A WEAR TEST OF MEN'S POLYPROPYLENE INDOOR EXERCISE PROTOTYPES WITH HEAT AND MOISTURE MEASUREMENTS: AN EXPERIMENTATION WITH INFRARED THERMOGRAPHY

by

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(ABSTRACT)

A wear test of men's polypropylene indoor exercise prototypes was conducted to investigate heat and moisture measurements during exercise and compare the results to a man exercising in a partially nude condition. The usefulness of infrared thermography as instrumentation for observation of surface temperature during a wear test was also investigated.

Based on Univariate Analysis of Variance with Repeated Measures, one prototype was shown to react in a more similar manner to the skin of a man exercising in a partially nude condition. Pearson Correlation was used to determine the relationships between the data from the infrared camera and the data from wearer sensation scales. Little correlation was found and the results were not consistent over time. Results from the data obtained with the infrared camera suggested other uses for the

instrumentation, such as observation of heat flow properties of various fibers.

A description of various methods and instrumentation for collecting heat and moisture data during a wear test is included. The wear test procedure and use of the infrared camera are described.

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Introduction

Wear testing with human subjects is the final test of a functional design. The test is done to assess the structure, fabric, and fastening systems when the garment is worn by the intended subject in the proposed activity and environment. Wear related pilling, stretch and recovery, dimensional stability, and color retention can be measured by test methods developed by the American Society for Testing and Materials (ASTM) or from test methods published by the American Association of Textile Chemists and Colorists (AATCC). Actual fit of a garment can be measured by observations of live models or with slow or stop motion filming. But how does one observe the transfer of heat and moisture from the human body into the environment?

This question became important to researchers who were wear testing men's indoor exercise garments developed in the Virginia Polytechnic Institute and State University Apparel Research and Development Laboratory. The answer was sought in the use of an infrared camera to "see" and measure heat radiating from the human subject while exercising in prototypes.

The prototypes were developed through a translation of a needs assessment of the wearer and the activity. Fabrics chosen were based on the needs assessment and the structure. Each prototype varied in structure and fabric.

The prototype was intended to perform on the body as a second skin. Since the intended environment for the prototype was an indoor exercise facility which would be heated in the winter and cooled in the summer, the primary function of the clothing was modesty without impeding the activity. A wear test with human subjects was conducted to determine the prototype with the least resistance to heat and moisture flow through the fabric.

The Purpose of the Study

A major purpose in the total function of a man's indoor exercise garment is to provide comfort while the wearer is exercising. Part of the comfort is due to the way the garment reacts to the hot, perspiring, exercising body. The garment must allow heat and moisture to pass through the fabric barrier into the air.

The primary purpose of this study was to investigate heat and moisture measurements during a wear test of two men's indoor exercise prototypes and compare the results to a man exercising in a partially nude condition. A secondary aspect was to evaluate infrared thermography as a technique for assessing heat flow through garments on a human body.

Operational Definitions

Men's indoor exercise protptypes. Clothing worn by men to perform exercise indoors.

Indoor exercise. Activities such as stationary bicycling, aerobics, and weight lifting which are performed by a person indoors.

Prototype. One of many garments prepared from a needs assessment for the wear testing of a garment design.

Second skin. A garment worn on the body which does not impede the physiological processes of the body from functioning as they would in a nude condition.

Modesty. For the customer of the study, the psychological comfort of believing that the body is clothed properly to be viewed in public.

Dance belt. A type of underwear usually worn by male ballet dancers for support under tights and leotard. The garment is constructed for full support in the front and around the hips, but bares the buttocks of the wearer.

Thermography. The process in which an infrared camera is used for the detection of heat radiating from the surface of an object or person.

Thermograms. Pictures of the visual data through the use of an infrared camera used to determine the surface temperature of the exercising subjects.

Warmth sensation. The subjective statement given by the exerciser to describe the feeling of heat of the body while exercising during this study.

Wetness sensation. The subjective statement given by the exerciser to describe the feeling of moisture on the body while exercising during this study.

Overall comfort sensation. The subjective statement given by the exerciser to describe the general feeling of the body while exercising during this study.

Moisture uptake. The amount of moisture collected in the prototype after exercise.

Partially nude condition. Exercising without a shirt, wearing only socks, shoes, dance belt, and sweat pants.

Test condition A. The subject exercises in a partially nude condition on a bicycle ergometer at 50% of the exerciser's predicted maximum heart rate.

Test condition B. The subject exercises in Prototype I on a bicycle ergometer at 50% of the exerciser's predicted maximum heart rate.

Test condition C. The subject exercises in Prototoype II on a bicycle ergometer at 50% of the exerciser's predicted maximum heart rate.

Time period. A point at which data were collected during observation of the exercising subjects.

time period 1 - at rest

time period 2 - 5 min into exercise

time period 3 - 15 min into exercise

time period 4 - 25 min into exercise

time period 5 - 30 min into exercise

cool-down begins

time period 6 - 35 min into exercise

The Objectives

The objectives of this study were:

1. To determine the prototype which reacts more like the skin in a partially nude condition when worn during exercise.

2. To determine the relationship between the infrared measurements and moisture uptake, warmth sensation, wetness sensation, and overall comfort sensation.

3. To determine the relationship between moisture uptake and warmth sensation, wetness sensation, and overall comfort sensation.

The Hypotheses

1. The average surface temperature of the subjects exercising differs under the three test conditions at each of six observed time periods.

2. The average moisture weight gain of the two prototypes differs at the end of exercise.

3. The average subjective data for warmth sensation of the subjects exercising differs under the three test conditions at each of six observed time periods.

4. The average subjective data for wetness sensation of the subjects exercising differs under the three test conditions at each of six observed time periods.

5. The average subjective data for overall comfort sensation of the subjects exercising differs under the three test conditions at each of six observed time periods.

6. There is a relationship between average surface temperature and subjective assessment of warmth sensation at each time period for each test condition.

7. There is a relationship between average surface temperature and subjective assessment of wetness sensation at each time period for each test condition.

8. There is a relationship between average surface temperature and subjective assessment of overall comfort sensation at each time period for each test condition.

9. There is a relationship between average surface temperature and moisture weight gain at the sixth time period for test conditions B and C.

10. There is a relationship between moisture weight gain and assessment of warmth sensation at the sixth time period for test conditions B and C.

11. There is a relationship between moisture weight gain and assessment of wetness sensation at the sixth time period for test conditions B and C.

12. There is a relationship between moisture weight

gain and assessment of overall comfort sensation at the sixth time period for test conditions B and C.

Assumptions

1. The subjects were representative of the population designated by the initial needs assessment used to develop the prototypes in the Laboratory.

2. The activity performed was representative of the activity designated by the needs assessment.

3. The environment was representative of the environment designated by the needs assessment.

Limitations

1. Application of the findings from this research will be limited to indoor activities where the temperature and relative humidity are similar to those used in this study.

2. Application of the findings from this research will be limited to wearers who meet the profile of this study.

3. Application of the findings from this research is limited to indoor exercise garments created from polypropylene fabrics in a knit construction.

4. Application of the findings related to surface temperature are limited to the backs of exercising subjects.

Review of Literature

Heat and Moisture and the Human Body

Heat and moisture transfer from the body to the environment occur whether the body is clothed or not. Clothing, however, acts as a hinderance to heat and moisture transfer (Gonzalez, 1987). Researchers have developed several ways to measure heat and moisture on the human body in an effort to describe the body's physiological functions with and without clothing. Procedures range from the simple technique of obtaining an oral temperature with a mercury and glass thermometer to the more complicated act of inserting needle probes into working muscles. The reason for developing these procedures has been to help keep man comfortable and healthy in his environment. This can be achieved by comparing objective measurements taken from the body in a nude or partially nude condition with subjective data collected while the person is wearing the clothing being investigated.

Heat and moisture pass from the human body into the environment by radiation, convection, conduction, and evaporation. Radiation accounts for 60% of the heat loss from the body into the ambient air. Convection accounts for 30%, and conduction and evaporation together account for 10% (Clark, 1974). In situations of physical exercise or environmental stress, heat loss by evaporation can increase up to 10 times more than when the body is at rest. As evaporation increases, the surface temperature of the skin decreases from the cooling that occurs. The result is a lowering in the amount of heat radiated from the body (Bazett, 1949).

Radiation is "the exchange of thermal energy between objects through a process that depends only on the radiating objects" (Gonzalez, 1987, p. 266). The sun is a highly radiating object of heat. The heat it radiates is absorbed by objects, as well as by humans, and then radiated back into the atmosphere. Shiny objects absorb only a small amount of heat that is radiated toward them so the majority of the heat is reflected back into the atmosphere. The human skin and most fabrics absorb and then emit over 98% of the radiation they come into contact with (Clark & Edholm, 1985).

Convection is "the exchange of heat between hot and cold objects by physical movement in liquid or gas" (Gonzalez, 1987, p. 265). Convective forces move the air from the environment through the layers of clothing thus cooling the body.

Conduction "occurs when heat from within the body flows through the skin and into cooler objects in contact with it" (Gonzalez, 1987, p. 265). Heat developed inside an exercising muscle is conducted through the tissue to the outer skin surface. At the skin surface, heat may be conducted into the clothing if the clothing is cooler than the skin surface or into the air if clothing is not present and the ambient air temperature is lower than the skin surface temperature.

Heat loss by evaporation "occurs at the skin's surface when liquid sweat passes into vapor, producing a cooling effect on the skin surface" (Gonzalez, 1987, p. 266). Clothing is cooled in the same manner as the skin. When the surface of the clothing is wet, the wetness evaporates into the air and the clothing feels cool to the touch. This is more evident when convective forces are combined with the evaporative process.

During a wear test these modes of heat and moisture transport can be observed in an objective or subjective manner. Various instrumentation and procedures can be used for collecting objective data. This data can then be correlated with the verbal accounts given by the subjects during the wear test. Some observations of occurances on the body may be made by the use of instruments, but the verbal acceptance by the wearer is also important in determining the success of a functional design.

Measurement of Heat on the Human Body

Thermocouples and thermistors. The measurement of skin temperature with thermistors or thermocouples combines several modes of heat transfer into one measurement. Convection across the surface of the skin, conduction to the surface, and radiation from the body are all a portion of the heat measured by thermocouples and thermistors. Evaporation of moisture on the surface being observed may also influence the temperature read by the instruments.

The thermocouple consists of two wires made from different metals soldered at the tip. As the temperature of the junction rises, a thermoelectric charge is produced (Englehardt & Hewgley, 1973). This charge is then read from a voltmeter or processed by a computer which can store and print the data collected. Thermocouples may be used in contact situations in which they read heat produced by several modes of heat transfer or in noncontact situations where only radiation and convection are measured.

Thermistors, thermally sensitive resistors, are semiconductors. As temperature rises, a reduction in resistance is measured (Englehardt & Hewgley, 1973). Again, computers are useful in conjunction with thermistors to convert voltage changes to temperature measurements.

Vokac, Kopke, and Keul (1972, 1973, 1976) made use of thermocouples on the human body in their research with physiological comfort of clothing. One study centered on an analysis of bellows ventilation of clothing. Thermocouples were used on the skin and between the clothing layers on subjects wearing "vest, shirt, and anorak" (Vokac et al., 1973, p. 475). The thermocouples were mounted onto plastic rings. The rings were taped with the thermocouples against the body for skin temperature measurement. With the rings against the body and the thermocouple raised from the skin surface, the temperature of the air next to the skin was measured. Some thermocouples were sewn directly to the garment for measurement of surface temperature of the clothing. The thermocouples were attached to the subject with adhesive tape and connected to a 12 point recorder for collection of data. A 12 point recorder can measure data from 12 thermocouples simultaneously giving a spot check of the temperature changes occuring on the subject. Analysis of temperature readings helped describe the patterns of radiating and convective heat flow under clothing for a walking individual.

Other research by Vokac, Kopke, and Keul (1972) centered around the relationship between temperature measured with thermocouples and comfort sensations described verbally by the subjects. This project examined the comfort sensations during rest and exercise in

Scandanavian ski dress. Thermocouples were used in the same manner as described earlier--on the skin, on the clothes, and between the layers of clothing--and as a rectal probe. Readings from the thermocouples were compared to subjective statements of heat, moisture, and overall comfort sensations for the torso of the body and for the peripheral areas (the appendages). Subjective statements for temperature corresponded well with thermocouple readings for the torso, but were much higher than actual temperature readings for the peripheral parts of the body. For this reason, the researchers suggested that special attention should be given to the peripheral areas of the body during wear testing of a garment. It was also found that in Scandanavian ski dress the general thermal sensations correlated better with the weighted average of the rectal and skin temperature than with either temperature alone.

As mentioned previously, thermocouples and thermisters can be used as rectal probes for measuring the core temperature of a human and as needle probes to measure heat in the exercising muscles. These are both measures of heat conductance and are used mainly as a monitor to insure against heat stroke of an exercising subject.

Gagge, Stolwijk, and Saltin (1969) used rectal and needle probe thermistors on exercising men to determine which method of temperature measurement coincided with subjective temperature sensations. Ambient air temperature, skin temperature measured with a spot radiometer (a hand held infrared instrument) at 10 locations, metabolic rate, and sweat loss measured by weight loss of the subject were also measured. Muscle and rectal temperatures had a high correlation with warmth discomfort. A relationship was found between rectal temperature and metabolism and between skin and ambient air temperature. Warm discomfort related primarily to skin wetness (sweat loss), while skin temperature and temperature sensation had a high correlation.

