of the helmet as well as the indirect influence of the jacket. Tables 9 and 10 show the two-way analysis and Figure 6 presents the corresponding graph. The helmet produced a significantly ($\alpha<0.01$) lower temperature after 40 minutes of exposure.

Figure 6 indicates the following:

1. The helmet treatment depressed the temperature almost 2 F (1.1 C) below the basal value.

2. The jacket treatment, after stabilization of the trend, held the average temperature rise to 0.3 F (0.2 C) above basal values.

3. It is interesting to note the sensitivity of head skin temperature to the walking - resting cycles: the odd numbered readings, taken after walking with the helmet and resting with the jacket, show a temperature rise with the helmet and a drop with the jacket. For the even readings the opposite effect is found.

Torso Skin Temperature

This criterion is an equally weighted average of the arm, stomach, and back temperatures and was intended to demonstrate the direct effect of the jacket as well as the indirect effect of the helmet.

The data is contained in Tables 11 and 12 and Figure 7.

Table 9

Mean Incremental Head Skin Temperature (F)

For Each Subject

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	- 1.5	- 1.4	- 1.5	0.6	1.7	1.2
B	- 3.0	- 0.6	- 1.8	- 2.0	0.9	- 0.6
C	- 1.0	- 0.3	- 0.6	- 0.3	0	- 0.2
D	- 1.6	- 0.5	- 1.1	-.5	0.5	0.5
E	- 2.1	- 1.8	- 1.9	0.6	1.9	1.3
F	- 2.3	- 1.1	- 1.7	1.3	- 0.9	0.2
Mean			- 1.4			0.4

- 1.4 for the Helmet is significantly ($\alpha<0.01$) less than 0.4 for the Jacket.

Table 10

Mean Incremental Head Skin Temperature (F)

For All Subjects For Each Exposure Reading

Minutes of Exposure	Helmet	Jacket
5	- 0.5	0.8
10	- 1.2	0.8
15	- 1.0	0.3
20	- 1.5	0.4
25	- 1.5	0.1
30	- 2.2	0.4
35	- 1.5	0
40	- 2.0	0.5
Mean	- 1.4	0.4

-1.4 for the Helmet is significantly ($\alpha<0.01$) less than 0.4 for the Jacket.

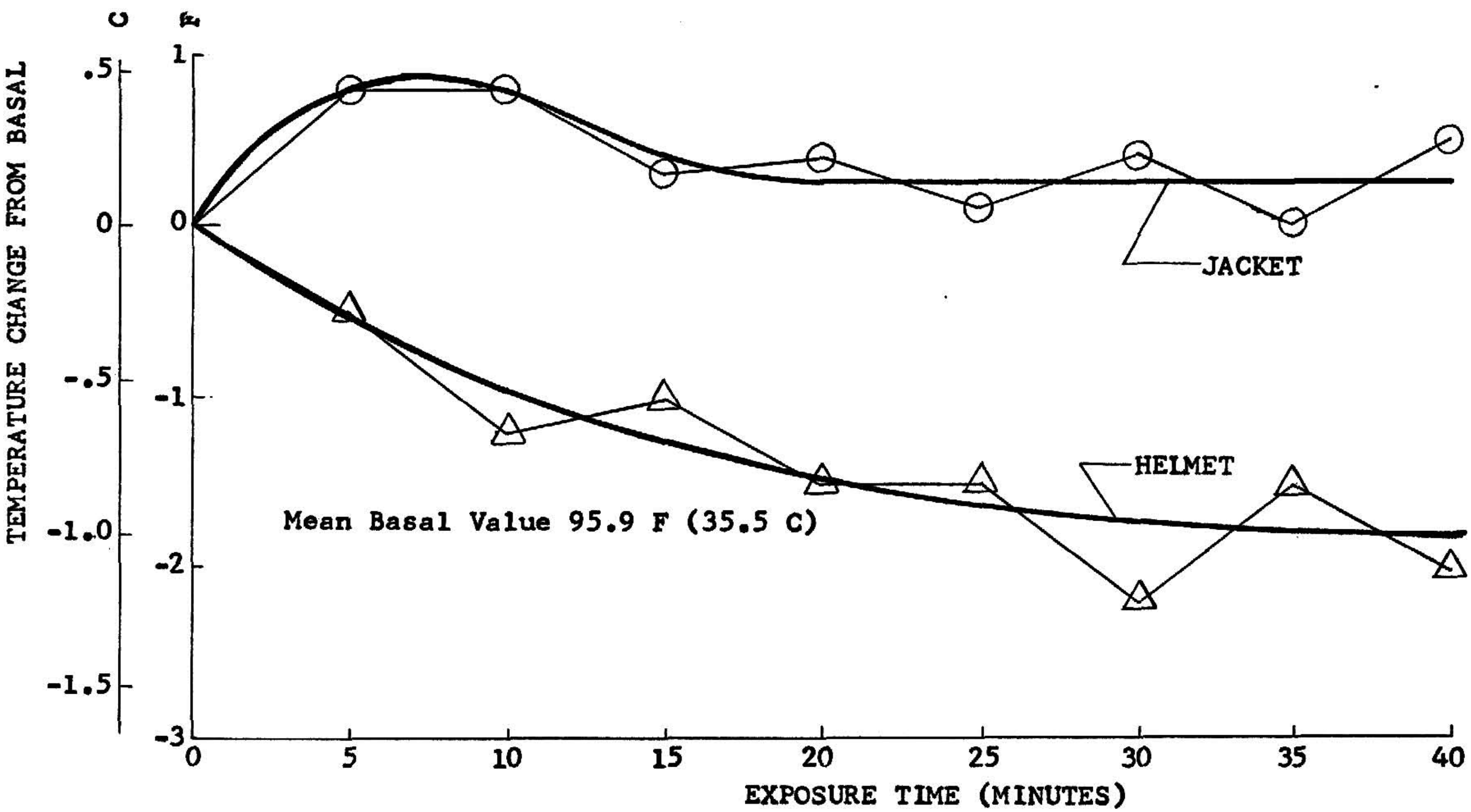

Figure 6. Mean Change in Head Skin Temperature During Exposure.

Table 11

Mean Incremental Torso Skin Temperature (F)

For Each Subject

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	6.1	5.8	6.0	- 0.2	1.3	0.6
B	3.5	6.8	5.1	- 0.7	1.9	0.6
C	3.7	4.6	4.2	- 1.4	0.2	- 0.6
D	3.8	5.1	4.4	- 1.8	- 1.4	- 1.6
E	5.1	2.7	3.9	- 0.8	0.3	- 0.3
F	3.1	2.7	2.9	- 1.0	- 2.1	- 1.6
Mean			4.4			- 0.5

4.4 for the Helmet is significantly ($\alpha < 0.01$) greater than - 0.5 for the Jacket.

