ABSTRACT

Title of Proposal:	**THE EFFECT OF INSPIRATORY AIR HUMIDITY AND TEMPERATURE ON PERFORMANCE TIME WHILE WEARING A RESPIRATOR**
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Respirators are worn in only about 20-30% of the appropriate circumstances. This research examined the effect of inspired air conditions on performance time. An environmental chamber supplied air at 27°C, 28°C, 37°C, and 55°C to a powered air-purifying respirator (PAPR) worn by the subject while exercising in a neutral environment. A mathematical model of performance time as a function of the heat index (HI), respirator familiarity (RF), personality type (SN), and minute volume (V_e) indicated that performance time increased with a decrease in HI and V_e and with an increase in RF and SN ratio. A model of performance time as function of user acceptability and the heat index indicated that time to reach a level of "fairly uncomfortable" decreased exponentially from 5.34 minutes to 2.85 minutes with an increase in the heat index. Performance at the heat index conditions may be described by physiological, subjective, and individual characteristics.

THE EFFECT OF INSPIRATORY AIR HUMIDITY AND TEMPERATURE ON PERFORMANCE TIME WHILE WEARING A RESPIRATOR

By

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Dedication

To JR and Grace

Acknowledgements

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List of Symbols

A - Acceptability
BACS – Breathing Apparatus Comfort Scale
BTPS – Body Temperature and Pressure Saturated
C_1 – y-intercept
C_2 – x-intercept
C_3 – scale parameter
C_4 – shape parameter
CLQ – Claustrophobia Questionnaire
EI – Extroversion/Introversion parameter
ECG – Electrocardiogram
F – calibration form parameter
F_i – factors that influence output variable O
FT – Facial thermal scale
HI – Heat Index
H_n - normalized half width
HRmax– maximal heart rate (beats/min)
HSI_{BH} - Heat Stress Index of Belding and Hatch
FT – Facial Thermal Scale
IRB – Institutional Review Board
JP – Judging/Perceiving parameter
MBTI- Myers-Briggs Type Inventory
n – sample size
O_0 – value of O at F_i
OT – Overall Thermal Scale
PAPR – Powered Air-purifying Respirator
PERQ – Perceived Effort and Reward Questionnaire
PT – Performance time
R – correlation coefficient
RF- Respirator Familiarity
RH – Relative Humidity
RI – Reference Index
RS – Relative Strain Index
RPE – Rating of Perceived Exertion
R_s – relative sensitivity
SCBA – Self contained breathing apparatus
S_e – standard error of the estimate
SN – Sensing/Intuition parameter
S_y – standard deviation of the criterion variable
TF – Thinking/Feeling parameter
$t_{\alpha/2}$ - t statistic at designated alpha
ν - degrees of freedom
V_e – Minute ventilation (L/min)
V_t – Tidal volume (L/min)
VO_2– Oxygen consumption (ml/kg)

VO_2max - Maximal oxygen consumption (ml/kg)
WBGT – Wet Bulb Globe Temperature (°C)
WGT – Wet Globe Temperature (°C)
$\overline{Y_i}$ -ith predicted value of criterion variable
Y_i - ith measured value of Y
YSI – Yellow Springs International

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Chapter 1: Justification

Respirators are worn in the workplace in order to protect the individual from toxic airborne substances; however, respirators are worn in only about 20-30% (Harber et al., 1991; Nielsen et al., 1987; Gwosdow et al., 1989; DuBois et al., 1990) of the appropriate circumstances due to several factors, such as ventilation, work limitation, subject discomfort, psychological effects, thermal loading, and cardiovascular changes. The focus of this research study will be on two of these factors: subject discomfort and thermal loading.

High facial skin temperature is a major source of discomfort while wearing a respirator and the most common way to alleviate this discomfort is to remove the mask, although most working conditions do not permit this to occur (Johnson et al., 1997). Firefighters, mine workers, toxic chemical disposal crews, and other persons who require the use of respirators at work are subjected to various ambient conditions that elicit a physiological response. This physiological response may impact performance and, ultimately, the quality of work produced.

According to several studies, facial skin temperature increases about 1-2ºC while wearing a respirator during resting conditions (Johnson et al., 1997; Fox and DuBois, 1993; DuBois et al., 1990). During the stressful situations that require the use of a respirator, these thermal effects are exaggerated, which makes it difficult for the wearer to determine their limitations; hence, performance is affected. Previous studies have focused primarily on the ambient conditions as a predictor of user acceptability. While this information is important, it is necessary to determine how this acceptability correlates to performance time.

This study focused on determining a correlation between combinations of humidity and temperature based on the National Weather Service Heat Index (HI) on performance time at a moderate work rate under various simulated inspiratory air temperatures and humidities. Other physiological parameters such as rectal temperature, facial skin temperature, and user acceptability were evaluated under warm environmental conditions. The temperature and humidity conditions necessary for thermal comfort and optimal performance while wearing a respirator were unknown; these relationships will help to facilitate improved respirator design.

Respirators have been studied extensively due to the technical features that impair work performance. A model developed to determine the relationship between inspired air conditions and performance time will provide a useful tool for respirator users. This information will enable an employer to determine where optimum performance is achieved under various warm ambient conditions. Employers will know how long an employee can perform safely according to both physiological and psychological factors. Furthermore, manufacturers may consider upgrading respirator equipment by providing the respirator wearer with a supply of fresh air kept at the most favorable ambient conditions, or design the inner surfaces of the respirator such that they absorb heat from the skin. Ultimately, respirator users will benefit due to increased comfort, easier breathing, and improved work efficiency.

Chapter 2: Literature Review

The following sections detail the known physiological responses to air temperature and humidity levels, as well as the effect of respirators on thermal discomfort and performance. Studies conducted on the effects of ambient conditions on user acceptability are discussed. Work rates discussed are represented as a percentage of VO_2max, which is defined as an individual's maximal aerobic capacity. The method for determining VO_2max is discussed in section 4.1.4.

2.1 <u>Physiological Response to Temperature and Humidity</u>

2.1.1. Evaporation

The primary means for heat dissipation during exercise is evaporation via sweat. This process accounts for about 80% of the total heat loss from a person's body during exercise. Under resting conditions, 20% of the body's total heat loss is due to evaporation (Wilmore and Costill, 2004). During exercise, the body's metabolic activity increases, blood flow increases, and the heart rate increases. Consequently, skin temperature increases, creating a positive temperature gradient with the surrounding air. When the surrounding air is unsaturated, evaporation occurs and heat is dissipated from the body. When the surrounding air is warm and humid, problems arise that create a smaller gradient for evaporation to occur, which inhibits adequate heat loss from the body.

2.1.2. Humidity Effects on Heat Loss

Humidity levels affect evaporation as well as the body's perception of thermal stress. When the air is humid, the air contains water molecules that decrease its capacity to accept more water due to the decrease in the concentration gradient. Thus, when a person is participating in vigorous activity in humid conditions, evaporation is greatly reduced. Low humidity results in a higher concentration gradient, and evaporation is maximized; however, if sweat is not produced in direct correlation with the evaporation of water from the skin, the skin may dry out. Thermal stress is often times associated with a person's psychological state, and the discernment of thermal stress may change with a change in the environmental conditions (Wilmore and Costill, 2004).

2.2 Heat Exchange in Respirators

Heat exchange at the face occurs through radiation, conduction, convection, and evaporation. While wearing a respirator, radiation, convection, and evaporation are inhibited. High facial skin temperature is a source of discomfort while wearing respiratory protective devices, as reported in several studies. The comfort levels at rest and during exercise are 34.5°C and 31°C, respectively (Fox and DuBois, 1993). Above these facial skin temperatures, the respirator user reported increasing mask discomfort.

The rate of radiation is approximately proportional to the temperature difference between the skin and the inner wall of the respirator face piece, though radiation inside the face piece is negligible. Evaporation through the wall of the respirator is minimal, at best. As for conduction and convection, heat is transferred through hot air from the lungs and bronchi to the skin; however, much of this heat is captured inside the mask and is unable to move through the respirator to the environment. Some heat is carried outside the mask with exhaled air (Fox and DuBois, 1993).

Although respirators have expiratory valves, expired air does not leave the mask without mixing in the mask and transferring heat to the mask wall under warm environmental conditions. If air left with minimal resistance, little residual heat would be left inside the mask. This is not the case, however, because the expired air does not form a narrow channel through the expiratory valve. The pressure required to open the valve broadens the air stream, re-circulating some of the expired air throughout the mask (Fox and DuBois, 1993). Consequently, heat builds up on the face and the person begins to sweat, which causes discomfort. These effects are exaggerated with increased exercise and heat stress.

2.3. Effect of Clothing and Respiratory Protection on Heat Exchange

In order to gain a greater perspective on thermal effects during exercise, several studies were consulted regarding the effects of heat stress while wearing protective clothing. Clothing effectively inhibits performance in hot, humid conditions by limiting heat exchange from the body to the surrounding air. Impermeable clothing inhibits effective cooling from the body so the head becomes a critical site for heat loss (James et al., 1984); however, wearing a respirator limits heat exchange from the face. Consequently, the effect of the clothing and the respirator limit total body heat loss, which increases discomfort, affecting an individual's work performance.

Clothing adds work by increasing the metabolic cost of performance by adding weight and restricting movement. In a study conducted by Nunneley (1989), results showed that clothing inhibited evaporation by creating a humid environment and inducing thermal strain. In a study conducted by Payne et al. (1994), the relationship between heat production and heat dissipation when wearing protective clothing that inhibited evaporation contributed to a rise in mean skin temperature. White et al. (1989) concluded that wearing protective clothing and respirators induced dangerous thermoregulatory stress to the subject at low intensities of exercise in a neutral environment.

In general, the combination of protective clothing and respiratory equipment results in a decrement in performance compared to the unencumbered individual. In most industrial settings where respiratory protection must be worn, impermeable clothing may be required as well. The combination of the two causes an increase in heart rate and core body temperature; these effects are often accompanied by a decrease in performance (White et al, 1989;White and Hodous, 1987; James et al., 1984).