Falls and Humphrey (1976) conducted a project to examine the effects of impermeable clothing on exercising wrestlers. Core temperature was continually monitored with a thermocouple rectal probe during exercise. Heart rate and weight were measured before and after exercise. Results showed that in the impermeable clothing, core temperature continued to rise even after exercise was stopped. While exercising in regular exercise clothing, core temperature leveled off after the first round of exercise, and a thermal equilibrium was maintained. The net result in the difference of core temperatures as measured with and without impermeable clothing was 0.9 ^{o}C.

Another situation in which impermeable clothing is a concern is during fire fighting. The garment construction is thick and heavy to ensure protection from the fire, and the garments must be worn in extremely hot conditions. Little air is allowed into the clothing. Research was done to compare new, breathable designs with the former protective clothing. Thermistors were used to examine the garments (Reischl, Stransky, DeLorme, & Travis, 1982). Enclosed in a wire cage, the thermistors were placed in the sleeves, chest, back, and legs of the garments while on the subject. Used in this manner, the thermistors measured radiating and convective heat transfer. The subject exercised on a series of bicycle ergometers to exercise both the arms and legs. The new design was shown to provide improved heat dissipation.

The Schlieren optical system. Although thermocouples and thermisters have been used in various ways, they are not the only methods for obtaining data of heat transfer. Systems have been developed for the observer to actually "see" the patterns of heat movement. The Schlieren optical system, liquid crystal film strips, and the infrared camera allow a visual observation of heat patterns on and around the human body.

The Schlieren optical system measures the convective forces around the human body. The body is usually at a higher temperature than the surroundings. As the air next to the skin surface becomes heated, it becomes less dense and rises. Since this layer of rising air has a different density than the ambient air, it has a lower refractive (bending of light rays) index. This principle allows the Schlieren optical system to work (Clark, 1974).

A car headlight reflected against two curved mirrors provides the lighting for the technique. As the last band of light reflects to the final mirror, it passes over the subject. The reflection from this mirror is processed through a filter made of colored gelatin film sheets. Deflections, changes in the pathway, in the focus of the beam of light are passed on when air temperature changes are met. These deflections are visible through the colored gels and can be photographed. The picture of the subject appears to have a cloud surrounding the body which is thin at the ankles and increases in thickness as it forms around the head. Areas which would stop the flow of air from rising, such as under the chin, appear especially cloudy.

Experiments using the Schlieren effect have shown a 15 to 20 cm thick boundary layer of warm air around the face. "A plume of hot air extends about 1.5 m above the head before dissipating into the atmosphere" (Clark, 1974, p. 59). The temperature of the air layer declines from the average skin temperature of 33 ^{o}C at the skin surface to the temperature of the ambient air at the outer edge of the boundary layer.

Liquid crystals. There are several procedures in current use which allow observation of heat transfer by radiation. These include the use of liquid crystal film strips and the infrared camera.

Liquid crystals are so called because they exhibit properties of both liquids and crystals. Most important, they begin to change color once the crystals reach a certain temperature and become liquid. Liquid crystals which are sandwiched between layers of plastic film are called film strips and can be laid upon or adhered to the surface of an object for temperature readings by analysis of color (Englehardt & Hewgley, 1973). Calibration against a known temperature source is easily achieved by adhering the film strip to an object of known temperature and recording the color of the strip. For precise measurement of temperature, the film strip must be viewed at a perpendicular angle to control refracted wavelengths. Under normal conditions, liquid crystal film strips can detect a temperature change of around 0.2 ^{o}C.

Liquid crystal film strips have been used in testing of fabrics in the laboratory in the flat form (Vigo, Hassenboehler, & Wyatt, 1982). These strips could be sewn onto garments in the same manner that thermocouples are sewn to clothing. This would enable the liquid crystal film strips to be used in the identification of the surface temperature of garments on the human body.

Infrared thermography. The Schlieren optical system allows the observation of heat in the form of convection around the body, and liquid crystals observe heat that is conducted to the surface of an object. The infrared camera observes heat radiating from an object. Since radiation provides the highest percentage of heat transfer, the infrared camera is a valuable instrument.

With infrared thermography, a photographic image of surface temperatures is produced. A camera containing a crystal cooled with liquid nitrogen senses infrared radiation emitted from the surface of the subject. Body temperature defines the intensity of the radiation. The camera sends an electronically processed image to a television monitor. Each temperature observed is shown in a different color on the television screen (Clark, 1974). The image can be in shades of grey or in a 10 scale color pattern. This image can be photographed with a 35 mm camera for slides or pictures or with 16 mm film for a moving picture (Grover, 1982). Video cassette recordings are also possible. With the use of a computer, digital analysis of areas of color provides the average surface temperature of the subject. A computer print of the thermal image is also possible. Any picture of the thermal image is called a thermogram.

One advantage of the infrared method over others is that it is a noncontact method; therefore, needles, tapes, or wires attached to the subject are not necessary. The camera is simply focused on the individual, and pictures are taken. One disadvantage is that the emissivity level of the object being observed must be known to determine exact temperature measurements. The emissivity level is the amount of heat that is allowed to be radiated back into the environment by an object. Surface temperatures of objects with low emissivity values cannot be taken at face value from thermograms. Mathematical equations which take into account the emissivity level of the object must be used to determine the true temperature being observed. Since the human skin and most clothing fabrics are close to 98% emissive (Clark & Edholm, 1985), this factor is not a problem when working with clothed or unclothed humans.

Veghte, Adams, and Bernauer (1979) completed a study of thermographic observations of exercisers engaged in static hand gripping, bicycling on an ergometer, and running. The purpose of the study was to explore the changes of surface temperatures during exercise due to vascular shifts. Measurements were also made with thermistors at various skin locations and as a rectal probe. Surface temperature data from the infrared camera and the thermistors were compared. The infrared measurements were accepted as a more refined method of measuring skin temperature due to the fact that an average temperature of an entire area was obtained while the thermistor provided data for only one spot. Using the static hand gripping as an example, the infrared camera scanned the entire arm while the thermistor was placed on the bicep.

Results of the study showed that with hand gripping, temperature loss in the hand and fingers was clearly visible. This agreed with past research using various heat measurement techniques such as thermocouples and themistors. Data from the cycling and running exercises also agreed with previous research. At the onset of exercise, an overall cooling was observed. After four minutes, the active muscles heated up while inactive muscles remained cool.

An observation reported by the researchers was that the presence of moisture on the body produced a mottled appearance in the thermograms. This did not interfere with the temperature readings.

Swimmers have been observed with thermography. The purpose of one study was to determine heat loss from the body during swimming in relation to fat content of the subject (Wade & Veghte, 1977). In this study, the resting subjects were scanned for two minutes with the infrared camera. The subjects were scanned again after immersion into a pool of 23.5 °C water (average body temperature is 33 °C) for five minutes. A third scanning took place after a 500 m freestyle swim. Skin temperature was also taken with thermocouples placed at four locations on the body at the same time that infrared measures were made. The researchers used the thermogram temperatures for reporting the results of the study and did not refer to the thermocouple measurements due to acceptance of the thermogram as a more valid measurement.

Skinfold thickness was found to correlate with changes in skin temperature before immersion and after five minutes of immersion without swimming. There was no correletion between skinfold thickness and temperature of the skin after a 500 m freestyle swim. The thermograms showed that before and after immersion without exercise the warmest areas of the body were the chest, groin, lower abdomen, and lower neck. The lack of fat in these areas and high blood flow were explained as the reason. After exercise in the pool, the warmest areas were associated with the active muscles (Wade & Veghte, 1977).

Two runners were compared in a thermographic study to show the difference in skin temperature patterns for an international-class runner and a "club-standard athlete"

(Clark, Mullan, & Pugh, 1977). The main reason for undertaking the study was to observe the validity of skin temperature measurements taken outdoors with conventional measuring techniques. The conventional technique chosen was a thermocouple probe. Thermograms and thermocouple readings were made at the same time. The thermocouple probe measured rectal temperature and gave two readings each for the head, trunk, arm, forearm, thigh, and leg. A comparison of the thermocouple and thermogram readings for each area individually showed up to a 4^{o}C difference in temperature measurements, but the overall surface temperatures for both methods agreed within 1.5^{o}C.

Observations of the color schemes showed that the international-class runner had a more defined arrangement of color on his thermograms with higher temperatures centered over working muscles, showing his ability to conduct heat directly through the muscles. The club-standard athlete had a less defined arrangement of colored areas due to more fatty tissue. The athlete had to retire from exercise before the observations were complete due to anhidrotic heat exhaustion. In this state, the skin stops sweating and skin temperature increases dramatically as the body struggles to cool itself. Thermograms were made of the club-standard athlete in this state, and the rise in skin temperature was evident (Clark et al., 1977).

Measurement of Moisture on the Human Body

Moisture transport. The measurement of moisture transport in relation to human subjects can also be approached in various ways. Moisture transport by the body in the form of weight loss is one measure often used. The difference in a person's weight before and after exercise is a measure of moisture loss by the individual. This moisture can evaporate into the air, soak into clothing being worn by the subject, or lie on the surface of the skin to be wiped off by a cloth. A small portion of this moisture is also evaporated into the air by respiration. Excessive weight loss during exercise should be avoided due to the physiological stress it places on the body in the form of elevated body temperature, elevated heart rate, and dehydration (Falls & Humphrey, 1976).

Falls and Humphrey (1976) observed physiological stress in a project which compared the weight loss, heart rate, and rectal temperature of wrestlers exercising in permeable and impermeable clothing. The results of the study indicated that most wrestlers lost weight at a faster rate and to a greater extent in impermeable clothing as compared to lightweight clothing. Other signs of stress included anxiety, nausea, and numbness in the appendages.

In another study, weight loss in relation to subjective measures of comfort was investigated (Gagge et al., 1969). It was determined that when subjects exercised in a nude condition, comfort was related to skin wetness as measured by weight loss.

Another measure of moisture transport concerns the weight gain of the clothing worn by the subject. Wetness of the clothing was shown to affect comfort sensations in a study which examined the comfort of warm-up suits during exercise (Morris, Prato, Chadwick, & Bernauer, 1985). Exercise running suits were made from three different fibers and fabrics to observe moisture transport properties of the fabrics and comfort sensations of the exercisers. The weight of the garments was taken before and after exercise and the garments were stored in preweighed plastic bags. This included the weight of undergarments, socks, and shoes. There was a high correlation (0.985) between wetness sensation and moisture in the undergarments, but no relationship was found when observing wetness sensation and the running suit. This led the researchers to believe that next-to-skin clothing wetness was most important in determining subjective comfort.

Wetness probes. Wetness probes which measure electric conductivity have been used to measure the amount of moisture on the surface of the skin. One of the earlier uses of such a device was in 1953 by Andreen, Gibson, and Wetmore in research concerning the physiological effects on the human body of coveralls constructed from all nylon, all cotton, and a wool/Orlon acrylic blend. The probe was a rather large device in comparison to today's equipment. Spring mounted, the actual sensing device touched the surface of the skin only when depressed manually by the subject. The size of the device required a harness to be worn by the subject under the test garments. Results of the study showed a higher skin wetness with the wool/acrylic blend. The garments made from cotton and the ones made from nylon were similar.

Humidity sensors. A humidity sensor observes moisture transfer between the layers of clothing. The humidity sensor, a semiconductor, measures an electrical charge in the presence of wetness. Vokac et al. (1972, 1973, 1976) made use of the sensors in their work with comfort of clothing. In their work with cotton and polypropylene vests (Vokac et al., 1976), objective measurements of humidity on the back of the subjects were compared with subjective measurements of sensations of moisture for the same area. Humidity sensors anchored onto plastic rings (in the same method described for thermocouples in a previous section) were taped to the back of the subject and sewn between the layers of clothing. Sudden changes of intensity in energy expenditure were seen clearly when subjective and objective data were graphed. However, subjective data at the immediate time of transition from rest to exercise and from exercise to rest were in opposite directions as compared to objective data.

Crystalline powders. Drierite is the brand name for a type of crystalline powder which is blue when dry and pink when wet. Research has been conducted with socks of various fiber types to determine which sock was more comfortable for exercise (Pontrelli, 1978). Athletes played basketball in socks of cotton, wool, or Orlon acrylic. The Orlon acrylic socks were chosen subjectively to be the most comfortable. With Drierite taped to the outside of the tennis shoe while the athletes exercised, it was determined that the Orlon acrylic socks helped move the moisture away from the foot to the outside of the tennis shoe. The Drierite turned pink. The wool and the cotton socks held the moisture against the foot. This was shown by the Drierite remaining blue in color on the outside of the exerciser's tennis shoe.

Theoretical Framework

Human Physiology during Exercise

During exercise it is necessary for the human body to expel heat to maintain a thermal balance. Excessive heat build up can cause heat stroke which may result in death (Clark & Edholm, 1985; Falls & Humphrey, 1976).