Table 12

Mean Incremental Torso Skin Temperature (F)
For All Subjects For Each Exposure Reading

Minutes of Exposure	Helmet	Jacket
5	4.1	0.1
10	4.5	- 0.2
15	4.6	- 0.3
20	4.2	- 0.3
25	4.5	- 0.7
30	4.2	- 0.3
35	4.6	- 1.3
40	4.4	- 0.8
Mean	4.4	- 0.5

4.4 for the Helmet is significantly ($\alpha < 0.01$) greater than - 0.5 for the Jacket.

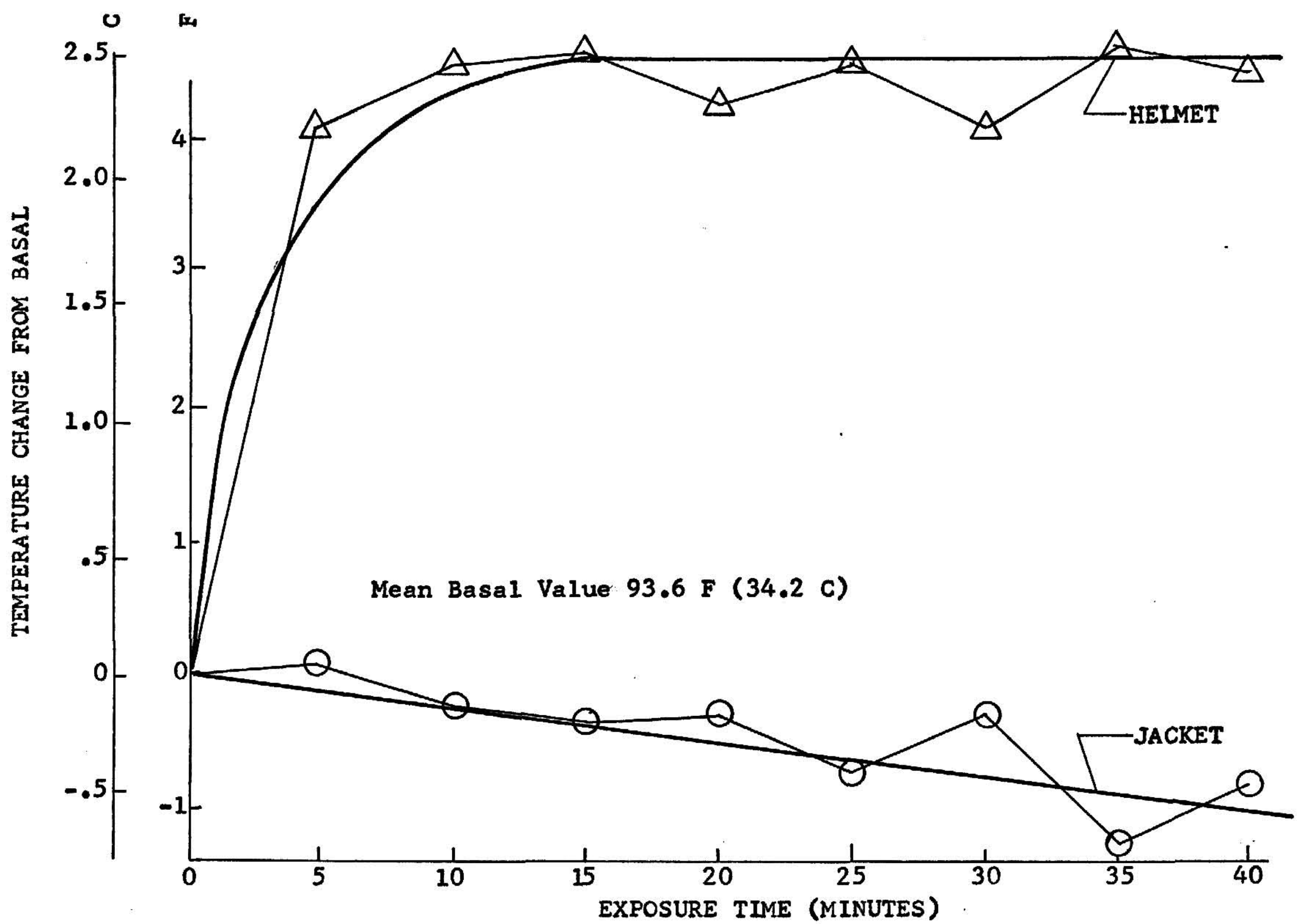

Figure 7. Mean Change in Torso Skin Temperature During Exposure.

Both method #1 and method #2 indicated a significant ($\alpha<0.01$) difference, with the jacket treatment producing 5.5 F (3.1 C) lower torso temperatures at the end of the 40 minute exposure.

Characteristics worth noting from Figure 7 are:

1. The jacket torso temperature was 5.5 F (3.1 C) below the temperature for the helmet treatment.

2. The jacket depressed the torso temperature to 1 F (0.6 C) below basal value after 40 minutes of exposure.

3. The helmet allowed a rapid initial torso temperature rise with a virtual stabilization after 10 minutes of exposure.

4. A downward sloped straight line appears to best represent the jacket data. There is a distinct possibility that this could be caused by a progressive degree of vasoconstriction caused by the steady circulation of cool air.

5. As with the head temperatures, torso skin temperature shows a sensitivity to the work - rest cycles in the reading fluctuations.

Thigh Skin Temperature

This criterion holds a two-fold importance: first, it measured the temperature of part of the working member and second, it was the only skin temperature not under the direct influence of the air from a cooling device. Data for thigh temperature is given in Tables 13 and 14 and Figure 8. Analysis methods #1 and #2 indicated that the jacket produced a significantly ($\alpha<0.05$) lower temperature. Figure 8 demonstrates

Table 13

Mean Incremental Thigh Skin Temperature (F)

For Each Subject

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	5.5	5.0	5.3	5.4	2.0	3.7
B	5.9	5.7	5.8	4.0	7.0	5.5
C	4.5	5.1	4.8	4.3	5.6	5.0
D	4.0	5.1	4.5	1.8	2.9	2.4
E	6.1	5.5	5.8	5.3	6.3	5.8
F	3.4	4.5	4.0	2.3	2.1	2.2
Mean			5.0			4.1

5.0 for the Helmet is significantly ($\alpha<0.05$) greater than 4.1 for the Jacket.