In a study conducted by White et al. (1989), two ensembles were worn with a Self Contained Breathing Apparatus (SCBA). The first consisted of light work clothing, and the second consisted of a two piece chemical protective suit. Work was performed at low intensity (23% VO_2max) under three warm environmental conditions (10.6°C, 22.6°C, and 34°C). Overall, it was concluded that in regards to rectal temperature, differences in the clothing ensemble were not significant, but the effect of thermal environment was significant. High rectal temperature (>39.0°C) was a parameter used to assess the subject's ability to continue work. Once an individual's rectal temperature exceeded this value, work was terminated. Furthermore, the thermal gradient of rectal temperature minus mean skin temperature was almost reduced to zero while wearing the chemical protective suit under hot conditions. This was determined as a critical factor in an individual's ability to tolerate heat. In a study conducted by White and Hodous (1987) the use of a SCBA and impermeable clothing resulted in a decrease of exercise tolerance time by as much as 95.6%. Tolerance time is a parameter defined by White et al. (1989) as the time required to achieve one of the following criteria: 1) 90% of maximum heart rate, 2) rectal temperature of 39.0°C, 3) skin temperature equaling or exceeding rectal temperature, or 4) objective or subjective sign of severe discomfort or fatigue (dizziness, nausea, etc.).

2.4 Temperature and Humidity as Determinants of User Acceptability

The effects of temperature and humidity as predictors of performance time have not been extensively studied; however, user acceptability of respirators according to these variables has been the topic of several studies, some of which are discussed below.

Nielsen et al. (1987) studied six subjects, all dressed similarly, in various ambient air temperatures, mask air temperatures, and air humidities inside the mask to determine user acceptability during exercise. The subjects exercised for 15 minutes on a cycle ergometer at different combinations of ambient air temperatures (7ºC, 16ºC, 25ºC), mask air temperatures (22ºC, 27ºC, 33ºC), and mask air humidities (61% and 86%). Skin temperature, heart rate, and skin wettedness were monitored during testing. Thermocouples were placed on the skin of the upper lip and on the cheek, and electrocardiogram (ECG) electrodes were fixed to the chest to monitor heart rate. User rating scales were used to assess acceptability of the mask and whole body conditions.

The results of the study found that a significant interaction existed between the combined lip temperature and mask acceptability. A significant interaction also existed between mean facial skin temperature and mask acceptability. A high facial skin temperature decreased the acceptability of the mask. Furthermore, low and high (22ºC and 33ºC, respectively) mask air temperatures resulted in low acceptability, whereas moderate mask air temperatures (27°C and 30°C) were acceptable. Mask acceptability was considerably lower when the mask air was warm and humid than when it was warm and dry. As expected, a higher mask air temperature resulted in a higher lip temperature when the mask air was humid compared to being dry.

Gwosdow et al. (1989) reported the effects of thermal discomfort on acceptability of respirators at rest under different combinations of ambient air temperatures (25ºC, 30ºC, 35ºC), mask air temperatures (27ºC, 30ºC, 33ºC), and mask air humidities (47% and 73%) via use of the climate box shown in Figure 2-1. A half-mask respirator was used that covered the mouth, nose, and part of the cheeks. The skin temperature was recorded with thermocouples on the forehead, upper lip, and cheek. Ratings of discomfort, thermal sensation, acceptability, and difficulty breathing were recorded during testing.

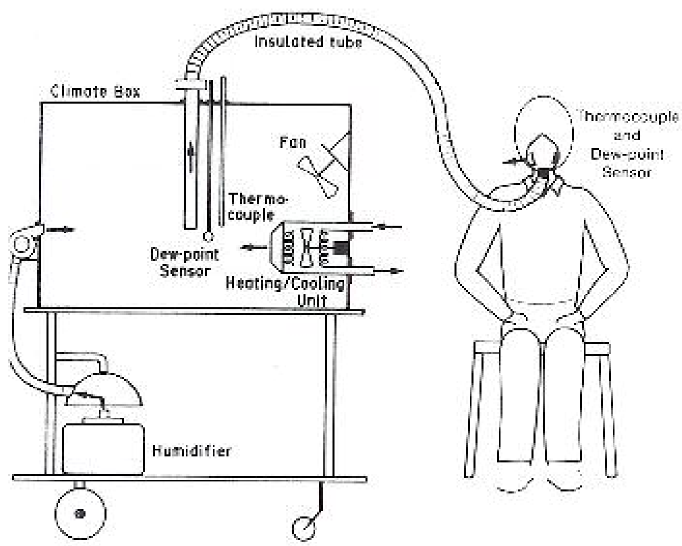

Figure 2-1. Diagram of the climate box used by Nielson et al. (1987), and Gwosdow et al. (1989).

The results of the study indicated that the face, in particular the cheeks and forehead, are the regions most sensitive to warm stimuli. The relationships between acceptability, discomfort, and thermal sensation versus lip temperature were the basis for this study. According to the results, respirator discomfort and thermal sensation of the face increased with an increase in lip temperature. Furthermore, acceptability decreased with an increase in lip temperature, especially above a lip skin temperature of 34.5ºC. The acceptability of a respirator was dependent on mask air temperature and humidity. Air temperatures of 27ºC and 30ºC with either of the two humidity conditions were always 100% acceptable regardless of room conditions. At room temperatures of 25ºC and 30ºC, the acceptability of the respirator decreased for a mask air temperature of 33ºC or above. Similarly, with 73% humidity, a mask air temperature of 33ºC or above had a lower acceptability than with 47% humidity. Subjective responses of respirator thermal sensation, discomfort, and acceptability correlated ($p<0.05$) to lip skin temperature.

DuBois et al. (1990) reported results similar to the previous studies mentioned. The study measured facial discomfort as a function of facial skin temperature while using respirators that utilized tidal breathing rather than continuous airflow. In respirators that utilize tidal breathing, heat and water vapor delivered by expired air contribute to the sense of increased temperature and humidity of the face. Skin temperature was recorded via a thermocouple attached to the left nasolabial fold inside the mask, and a rating scale was used to record subject discomfort levels. In this study, the subjects remained at rest.

The results of the study indicated that skin temperature of the face increased within a few minutes of putting on the mask. Furthermore, discomfort was correlated with an increase in skin temperature. As the skin temperature increased by 2.0ºC, discomfort increased 1 unit.

Similar to the previous study, Fox and DuBois (1993) studied the effect of evaporative cooling of respirators on skin temperature and overall thermal sensation and comfort. Resting subjects with lip skin temperatures of 34ºC or less reported that the mask conditions were comfortable and almost 100% acceptable. The study by Fox and DuBois (1993) reported results indicating that a high facial skin temperature (above 31°C) is a major source of discomfort.

Two masks were used by Fox and DuBois (1993): an aluminum mask with inspiratory and expiratory valves and a modified Scott model 66 twin-cartridge respirator. The facial skin temperature was measured with a thermocouple attached to the nasolabial fold inside the mask. The subjects were measured at rest and during submaximal exercise. The major results from this study indicated that the threshold for the comfort zone of skin temperature inside the mask for resting subjects began at a lip temperature of 34.5ºC, and at about 31ºC for exercising subjects.

Laird et al. (2002) considered the effects of wearing a respirator on heart rate, and facial skin temperature on user acceptability. The study conducted was two-fold: a laboratory study and a workplace study. In the laboratory study, a standard filter respirator was worn for the first 15 minutes of exercise in the first session, and in the second session, the respirator was worn for only the second half of the exercise. The respirator covered the mouth and nose only, and the facial skin temperature was recorded via bead thermistors positioned on the cheek and upper lip. In the workplace study, subjects were asked to simulate their work tasks without a respirator, and then asked to carry out the tasks while wearing the respirator.

In the laboratory study, the mean temperature of the lip decreased when the respirator was removed and increased when the respirator was put on. Wearing the respirator did not have a significant effect on heart rate or on the temperature of the cheek.

Selkirk et al. (2004) recently studied the limits of firefighters in warm and humid environments. The relationship between tolerance time to the work while wearing a respirator and work rate at three different environmental temperatures (25ºC, 30ºC, 35ºC at 50% humidity) while wearing protective clothing was the main focus of the study. The results showed that tolerance time decreased in response to an increase in temperature regardless of the work rate.

2.5. Sensitivity of the face in response to temperature and humidity

In many industrial situations, workers are required to wear protective clothing, which effectively inhibits evaporation from the body, so the head becomes the primary outlet for heat escape. In many situations where protective clothing is required, a respirator may also be required. In this case, evaporation from the face is repressed, forcing heat to build up in the body. White et al (1991) indicated that the most common cause of discomfort while wearing respiratory protection was excessive heat inside the devices. According to Gwosdow et al. (1989), these thermal conditions may often lead to subjective fatigue and an increase in the number of mental errors. Preliminary research in our lab indicates that out of 165 surveyed respirator users, more than 40% indicated the most common reason for removing the respirator or not wearing it at all is that the respirator caused them to become too hot and sweaty (unpublished results).

The heat flux per unit area of the bare face, 104 W/m^2, is double that of the rest of the body, which is about 50 W/m^2 (DuBois et al., 1990). While wearing a respirator, the heat flux diminishes, causing an increase in temperature of the skin under the mask (DuBois et al., 1990). Whereas the mechanism for discomfort is unknown, it is acknowledged to be a function of facial skin temperature, and may be caused by thermal sensation, sweating and hydration, condensation of expired air, or cutaneous blood flow (Gwosdow et al., 1989; DuBois et al, 1990; Nielsen et al., 1987).

Under normal conditions, the whole body thermal sensation is proportional to the area-weighted mean skin temperature; the findings by Gwosdow et al (1989) indicated that this relationship changed when thermal conditions inside the respirator changed. For example, at a room air temperature considered neutral (25°C), increasing the respirator thermal conditions (temperature and humidity) changed the whole body thermal sensation from neutral to warm. Nielsen et al. (1987) reported similar findings. According to Nielsen et al. (1987), the use of different air temperatures in the mask compared to the ambient air produces local thermal stimuli to the skin surface beneath the mask, changing both the heat exchange from the skin surface to the air inside the mask and the heat exchange from the skin area under the edges of the mask.

2.6. Breathing effects due to environmental conditions

In a study conducted by Louhevaara et al. (1984), the effects of three different respirators on pulmonary ventilation, oxygen consumption, and heart rate were examined during rest, submaximal work, and recovery in well-trained young healthy men. The conclusions of the study indicated that the dead space within the respirator increased the concentration of carbon dioxide in the inspired air, stimulating an additional effort in breathing, which subsequently increased oxygen consumption and heart rate. However, according to Johnson et al. (2003), air-purifying respirator use under a variety of work conditions did not stress the cardiovascular system. Thus, this phenomenon can be readily disputed.

In the studies discussed in the previous section conducted by Nielsen et al. (1987) and Gwosdow et al. (1989), the results indicated that local thermal strain interfered with respiratory heat exchange. The perceived work of breathing became more difficult as the heat content of the inspired air increased. This was the case for only the conditions in which a mask was worn, and breathing was most difficult in the condition where the mask air was humid.