As a person exercises, the moving muscles generate heat. Blood flow increases to cool the body by bringing the warm blood close to the cool surface of the skin. This occurs through the process of vasodilation. The closer the blood is to the skin surface, the more effect the temperature of the environment has on the blood. The warmth of the blood circulating to the surface of the body causes heat to radiate from the skin. As the heat is released, the blood is cooled. The cooler blood returns to the inside of the person to cool the core (McArdle, Katch, & Katch, 1986).

Sweat secretion begins when the action of the dilating blood vessels no longer cools the body adequately. The release of moisture from the pores develops a wetness on the skin. The action of perspiration evaporating into the air cools the skin to a lower temperature than is possible without the presence of moisture. This in turn relates back to the blood flow of the person. The cooler skin results in cooler blood which is transported inward to cool the core of the person and maintain thermal balance (McArdle et al., 1986).

During indoor exercise, clothing acts as a barrier to heat and moisture passage from the body into the environment (Clark & Edholm, 1985; Gonzalez, 1987; Watkins, 1984). Since clothing is required by our society, a system of indoor exercise clothing which interferes little with the physiological processes is desirable. This system should allow for maximum heat radiation and moisture evaporation.

Fibers and fabrics

Air is an excellent form of insulation. A fabric is a combination of fibers and air. The more air that is trapped in a layer of fabric, the more the fabric will insulate the body it covers. A lightweight, porous fabric with high air permeability will allow maximum air passage. Thick fabrics, which contain much dead air space, will hinder air passage and therefore hinder heat radiation (Watkins, 1984).

Moisture transport is hindered by fibers with a natural tendency to absorb water. Natural fibers such as wool and cotton absorb moisture in contrast to synthetic fibers such as polyester and polypropylene which wick the moisture away. The wicking process involves moisture traveling along the fiber instead of through the fiber. A combination of other factors such as twist of a yarn, tightness of a knit or weave, and air permeability of a fabric will also affect the moisture transport. A fiber that wicks made into a fabric with high air permeability will allow moisture evaporation to occur quickly (Watkins, 1984).

Laws of thermodynamics

Heat will flow from a warm body to a cool body until an equilibrium is reached. For moisture, evaporation will take place from a wet surface into the atmosphere until complete saturation of the air occurs (Tipler, 1987). Thus, an exercising person will release heat and moisture into a room as long as the air temperature is lower than body temperature and the relative humidity is lower than 100%.

Conclusion

From theories concerning the body processes, structures of fabrics, and thermodynamics, the most comfortable garment for indoor exercise would be a garment that allows maximum air passage so that the body can release heat and moisture into the environment.

Method

In this study, two men's indoor exercise prototypes were examined to compare the exercisers' objective and subjective physiological response in each garment with their objective and subjective physiological response in a partially nude condition during exercise. Surface temperature as observed with an infrared camera and moisture uptake of the prototypes were the objective measures used. Subjective ratings of warmth sensation, wetness sensation, and overall comfort sensation were also made. Comparisons of responses were used to evaluate the prototypes and the the use of the infrared camera as instrumentation for measuring heat flow through a garment while on a human body.

Measurement Methods Selected for the Study

In an effort to use instrumentation which would give a visual reading, the infrared camera was chosen as a means of examining the surface temperature of the prototypes worn. Since this was a noncontact method of measuring heat, there was no interference from leads, wires, or adhesive tape with the clothing being examined. Contact thermocouples which must be held to the body with tape can insulate the skin and affect temperature and capillary circulation in the taped area (Yaglou, 1949).

Also to keep the subjects free of contact equipment, moisture uptake of the prototypes was measured by weight changes. In this manner, a comparison of the infrared data, moisture uptake, and the subjective measures was made to explore possible relationships among the test methods.

Exercising Conditions

Five subjects exercised three times in each of three conditions for a total of nine observations per subject. During Condition A the subject exercised in the partially nude condition. The exerciser was nude from the waist up. During Condition B the subject exercised in Prototype I, and during Condition C, Prototype II was worn. The prototypes consisted of a top, leggings, and shorts. Observations for the infrared portion of the study were made only on the top. The prototypes differed in structure and fabric (Appendix A). One of each prototype was provided for each subject.

A man's dance belt was provided for each subject. Since it has been shown that subjective wetness sensation of skin relates to underwear wetness (Morris, et al., 1985), a dance belt which bared the buttocks of the exerciser to the prototype, but allowed support, was used. Socks were also supplied. The subject provided his own tennis shoes for all test conditions and sweat pants for the partially nude condition.

Emissivity levels of the fabrics for the prototypes were examined prior to the wear test. This was necessary to determine whether each fabric used in the prototypes would produce the same readings with the infrared camera before being subjected to body heat. The test was conducted by pinning samples of the fabrics to a sheet of cardboard, conditioning them overnight in the climate controlled laboratory, and viewing them with the infrared camera. When viewed with the infrared camera, the samples appeared to have the same color. This showed that the emissivity levels were the same for the observed fabrics.

Subjects

Five adult men participated in the study. Criteria for the subject sample was: 1) ages 35 to 55, 2) height 5'8" to 5'11", 3) weight 160 to 175 pounds, 4) a habitual physical activity level equivilant to 1 hour of exercise, 3 days a week, and 5) passage of a graded exercise test. This gave a sample of healthy, medium build subjects acclimated to the type of exercise used in the study. This type sample fit the average customer base of the company that the research was conducted for. The variable of physical build was necessary to control because it has been shown that physical activity and physical build effect the wear of a garment (Morris, Schultz, & Prato, 1972). It was also necessary because all prototypes were constructed in a sample size 40.

Subjects were obtained by personally asking individuals acquainted with the Apparel Research and Development Laboratory and by recruiting individuals through posters placed in two gymnasiums. The subjects were compensated for their time by the company funding the research.

Screening Procedures

Subjects interested in participating in the study were screened through physical measurements of the individual and through a graded exercise test. The graded exercise test was a prerequisite for exercise testing of human subjects over the age of 35 at the research facility.

Physical measurements and questions. Physical measurements of the individuals were made on a scale which weighed the subject in kilograms and by a tape measure permanently attached to a wall for taking height measurements. Chest, waist, and hip measurements were made over the shirt and pants with nothing in the pockets. At the time the physical measurements were taken, the subjects were questioned about their weekly exercising habits and their general health (Appendix B).

Graded exercise test. A graded exercise test, guidelines set by the American College of Sports Medicine (1986), was given prior to selection of subjects (Appendix

C). The test allowed the examining doctor to determine whether the subject's physical health would be in jeopardy by participating in the wear test. Information gained from this test was also used to control the heart rate of the subjects during the wear test.

The graded exercise tests were performed in the Human Performance Laboratory at Virginia Polytechnic Institute and State University. Results of the tests and consent forms for participation in the research project were given to the Review Board for Research Involving Human Subjects.

Pretest

Subjects selected were given a pretest to familiarize them with the testing exercise routine and to reduce anxiety. This pretest provided the researcher with the opportunity to coordinate the testing routine. The routine used in the pretest was the same routine used in the actual testing procedure.

Measurement Procedures

Each subject exercised three times a week for three weeks alternating the two prototypes and the partially nude condition. The prototypes were laundered after each wear according to AATCC Test Method 135 - 1987 (American Association of Textile Chemists and Colorists, 1988) and conditioned in the climate controlled laboratory (average of 69 ^{o}F and 54% RH) overnight. Heat radiation and moisture uptake measurements were made during each exercise session. Moisture uptake was not measured during exercise in the partially nude condition because no clothing was worn on the measured area.

Testing took place in a climate controlled laboratory with an average temperature of 69 ^{o}F and an average relative humidity of 54%. The use of the climate controlled laboratory was necessary to reduce differences in exercising individuals that occur at varying temperatures and relative humidities. All tests were performed on a Monark bicycle ergometer. Each subject exercised at approximately the same time of day to avoid possible water weight differences which occur to an individual over the course of a day and influence the rate of perspiration (McKardle et al., 1986).

Subjects exercised at a heart rate of 50% of the predicted maximum for that subject's age. Resistance applied to the bicycle ergometer to maintain the proper heart rate was determined by data obtained during the graded exercise test (American College of Sports Medicine, 1986).

Heat radiation. The surface temperature of the body and the surface temperature of the prototypes on the exercisers were measured with an AGA Thermovision Infrared Camera. The infrared camera was set up in the laboratory eight feet from the back base of the bicycle ergometer. The camera rested on an adjustable tripod which could be set at various levels to accomodate the height of the subject.

A video (television) screen in a grey scale was interfaced with the infrared camera as a control source for the infrared picture. The video screen in grey scale was then interfaced with a color video screen which depicted the infrared image in 10 colors: black, yellow, royal blue, green, red, sky blue, pink, aqua, gold, and white. Black was the coolest and white the warmest. The system was set so that each color depicted a temperature 0.5 ^{o}C warmer than the previous color. Red was used as the reference temperature and was set at 24 ^{o}C for subjects exercising with clothing and at 26 ^{o}C for subjects exercising without clothing. The temperature difference was necessary because the surface temperature of the bare skin was warmer than the surface temperature of the clothing when worn by the exercisers. This occured because the presence of the clothing blocked a portion of the radiating heat causing the clothing surface temperature to be a bit cooler than the surface of the bare body (Clark & Edholm, 1985; Gonzalez, 1987; Watkins, 1984).

An AGA Model 1010 Temperature Reference which had been calibrated with thermistors was used to maintain constant focus with the infrared camera. The reference was placed next to the subject within the field of vision of the infrared camera. A specific temperature was set on the reference by use of a dial on the instument. Once heated to the specific temperature, the infrared camera was focused to make the heat source appear red on the video screen. In this way, the red that appeared on the thermogram was the same temperature as the reference, and a temperature scale could be developed throughout the other colors of the image. A 35 mm camera with Ecktachrome 200 slide film was placed on a tripod and focused on the video screen to capture the infrared image (Grover, 1982). The camera and video screen were draped with a black cloth to reduce unwanted light and reflections on the screen. A slow shutter speed (f4, speed of one fourth sec) was necessary to capture the complete image since the video screen had a visible "flicker" during projection of the image. The resulting slides were used for calculating the average surface temperature of the object being viewed.

Moisture uptake. Moisture uptake was measured by weight change in the garment. Each item of clothing, including the socks and shoes, were weighed prior to exercise with the prototype in one bag and accessories in another. Immediately after exercise, the prototypes were placed back into the plastic bags and weighed to determine moisture gain. Measures were made to hundredths of a gram on a metric scale.

Warmth, wetness, and overall comfort sensation. Scales used for subjective ratings of warmth, wetness, and overall comfort are given in Appendix D. Charts with these scales were placed on the wall in front of the exerciser for ease in reading. They were labeled A, B, and C to avoid confusion. The subject responded verbally when questioned about sensations. A laboratory assistant recorded the response. The subjective ratings of warmth, wetness, and overall comfort sensations of the garment were taken every five minutes from beginning of exercise through the cool-down period.

Testing Procedure

The testing procedure for each subject for each prototype took approximately one hour and thirty minutes. The individual entered the climate controlled laboratory. He weighed himself in the nude and reported the weight to the laboratory assistant to be recorded. A clock began timing at -30 minutes. He put on the specified, preweighed, exercise prototype, dance belt, socks, and shoes (Appendix E). The subject sat for the remainder of the 30 minutes. This resting period acclimated each subject to the temperature and humidity of the climate controlled laboratory. After 30 minutes the subject mounted the bicycle ergometer to exercise. Heart rate was determined at this time and every five minutes thereafter (Appendix F). The subject exercised 30 minutes at 50% of predicted heart rate for his age. The percentage was a standard heart rate for testing exercising individuals set by the American College of Sprots Medicine. This heart rate was maintained by controlling the resistance against the exerciser on the ergometer.

The Thermovision camera was activitated upon mounting the bicycle ergometer and two 35 mm slides were made at rest. The infrared camera was turned off. Two pictures were made at 5, 15, 25, 30, and 35 minutes thereafter. This gave a series of pictures from rest through the cool down period. Pictures were taken of the subjects' back with arms extended away from the body to avoid a blending of the arms with the body in the thermographic image.

Subjective ratings of warmth sensation, wetness sensation, and overall comfort sensation were taken every five minutes. This was done by asking the subject to rate himself on charts A, B, and C. A cooldown of five minutes at free wheeling was included. Responses were recorded immediately by the laboratory assistant (Appendix F).

After the cool down, the subject undressed, placed his prototype in air tight plastic bags, weighed himself in the nude, and reported the weight to the laboratory assistant to be recorded. Weight in grams of the prototype was taken immediately to avoid further evaporation.

As the testing progressed, the researchers wondered whether or not a typical exercise garment would react in a similar manner to the prototypes. For this reason, one set of observations was made on each subject exercising in a T-shirt, a product of the sponsoring company, made from 97% cotton and 3% rayon. This replaced one set of Condition A observaitons. The T-shirt observations were included in the statistical analyses, but since only one set of observations was made on each subject, the results on this group of data were treated as assumptions and not as results of the research study.

Analysis of Thermograms

The Numonics Digital Analyzer and a personal computer, were used for analysis of the surface temperature of the bare back and the fabrics of the prototypes during exercise.