Table 14

Mean Incremental Thigh Skin Temperature (F)

For All Subjects For Each Exposure Reading

Minutes of Exposure	Helmet	Jacket
5	4.6	3.3
10	4.8	3.8
15	5.2	4.1
20	5.0	4.4
25	5.3	4.3
30	5.0	4.5
35	5.2	3.9
40	5.1	4.3
Mean	5.0	4.1

5.0 for the Helmet is significantly ($\alpha<0.01$) greater than 4.1 for the Jacket.

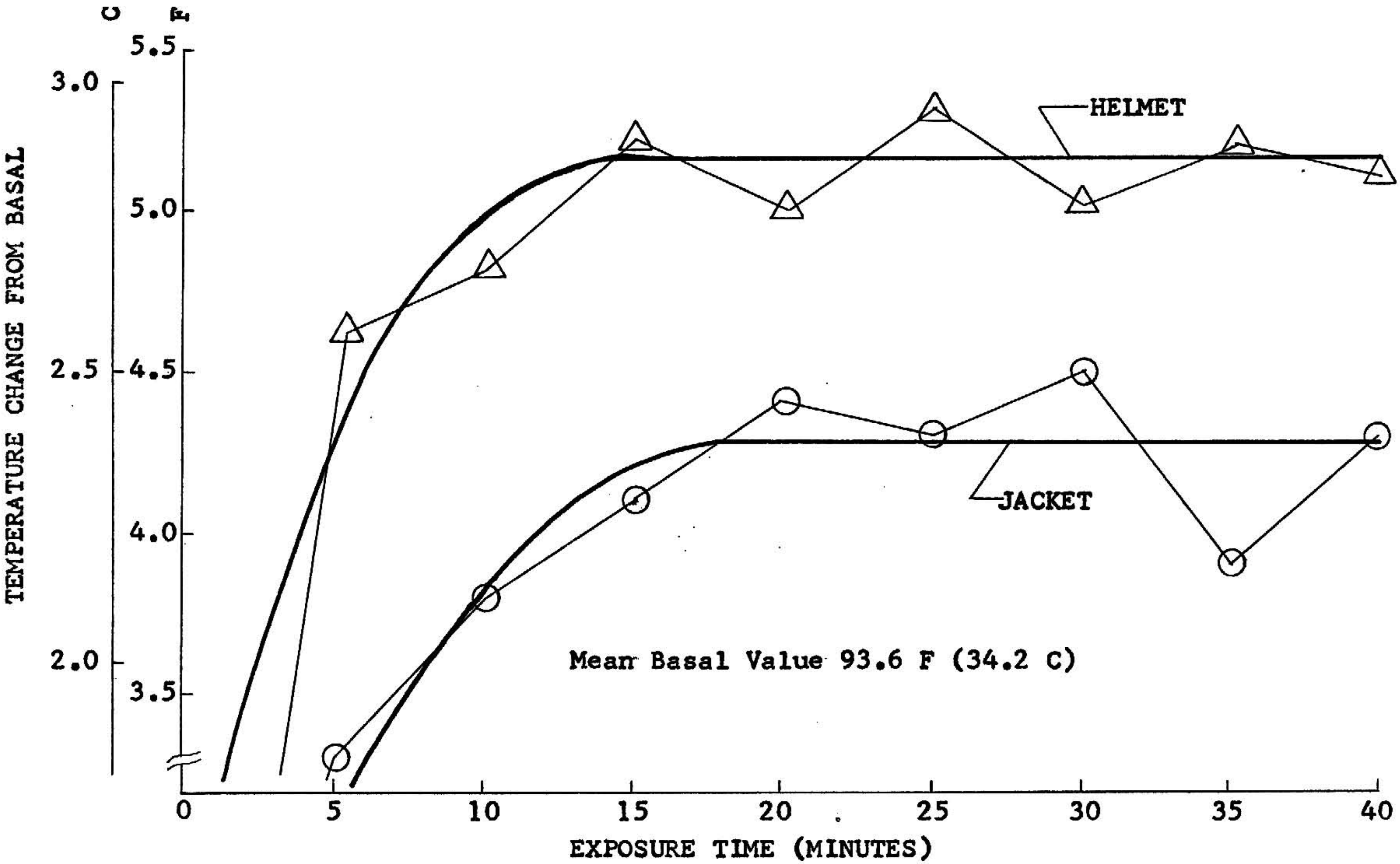

Figure 8. Mean Change in Thigh Temperature During Exposure.

that this temperature difference had stabilized at 0.9 F (0.5 C) by the end of the 40 minute exposure. This difference, although significant, would not be considered extreme. Again it is interesting to note the response to the work - rest cycle.

Rectal Temperature

This analysis is summarized in Tables 15 and 16 and Figure 9. The jacket temperature proved to be significantly ($\alpha<0.05$) lower than the helmet treatment. The spread between the two was quite small, however, the maximum at any time during the exposure being on the order of 0.2 F (0.1 C). A striking feature of Figure 9 is that the rectal temperature for both treatments very quickly stabilized into an inexorable climb and gave no hint of leveling off even after 40 minutes of exposure. Normally a lag or slight drop would have been expected at the beginning of the exposure instead of the immediate climb evident in Figure 9. A possible explanation for this is that the subjects were exposed to 80 to 85 F (27 to 29 C) during pretest preparation and rectal temperature may have transitioned to a climb prior to the test exposure.

Body Heat Storage Rate

An overall average heat storage rate for each treatment is calculated here for comparative purposes. The equation suggested by Webb (1969) was used.

$$Q = 0.83\ W\ (0.8\Delta t_r + 0.2\Delta t_s)$$

where

Table 15

Mean Incremental Rectal Temperature (F)

For Each Subject

Treatment	Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean
Subject						
A	0.10	0.59	0.35	- 0.06	0.20	0.07
B	0.31	0.06	0.19	0.36	0.01	0.19
C	0.38	1.25	0.82	0.40	0.91	0.66
D	0.49	0	0.25	0.33	- 0.04	0.15
E	1.23	1.71	1.47	1.05	0.29	0.67
F	0.53	0.71	0.57	0.71	0.65	0.68
Mean			0.61			0.40

0.61 for the Helmet is significantly ($\alpha<0.05$) greater than 0.40 for the Jacket.

Table 16

Mean Incremental Rectal Temperature (F)
For All Subjects For Each Exposure Reading

Minutes of Exposure	Helmet	Jacket
5	0.37	0.13
10	0.44	0.18
15	0.47	0.29
20	0.54	0.42
25	0.64	0.43
30	0.74	0.57
35	0.80	0.56
40	0.90	0.65
Mean	0.61	0.40

0.61 for the Helmet is significantly ($\alpha<0.01$) greater than 0.40 for the Jacket.