Lekeux (1988) studied the effect of environmental conditions on the breathing pattern of ponies. The ambient temperature and humidity varied only according to the daily environmental conditions. Temperature and humidity were recorded prior to exercise and combined together to form a unitless measurement of the environmental condition. Measurements less than 85 indicated cold and dry conditions, while measurements greater than 85 indicated warm and humid conditions. The results of the study indicated that the conditions did increase the frequency of breathing. Turner et al. (1992) performed a similar experiment on human subjects. The results of Lekeux (1988) indicated that the frequency of breathing decreased in the cool, dry conditions, and tidal volume increased in the warm, humid conditions. The increase in tidal volume likely contributed to an increase in minute ventilation.

Johnson et al. (2005) performed a study to determine peak inhalation flow rates during strenuous exercise. Flow rates were measured at 80-85% VO_2max without a respirator, with a powered air-purifying respirator (PAPR) and at the conclusion of the VO_2max test without a respirator. Major conclusions of the study indicated peak flow rates of up to 359 L/min (BTPS) for both respirator conditions, with flow rates for the

PAPR exceeding breathing flow rates. Furthermore, peak flow rates of up to 579 L/min (BTPS) were observed at 100% VO_2max.

2.7. Heat Stress Indices

Several attempts have been made at trying to find heat stress indices that predict the effects of hot environments on human physiological conditions and performance. There are over a dozen heat stress indices available; however many of them utilize heat loss, sweat loss, rectal temperature, and other physiological parameters in their calculation. For the purposes of this study, a heat stress index is required in order to relate temperature and humidity. One of the most widely used is known as the wet bulb-globe temperature (WBGT) index because it incorporates the effect of temperature, humidity, radiation, and air movement.

McCann and Adams (1997) correlated WBGT index with performance in competitive distance runners. Their results indicated that optimal conditions, designated by the best performance times were difficult to predict with a linear model. Instead, they found that a curvilinear relationship more accurately described the relationship between several combinations of hot and humid environments and physiological responses. Their major results showed that, regardless of how high the WBGT index was, runners performed better at lower humidity levels than at higher humidity levels. Thus, the same WBGT index may produce different results in performance if in one case, temperature is high and humidity is low, and in the other, if temperature is lower but humidity is high.

Klemm and Hall (1972) delved into the issue of the utility of heat stress indices on physiological strain. In their study, 20 different combinations of dry bulb-wet bulb temperatures were selected. The participants remained at rest as physiological measurements were recorded. Their results indicated that indices with lower dry bulb temperatures and higher wet bulb temperatures induced lower strains than those with higher dry bulb temperatures and lower wet bulb temperatures. The conclusion, then, was that temperature and humidity differently affected the physiological response of the individual.

Ramanathan and Belding (1973) performed a study to determine the utility of the WBGT. The objective of their study was to evaluate the WBGT index under combinations of environmental conditions and work rate. Their results proved that a given level of WBGT had meaning dependent on environmental conditions, but that higher levels on the WBGT scale do not necessarily signify greater strain than lower levels.

Pulket et al. (1980) performed a study to compare available heat stress indices in a hot-humid environment. His results indicated that the wet globe temperature (WGT) index gave the best correlation with physiological strain related to heat loss through the skin. The WGT index is a single reading of the Botsford wet globe thermometer that exchanges heat with the surroundings by convection, evaporation, and radiation in a manner similar to that of a sweating man. However, the WGT may not be completely suitable as a field heat stress index, but it did give a higher correlation with physiological strain than did the WBGT index. Several other indices were studied, including the Relative Strain (RS) index, Reference Index (RI), and the Heat Stress Index of Belding and Hatch (HSI_{BH}). These all correlated with composite physiological strain; however, these heat stress indices incorporated heat loss, clothing effects, and other non-environmental factors.

In order to evaluate the physiological strain of an individual with the environment, it is necessary to determine a heat index that effectively combines the effects of temperature and humidity. The National Weather Service (2005) has developed a heat index equation as a result of extensive biometeorological studies. The index is a measure of how hot it feels when relative humidity (RH) is added to the actual air temperature. However, the equation is only useful for temperatures of 27°C (80°F) or higher, and relative humidites of 40% or greater.

2.8. Research Surveys

One of the objectives of this research was to model work performance time. This includes fitting coefficients of the model and explaining the factors that influence the values of the coefficients. Therefore, several surveys were administered to each of the subjects in order to explain why some of the subjects had a good fit with the performance time model while others did not exhibit a good fit. Five surveys were administered to each individual at the completion of their four testing sessions: Perceived Effort and Reward Questionnaire (PERQ) (Tremblay et al., 2002), Claustrophobia Questionnaire (CLQ) (Radomsky et al., 2001), Raffenbarger Physical Activity Questionnaire (Raffenbarger et al.,1978), Respirator User Questionnaire (unpublished research), and the Myers-Briggs Type Inventory (MBTI) (Culp et al., 2001). All surveys are located in Appendix 8.

The respirator could be perceived by some as a constraint, specifically, one that is claustrophobic. The CLQ was selected to measure this aspect of the test. The CLQ is a quantitative measure of a person's tendency to feel claustrophobic in certain situations. Claustrophobia is the fear of enclosed spaces and can often be unpleasant for people who are unable to cope with the fear of what might happen in that enclosed space. Claustrophobia is a combination of two separate fears: fear of suffocation and fear of restriction. The CLQ consists of 14 questions that pertain to fear of suffocation and 12 questions that pertain to fear of restriction. The test demonstrates high test-retest reliability, consistency, good discriminant validity, and predictive validity (Radomsky et al., 2001). Because of its strong predictive and discriminant validity, the CLQ may be used in a variety of research applications.

The coefficients of the model may depend on the physical conditioning of the subject. Therefore, a test was selected to provide a measure of the subject's usual level of physical activity. The Raffenbarger Physical Activity Questionnaire was developed by Dr. Ralph Raffenbarger Jr. for disease epidemiology studies. The questionnaire estimates the number of kilocalories people expend per week in both sports and leisure activities. The survey is easy to complete and consists of questions that pertain to the number of stairs climbed per day, number of city blocks walked per day, and any sports or activities performed, including frequency and duration. The subject is asked to average their activity over the entire year, and the researcher performs simple calculations to convert the activity to total energy expenditure.

A person's performance can be influenced by their familiarity with the equipment. Therefore, an index of mask familiarity was selected. The Respirator User Questionnaire was developed by Dr. Arthur T. Johnson (unpublished research). The questionnaire evaluates a person's familiarity with the respirator, reasons for discomfort while wearing the respirator, their overall attitude toward respirator use, and their ability to perform work while wearing the respirator. The questionnaire was shortened to contain only questions relevant to respirator use during the current study and was used to assess the individual's familiarity with the respirator, as well as their overall attitude toward the respirator.

The MBTI has been used for over 60 years and over this time, it has become one of the most widely used psychological instruments. According to Consulting Psychologist Press, Inc. (Mountain View, CA), the MBTI is completed by approximately 2 million people per year. Many schools and employers use the instrument as a means for profiling characteristics associated with different personality types. These personality types have been characterized (Culp et al., 2001) by four scales with opposite poles: extraversion (E)-introversion (I), sensing (S)-intuition(N), thinking(T)-feeling(F), and judging(J)-perceiving(P) Based on these scales, 16 distinct personality types emerge.

The tendencies of each scale (SN,TF, JP, and EI) were represented by a fraction in order to reduce the number of predictor variables within the MBTI parameters. The following equations represent each grouped variable (Koh, 2004):

- EI = number of Extraversion positives ÷ Total number of questions for Extraversion-Introversion
- SN = number of Sensing positives ÷ Total number of questions of Sensing-Intuition.

- TF = number of Thinking positives ÷ Total number of questions for Thinking-Feeling.
- JP = number of Judging positives ÷ Total number of questions for Judging-Perceiving.

A person who is extraverted (E) acts first and thinks later, feels deprived when cutoff from interaction with the outside world, is usually open to and motivated by people, and enjoys a wide variety of relationships. A person who is introverted (I) thinks first then acts, requires private time to recharge, is motivated internally, and prefers one-on-one communication.

A person who exhibits sensing (S) characteristics mentally lives in the present, uses common sense and creates practical solutions by instinct, has rich memory recall, and likes clear and concrete information. An intuitive (N) person mentally lives in the future, uses their imagination and creates new possibilities by instinct, improvises best through theoretical understanding, and is comfortable with ambiguous, fuzzy data.

A person who exhibits thinking (T) characteristics instinctively searches for facts and logic in a decision situation, naturally notices work that must be accomplished, is able to provide an objective analysis easily, and accepts conflict as a natural part of relationships. A person who exhibits feeling (F) characteristics instinctively employs personal feelings in decision situations, is naturally sensitive to people's needs, naturally seeks popular opinions, and is unsettled by conflict.

A person who exhibits judging (J) characteristics plans in advance before taking action, is focused on task-related action, works best when keeping ahead of deadlines, and naturally uses targets and standard routines to manage life. A person who exhibits perceiving (P) characteristics is comfortable moving into action without a plan, likes to multitask, is naturally tolerant of time pressure and works best close to deadlines, and instinctively avoids commitments that interfere with flexibility and freedom.

Some subjects were able to tolerate the hot, humid conditions better than others. The physiological and psychological factors inferred from the surveys were used to explain variations in performance time with the environmental conditions.

Chapter 3: Research Goal and Objectives

The goal of the proposed research project is to develop a mathematical model that correlates performance time with the National Weather Service Heat Index (HI) to provide manufacturers with a useful tool for designing masks with the most favorable characteristics that are appropriate for optimal performance at the environmental conditions (i.e. temperature and humidity) prevalent at the location of use.

To meet this goal, this research will address the following three objectives:

- Model the relationship between inspired air conditions (humidity and temperature) and performance time while wearing a respirator;
- Evaluate the user acceptability parameter (Breathing Apparatus Comfort Scale, or BACS) and assess its relationship with facial skin temperature;
- Model the relationship between performance time with several parameters that may serve as predictors of performance time at the four environmental conditions
    - Correlate performance time with rectal temperature, facial skin temperature, and user acceptability
    - Examine factors that may pre-determine an individual's performance time for screening purposes

Chapter 4: Research Methods

This research consisted of three stages: obtain subject consent and orientation, perform the VO_2max graded exercise test, and complete 65-70% VO_2max testing under three different conditions. A total of 10 subjects were recruited for the study.