The 35 mm slide was projected onto a viewing cabinet that was a component of the digitizer. The area to be measured (a 6" X 10" rectangle) was drawn onto a sheet of acetate film and taped to the screen. The top of the rectangular area was aligned with the shoulders, centering the neck. This gave the maximum colored surface area possible for measurements of temperature.

The digital analyzer was interfaced with a personal computer programmed to accept and print the data collected by the analyzer (Appendix G). The final print displayed the area measured for each color and gave an overall surface temperature for the complete area measured.

<u>Statistical Analyses</u>

The analysis of the data was completed with the use of the SAS statistical computer package contained in the mainframe computer system at the research facility. Analysis of Variance, Univariate Analysis of Variance with Repeated Measures, and Pearson Correlation were the statistical procedures used (Hinkle, Weirsma, & Jurs, 1979). Plots of various groups of data were created to express relationships in a visual context. Although data collected from observations of the T-shirts were analyzed statistically, they were not included in the statistical explanations because only one observation per subject was made. References to the data obtained from the T-shirts will be included in the Discussion.

A 95% probability level was set for retaining or rejecting the research hypotheses. Hinkle's (1979, p. 85) suggestions for determining a high or low correlation for Pearson Correlation were used.

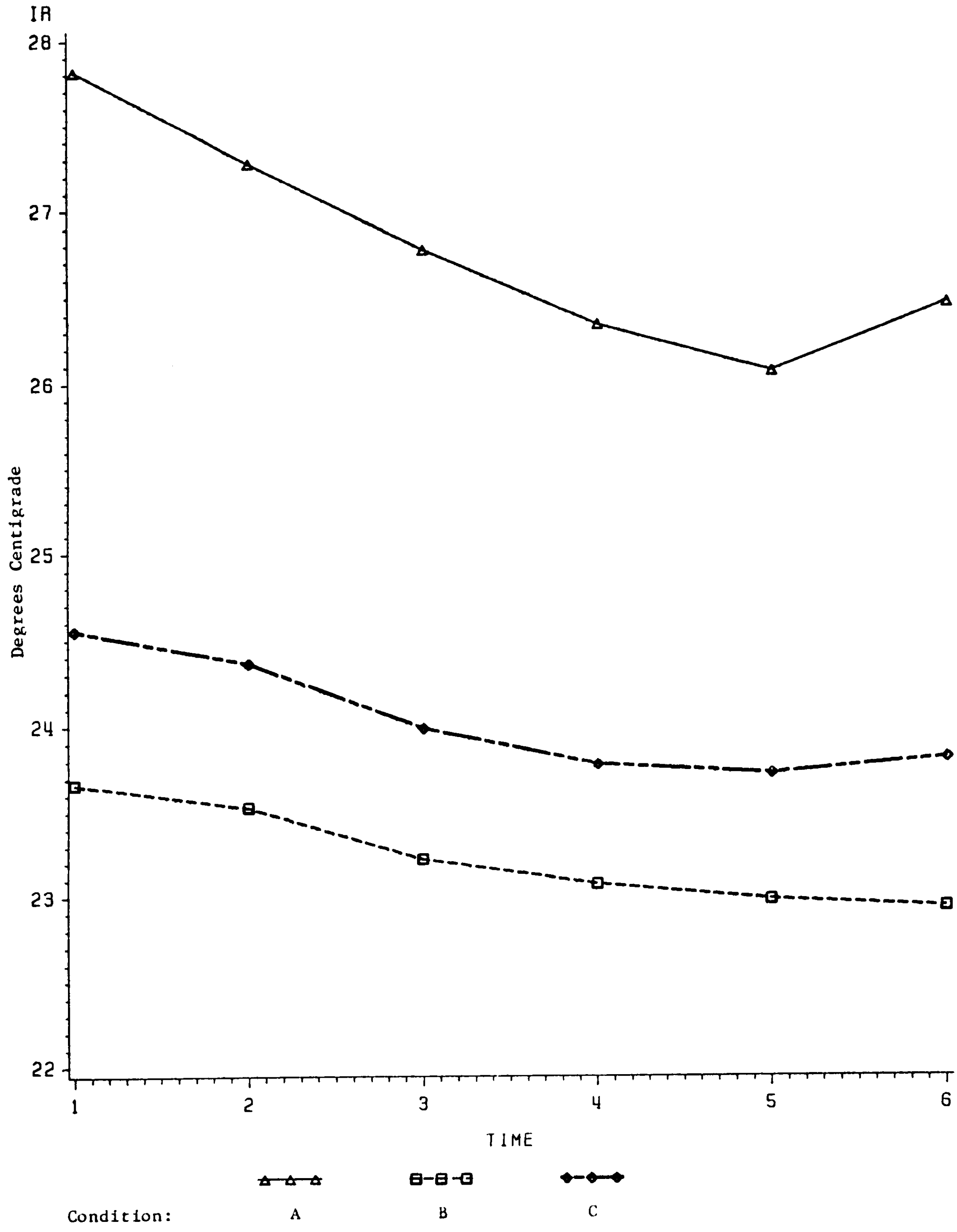
Findings

Results of the statistical analyses for each hypothesis are as follows:

Hypothesis 1

The average surface temperature of the subjects exercising differs under the three test conditions at each of six observed time periods.

The plot containing means over time for surface temperature for each condition is contained in Figure 1. Univeriate Analysis of Variance with Repeated Measures was used to test this hypothesis. The variance in the means of the data collected was compared for the three test conditions over time. When the conditions were compared as a group, Hypothesis 1 was retained, $F(3, 25.1) = 125.46$, $p < .05$, meaning that one or all of the prototypes reacted in a different manner from each other over time. From observations of the plotted data it could be seen that conditions A, B, and C were similar to each other over time; therefore, a test to see if the plotted lines were statistically parallel to each other was made. Again, Univariate Analysis of Variance with Repeated Measures was used, but this time the conditions were arranged into all possible pairs and compared. The following results occured:



<u>Figure 1.</u> Mean surface temperature over time for all conditions.

Table 1

Means and Standard Deviations for the Surface Temperatures Over Time for All Conditions

	Conditions					
	A		B		C	
Time Period	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	27.8	.413	23.7	.461	24.6	.688
2	27.3	.456	23.5	.379	24.4	.678
3	26.8	.592	23.2	.429	24.0	.639
4	26.3	.822	23.1	.372	23.8	.547
5	26.1	.685	23.0	.372	23.7	.621
6	26.5	.911	22.9	.269	23.8	.595

A and B were not statistically parallel, $F(5, 25.01) = 7.19$, $p < .05$.

A and C were not statistically parallel at a 95% probability level, but were at a 99.9% level, $F(5, 25.41) = 4.04$.

B and C were statistically parallel, $F(5, 23.64) = .39$, $p < .05$.

Hypothesis 2

The average moisture weight gain of the two prototypes differs at the end of exercise.

Data were collected for moisture weight gain of the garments immediately after exercise. For this reason, data was not available over time. Since Univariate Analysis of Variance with Repeated Measures is a statistic that is employed for data collected over time, it could not be used for this analysis. Analysis of Variance was chosen as the method to test the variance in the means. There was no difference in the prototypes for amount of weight gain, and Hypothesis 2 was rejected.

Hypothesis 3

The average subjective data for warmth sensation of the subjects exercising differs under the three test conditions at each of six observed time periods.

The plot containing means over time for subjective responses of warmth sensation for each condition is contained in Figure 2. Univariate Analysis of Variance with Repeated Measures was used to test the variance in the means of the data collected for the test conditions over time. There was no difference among conditions in the subjective data collected for warmth sensation over time, $F(3, 3.4) = .16$, $p < .05$, and Hypothesis 3 was rejected.

Hypothesis 4

The average subjective data for wetness sensation of the subjects exercising differs under the three test conditions at each of six observed time periods.

The plot containing means over time for subjective responses of wetness sensation for each condition is contained in Figure 3. Univariate Analysis of Variance with Repeated Measures was used to test the variance in the means of the data collected for the conditions over time. There was no difference among conditions in the subjective data collected for wetness sensation over time, $F(3, 2.3) = .24$, $p < .05$, and Hypothesis 4 was rejected.

Hypothesis 5

The average subjective data for overall comfort sensation of the subjects exercising differs under the three test conditions at each of six observed time periods.

The plot containing means over time for subjective responses of overall comfort sensation for each condition is contained in Figure 4. Univariate Analysis of Variance

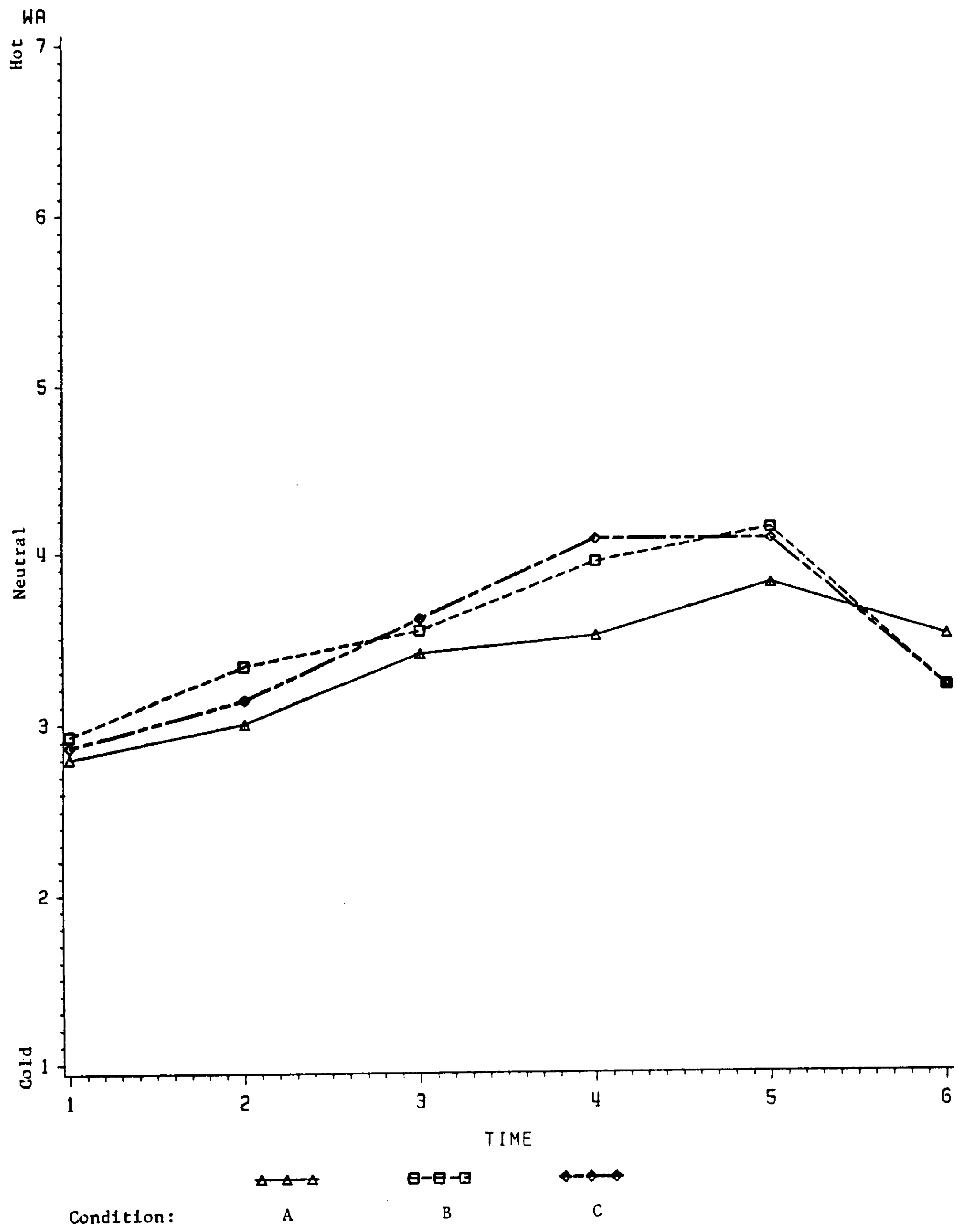


Figure 2. Mean warmth sensation over time for all conditions.