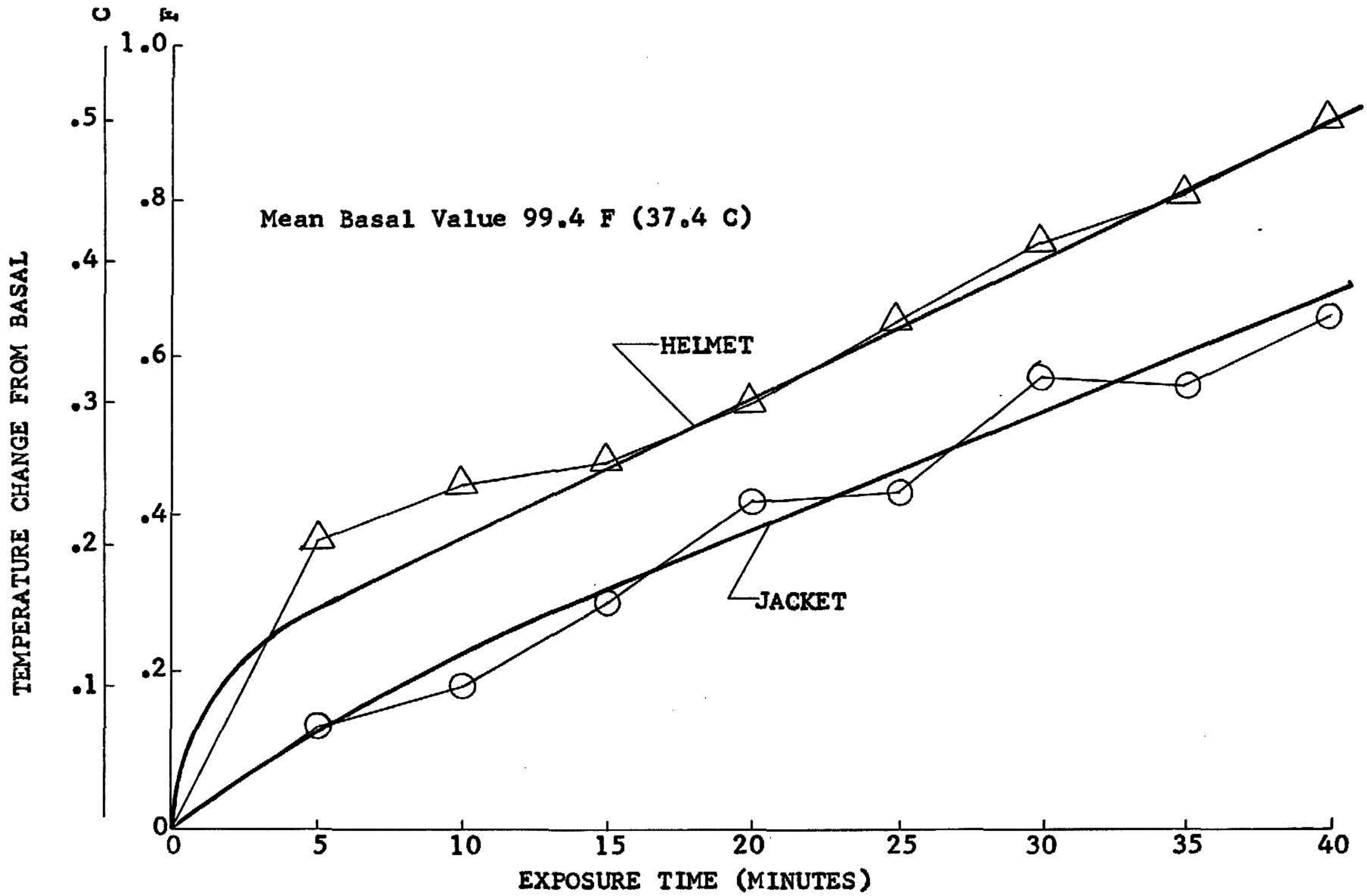

Figure 9. Mean Change in Rectal Temperature During Exposure.

Q = Heat storage (kilocalories) during exposure

W = Average body weight (kilograms) of all subjects (63.9 kg)

Δt_r = Change in rectal temperature (C) at end of exposure. Figure 9. (Helmet = 0.5 C, Jacket = 0.4 C)

Δt_s = Change in skin temperature (C), estimated from a weighted average of head, torso, and thigh temperature (Mitchell and Wyndham, 1969) from Figures 6, 7, and 8.

	Helmet			Jacket		
	Δt	weight		Δt	weight	
Head	-1.00	(0.10)	= -0.10	0.17	(0.10)	= 0.02
Torso	2.44	(0.65)	= 1.59	-0.56	(0.65)	= -0.36
Thigh	2.83	(0.25)	= 0.71	2.39	(0.25)	= 0.60
Δt_s			2.20 C			0.26 C

Substitution in the formula gives:

Q (helmet) = 45 kcal (179 BTU) or 67 kcal (266 BTU) per hour

Q (jacket) = 20 kcal (79 BTU) or 29 kcal (115 BTU) per hour

The 38 kcal (151 BTU) per hour difference in heat storage rate for this average condition is significant ($\alpha < 0.01$) but not substantial. It should be recalled that two of the three skin temperatures were directly influenced by one of the treatments. The possibility of some distortion due to this cannot be discounted. Thigh and rectal temperature corroborate a lower heat storage rate for the jacket treatment but the difference is by no means dramatic.

Saliva Biochemistry

Creatinine. Table 17 summarizes the results of this test. As was previously mentioned, each value in the table for a particular replication is an average of two samples. In Table 17, for instance, for Subject A, Helmet Treatment, Replication #1, the "Before Stress" value of 2.16 is the average of saliva samples #1 and #2, taken prior to exposure, and similarly the "After Stress" value of 0.58 is the average of saliva samples #3 and #4 taken after exposure. This arrangement is used for all the saliva component tables. For creatinine, unfortunately, a variation in the laboratory analysis technique caused a loss of the second day's data, consequently degrading the statistical test power. Due to the missing data, it was necessary to average the two replications of each treatment to provide a basis for comparison. Significance was tested by comparing the mean "Before Stress" readings of each treatment for a subject with the mean "After Stress" readings for that treatment for the same subject. For the overall before versus after stress paired comparisons, the creatinine concentration decreased in 11 out of 12 cases, which is highly significant ($\alpha<0.01$). All 6 pairs of the jacket treatment decreased and hence that decrease is statistically significant ($\alpha<0.05$). The pair for Subject B in the helmet treatment pairs frustrates statistical significance for

Table 17

Creatinine Concentration (mgs./100ml.) in Saliva Before Heat Stress Versus After Heat Stress