4.1 Procedures

4.1.1. Equipment/Apparatus

4.1.1.1. Environmental Chambers

In order to supply warm humid air to the respirator mask, two Kolpak environmental growth chambers (Integrated Development & Manufacturing Company Chagrin Falls, OH) were used. One environmental chamber was maintained at 30°C and 40% humidity. The subject exercised in this chamber, while air from the other environmental chamber was drawn into the exercise chamber via a long hose that was connected to the respirator mask (Figure 4-1). The temperature and humidity in this chamber changed for each testing session, whereas the temperature and humidity in the chamber used for exercise remained constant.

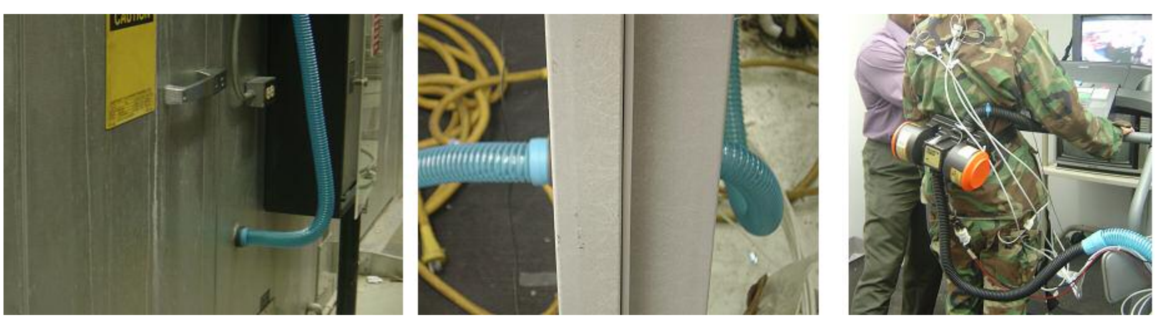

Figure 4-1. Hose connected from one environmental chamber through the exercise chamber to the respirator mask of the subject.

The walk-in chambers are modular and consist of several aluminum tongue and groove sectional panels that contain four inches of foamed in-place polyurethane for insulation. Each chamber consists of temperature control, a humidifying system, and a dehumidifying system. A digital display on the exterior of each chamber allows for programmed control of these systems. The temperature control ranges from 1.7°C to 46.1°C (35°F to 115°F) and the humidity control ranges from 0% to 99%.

4.1.1.2. Temperature/Humidity Sensor

The Taylor Series 1452/1455 temperature and humidity sensor (Speranza's Weather House; Hendersonville, NC) used for the research consists of an LCD display and external sensor probe with a 10 foot fixed cable. The sensor measures indoor temperatures of -5°C to 50°C (23°F to 122°F) and outdoor temperatures of -50°C to 70°C (-58°F to 158°F), and measures indoor humidity from 20% to 99%. The resolution is 0.1 degrees F/C and 1% for humidity. Although the resolution is good and the calibration with a sling psychrometer (Belfort Instrument Company Baltimore, MD) is sufficient, the reaction time for displaying a change in humidity is relatively poor.

The indoor-outdoor temperature and humidity sensor was calibrated using a sling psychrometer (Belfort Instrument Company Baltimore, MD) at temperatures ranging from 62°F to 93°F and humidity ranging from 44% RH to 78% RH. The sensitivity of the apparatus was relatively low, requiring an average time of 2 minutes to accurately display the relative humidity. An analysis of variance performed indicated no significant difference ($p < 0.05$) between the actual temperature and humidity recorded by the psychrometer and the temperature and humidity displayed on the sensor. The R^2

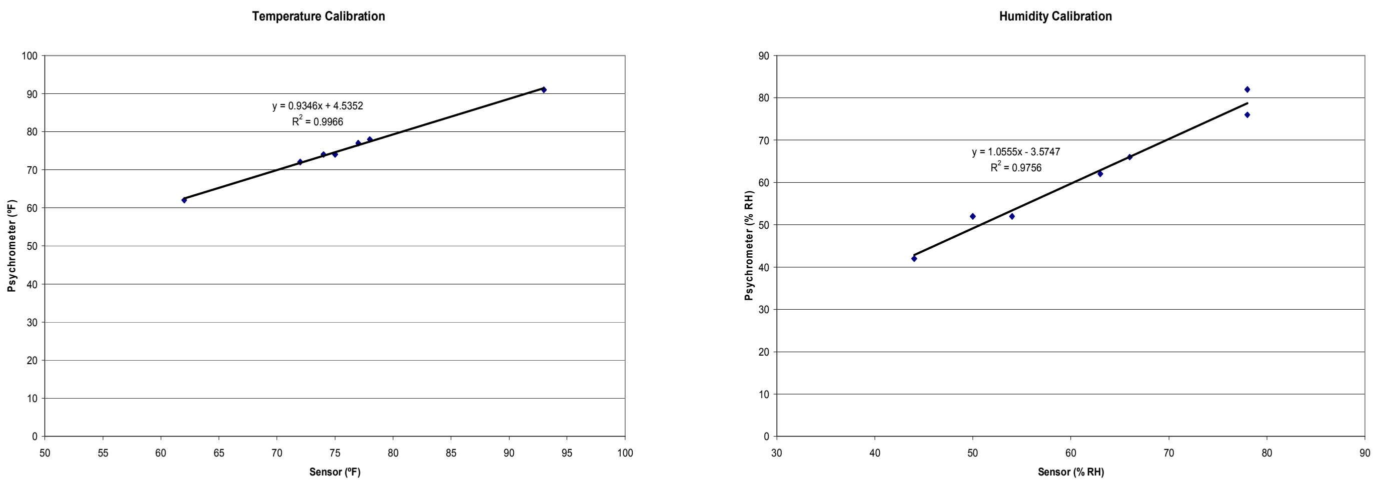

Figure 4-2. Calibration curves of humidity sensor and sling psychrometer for temperature and humidity (n=7).

value for the temperature calibration was 0.99 and the R^2 value for the humidity calibration was 0.97 as seen in Figures 4-2 above.

4.1.1.3. Powered Air Purifying Respirator (PAPR) with blower

The respirator mask chosen for this research was a Breathe Easy Turbo tight-fitting powered air purifying respirator (3M St. Paul, MN) with a belt-mounted blower and filtration unit; however the filtration was excluded from the study. The complete system used in the research included a blower unit, respirator headpiece, breathing tube, and a 4.5V external power source.

Johnson et al. (2005) published voltages as well as the corresponding flow rates produced, and percentages of the maximum flow rate while wearing the tight fitting powered air purifying respirator (PAPR). Based on this research, at 4.5V supplied to the motorized blower, the average flow rate produced is 103.46 L/min, which is 94% of the maximum flow rate able to be sustained by the blower unit.

4.1.2. Environmental Testing Conditions

During each testing session, the subject exercised in an environmental chamber that remained at 30°C and 40% humidity. The respirator was supplied with the following four combinations of temperature and humidity:

- 27ºC, 50% humidity
- 27ºC, 70% humidity
- 32ºC, 60% humidity
- 37ºC, 70% humidity

In order to compare the conditions according to one variable, each state was assessed by the heat index developed by the National Weather Service. Regardless of the magnitude of the individual environmental factors, the physiological responses will likely be different at different heat index values. Choice of the conditions was based upon the heat index to see if there is a difference in performance time as the conditions feel warmer.

The following equation calculates HI based on two environmental variables and was developed for temperatures greater than 27°C (80°F) and relative humidity greater than 40% (National Weather Service, 2005):

$$HI = -42.379 + 2.04901523T + 10.14333127RH - 0.22475541TRH - 6.83783\times10^{-3}T^2 - 5.481717\times10^{-2}RH^2 + 1.22874\times10^{-3}T^2RH + 8.5282\times10^{-4}TRH^2 - 1.99\times10^{-6}T^2RH^2 \quad (4\text{-}1)$$

where *HI* = Heat Index (°F); *T* = ambient dry bulb temperature (°F); *RH* = relative humidity (integer percentage). All heat index values were converted to °C.

According to the above equation, each of the testing conditions may be converted to following heat index:

- At 27°C, 50% humidity, HI = 27°C
- At 27°C, 70% humidity, HI = 28°C
- At 32°C, 60% humidity, HI = 37°C
- At 37°C, 70% humidity, HI = 55°C

4.1.3. Orientation and Consent

Institutional Review Board (IRB) approval on IRB application #05-0245 was received on May 18, 2005 (Appendix 10). Ten young, healthy, normally conditioned subjects were recruited for the study. Of these subjects, approximately half were not familiar with wearing the respirator; therefore, each subject was fully advised as to the requirements of their participation. The subjects read and signed the informed consent document and medical history questionnaire. The orientation session provided the subject with a detailed description of their rights, and it provided the investigators with information about the subjects' health and ability to partake in vigorous activity. Any demographic or experimental data collected corresponded only to a subject number and may not be traced back to the individual.

4.1.4. VO_2max Graded Exercise Test

All prospective participants performed a maximal oxygen consumption test on a motorized treadmill (model 15.0Q, Image, Logan, UT) in order to determine each subject's maximal aerobic capacity. This test was used to develop each subject's work rate during each of the testing sessions and each subject's critical end point values.

Participants warmed-up and stretched for approximately ten minutes prior to the start of the test. The mask used during the test was a half-mask equipped with one-way inhalation and exhalation valves (Hans Rudolph Inc., Kansas City, MO). This apparatus was interfaced with a standard Fleisch pneumotach (Phipps & Bird, Richmond, VA) and mass spectrometer (Perkin-Elmer, Pomona, CA) to monitor continuous expired airflow. Heart rate measurements were assessed using a Polar S810i wireless heart rate monitor (Polar Electro Inc. Lake Success, NY).

In order to determine VO_2max, the subject participated in a graded exercise test to exhaustion. The work rate was adjusted every three minutes until the participant became fatigued, failed to display a rise in oxygen consumption in accordance with the increase in work rate, or reached a maximal heart rate as determined from the following equation (Johnson, 2004):

$$HR_{max} = 220 - age \qquad (4\text{-}8)$$

where HR_{max}=maximum heart rate (beats/min). All subjects' VO_2max data may be found in Table A1.2. in Appendix 1.

4.1.5. 65-70% VO_2max Subject Testing

Each session was conducted at 65-70% of the participant's maximal oxygen consumption using the motorized treadmill. All sessions utilized a tight-fitting powered air purifying respirator (PAPR), which covered the entire face including the cheeks and forehead and supplied air to the respirator via a motorized blower. The advantage to using the PAPR is to ensure a constant flow of the humid air to the user. The subject exercised at a constant work rate throughout all four sessions. Furthermore, each of the subjects dressed similarly, wore the same mask throughout all sessions, and exercised at the same temperature and humidity within an environmental chamber. The only changing variables were temperature and humidity within the respirator. Testing conditions were randomized for each subject prior to the commencement of the study.