Table 2

Means and Standard Deviations for the Warmth Sensations Over Time for All Conditions

Time Period	Conditions A Mean	A S.D.	B Mean	B S.D.	C Mean	C S.D.
1	2.8	.919	2.9	.594	2.9	.990
2	3.0	.667	3.3	.488	3.1	.743
3	3.4	.699	3.5	.640	3.6	.633
4	3.5	.707	3.9	.704	4.1	.80
5	3.8	.633	4.1	.743	4.1	.799
6	3.5	.850	3.2	.941	3.2	1.08

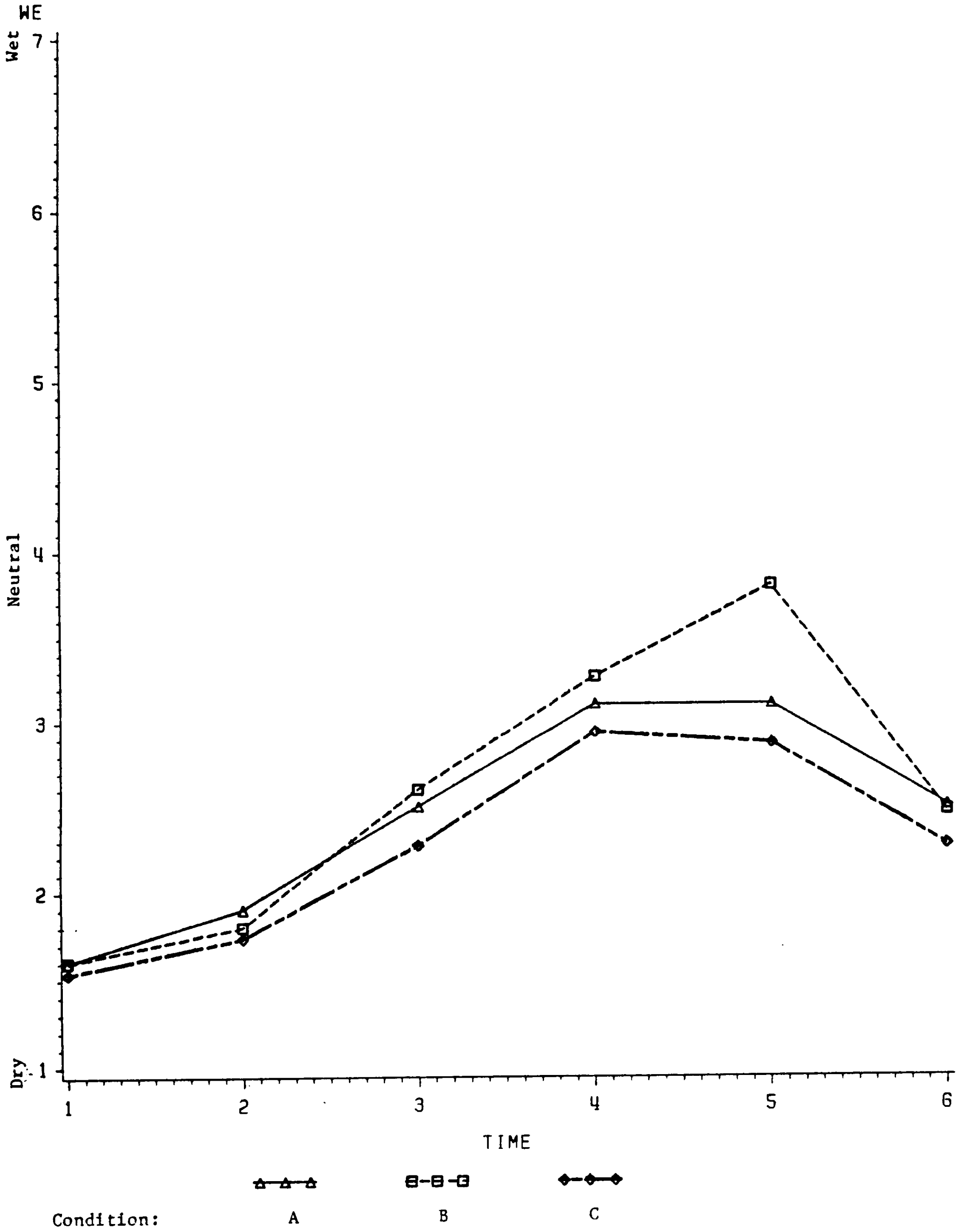


Figure 3. Mean wetness sensations over time for all conditions.

Table 3

Means and Standard Deviations for the Wetness Sensations Over Time for All Conditions

	Conditions					
	A		B		C	
Time Period	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1.6	.843	1.6	.828	1.5	.834
2	1.9	.876	1.8	.862	1.7	.799
3	2.5	1.18	2.6	1.12	2.3	.884
4	3.1	1.27	3.3	1.28	2.9	1.16
5	3.1	1.27	3.8	1.26	2.9	1.06
6	2.5	1.51	2.5	.743	2.2	.799

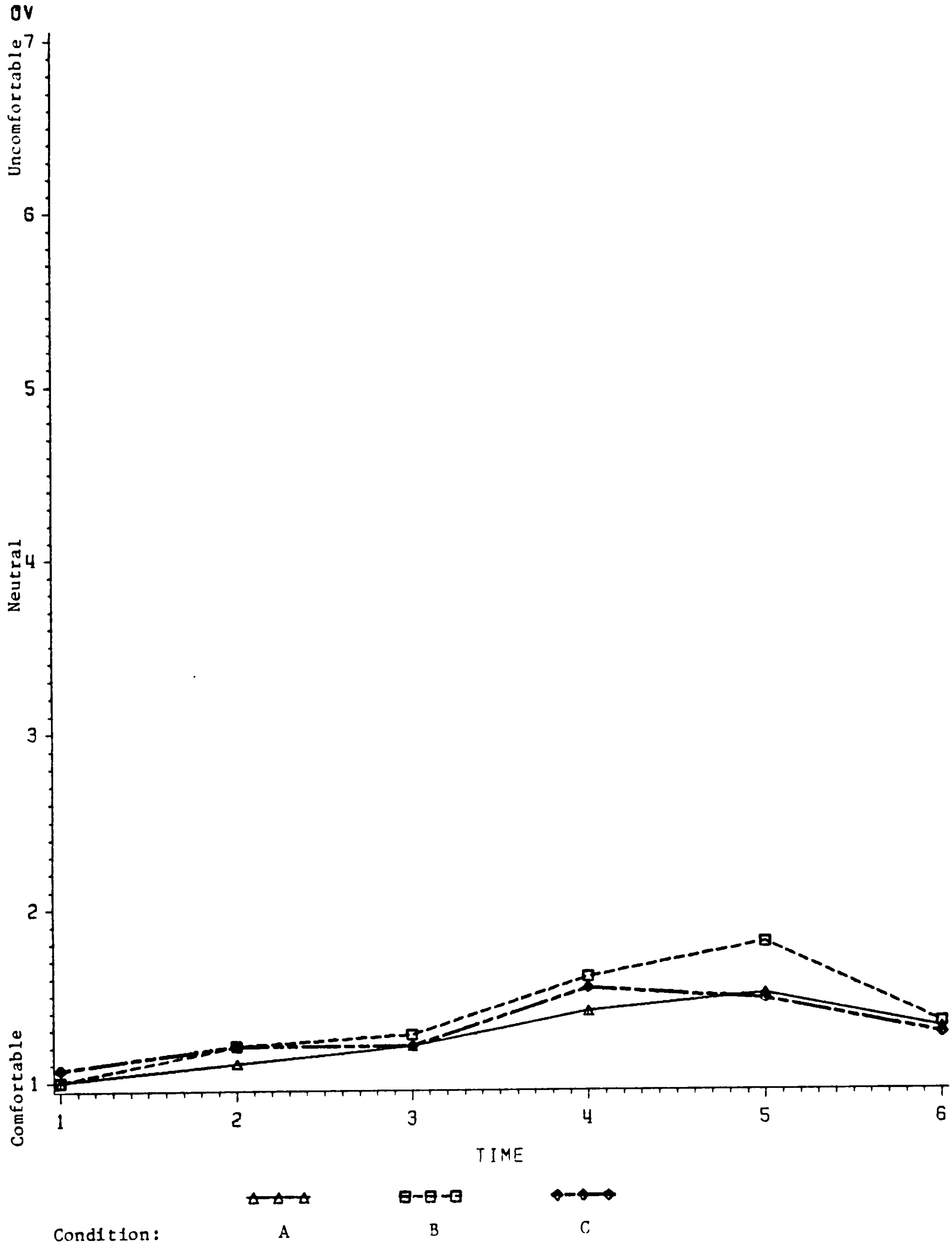


Figure 4. Mean overall comfort sensations for all conditions.

Table 4

Means and Standard Deviations for the Overall Comfort Sensations Over Time for All Conditions

	Conditions					
	A		B		C	
Time Period	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1.0	.000	1.0	.000	1.1	.258
2	1.1	.316	1.2	.414	1.2	.414
3	1.2	.422	1.3	.594	1.2	.414
4	1.4	.516	1.6	.737	1.5	.640
5	1.5	.707	1.8	.676	1.5	.516
6	1.3	.483	1.3	.488	1.3	.458

with Repeated Measures was used to test the variance in the means of the data collected for the conditions over time. There was no difference among conditions in the subjective data collected for overall comfort sensation over time, $F(3, 1.3) = .18$, p .05, and Hypothesis 5 was rejected.

Hypothesis 6

There is a relationship between average surface temperature and subjective assessment of warmth sensation at each time period for each test condition.

Pearson Correlation was used to examine the relationship between the data collected with the infrared camera and the data given by the subjects concerning warmth sensation. For condition A there was little or no correlation across the time periods ($r = -.06$ to $-.28$) except for the sixth ($r = -.55$). Condition B responded in a similar manner with little or no correlation from time periods one to five ($r = .06$ to $-.26$) and a low negative correlation at time period six ($r = -.32$). Little or no correlation was found in time periods one through five for condition C ($r = .07$ to $-.23$). The sixth period for C had a low negative correlation ($r = -.33$). Hypothesis 6 was rejected.

Hypothesis 7

There is a relationship between average surface temperature and subjective assessment of wetness sensation at each time period for each test condition.

Pearson Correlation was used to examine the relationship between the data collected with the infrared camera and the data given by the subjects concerning wetness sensation. Condition A produced a high and a moderate correlation for time periods 1 and 2 ($r = -.79$ and $r = .57$ respectively). There was little or no correlation for the rest of the time ($r = .04$ to $r = .17$). Condition B had no significant correlations ($r = -.007$ to $r = .29$) except for the third period which had a low negative correlation ($r = .32$). Condition C reponded in a similar manner to A with the first two time periods giving moderate positive correlations ($r = .59$ and $r = .40$ respectively) and the rest of the data having little or no correlation ($r = .08$ to $r = .24$). Hypothesis 7 was rejected.

<u>Hypothesis 8</u>

There is a relationship between average surface temperature and subjective assessment of overall comfort sensation at each time period for each test conditon.

Pearson Correlation was used to examine the relationship between the data collected with the infrared camera and the data given by the subjects concerning overall comfort sensation. There was little or no correlation between the two groups of data for Condition A ($r = 0$ to $r = .31$). Condition B showed time periods 4 and

5 with a low negative and a moderate negative correlation (r = -.32 and r = -.45, respectively) and little or no correlation across other time periods (r = 0 to r = -.18). Condition C began with little or no correlation (r = .04 to r = -.24), but gave low negative to moderate negative correlations for the last 3 time periods (r = -.31 for 4, r = -.35 for 5, and r = -.58 for 6). Hypothesis 8 was rejected.

Hypothesis 9

There is a relationship between average surface temperature and moisture weight gain at the sixth time period for test conditions B and C.

Using Pearson Correlation, the relationship between the infrared data obtained at the end of exercise and the amount of moisture gained by the prototypes at the end of exercise was examined. There was very little correlation between the two measurements (r = -.29 for B and r = .13 for C). Hypothesis 9 was rejected.

Hypothesis 10

There is a relationship between moisture weight gain and assessment of warmth sensation at the sixth time period for test conditions B and C.

The relationship between moisture weight gain of the prototypes at the end of exercise and the subjective measure of warmth sensation was examined by Pearson

Correlation. Little relationship was observed ($r = -.18$) for Condition B and a moderate negative relationship ($r = -.41$) was observed for Condition C. Hypothesis 10 was rejected.

<u>Hypothesis 11</u>

There is a relationship between moisture weight gain and assessment of wetness sensation at the sixth time period for test conditions B and C.

The relationship between moisture weight gain of the prototypes at the end of exercise and the subjective measure of wetness sensation was examined by Pearson Correlation. A moderate positive relationship was observed for both prototypes ($r = .63$ for B and $r = .42$ for C). Hypothesis 11 was retained.

<u>Hypothesis 12</u>

There is a relationship between moisture weight gain and assessment of overall comfort sensation at the sixth time period for test conditions B and C.

The relationship between moisture weight gain of the prototypes at the end of exercise and the subjective measure of overall comfort sensation was examined by Pearson Correlation. Little relationship was found for the two measurements for either prototype ($r = -.19$ for B and $r = -.34$ for C). Hypothesis 12 was rejected.

Discussion

The primary purpose of this study was to investigate heat and moisture measurements during a wear test of two men's indoor exercise prototypes and compare the results to a man exercising in a partially nude condition. A secondary aspect was to evaluate infrared thermography as a technique for assessing heat flow through garments on a human body.