	BEFORE STRESS						AFTER STRESS					
Treatment	Helmet			Jacket			Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean
Subject												
A	2.16	1.17	1.67	*	2.95	2.95	0.58	1.41	1.00	*	1.02	1.02
B	*	0.21	0.21	0.33	0.59	0.46	*	0.25	0.25	0.25	0.46	0.36
C	0.30	0.37	0.33	*	0.24	0.24	0.32	0.28	0.30	*	0.18	0.18
D	*	0.41	0.41	1.13	0.50	0.82	*	0.42	0.42	0.28	0.45	0.37
E	0.38	0.73	0.56	*	0.57	0.57	0.37	0.38	0.38	*	0.27	0.27
F	*	0.88	0.88	1.33	1.23	1.28	*	0.77	0.77	0.95	0.53	0.74
Mean			0.68			1.05			0.52			0.49
Overall Mean				0.88						0.51		

*No Data

Helmet decrease from 0.68 to 0.52 not significant ($\alpha > 0.05$)
Jacket decrease from 1.05 to 0.49 significant ($\alpha < 0.05$)
Overall decrease from 0.88 to 0.51 significant ($\alpha < 0.01$)

that treatment. It could be expected, however, that additional data would verify a significant decrease for the helmet as well.

Amylase. This data is given in Table 18. A tendency for an increase in concentration is evident but this tendency was not statistically significant. There is considerable individual variability here, however, and an underlying significance cannot be discounted. For instance, if the "jacket" readings of subject "F" were disregarded (27,910 "before stress" and 14,000 "after stress"), the overall "before stress" - "after stress" analysis would show a significant concentration increase. Those values were not sufficiently inconsistent with other data to classify them as outliers, however, and are retained for analysis. Notwithstanding the non-significant results, it must be suspected that the concentration did increase. The amylase values are Somogyi Units, defined as the amount of amylase which will cause the formation of reducing power equivalent to 1 mg. of glucose in 30 minutes at 40 C (104 F) when the reduction is carried out by the Saccharogenic method of Somogyi (Sigma Manual, 1965).

Sodium. The sodium concentration data presented in Table 19 failed to demonstrate a significant change, either for the individual treatments or for the overall condition, despite an apparent tendency for the concentration to increase.

Potassium. This criterion, presented in Table 20, showed a significantly ($\alpha<0.01$) increased concentration after exposure.

Table 18

Amylase Concentration (Somogyi Units/100ml.) in Saliva Before Heat Stress Versus After Heat Stress

	BEFORE STRESS			AFTER STRESS		
Subject	Helmet	Jacket	Mean	Helmet	Jacket	Mean
A	69,440	42,150	55,795	75,200	57,125	66,163
B	3,880	720	2,300	776	1,920	1,348
C	12,760	42,750	27,755	6,560	56,750	31,655
D	28,200	61,750	44,975	48,150	62,650	55,400
E	28,110	35,500	31,805	58,775	46,450	52,613
F	29,875	27,910	28,893	34,550	14,000	24,275
Mean	28,711	35,138	31,921	37,335	39,816	38,567

No significant change ($\alpha > 0.05$), either by treatment or overall.

Table 19

Sodium Concentration (mgs./100ml.) in Saliva Before Heat Stress

Versus After Heat Stress

	BEFORE STRESS						AFTER STRESS					
Treatment	Helmet			Jacket			Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean
Subject												
A	14	18	16	17	19	18	17	17	17.0	19	30	24.5
B	10	10	10	11	10	10.5	6	8	7.0	9	8	8.5
C	11	11	11	12	10	11	17	10	13.5	10	13	11.5
D	6	8	7	11	8	9.5	6	12	9.0	12	8	10.0
E	10	8	9	14	10	12	14	11	12.5	14	5	9.5
F	35	22	29	18	8	13	22	30	26.0	24	12	18.0
Mean			13.7			12.3			14.2			13.7

No significant ($\alpha > 0.05$) change, either by treatment or overall.

Table 20

Potassium Concentration (mgs./100ml.) in Saliva Before Heat Stress

Versus After Heat Stress

	BEFORE STRESS						AFTER STRESS					
Treatment	Helmet			Jacket			Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean
Subject												
A	12.3	19.0	15.7	19.5	14.0	16.8	18.5	21.5	20.0	22.0	20.5	21.3
B	18.0	19.5	18.7	18.4	22.5	20.4	18.0	20.0	19.0	16.0	23.0	19.5
C	14.5	19.0	16.8	17.0	14.5	15.8	17.5	22.5	20.0	19.0	15.0	17.0
D	20.5	17.5	19.0	23.8	22.5	23.1	21.5	28.5	25.0	27.8	24.5	26.2
E	22.5	20.0	21.2	25.0	22.0	23.5	21.0	21.5	21.3	25.5	21.5	23.5
F	30.5	28.5	29.5	23.5	24.5	24.0	42.0	36.0	39.0	32.8	24.0	28.4
Mean			20.2			20.6			24.1			22.7
Overall Mean			20.4						23.4			

Helmet increase from 20.2 to 24.1 significant ($\alpha<0.01$)
Jacket increase from 20.6 to 22.7 significant ($\alpha<0.05$)
Overall increase from 20.4 to 23.4 significant ($\alpha<0.01$)

The individual treatments likewise demonstrated an increased concentration but with the significance level being lower for the jacket treatment ($\alpha<0.05$) than for the helmet treatment ($\alpha<0.01$).

Sodium to potassium ratio. The results of this test in Table 21 are curious when considered in light of the two elements considered separately. This ratio demonstrated no significant change for either the overall situation or for the individual treatments. Recalling that the sodium concentration was not significantly increased, the fact that the ratio of the two failed to decrease significantly would suggest that the sodium concentration in reality did increase sufficiently to preclude a significant change in the ratio. In any case, the sodium to potassium ratio failed to demonstrate a significant indication of stress.