Before exercise, the subject completed a five minute warm-up on the treadmill followed by five minutes of stretching. The subject donned the heart rate monitor, a rectal probe (YSI 423, Yellow Springs International, Dayton, OH) was self-inserted 10 cm inside the sphincter for measuring core body temperature, and three surface temperature sensors (YSI 4400, Yellow Springs International, Dayton, OH) on the face. The accuracy of the YSI 423 rectal probe was ±0.2°C from -1 to 60°C, ±0.1°C from 25 to 45°C and the accuracy of the YSI 4400 temperature sensors was ±0.2°C for a range of -41° to +105°C. A Yellow Springs International (YSI) Precision 4400 Series telethermometer was connected to the sensors to record instantaneous skin temperature measurements (Yellow Springs, OH). The sensors were placed on the mid-forehead, right cheekbone, and upper lip under the left nostril. Mean skin temperature was calculated based on an equation proposed by Gwosdow et al (1989) for a weighted mean of ten local skin temperatures. The weightings for the forehead, cheek, and upper lip were 0.046, 0.012, and 0.012 respectively. Dividing each by the sum of the three yields the following equation for mean skin temperature:

$$T_{face} = 0.657T_{fo} + 0.171(T_{ch} + T_l) \qquad (4\text{-}9)$$

where T_{face} is the surface area weighted mean skin temperature for the face in °C, T_{fo} is the forehead sensor temperature in °C, and T_{ch} is the cheek sensor temperature in °C, and T_l is the upper lip sensor temperature in °C.

After the subject donned the heart rate monitor, skin temperature sensors, and inserted the rectal probe, the subject dressed in standard military fatigues and tennis shoes. A full face piece respirator was fitted to the subject for a comfortable, but snug fit. The inlet of the respirator was connected via a breathing hose to the motorized blower that supplied air to the user from an environmental chamber. At the outlet of the respirator, a combined temperature/humidity sensor probe monitored temperature and humidity of the expired air.

The subject began to exercise at a treadmill speed and grade set at a work rate below 65-70% VO_2max; the speed and grade were increased for approximately 90 seconds before the final speed and grade corresponding to 65-70% VO_2max was reached. At this work rate, the subject exercised until he or she reached exhaustion. While the measure of exhaustion is purely subjective, the human monitor during subject testing observed whether substantial effort had been achieved based on maximum heart rate, Rating of Perceived Exertion (RPE), or whether the subject expressed signs of severe discomfort. The same human monitor was present throughout each of the testing sessions. After each testing session, the subject was given a 5 minute cool-down then asked to provide reasons for termination.

Four scales were used to determine how the subject felt every two minutes. The Rating of Perceived Exertion (RPE) scale was used to determine how difficult the subject felt the work was. A low score of 6 indicated that the work was very, very light, and a high score of 20 indicated that the work was very, very hard. The Breathing Apparatus Comfort Scale (BACS) was used to determine how comfortable the subject felt the respirator was. A low score of 0 indicated that the mask was very, very uncomfortable, and a high score of 10 indicated that the mask was very, very comfortable. The Facial Thermal (FT) scale was used to determine how warm the subject's face felt. A low score of 1 indicated that the subject's face felt very cold, and a high score of 7 indicated that the subject's face felt very hot. The Overall Thermal (OT) scale was used to determine how warm the subject's overall body felt. This scale is identical to the FT scale. All scales are found in Appendix 9.

Temperatures and humidities of both chambers were recorded prior to each testing session and following each testing session. Heart rate was recorded every 5 seconds and downloaded to a computer using the Polar Precision Performance software. Facial skin temperatures and core body temperatures were recorded every 30 seconds. Chamber temperature and humidity, the RPE, BACS, FT, and OT were recorded every two minutes.

For the model, the dependent variable is performance time, indicated by the amount of time the subject was able to exercise until he or she reached exhaustion. Performance time was modeled as a function of the HI to determine the effect of the respirator. Since performance time was an individual subject's termination time, it was very subjective. Therefore, several physiological and psychological factors may explain the variability of performance time.

4.2 Method of Statistical Analysis

4.2.1. Outlier Detection

The Dixon-Thompson outlier test is used to statistically decide if an extreme event can be considered as an outlier (McCuen, 2003). The test is applicable for sample sizes as small as three. In order to conduct the test, the data are ranked from smallest (X_1) to largest (X_n), and the test statistic R is computed according to the sample size. For a sample size of 8 to 10, the following equation for R is used:

$$R = \left(\frac{X_n - X_{n-1}}{X_n - X_2} \right) \tag{4-10}$$

where X_{n-1} is the next to largest sample value, X_2 is the next to smallest value. The following are critical values (per % level of significance) for a sample size of 10:

Table 4-1. Critical Values R_c for a sample size of 10

Critical Value		
5%	2.50%	1%
0.472	0.528	0.59

If the computed R is greater than R_c, then the null hypothesis that the data point is not an outlier is rejected, and the data point (X_n) is considered to be an outlier.

4.2.2. Model Structure

4.2.2.1. Graphical Analysis

Graphical analyses are a useful first step in modeling to understand the structure of data. Graphical analyses provide information on the effects of the independent variables on dependent variables. For the proposed research, an association was expected between performance time and the HI. Similarly, a correlation was expected between facial skin temperature and acceptability. This part of the modeling effort provided a qualitative assessment of the degree to which one variable may be used to predict another variable (McCuen, 1985). Graphical analyses are useful for identifying possible extreme events (outliers), the degree of association between variables, and the form of the relationships. Misrepresenting the form of a relationship can reduce the accuracy of predictions made based on a model developed from the data.

Data may take several forms, each of which may be affected by the occurrence of extreme events, or outliers. The first step is to identify the presence of outliers, then to identify the form and type of relationship between the variables (McCuen, 1985). If extreme events occurred, these data points may affect the general trend of the data.

The data may take a linear or nonlinear form and have different degrees of correlation. The data may be positively or negatively correlated, and the degree of correlation differs depending on the shape, trend, and slope of the data. Graphs aid in the selection of the model structure that most accurately represents the data and the physical processes being modeled.

4.2.3. Calibration

Linear models do not always fit data to an acceptable degree; additionally, they may provide irrational predictions when the intercept is negative. Thus, numerical optimization is a method of fitting nonlinear functions. Calibration may occur via analytical, numerical, or subjective optimization. Once the graphical analyses have been performed and a model structure identified, calibration is a process that determines the coefficients by minimizing the sum of the squares of the errors. This equation takes the following form:

$$F = \min \sum_{i=1}^{n} (\overline{Y}_i - Y_i)^2 \tag{4-11}$$

where $\overline{Y}_i$ is the i^{th} predicted value of the criterion variable, Y_i is the i^{th} measured value of Y, and n is the number of observations on the criterion variable. Analytical optimization utilizes differential equations to derive the unknown coefficients from objective functions. For example, the derivative of Equation 4-11 with respect to the unknowns is set equal to zero, and the coefficients are determined by solving a set of simultaneous equations. For numerical optimization, on the other hand, the coefficients are determined using an iterative, but systematic process. The advantage to using the numerical process as opposed to the analytical process is that it can be used with more complex model structures and for non-differentiable model forms.

4.2.4. Sensitivity Analysis

A model is intended to reflect the physical processes from which the data were measured. A sensitivity analysis is a useful tool for assessing whether or not the model is a rational reflection of the processes. In order for the model developed to be applicable to determining responses on a larger scale, the sensitivity of the model should be analyzed. In other words, how sensitive the model is to errors, how important each of the variables and coefficients are in affecting the output, and how sensitive the goodness of fit is. The general definition of sensitivity can be described as a function that reflects the effects of inputs on the output of the model. Differentiating the output variable with respect to each factor and including system responses yields the general equation for the relative sensitivity of output variable (O) with respect to the factors (F) (McCuen, 2003):

$$R_s = \frac{\Delta O / O_0}{\Delta F_i / F_i} \tag{4-12}$$

where O_0 is the value of O at some specified level of F_i, F_i are the factors that influence O, and R_s is the relative sensitivity. Given the sensitivity of input F_i with respect to a variation in the output O of the system response, this equation determines the relative importance of the factor. The quantity R_s from Equation 4-12, is an indication of the relative importance of the factor F_i on predictions of O_i.

4.2.5. Assessing Model Prediction Accuracy

Model accuracy may be determined by examining the bias of the model, the standard error of the estimate, and the correlation coefficient. Bias is a statistical measure of the systematic variation of the errors of prediction. Positive bias exists if the model consistently overestimates the value being measured, and negative bias exists if the model consistently underestimates the value being measured. The general equation to calculate bias is:

$$bias = \bar{e} = \frac{1}{n}\sum_{i=1}^{n}(\bar{Y}_i - Y_i) = \frac{1}{n}\sum_{i=1}^{n} e_i \qquad (4\text{-}13)$$

A biased model exists if $\bar{e}$ is greater than zero and often indicates an incorrect model structure.

The standard error of the estimate (S_e) is the square root of the sum of squares of the errors divided by the degrees of freedom. It is a measure of the nonsystematic error variation of the data. If the relationship between two variables is strong, then the standard error of the estimate will be smaller than the standard deviation of the criterion variable (S_y). The ratio of S_e/S_y is a measure of the relative improvement of the accuracy of predictions over predictions made with the mean of the variable. A low S_e/S_y is more acceptable than a value closer to one.

The correlation coefficient (R) is a measure of the degree of linear relationship between two variables. This index measures the goodness of fit of the model. R^2 may also be used as a measure of the accuracy of predictions made by the model; however, the standard error of the estimate is a better measure because it is valid for nonlinear models as well as linear models (McCuen, 1993). The following equation is used to estimate R:

$$R = \left[1 - \left(\frac{n-v}{n-1}\right)\left(\frac{S_e}{S_y}\right)^2\right]^{0.5} \tag{4-14}$$

where *v* is the degrees of freedom, and *n* is the sample size.

4.2.6. Sample Size Determination

Three factors are used to determine sample size, two of which must be selected by the researcher: the tolerable error and the level of confidence. It is important to choose these values carefully because a large confidence interval will indicate an imprecise measure of the mean. In most situations, the level of confidence is set between 90-95% and the tolerable error is chosen arbitrarily by the researcher. The following equation was used to determine if the correct sample size had been chosen once the variance was known (Ott and Longnecker, 2001):

$$n = \frac{(z_{\alpha/2})^2 \sigma^2}{E^2} \tag{4-15}$$

where n = sample size, $z_{\alpha/2}$ = z test statistic, σ^2 = population variance, and E = W/2 where W is the tolerable error.