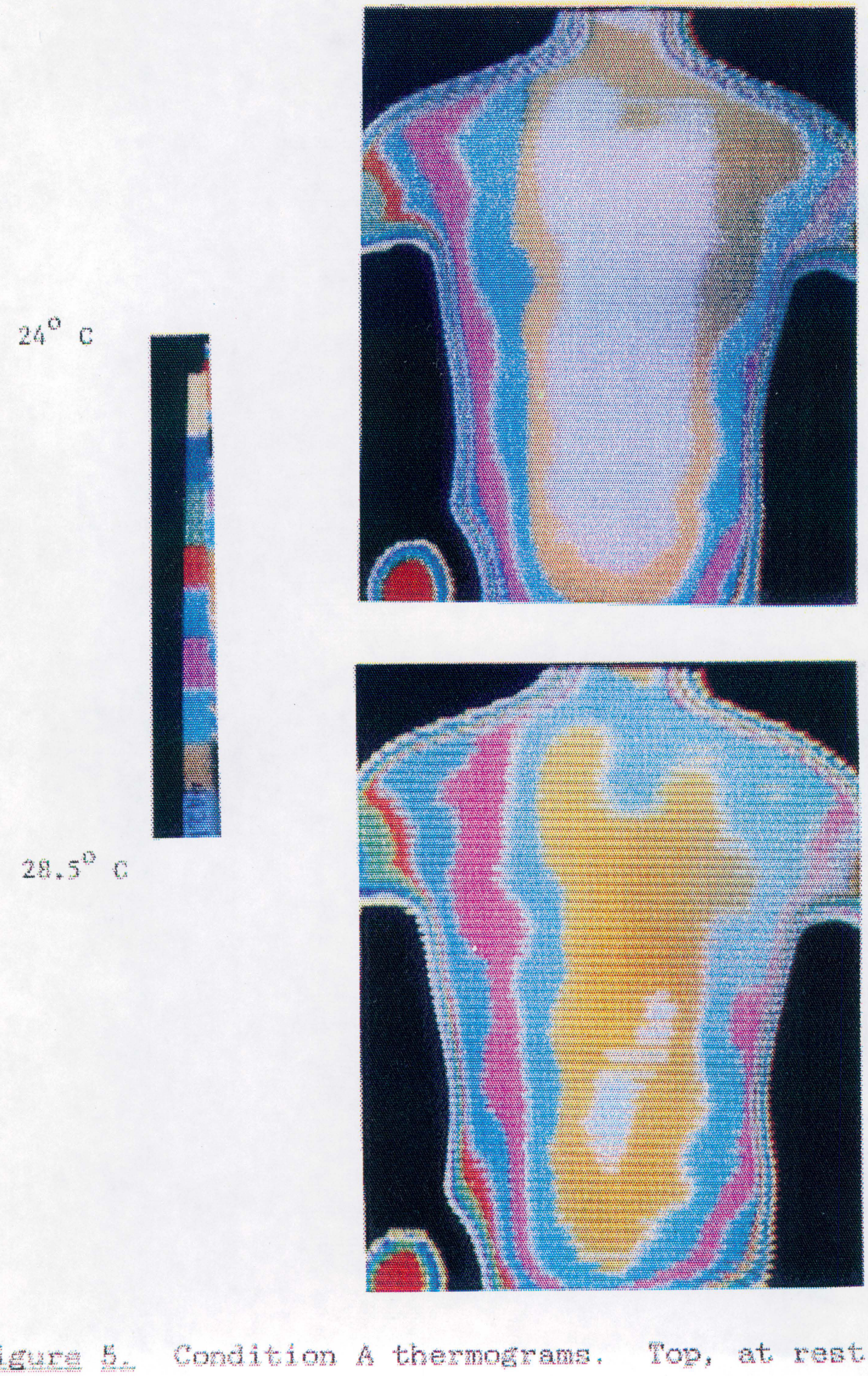
Objective 1

Objective 1 was to determine the prototype which reacts more like the skin in a partially nude condition when worn during exercise.

The infrared camera did provide data that showed differences between the conditions, but the differences were slight and only accepted at a very conservative probability level of 99.9%. When tested in pairs (Condition A with B and Condition A with C) with the Univeriate Analysis of Variance with Repeated Measures procedure for observation of parallel lines, Prototype II (Condition C) was statistically parallel over time to the partially nude condition while Prototype I was not. The difference was small enough so that when Prototype I and Prototype II (Condition B with C) were compared to each other, there was no difference in the reaction over time. The thickness and structure of the two fabrics may have contributed to the differences.

A conclusion made from the data obtained with the infrared camera in this portion of the study involved the range of temperatures among the test conditions. Researchers agree that a layer of fabric over the body will block heat from escaping the skin (Clark & Edholm, 1985; Gonzalez, 1987; Watkins, 1984). This was evident from rest through the exercise and cool down periods. The partially nude scale began at 27.8 ^{o}C while Prototype I began at 23.65 ^{o}C and Prototype II began at 24.55 ^{o}C (Figure 1). This range of temperatures offers another reason for Prototype II (Condition C) to be considered more similar to the partially nude condition. Prototype II did not block as much heat from escaping the body as Prototype I.

A logical outcome from observations and plotting of the data from the infrared camera was the fact that surface temperatures of the exercisers cooled as exercise progressed over time for all test conditions (Figures 1 & 5). A rise in surface temperature was expected. An explanation for this outcome can be that as perspiration began, evaporation cooled the surface temperature. Another explanation can be due to the fact that the back was not a working group of muscles during the testing procedure. Cooling of unused muscle groups and heating of worked muscle groups to maintain thermal balance at the core is a



<u>Figure 5.</u> Condition A thermograms. Top, at rest; bottom, 5 min into exercise.

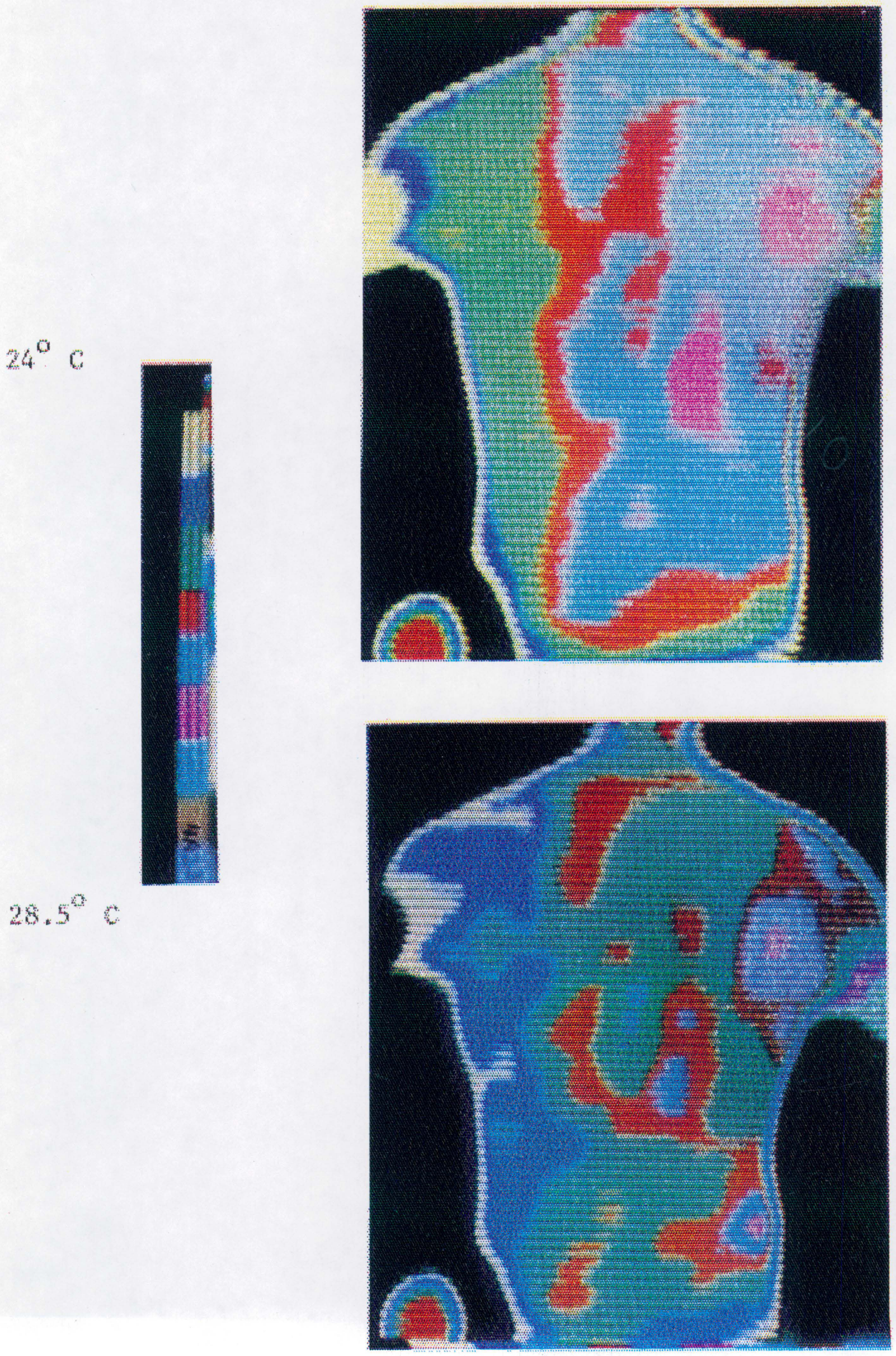


Figure 5 (con't). Condition A thermograms. Top, 15 min into exercise; bottom, 25 min into exercise.

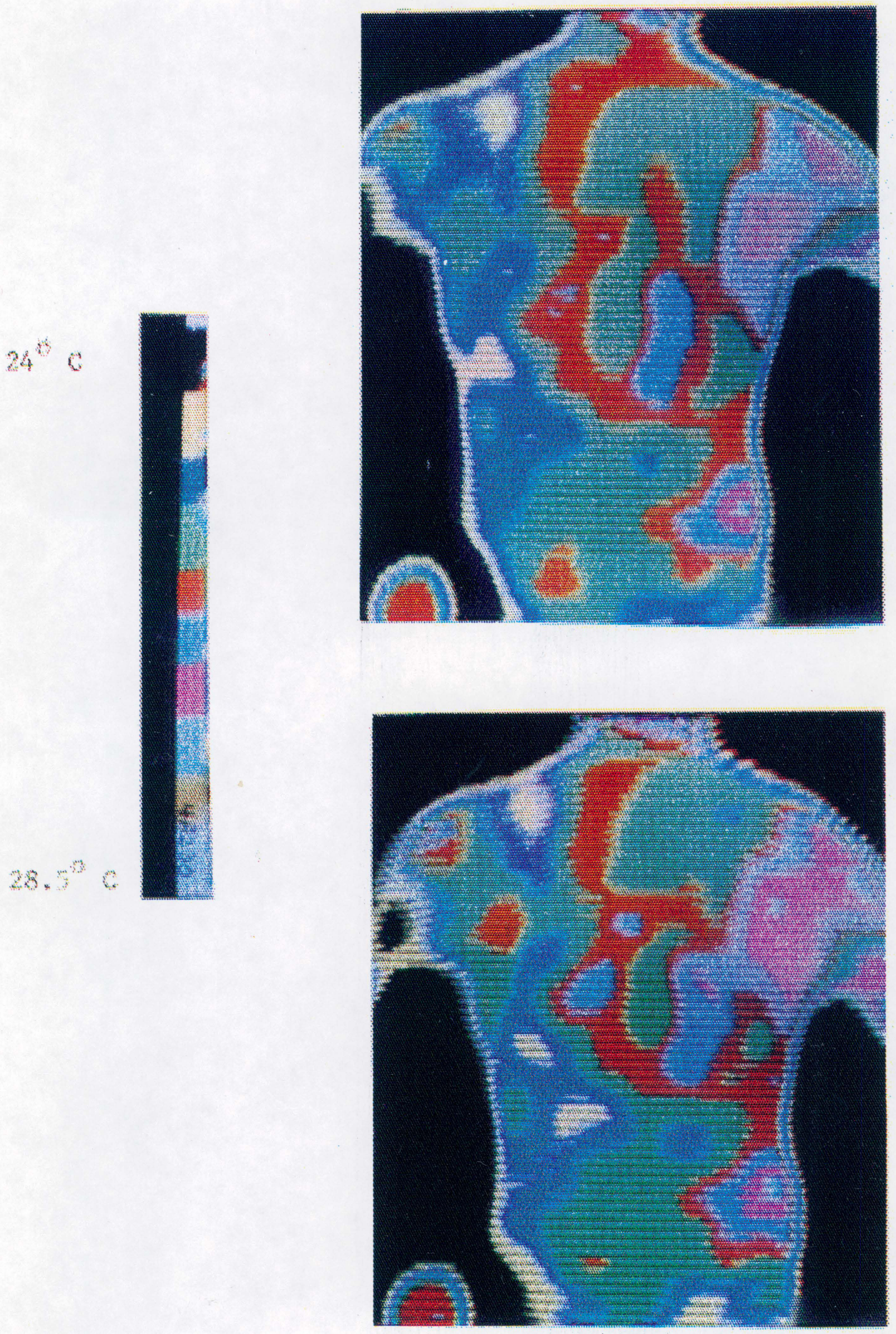


Figure 5 (con't). Condition A thermograms. Top, 30 min into exercise; bottom, 35 min into exercise.

normal physiological process of the body during exercise (Veghte et al., 1979; Wade & Veghte, 1977).

Another outcome from this portion of the study involved the differences in the patterns over time that were shown when the average temperature for each condition and the T-shirt were plotted (Figure 6). Test conditions A, B, and C followed a similar path while the T-shirt made from cotton took a completely different course. The difference in fiber content may be the cause of this outcome. Many fabrics of various structures and fiber contents were tested before the choices were made for the prototypes. Throughout the testing, the main goal was to evolve prototypes that would react as a second skin and not interfere with the body processes as a person exercised indoors while wearing the clothing. The visual data suggest that the polypropylene prototypes were more successful in accomplishing the goals than a T-shirt made out of cotton.