Control Data Comparison

Sharma (1970) and Gandhok (1970) found both the helmet and the jacket to be basically effective in reducing physiological heat strain. Therefore no attempt was made in this thesis to reestablish those findings by gathering control data and comparing it with the helmet and jacket treatments. The term "control data" is used here to describe data taken from subjects exposed to the stress conditions without the protection of a cooling device. Since Sharma's and Gandhok's experimental conditions were quite similar to those of this experiment, a useful

Table 21

Sodium to Potassium Ratio in Saliva Before Heat Stress Versus After Heat Stress

	BEFORE STRESS						AFTER STRESS					
Treatment	Helmet			Jacket			Helmet			Jacket		
Replication	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean
Subject												
A	1.138	0.947	1.043	0.872	1.360	1.116	0.919	0.791	0.855	0.864	1.460	1.162
B	0.556	0.513	0.534	0.598	0.440	0.519	0.333	0.400	0.367	0.563	0.350	0.457
C	0.760	0.580	0.670	0.706	0.690	0.698	0.970	0.440	0.705	0.526	0.867	0.696
D	0.290	0.460	0.375	0.462	0.356	0.409	0.280	0.650	0.465	0.432	0.327	0.379
E	0.444	0.400	0.422	0.560	0.450	0.505	0.667	0.512	0.589	0.549	0.230	0.390
F	1.150	0.772	0.961	0.766	0.330	0.548	0.520	0.833	0.677	0.732	0.500	0.616
Mean			0.668			0.633			0.610			0.617

No significant ($\alpha>0.05$) change, either by treatment or overall.

comparison of their control data with the results of this experiment is possible. Sharma's control data was used for this comparison (see Table 22). The limitations of this comparison are evident: the values are taken from a different experiment, using different subjects, at a different time of the year, using a somewhat different task, etc. These limitations notwithstanding, however, the treatment values for heart rate, sweat loss, and body heat storage are all substantially lower than the control values, and are indicative of the basic effectiveness of the treatments. Creatinine values are presented as well but individual variability probably nullifies the usefulness of these mean values.

Subject Comments

After their final trial the subjects were asked to comment on the merits and shortcomings of the two cooling concepts. Following is a generalized summary of their responses.

Preferred device. The subjects indicated a subjective preference for the head cooling. Having the face and head cooled, and breathing the cool dry air was apparently psychologically refreshing if not physiologically advantageous. Subject "F" did report that the cool air from the helmet made him "wheezy" and indicated a preference for the jacket on that basis. The more general feeling seemed to be summed up by another subject's comment, "I don't much care how hot I am as long as I can breathe okay and my face is cool".

Table 22

Control Data Comparison

Criterion	Sharma's Control Values	Treatment Values for this Experiment	
		Helmet	Jacket
Heart Rate (incremental beats/min.)	59	29	19
Sweat Loss ($g/m^2/hr.$)	781	475	346
Body Heat Storage (kcal./hr.)	133	67	29
Decrease in Creatinine Concentration (mgs./100 ml.)	0.16	0.16	0.56

Critical Comments. The critical comments did not address either concept, except for those by subject "F", but were oriented towards unfavorable features of device design, such as the air feed hoses that pulled back on both devices and brushed against the legs. The helmet was felt to be unnecessarily heavy and bulky, although it was not reported to have reduced general mobility in any way. The ballooning of the jacket was reported to be inconvenient only because of the bulk it created, as the low pressure of the system allowed full mobility. Vision was occasionally restricted in the helmet due to condensation but hearing was not a problem for either device since no high pressure hiss existed. Verbal communication from the helmet was understandable but somewhat muffled. Communication could be a problem in a practical situation.

DISCUSSION

General

Evaluation of the results of this experiment should be qualified from the outset. The short term physiological effects of the local cooling done in this experiment are evident for the criteria examined and are apparently favorable. It should be remembered though, that the observations reported here are for a limited short term condtion and inferences should be drawn accordingly. What are the physiological implications, for instance, of locally cooling a man's head or torso eight hours a day, five days a week, 50 weeks per year? Is it possible that locally cooling part of a man's body somehow deceives the thermoregulatory mechanism and upsets his metabolism in such a way as to produce an unfavorable long term reaction? Such questions as these should be considered when drawing inferences from the conclusions of this experiment.

Helmet Versus Jacket

From the physiological standpoint the jacket demonstrated a decided advantage over the helmet for the short exposure and moderate stress used in this experiment. The comparatively low difference in heat storage only serves to emphasize the human body's capability of maintaining its thermal equilibrium over a rather wide range. The results showed, however, that despite the not drastically different thermal body balances evident with both treatments, this condition was obtained by a dramatically significant lower physiological cost for the jacket treatment as inferred by the heart rate and sweat loss criteria. This result is not particularly surprising. It seems apparent that the primary influence of these two treatments was to remove body heat by evaporation of body sweat with the cool dry air flowing over the portion of the body covered by the device, and secondly to isolate that part of the body from the stress of the ambient environment. The jacket influenced a larger body surface and hence was more effective.

The one criterion examined which leaves room for concern is the rectal temperature. As can be seen in Figure 9, the rectal temperatures continued to rise at what appeared to be an unwavering rate, even at the end of the 40 minute exposure. Failure of this criterion to stabilize at a reasonable level, below 2 F (1.1 C) rise over basal, would most assuredly limit exposure time and hence the utility of either device.

The conditions of this experiment and Gandhok's (1970) and Sharma's (1970) experiments are similar enough to allow some qualified comparison. The salient difference with this experiment was that an ample supply of ventilating air was available and was supplied to the devices at the rate of 35 cfm (990 l./min.) as opposed to approximately 6 cfm (170 l./min.) supplied by the vortex tube used by Gandhok and Sharma. For his test of the jacket, Gandhok reported a mean heart rate increase of 70 beats per minute during exposure and a heat storage increase of 83 kcal (330 BTU) per hour as opposed to 18 beats and

29 kcal (115 BTU) per hour for the jacket in this experiment. Similarly, Sharma reported a mean heart rate increase of 53 beats and 108 kcal (430 BTU) for his helmet test as opposed to 34 beats and 67 kcal (266 BTU) for this experiment. Both Gandhok and Sharma concluded that the flow rate was inadequate and the results of this experiment indicate that the more ample flow rate did provide a considerable advantage.

Despite the clear physiological advantage of the jacket cooling, the helmet has several advantages that should not be lightly discarded. Not the least of these is the psychological benefit reflected by the subject comments. In addition, the helmet provides protection in contaminated atmospheres that would pose at least a nuisance if not a health hazard. Finally, the fact that physiological heat strain was significantly reduced with the helmet in Sharma's experiment, even with the low flow rates he used, cannot be ignored. Application of the concepts of head cooling and torso cooling in practice would result in a composite device.

Composite Device

The next generation of air cooling devices, based upon the results of this experiment and combined with engineering judgment, would incorporate the following concepts:

1. The physiological advantage of the jacket should be combined with the psychological and physiological advantages of the helmet.

2. Modern materials and techniques should optimize device design and construction.

3. Advantages of water as a conducting medium could be used to avoid the considerable heating of air ducted over long distances.