For the current study, the standard deviation (σ) was computed for each testing condition and an average of the computed standard deviations was taken. This value was 5.98. The tolerable error, which is representative of the width of the confidence interval of the mean, was arbitrarily chosen. If the width is too narrow and confidence level too high, a large sample size will be necessary. Therefore, W = 6, and E = 3. A 95% confidence interval use used, which corresponds to a z value of 1.96. Therefore, the sample size necessary to be 95% confident that the population mean is contained in the interval, is:

$n = [(1.96)^2*(5.98)^2]/3^2 = 15$

Although 22 subjects are necessary for a confidence interval of 95% with a width of 5, due to time constraints, 10 subjects were chosen for participation in the study. Therefore, using a sample size of 10, the value of the z test statistic is:

$z_{\alpha/2} = (10^{.5}*3^2)/5.98^2 = 0.79$

This z value corresponds to a confidence level of 78%. In order to improve this value to 95%, more subjects must be tested or the width of the interval (W) must be expanded to 7.5.

Chapter 5: Research Results and Discussion

5.1. Subject Demographics and Characteristics

Ten healthy individuals participated in the research study: three female and seven male. A retrospective analysis of the sample size indicated that a sample size of 15 would have resulted in a 95% level of confidence. A sample size of 10 resulted in an 88% level of confidence. Sample size determination is discussed in section 4.2.6. The average age of the subjects was 26 ± 7.3 years, the average height was 67.7 ± 2.2 inches, and the average weight was 165.9 ± 32 lbs (Table A1.1 in Appendix 1). The average VO_2max of the subjects was 29.16 ± 5.87 ml/kg/min (Table A2.1. in Appendix 1).

All tests were randomized for each subject prior to commencement of the study. Three females and seven males participated in the study with ages ranging from 21 to 40. Of the ten subjects, four were familiar with respirator wear during manual labor. Three of these four subjects (001, 145, and 358) had performance times that followed the expected trend for each of the conditions. In other words, their shortest performance time occurred at the warmest condition, and the longest performance time occurred at the coolest condition. The other seven subjects had performance times that did not vary greatly as a function of the heat index. Although some of the subjects' performance times did not indicate that the warm and humid conditions affected them more than the more neutral conditions, all subjects were able to discriminate between the warmest (37°C, 70% RH) and the coolest (27°C, 50% RH) conditions. All subjects indicated that the warmest condition made breathing very difficult from the beginning and some felt as though they were suffocating, leading to termination. For the coolest condition, all subjects indicated that breathing became difficult toward the end of exercise, but termination occurred due to fatigue, boredom, or leg and muscle pain. For the other two conditions (27°C, 70% RH and 32°C, 60% RH) subjects terminated for a variety of reasons including leg and muscle pain, fatigue, boredom, overall body discomfort due to heat, and difficulty breathing.

5.2. Sensitivity Analysis of Heat Index

The heat index played a central part in this modeling effort. Therefore, it was important to understand how it functioned as a variable. For this reason, a sensitivity analysis of the heat index was undertaken prior to its use. The sensitivity of a model is useful for assessing the relative importance of the predictor variables and making error analyses. A sensitivity analysis was performed on the Heat Index equation developed by the National Weather Service (Equation 4-1) in order to determine how sensitive the equation was to changes in both temperature and humidity. The analyses were performed on temperatures ranging from 25°C to 40°C and humidities ranging from 40% RH to 80% RH. These bounds were selected as representative of normal test conditions. Both absolute and relative sensitivities were computed for temperature and humidity. The absolute sensitivity is the first derivative of the dependent variable with respect to the independent variable and is useful in error analyses. The relative sensitivity (Equation 4-12) is the percentage change in the dependent variable for a 1% change in the independent variable; therefore, it is a useful indication of the relative importance of the independent variable.

As shown in Tables 5-1 and 5-2, a 1% change in the temperature at 40°C and 70% RH produced a 6.5% change in the actual heat index. A 1% change in relative humidity at 40°C and 70% RH caused a 2.3% change in the actual heat index. Therefore, at these values of T and RH, T was almost three times more influential than RH.

This indicated that the commonly used heat index equation may not be the best option for analyses of data collected during testing. The coefficients of the heat index equation placed more emphasis on temperature than on the humidity.

Table 5-1. Absolute and Relative Sensitivities for Temperature

	Temperature (°C)				
RH (%)	25	30	35	40	
50	0.5824	1.4787	2.3719	3.2651	absolute
	0.5735	1.6179	2.8668	4.3203	relative
60	0.8311	1.9061	2.9811	4.0561	absolute
	0.8123	2.0808	3.5949	5.3546	relative
70	1.1861	2.4357	3.6853	4.9349	absolute
	1.1594	2.6593	4.4446	6.5156	relative

Table 5-2. Absolute and Relative Sensitivities for Relative Humidity

	Temperature (°C)				
RH (%)	25	30	35	40	
50	0.0275	0.2829	0.705	1.294	absolute
	0.0269	0.3095	0.8522	1.7122	relative
60	0.0085	0.359	0.8699	1.5411	absolute
	0.0083	0.3919	1.049	2.0344	relative
70	-0.0105	0.4352	1.0347	1.7881	absolute
	-0.0102	0.4751	1.2479	2.3609	relative

The absolute sensitivities in Tables 5-1 and 5-2 were also useful to show the effect of errors in measurements of T and RH. Mathematically, an error in T of ΔT or in RH of ΔRH can be used to compute the error in the heat index ΔHI by:

$$\Delta HI = \delta HI/\delta T * \Delta T \tag{5-1}$$

$$\Delta HI = \delta HI/\delta RH * \Delta RH \tag{5-2}$$

Errors in values of a computed heat index were more sensitive to errors in recorded temperature than to errors in recorded humidity. For example, at 40°C and 70% RH, an error of 2°C led to a change of 9.8°C in the heat index. At 40°C and 70% RH, an error of 2% RH led to a 3.5°C change in the heat index. The analysis indicated that the Heat Index Equation was almost three times more sensitive to errors in temperature than to errors in relative humidity.

5.3. Performance Time – Heat Index Model

In order to predict performance time according to the heat index of environmental conditions, a model was fit to the data collected from each subject using the numerical least squares technique. All performance time data are in Table A1.3. in Appendix 1. Graphing the data indicated that the structure of the model was nonlinear and that performance time was negatively correlated with the heat index of the environmental condition. Two coefficients were used to define the model, which had the following form:

$$PT = C_1 e^{-C_2 * HI} \quad (5\text{-}3)$$

where PT=performance time (min), C_1 and C_2 are coefficients, and HI=heat index (°C). C_1 was the coefficient that represented the magnitude of the predicted values, while C_2 was the coefficient that described the rate of decline of the function as HI increased. Relatively high values of C_2 indicated a steep decline while relatively low values of C_2 indicated a gradual decline. Generally, the two coefficients were correlated such that an increase in C_1 occurred simultaneously with a decrease in C_2.

Because the model was a nonlinear model, analytical methods for fitting C_1 and C_2 would not suffice; thus, numerical least squares was the appropriate technique. For this technique, the coefficients for the model were determined using an iterative, but systematic process, which resulted in minimization of the sum of the squares of the errors. The process involved numerically computing the derivatives of the objective function (Equation 5-3) and iteratively solving for the point where the derivatives were equal to zero (McCuen, 2003). Model results may be found in Table 5-3.

Table 5-3. Model results for the performance time-heat index (PT-HI) model where $PT=C_1e^{-C2*HI}$.

Subject	S_e	S_e/S_y	R^2	C_1	C_2
001	4.901	0.5634	0.7884	71.6	0.0358
145	0.306	0.0262	0.9995	140.7	0.05516
358	1.807	0.2627	0.954	58.95	0.03066
359	1.864	1.197	0.001	22.23	0.001219
379	1.001	1.193	0.001	13.75	0.001092
419	0.606	1.061	0.001	11.482	0.002157
420	1.213	1.174	0.001	14.442	0.00167
405	1.459	1.039	0.001	11.079	0.007195
401	0.89	0.57	0.7832	21.808	0.006405
343	0.555	0.15	0.9888	3.188	-0.04652

Model accuracy may be determined by examining the bias of the model, the standard error of the estimate, and the correlation coefficient. For the PT-HI model, all models resulted in a bias very close to zero, suggesting that the correct model structure had been chosen.

The ratio of S_e/S_y is a measure of the improvement of the accuracy of predictions over predictions made with the mean of the variable. A low Se/Sy is more acceptable than a value closer to one. Subjects 001, 145, and 358 had low values of Se/Sy, indicating that the model accuracy for these three subjects was good. Because of sampling variation inherent to the measured data, five of the models were inaccurate as evidenced from the high Se/Sy values and low R^2 values. These subjects had performance times that did not vary greatly with a change in the heat index of the environmental conditions resulting in flat curves and an R^2 value close to zero as shown in Figure 5-1. Calculations of performance time across a range of heat indices for each subject are in Appendix 5.

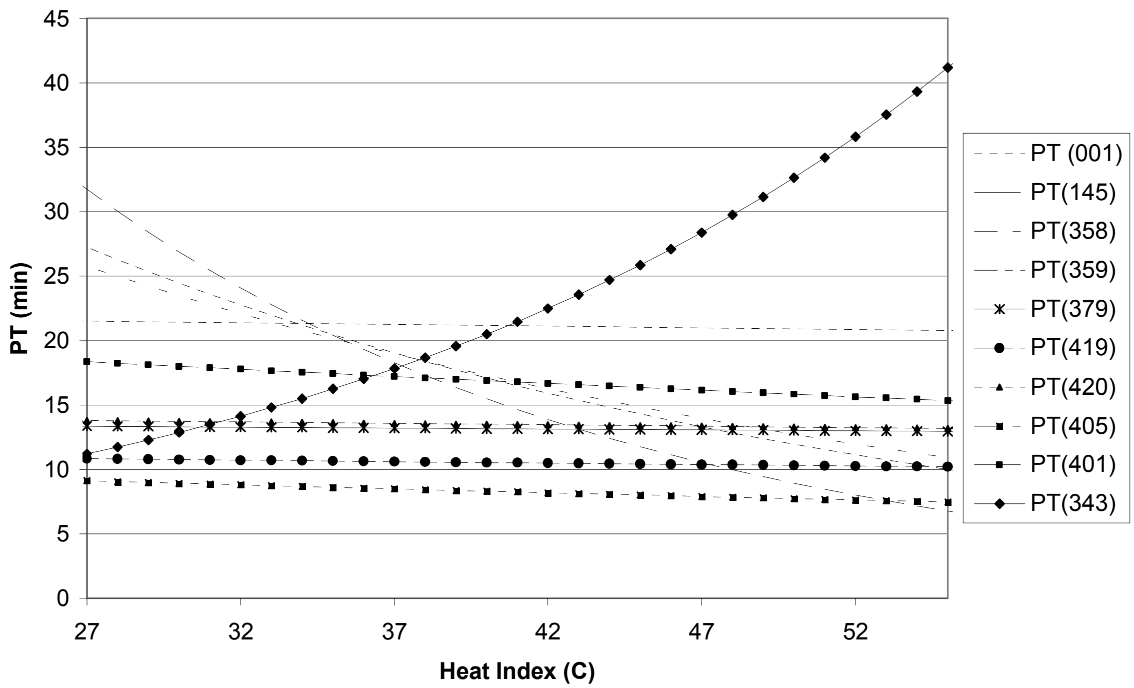

Figure 5-1. Functions (n=29) for the PT-HI model (Equation 5-3) for all ten subjects.