No differences were found in the amount of moisture that the prototypes retained after exercise. From this portion of the study, no conclusion could be made concerning the prototype when worn during exercise which acted more similar to a man exercising in a partially nude condition.

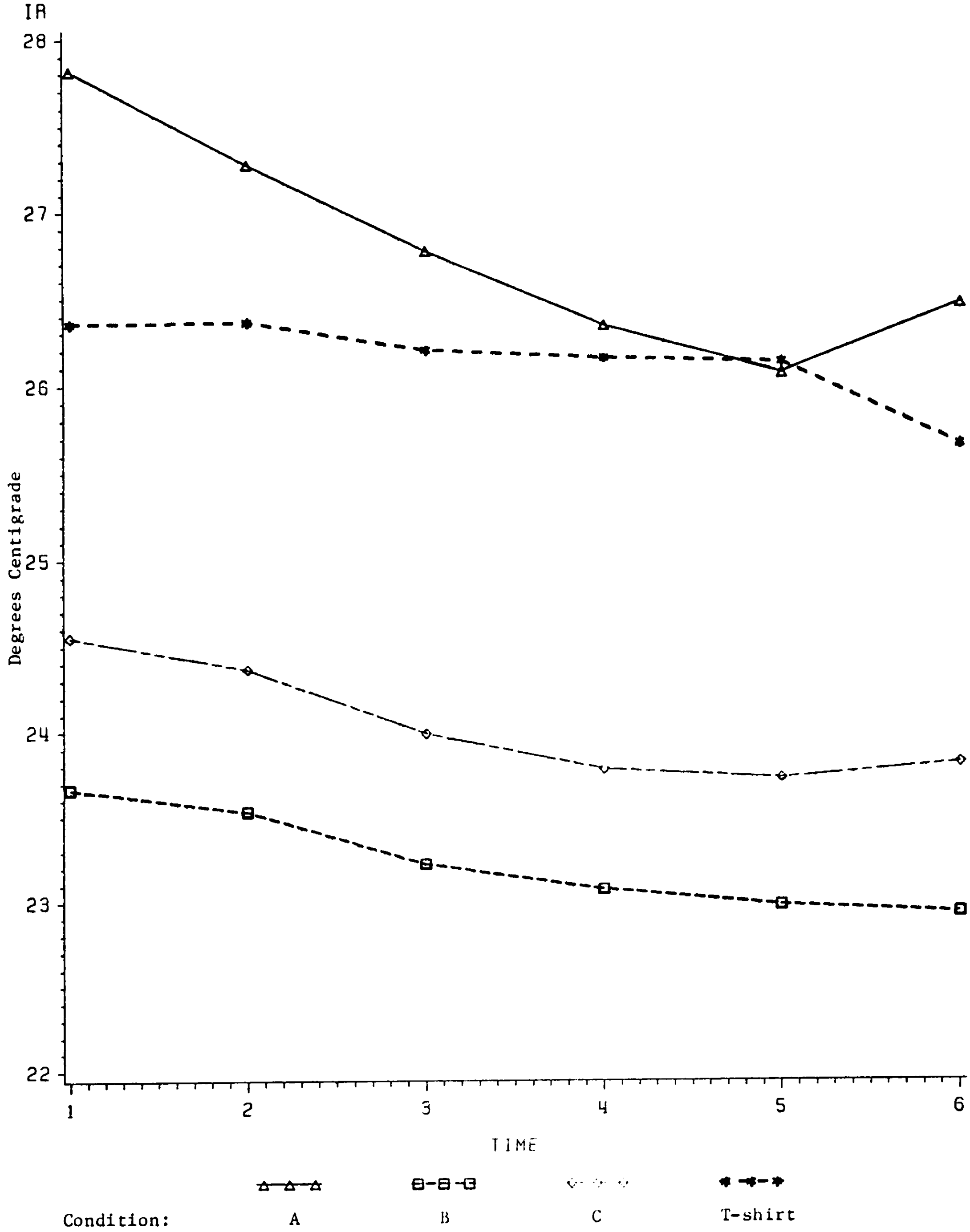


Figure 6. Mean surface temperature over time for all conditions and the T-shirt.

Table 5

<u>Means and Standard Deviations for the Surface Temperatures Over Time for All Conditions and the T-shirt</u>

	Conditions							
	A		B		C		D	
Time Period		S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	27.8	.41	23.7	.46	24.6	.68	26.4	.424
2	27.3	.45	23.5	.37	24.4	.67	26.4	.181
3	26.8	.59	23.2	.42	24.0	.63	26.2	.439
4	26.3	.82	23.1	.37	23.8	.54	26.2	.220
5	26.1	.68	23.0	.37	23.7	.62	26.1	.111
6	26.5	.91	22.9	.26	23.8	.59	25.7	.593

The lack of difference between the prototypes in moisture uptake was interesting because of the differences in thickness, air permeability, and fabric construction of the fabrics used in the garments (Appendix A). For Prototype I (Condition B), the majority of the back was covered by a fabric napped on the side next to the skin, Fabric 1. The back was covered by a thin, extremely air permeable knit with visible holes knit into the structure of the fabric, Fabric 3, for Prototype II (Condition C). Reasons for the lack of difference in moisture uptake may be due to the low temperature of the climate controlled laboratory (69 ^{o}F, 54% RH). The subjects may not have perspired as much as they would have in a warmer climate. Another reason may be due to the fact that both prototypes were made of polypropylene fibers which are known for their ability to move moisture quickly into the atmosphere (Watkins, 1984).

A conclusion made from the thermograms of the moist garments coincides with observations made in a previous study. Veghte et al. (1977) reported that as nude subjects exercised and became wet with perspiration, infrared thermograms took on a mottled appearance. By looking at thermograms of the prototypes that retained the most moisture, this spotted appearance was evident. Figure 5 contains thermograms for observation. The color pattern of the thermograms changes from more concentric areas at rest when dry to a randomly spotted grouping at the end of exercise when wet.

Comparisons of the test conditions for the subjective measures of warmth sensation, wetness sensation, and overall comfort sensation showed no differences. Responses by the subjects for both prototypes were similar to responses given by the subject exercising in the partially nude condition. From this portion of the study, no conclusion could be made concerning the prototype when worn during exercise which acted more similar to a man exercising in a partially nude condition.

A contaminant in the testing procedure may have influenced the results of the analysis of variance for the infrared data. During the partially nude condition (Condition A), sweat pants were worn. More significant results might have occured if the subjects had exercised in the prototype bottoms for Condition A. Theoretically, a better observation might have been made if the subjects had exercised totally nude for Condition A. Practically, a difficult situation would have been created in obtaining and implementing the exercise of male subjects of the specified age group in the totally nude condition.

Objective 2

Objective 2 was to determine the relationship between the infrared measurements and moisture uptake, warmth sensation, wetness sensation, and overall comfort sensation.

Correlations between the infrared measurements and moisture uptake of the garments at the end of exercise showed very little relationship between the two measures.

Correlations between observations with the infrared camera and subjective statements of bodily sensations were inconsistent. A couple of factors may be responsible for this outcome. Active muscles gain heat and inactive muscles cool down during exercise. The subjects exercised on a bicycle ergometer. Higher correlations might have been observed if the camera was focused on the leg of the exerciser which was the working group of muscles in the exercise procedure. Better yet, a full length picture of the subjects front and back would have been desirable. Full length pictures were not possible with the instrumentation used in this study due to the range of view of the camera, but observations of the leg instead of the back could have been made. It is also possible that the infrared camera was not measuring data that would relate to bodily sensations.

Objective 3

Objective 3 was to determine the relationship between moisture uptake and warmth sensation, wetness sensation, and overall comfort sensation.

A relationship was observed between moisture uptake of the prototypes and wetness sensation. This agrees with research done by Morris et al. (1985) on warm-up suits worn during exercise. The fact that a moderate relationship was determined helps to validate the statements given by the subjects. They were reporting sensations that they felt. No relationship was found between moisture uptake of the prototypes and warmth or overall comfort sensation.

It should be noted that the sensation ratings had very little variation, and at some points all the wearers gave the same rating.

Conclusions

The primary purpose of this study was to investigate heat and moisture measurements during a wear test of two men's indoor exercise prototypes and compare the results to a man exercising in a partially nude condition. A trend was shown by the statistical analysis that Prototype II (Condition C) was shown to react more similarly to the partially nude exercising body (Condition A) than Prototype I (Condition B).

A secondary aspect was to evaluate infrared thermography as a technique for assessing heat flow through garments on a human body. From the review of literature, a common practice in a wear test when heat and moisture were being considered was a comparison of the objective and subjective data. This was usually done to determine if the objective instrument (such as thermocouples) was measuring what it was intended to measure (i.e. heat). For this reason, the decision was made to compare the objective data from the infrared camera to the subjective data of bodily sensations. Most methods of measuring heat on the human body give data relating to one point of observation. The thermocouple sensor is less than 1 cm in diameter and reads heat for the point where it is placed. A liquid crystal film strip may measure 1 cm X 5 cm, but heat is observed only where it is placed. For observations with this type of instrumentation, higher correlations between objective and subjective measures may be possible. With the infrared camera, data is collected across the entire subject being observed, and not at one point. The fact that moisture uptake of the garments correlated well with wetness sensation validates the responses given by the subjects. They were reporting the sensations they felt. The fact that readings from the infrared camera did not correlate with bodily sensations suggests that the infrared camera was observing something other than sensations, such as heat transfer properties of various fibers.

Suggestions for Further Research

It is possible that the infrared camera can give valuable information concerning the differing heat flow properties of various fibers and their relationship to the body. A research project which observes garments made from different fiber types in the same yarn, fabric, and garment structure may add to the knowledge already acquired concerning heat flow properties of fibers.

Exploration of the mottled appearance of thermograms of moist or wet objects may provide other reasons for using the infrared camera than for measures of heat. A scale could be developed picturing the changes that occur over time as the surface of the object becomes wet. Once a scale is developed, the infrared camera could aid in determining the point at which perspiration begins on a body or the point at which a garment becomes moist. Since heat transfer properties react in a different manner depending on whether or not the object observed is wet or dry (Spencer-Smith, 1978), a visual scale of spotted thermograms would contain valuable information.

This study took one step forward toward collecting data of heat transfer across the entire subject instead of at one point as previously done with instrumentation such as thermocouples. With the infrared camera, the back of the subject from waist to neck, including arms, was viewed.

Further research could employ infrared instrumentation in which the body is observed from head to foot for wear test observations.

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Appendix A

Prototype Fabrics and Structures

Measures from Laboratory Testing

Measure	Fabrics 1	Fabrics 2	Fabrics 3
Thickness (mm)	1.30	0.59	0.67
Weight (g/m^2)	229.9	221.8	116.4
Bulk Density (kg/m^3)	173.8	378.2	173.0
Air Permeability (ft^3/ft^2 X min)	236.2	212.3	647.6
Absorbency (percent)	12.45	47.92	29.68
Lengthwise Wicking (cm/10 min)	5.88	3.87	3.90
Crosswise Wicking (cm/10 min)	5.13	3.99	3.75

Fiber Content and Fabric Construction

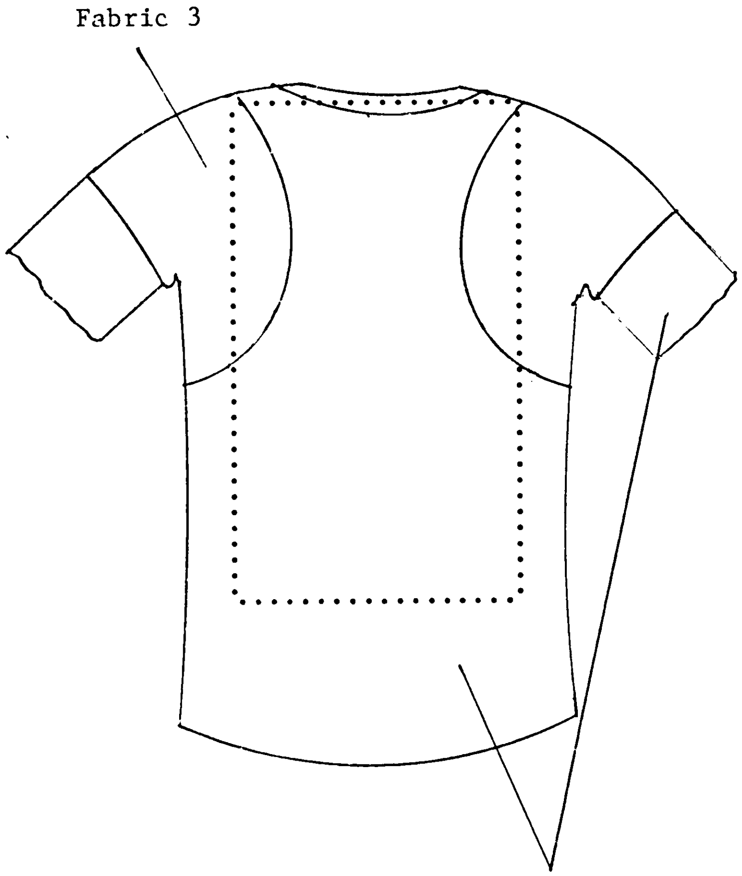
Fabric 1. 100% polypropylene, interlock knit napped on one side.