The above specifications could be met by designing a light weight, flexible clear plastic head covering which would serve the exact function of the helmet in this experiment and which could be worn alone for conditions of contaminated atmosphere and/or relatively low level heat stress. The head covering would be made in two layers with approximately 0.5 inch of "dead" air between the layers in order to preclude condensation. A compatible jacket, capable of being worn over light clothing, such as a T-shirt, would be a waist length, armless or half arm length device with adjustable openings and adjustable intermediate dimensions to limit ballooning. The material would depend upon the particular protection requirements: an impermeable, strong, lightweight material such as mylar could be appropriate for moderate heat stress or when protection from particulate or chemical contamination is required. If high radiant heat is a factor, consideration should be given to using a permeable insulated material to achieve the more effective "dynamic insulation" (Crockford and Hellon, 1964). Compatible optional ventilated trousers would complete the protective device if required. If contamination or high radiant heat is a factor, the same material requirements of the jacket apply. For more conventional circumstances air could very well be circulated in the regular work trousers, perhaps by circulating air up the trouser legs.

Water could be cooled at a remote location and transmitted in well insulated pipes to local heat exchanger assemblies which would contain an air blower, air filter, and a dehumidifier (see Figure 10). This assembly would process ambient air into a cool, clean, and dehumidified state suitable for short distance distribution of perhaps 15 feet (4.6 m) to cooling devices. The air distribution hoses would be constructed of an insulated, permeable material which would allow limited radial air leakage from the line. The "dynamic insulation" effect of such a line would minimize heating of the cooling air.

In practice, the cooling capacity of the heat exchanger could be used to cool a small volume, 2 to 3 cfm (57 to 85 l./min.), of cooling air for the helmet to about 70 to 75 F (21 to 24 C) to obtain the favorable psychological effect, while cooling a larger volume, 25 cfm (710 l./min.), to about 86 F (30 C) or below for body cooling. Crockford et al. (1961) reported that varying the temperature of the ventilating air in their ventilated suit did not affect physiological response for air temperatures between 86 to 100 F (30 to 38 C). They did, however, recommend an air temperature of 86 F (30 C) or less.

This system would have to be evaluated against other available possibilities but tentatively it appears to have merit.

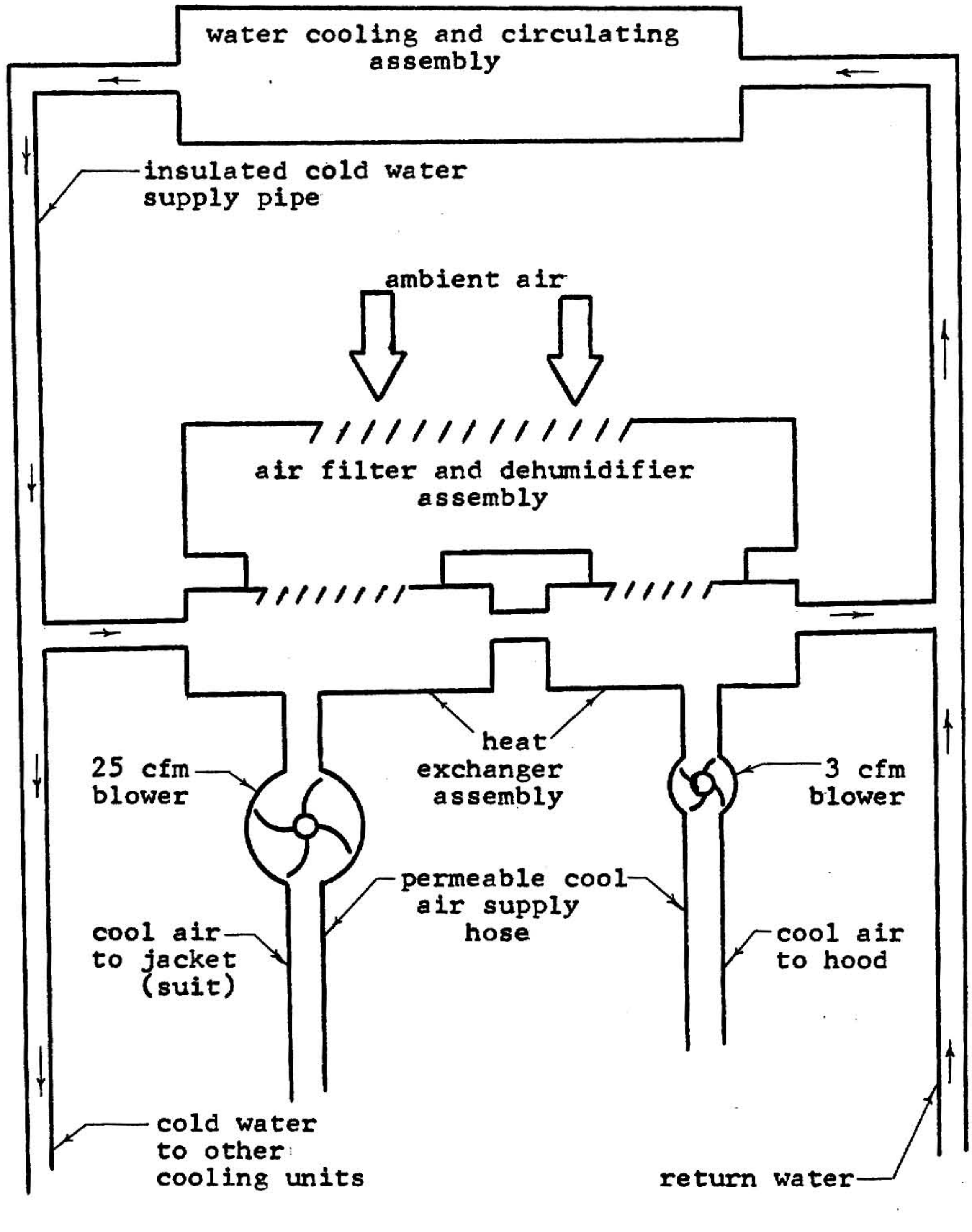

Figure 10. Schematic Diagram of Proposed Cooling System.

Saliva Biochemistry

General. Changes in the saliva components constituted a special area of interest in this experiment. The results observed in the criteria examined are duly reported in this thesis; the precise causes and meaning of these observations, however, are not particularly manifest. Although limited on this subject, the literature has been useful in suggesting explanations for the observed results, but such conjecture must be considered to be quite tentative.

Probably the most immediate benefit from the saliva observations is realized by considering the results on a primarily empirical basis: measurable and significant changes did, in fact, occur. Furthermore, these changes occurred under less-than-extreme conditions of heat stress and exercise, and they occurred in a relatively short period of time. The fact, then, that body chemistry criteria have been identified which are both sensitive and react rapidly is the salient feature of saliva biochemistry considerations.