The square of the correlation coefficient (R^2) is a measure of the degree of relationship between performance time and the heat index. This index measures the proportion of variation explained by the model. For the subjects whose model accuracy was good, the goodness of fit of the model was very close to one. Subject 001 had an R^2 of 0.7884, subject 145 had an R^2 of 0.9995, and subject 358 had an R^2 of 0.954. Figure

5-2 shows the functions for each of the subjects whose model accuracy and goodness of fit were adequate.

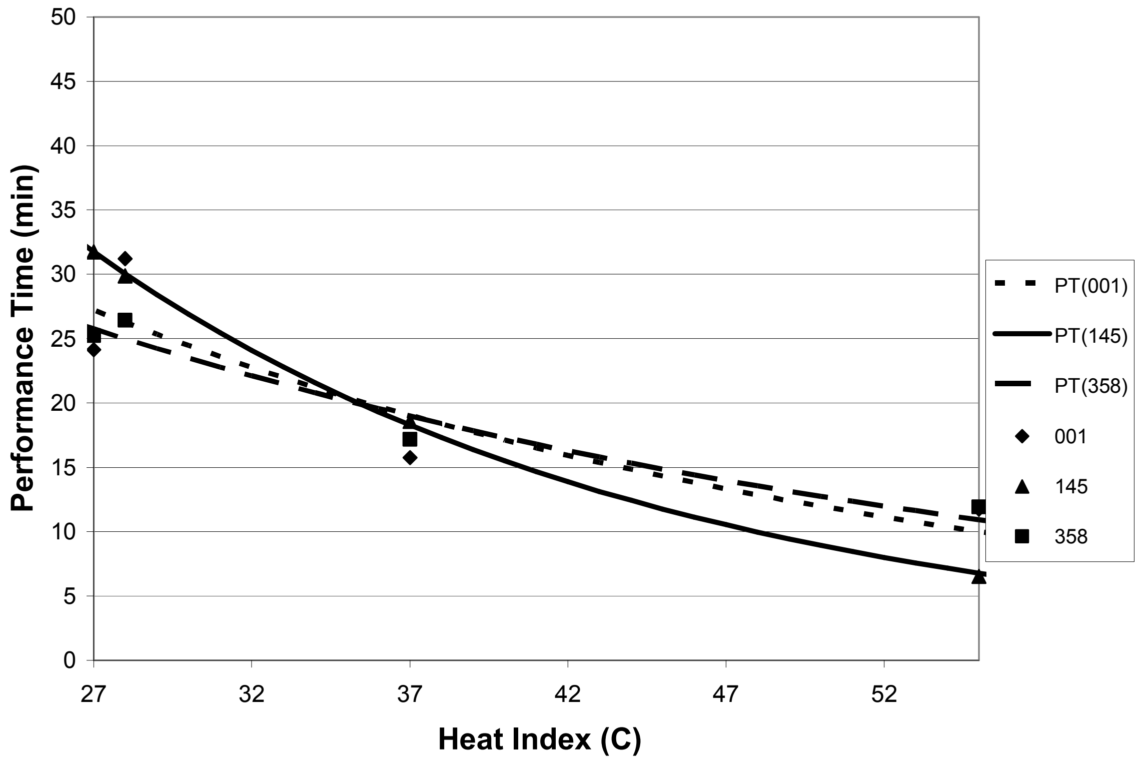

Figure 5-2. Functions (n=29) for the PT-HI model (Equation 5-3) for subjects 001, 145, and 358 including original data points.

It was evident from the PT vs. HI data that sampling variation can be very significant and adversely affect the modeling. The sampling variation was evident from comparing the performance times measured at 27°C and 28°C in Table A1.3 in Appendix 1. While these should not vary by much relative to the variation of the measurements made at 37°C and 55°C, for many subjects the PT differences for a 1°C change in HI were large. This would suggest that future studies might include replications to quantify the effects of sampling variation of each heat index.

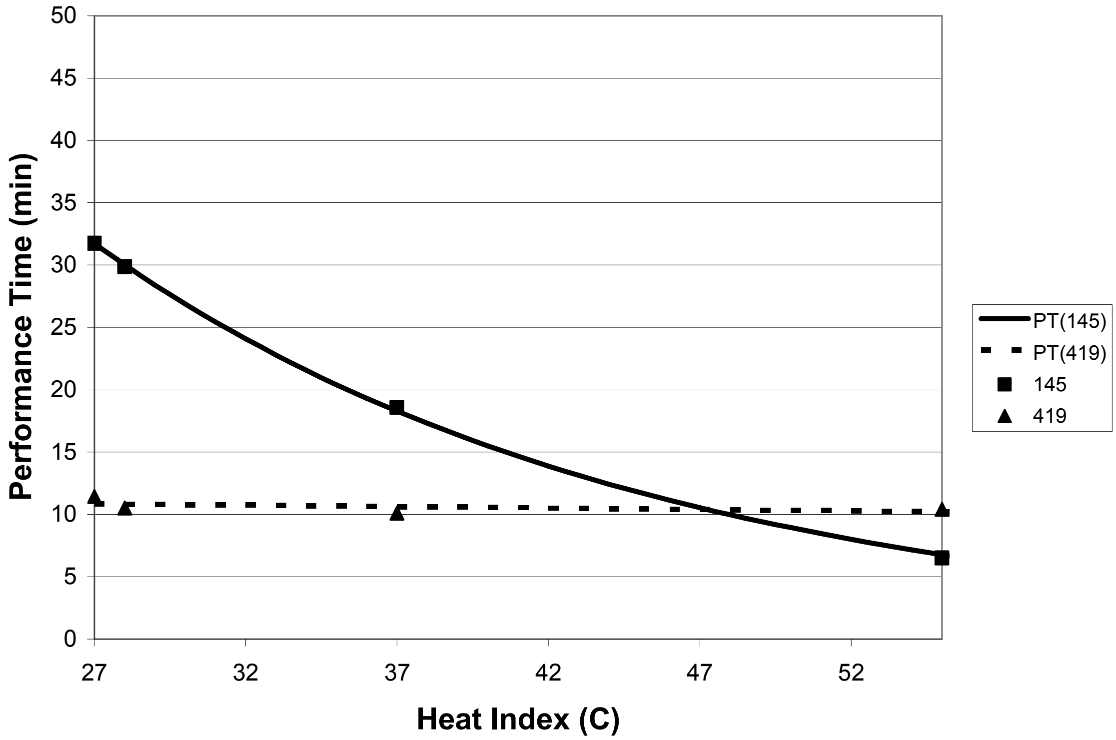

Figure 5-3. Comparison of Subject 145 (n=29) and Subject 419 (n=29). Model functions and original data points are shown. Subject 145 has a C_1 value of 140.7 and a C_2 value of 0.05516. Subject 419 has a C_1 value of 11.482 and a C_2 value of 0.002157.

Figure 5-3 shows the relationship between a subject who was sensitive to the change in the heat index (Subject 145) and a subject who was insensitive to the change in the heat index (Subject 419). The function for subject 145 indicates a large difference in performance time for a heat index of 27°C versus a heat index of 55°C, whereas that for subject 419 shows almost no difference in performance times between these heat indices. Furthermore, the rate of decline for each function is indicative of the 25 fold difference in C_2 values.

The shape of the PT-HI relationship reflected a number of characteristics about the subject on which the relationship was based. A steep decline was not necessarily indicative of good subject data, as the rate of decline can reflect the attitude and/or physical capability of the subject; however, a flat curve generally indicated data insensitive to differences in the environmental condition. For example, subject 419 terminated each testing session except that at 55°C due to sore legs, not because the condition became difficult.

Due to subject motivation, muscle soreness from other activities, and other external factors, only three subjects fit the model well. In order to obtain a better understanding for why this was the case, explanation of differences in C_1 was attempted using several subjective and objective parameters. Furthermore, once the differences had been accounted for, a new PT-HI model (Equation 5-9) was developed as a function of the new factors and combined all of the subjects.

5.4.Sample Graph Explanation

5.4.1. Rectal Temperature vs. Time

Rectal temperature varied linearly with time and increased with a similar slope at each heat index value. Figure 5-4 shows how rectal temperature varied over time for all ten subjects. Each of the four heat index conditions showed little variation from one another, which indicated that rectal temperature increased independently of the environmental conditions, but nonetheless showed good correlation with time. Rectal temperature data for all heat indices are located in Tables A4.1. to A4.4. in Appendix 4.