Fabric 2. 87% polypropylene, 11% Lycra spandex, single jersey knit with tucks producing small holes

Fabric 3. 97% polypropylene, 3% textured polyester, single jersey knit with tucks producing medium holes.

Structures and Fabric Placement

Prototype I (Condition B)

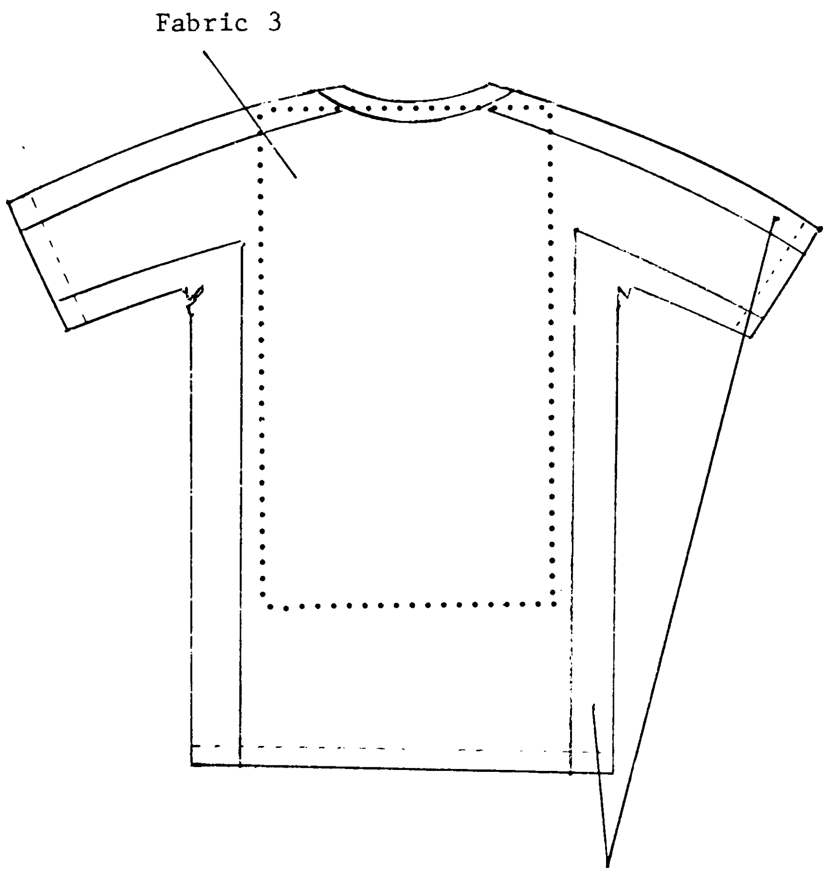


The shirt was worn with skins and shorts.

The dotted area represents the area measured with the digital analyzer.

Structures and Fabric Placement

Prototype II (Condition C)



The shirt was worn with skins and shorts.

The dotted area represents the area measured with the digital analyzer.

Appendix B

Background Information Summary

Name

Height

Weight

Circumference measurements

Chest

Waist at belt line

Full hip

Weekly exercise routine

Phone numbers

Office

Home

Appendix C

Graded Exercise Test Screening Form

Subject

Are you taking any medications?

Have you taken any medication today?

Have you been exercising regularly? (type, frequency, duration)

Have you experienced any problems while exercising? (breathing, chest pain, dizziness, joints aching)

Do you presently have orthopedic problems?

Have you had orthopedic problems in the past or orthopedic surgery performed?

Have you been sick recently? (explain)

Is there anything you wish to tell or ask the physician?

Do you smoke or use tobacco products?

If yes, what type/brand?

If cigarette smoker, average number smoked per day:

number smoked today:

time elapsed since you smoked last:

Physician(s) to whom you wish medical records sent:

M.D. name
Address

Informed Consent for Graded Exercise Test

NAME:

1. Purpose and Explanation of Procedure

I hereby consent to voluntarily engage in an exercise test to determine my circulatory and respiratory fitness. It is my understanding that the information obtained will help me evaluate future physical fitness and sports activities in which I may engage.

Before I undergo the test, I certify that I am in good health and have had a physical examination conducted by a licensed medical physician within the last month. Further, I have completed the pre-test history interview presented to me by the program staff and have provided correct responses to the questions as indicated on the history form or as supplied to the interviewer. It is my understanding that I will be interviewed by a program staff member person prior to my undergoing the test, who will in the course of interviewing me determine if there are any reasons which would make it undesireable or unsafe for me to take the test. Consequently, I understand that it is important that I provide complete and accurate responses to the interviewer and recognize that my failure to do so could lead to possible unnecessary injury to myself during the test.

The test which I will undergo will be performed on a bicycle ergometer with the amount of effort gradually increasing. As I understand it, this increase in effort will continue until I verbally report to the operator any symptoms such as fatigue, shortness of breath or chest discomfort which may appear. It is my understanding and I have been clearly advised that it is my right to request that a test be stopped at any point if I feel unusual discomfort or fatigue. I have been advised that I should immediately upon experiencing any such symptoms or if I so choose, inform the operator that I wish to stop the test at that or any other point. My stated wishes in this regard shall be carried out.

It is further my understanding that prior to beginning the test, I will be connected by electrodes and cables to an electrocardiographic recorder which will enable the program personnel to monitor my cardiac (heart) activity. During the test itself, it is my understanding that a trained observer will monitor my responses continuously and take frequent readings of blood pressure, the electrocardiogram and my expressed feelings of effort. I realize that a true determination of my exercise capicity depends on progressing the test to the point of 85% of my predicted maximum heart rate.

2. Risks

It is my understanding and I have been informed that there exists the possibility during exercise of adverse changes during the actual test. I have been informed that these changes could include abnormal blood pressure, fainting, disorders of heart rhythm, and very rare instances of heart attack. Every effort, I have been told, will be made to minimize these occurrences by preliminary examination and by precautions and observations taken during the test. I have also been informed that emergency equipment and personnel are readily available to deal with unusual situations should these occur. I understand that there is a risk of injury or heart attack as a result of my performance of this test but knowing those risks, it is my desire to proceed to take the test as herein indicated.

3. Benefits to be Expected and Alternatives Available to the Exercise Testing Procedure

The results of this test may or may not benefit me. Potential benefits relate mainly to my personal motives for taking the test, i.e., knowing my exercise capacity in relation to the general population, understanding my fitness for certain sports and recreational activities, planning my physical conditioning program or evaluating the effects of my recent physical activity habits. Although my fitness might also be evaluated by alternative means, e.g., a bench step test or an outdoor running test, such tests do not provide as accurate a fitness assessment as the treadmill or bike test nor do those options allow equally effective monitoring of my responses.

4. Confidentiality and Use of Information

I have been informed that the information which is obtained in this exercise program will be treated as privileged and confidential and will consequently not be released or revealed to any person without my express written consent. I do however agree to the use of any information which is not personally identifiable with me for research statistical purposes so long as same does not identifty my person or provide facts which could lead to my identificaion.

5. Inquiries and Freedom of Consent

I have been given an opportunity to ask certain questions as to the procedures of this program. Generally these requests which have been noted by the interviewing staff member and his/her responses are as follows:

6. Program personnel notes and observations as to conduct of the informed consent procedure:

7. Release

In consideration of my participation in this program, I hereby release, hold harmless and indemnify Virginia Polytechnic Institute and State University, and its agents, officers and employees from any and all liability or responsibility for any injury, illness or other similar occurrences, including heart attack or its resultant complications which might arise out of my participation in this program.

Patient name (print)

Patient signature Date

Staff name (print)

Staff signature Date

Graded Exercise Test

Attending Physician Evaluation

Subject

Rest ECG: interpret:

Rest BP: interpret:

Comments:

This subject may continue with the graded exercise evaluation.

attending M.D.:

Exer ECG: interpret:

Exer BP: interpret:

Post-exer ECG: interpret:

Post-exer BP: interpret:

NYHA Functional Class: IV (2), III (3-4), II (5-6),

I (>7) True METS

Conclusion:

Upper safe functional level: Max HR b min

THR =

Attending M.D.:

Graded Exercise Test

Name: age: date:

HR @ rest sitting: BP @ rest sitting: Weight:

EXERCISE MEASURES

METS	WORKLOAD	MIN	HR		SYS/DYS	RPE	SYMPTOMS
				1			
				2			
				3			
				4			
				5			
				6			

Technician signature:

Appendix D

Subjective Rating Scales

<u>Warmth Sensation</u>

1. Cold
2.
3.
4. Neutral
5.
6.
7. Hot

<u>Wetness Sensation</u>

1. Dry
2.
3.
4. Neutral
5.
6.
7. Wet

<u>Overall Comfort Sensation</u>

1. Comfortable
2.
3.
4. Neutral
5.
6.
7. Uncomfortable

Appendix E

Weight Measures during Exercise

Subject: Date:

Prototype:

Subject weight before exercise:

Subject weight after exercise:

Total weight loss of subject:

Prototype weight before exercise:

Prototype weight after exercise:

Total weight gain of prototype:

Accessories weight before exercise:

Accessories weight after exercise:

Total weight gain of accessories:

Appendix F

Heart Rate and Sensations during Exercise

Subject: Date:

Prototype:

	Heart Rate	Warm	Wet	Overall
rest				
5 min				
10 min				
15 min				
20 min				
25 min				
30 min				
35 min				

Appendix G

Program to Link Numonics Analyzer
to the Personal Computer

```
20 OPTION BASE 0
30 DIM K$(10): DIM T(10): DIM A(10) : DIMB$(10)
40 DATA BLACK,YELLOW,ROYAL BLUE,GREEN,RED,SKY BLUE,PINK,
    AQUA,GOLD,WHITE
45 DATA B,Y,RB,GR,R,SB,P,A,G,W
50 DATA 22,22.5,23,23.5,24,24.5,25,25.5,26,26.5
60 FOR I=0 TO 9
70 READ K$(I)
71 NEXT I
72 FOR I=0 TO 9
73 READ B$(I)
80 NEXT I
90 FOR J=0 TO 9
100 READ T(J)
110 NEXT J
120 REM initialize the com port
130 OPEN "com1:9600,e,7,,cs,ds,cd" AS#1
140 CLS
150 INPUT "ENTER THE DRAWINT NUMBER OR  Q  TO QUIT NOW",D$
160 IF D$="Q", THEN GOTO 720
170 CLS: PRINT "DRAWING; ",D$
175 LPRINT "                        DRAWING: ",D$:LPRINT
180 FOR J=0 TO 9
190 1(J)=0
200 NEXT J
210 CLS
230 INPUT "ENTER A COLOR OR 'Q' TO QUIT NOW    ",C$
240 REM
250 REM USER CAN ENTER Q TO FINISH THIS COLOR & DO
     TOTALLING (3000)
260 IF C$="Q" THEN LPRINT:GOSUB 480: LPRINT CHR$(12):
     GOTO140
270 REM
280 REM - CHECK COLOR AGAINST B$() AND DETERMINE ARRAY #
290 I=0: GOSUB 430
300 REM
310 IF I=10 GOTO 210
320 LPRINT "         "+K$(I):S=0
330 PRINT "WAITING FOR INPUT"
340 LINE INPUT #1,L$
350 REM PRINT "TYPE SOME VALUE": INPUT L$
360 IF VAL(L$)<>0 THEN LPRINT L$
370 IF VAL(L$)=0 THEN A(I)=S
380 IF VAL(L$)=0 THEN LPRINT "   "+K$(I)+ " totals:
```

```
    "+STR$(S)
385 IF VAL(L$)=0 THEN LPRINT: GOTO 210
390 S=S+VAL(L$)
400 GOTO 330
410 REM
420 REM subroutine from 210 to check color name (2000)
430 WHILE (B$(I)<>C$ AND I<10)
440 I = I + 1
450 WEND
460 RETURN
470 REM
480 REM SUBROUTINE FOR TOTALLING (3000)
490 R=0
500 FOR K=0 TO 9
510 R=R+A(K)
520 NEXT K
540 Z=0
550 FOR K=0 TO 9
560 IF A(K)=0 GOTO 680
570 IF MID$(D$,2,1)="A" GOTO 630
580 LPRINT K$(K) + " TEMP.= " + STR$(T(K)) + "  TOTAL AREA:
    "+STR$(A(K))
590 LPRINT "FRACTION = "+STR$(A(K)/R)+"    x TEMP = "+STR$
    ((A(K)/R)*T(K) )
610 Z=Z+(A(K)/R)*T(K)
620 GOTO 680
630 REM
640 LPRINT K$(K)+" TEMP.= "+STR$(T(K)+2)+"  TOTAL AREA:
    "+STR$(A(K))
650 LPRINT "FRACTION = "+STR$(A(K)/R)+"   xTEMP = "+STR$
    ((A(K)/R)*(T(K)+2))
670 Z=Z+(A(K)/R)*(T(K)+2)
680 NEXT K
685 LPRINT: LPRINT "TOTAL AREA= "+STR$(R)
690 LPRINT : LPRINT "SUM OF (FRACTION x TEMP)= ",STR$(Z)
700 RETURN
710 REM
720 END
```

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