Creatinine. Gandhok (1970), in his evaluation of an air cooled jacket, found that the concentration decreased for the jacket treatment. Sharma (1970), in testing the air cooled helmet, found no significant change in the concentration. These data agree with the results of this experiment. The literature (Strauss, 1957; Grollman, 1969) indicates that 24-hour creatinine excretion rate by the kidneys is quite constant and is quite constant even when measured over several hours. Osbaldiston (1969) states further that the continuous creatinine secretion rate of the kidneys is essentially constant and the absolute amount of creatinine present in the saliva should be constant at any given time. If this is in fact the case, the decrease in creatinine concentration demonstrated in this experiment would be indicative of an increased saliva flow.

The creatinine change was significant neither in Sharma's helmet experiment nor in this one, and further, the average change was considerably less for the helmet than for the jacket in this experiment. These indicators, although in no manner conclusive, imply that a greater saliva flow was elicited by the jacket treatment. Such an effect could be the result of a local thermoregulatory reaction intended to protect the respiratory system from the hot humid air inspired with the jacket treatment. Further investigation would be necessary to verify such an assumption.

Sodium and potassium. In a biological heat strain, the adrenal cortex of the kidneys increases the production of aldosterone which acts to withdraw sodium from body secretions in order to conserve it in the body. The lack of a significant change in the sodium to potassium ratio would seem to indicate that the mechanism to conserve sodium had not yet been activated and a true biological strain was not imposed by the conditions of this experiment. However, the inferences drawn from the previously discussed creatinine results were that a greater saliva flow existed for both helmet and jacket. According to Campbell *et al.* (1968), an increased saliva secretion rate could be expected to demonstrate an increased sodium concentration and a decreased potassium concentration. Exactly the opposite result was observed in this experiment. The inferred conclusion is that the kidneys in fact had begun to conserve the body sodium by increased secretion of aldosterone from the adrenal cortex. The aldosterone was acting on the saliva secreted by the parotid gland to reverse the effect of sodium-potassium balance which would have been expected from the higher saliva flow rate. The conclusion is that a true biological heat strain was a factor in this experiment.

Amylase. Despite the non-significant results obtained for this criterion, there was a very apparent tendency for the concentration to increase during heat stress. The fact that values for this substance were determined for only the latter half of the experiment is indeed unfortunate from a statistical point of view. It is suspected that increased replications and increased samples would confirm that amylase concentration does increase during heat stress. Again, the basic reason for this increase is open to conjecture. Since it is suspected that amylase secretion is related to blood circulation it is possible that either heat stress or exercise, both of which elicit a higher blood circulation rate, could account for a higher amylase concentration.

SUMMARY AND CONCLUSIONS

An air cooled helmet and an air cooled jacket were tested in a heat stress environment of 110 F (43 C) and 60% relative humidity, and their effectiveness compared using physiological and psychological criteria.

Six subjects were tested in pairs, with one subject wearing the helmet and one the jacket during a given exposure trial. Each subject was tested twice with each device for a total of four exposure trials per subject.

The following conclusions were made:

1. The heart rate for the jacket treatment was 14 beats/minute lower than for the helmet treatment after 40 minutes of exposure.

2. Sweat loss of 231 g/m^2 for the jacket treatment was significantly and substantially lower than the 317 g/m^2 for the helmet treatment.

3. Temperatures for body areas directly acted upon by a treatment were significantly lower than for the other treatment.

a. Head and ear canal temperatures were 2.3 F (1.3 C) lower for the helmet and 1.4 F (0.8 C) lower for the jacket, indicating that both surface and deep head temperatures were affected by the helmet.

b. Torso skin temperature for the jacket treatment was 5.5 F (3.1 C) lower than for the helmet treatment.

4. Head skin temperature rose only 0.3 F (0.2 C) above the basal value for the jacket treatment, although the head was

not directly cooled by the jacket.

5. Thigh and rectal temperatures, neither of which were directly acted upon by either treatment, were 0.9 F (0.5 C) and 0.2 F (0.1 C) lower for the jacket treatment. The differences were significant but not substantial.

6. Body heat storage was 38 kcal/hr (151 BTU) lower for the jacket treatment.

7. The biochemical data from the saliva samples indicate that changes did occur in the saliva components during the heat stress exposure.

a. Creatinine showed a significant concentration decrease after stress overall and similarly for the jacket treatment alone.

b. Amylase failed to demonstrate a significant increase but additional data could be expected to show an increased concentration under heat stress.

c. Sodium concentration did not show a significant increase but inference from the potassium and sodium-potassium ratio would suggest that it did tend to increase.

d. Potassium demonstrated a significant increase in concentration, suggesting some relationship between it and the stress conditions of this experiment.

e. Sodium to potassium ratio failed to demonstrate a significant change, suggesting that aldosterone secretion was not yet being increased to retain sodium. Assuming, however, that decreased creatinine concentration indicates an increased saliva flow, it is concluded that aldosterone in fact was acting to conserve sodium with the net effect being a reduction of the sodium concentration increase normally expected from an increased saliva flow.

8. A practical application of the cooling concepts investigated by this experiment would incorporate both head and body cooling with a practical light weight hood for contaminated atmosphere and/or low heat stress, a compatible optional jacket where a significant heat stress exists, and optional ventilated trousers if still greater cooling is required. The selection of protective garment material would depend upon the protective requirements. Cool water would be used to transport cooling power to local heat exchanger units where ambient air would be dehumidified, filtered, cooled, and distributed short distances to cooling devices with dynamically insulated hoses.

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THE EFFECT OF HEAT STRESS ON SALIVA

BY

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ABSTRACT

An air cooled helmet and an air cooled jacket were compared in a heat stress environment of 110 F (43 C) and 60% RH. Each device was furnished with 35 cfm (990 l./min.) of air at 70 F (21 C). The six subjects were tested in pairs, one subject wearing the helmet, the other the jacket for a given trial. The subjects walked at 2 miles (3.2 km) per hour for 5 minutes on a treadmill sloped at 5%, and rested for 5 minutes during their 40 minute exposure. The jacket resulted in lower physiological cost as determined by sweat rate, heart rate, and heat storage. The helmet, however, was preferred by the subjects due to the refreshing feel of the cooler air and easier breathing.

Analysis of saliva indicated that heat:

1. Increased sodium concentration
2. Increased potassium concentration
3. Decreased creatinine concentration, inferring greater saliva flow rate
4. Did not change sodium to potassium ratio
5. Apparently increased amylase concentration although the change was not statistically significant.

The saliva data infer that increased saliva flow and increased adrenal cortical activity (aldosterone secretion) acted as countervailing mechanisms to defer a change in the sodium to potassium ratio.