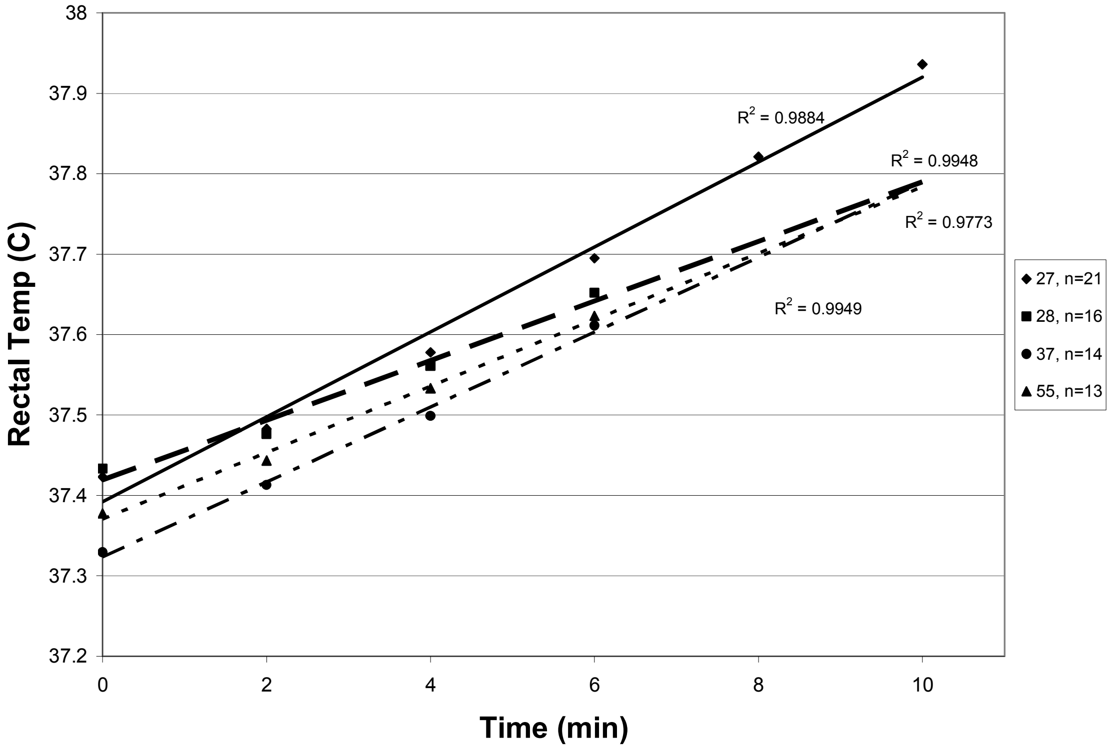

Figure 5-4. Average rectal temperature vs. time for all four heat index values. R^2=0.9884 for HI=27°C, R^2=0.9773 for HI=28°C, R^2=0.9949 for HI=37°C, and R^2=0.9948 for HI=55°C

5.4.2. User Acceptability vs. Time

User acceptability of the respirator was measured using the BACS scale (0-10) with 0 indicating very, very uncomfortable conditions and 10 indicating very, very comfortable conditions. All comfort scales are located in Appendix 9. The scale was converted to a percentage to measure the acceptability of each of the heat index conditions using the following method:

(BACS score/10)*100 (5-4)

During each testing session, each subject expressed his or her level of discomfort every 2 minutes using the BACS scale. This data is located in Tables A3.1. to A3.4. in

Appendix 3. Averages were taken for each heat index across all ten subjects. Table 5-4 shows these values for each of the four heat indices.

Table 5-4. Average of user acceptability (%) for each of the subjects at the four heat index conditions.

	HI=27	**HI=28**	**HI=37**	**HI=55**
Time (min)	**Acceptability (%)**	**Acceptability (%)**	**Acceptability (%)**	**Acceptability (%)**
0	72	75	75	66
2	55	61	52	43
4	46	48	41	29
6	41	39	36	26
8	32	32	24	25
10	24	29		21
12	19			

The subject acceptability data of Table 5-4 were plotted in Figure 5-5 to show how acceptability declined over time. However, the effect of the heat index was very minimal, since the trend at each heat index was nearly identical. At any time, differences in acceptability were evident, but the trend was not consistent. For example, at a time of 0, the order was 28°C and 37°C (tie), then 27°C, and then 55°C. At a time of 8 minutes, the order was 27°C and 28°C (tie), then 55°C, then 37°C.

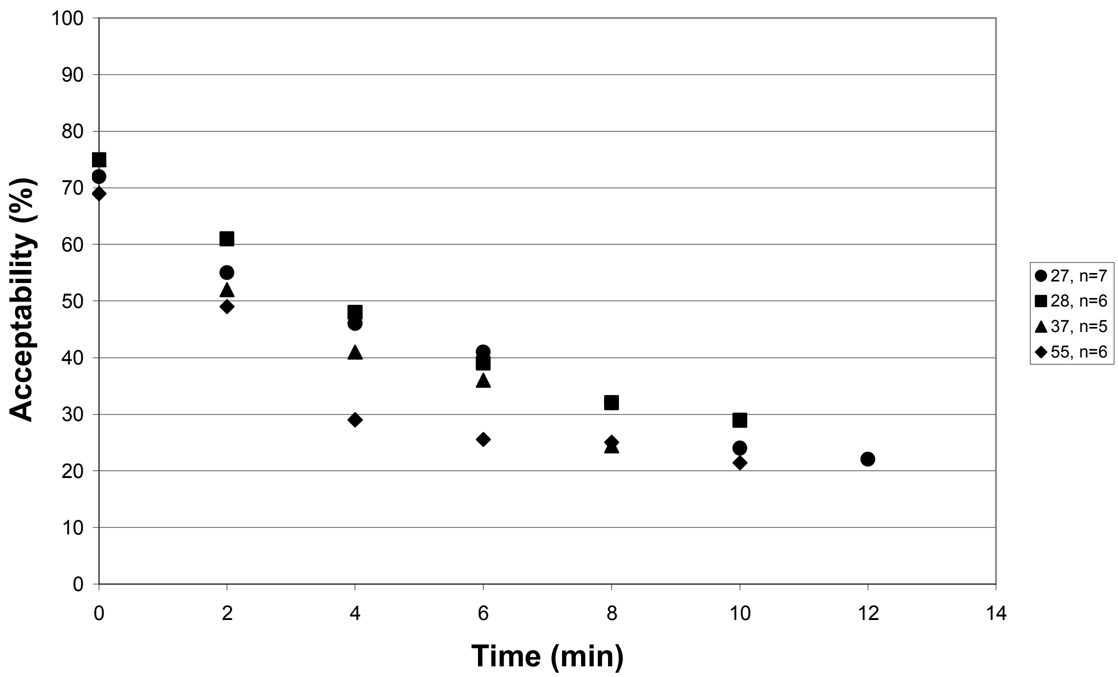

Figure 5-5. Average user acceptability (%) vs. time (min) for each of the four heat index conditions.

A model was developed to represent the relationship between acceptability and time. A comfort level of 40% corresponded to a BACS score of 4, “fairly uncomfortable.” Any scores below this level indicated that the subject felt that the respirator was uncomfortable. An equation was derived to predict the amount of time in minutes it took for a person to deem the respirator unacceptable based on the heat index of the environmental condition. Graphical analyses such as in Figure 5-5 indicated that the time (T, minutes) to reach a condition of unacceptability varied as an exponential decay function with the acceptability index (A,%), and that the rate coefficient of the exponential function varied approximately linearly with the heat index (HI). These trends suggested the following model:

$$T = e^{(\beta_1+(\beta_2+\beta_3*HI)*A)} \tag{5-5}$$

where T=time (minutes), β_1, β_2, and β_3 are model coefficients, HI=heat index (°C), and A=acceptability (%). Raw data (Table A3.5.) and functions (Figure A3.1.) showing the relationship between acceptability level and time for the four heat index conditions are found in Appendix 3.

The empirical coefficients β_1, β_2, and β_3 were fitted using numerical least squares analyses of measured values of T, A, and HI. The data of Table 5-4 were used to fit values of β_1, β_2, and β_3. An initial analysis showed that the data for a heat index of 27°C did not follow the trend expected; specifically, some of the acceptability values for 27°C are lower than the values for 28°C at the same time. The model, including constants took the form:

$$T = e^{(3.39-(0.02784+0.00056*HI)*A)} \tag{5-6}$$

where T is the predicted value of the time to unacceptability (min), and A is the level of acceptability (%). Equation 5-6 over-predicted measured times by 0.13 minutes. The standard error estimate of Equation 5-6 was 0.94 minutes (standard error ratio = 26%). This suggested that the model provided excellent accuracy. The correlation coefficient was 0.97 or 94% explained variance. These goodness of fit statistics indicated that the model provided accurate estimates of the time to unacceptability. Figure 5-6 shows the relationship of Equation 5-6 between the time to reach an unacceptable level according to the heat index of the environmental condition for three levels of percent acceptability.

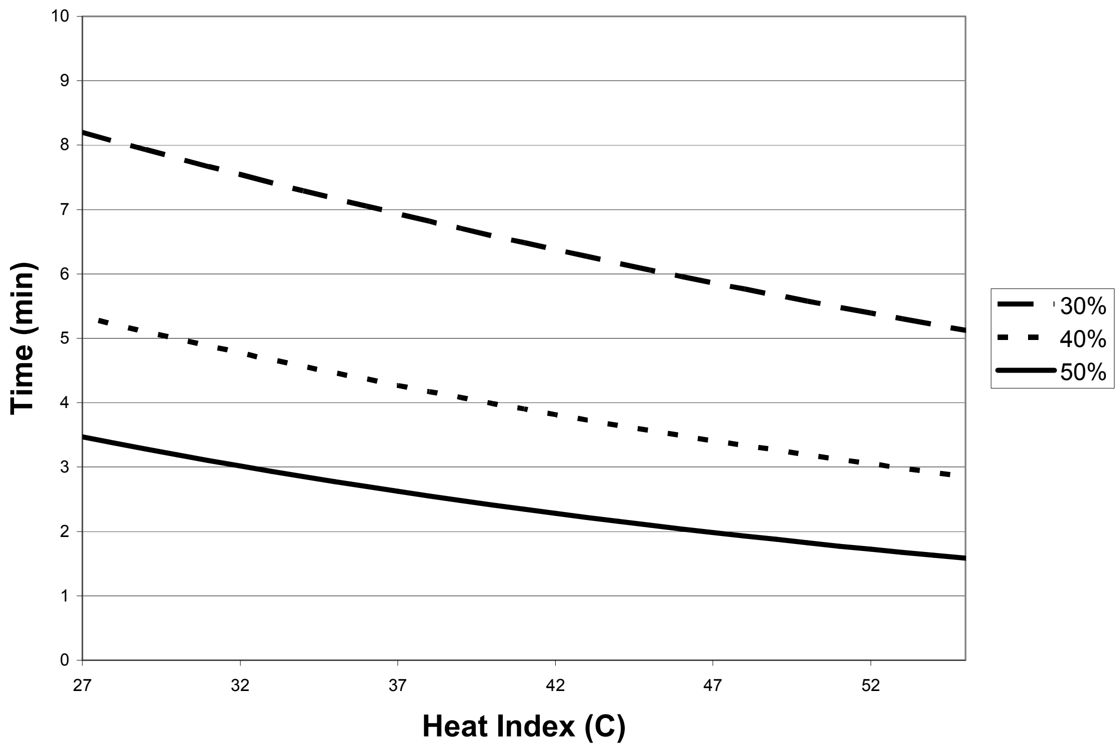

Figure 5-6. Model functions (n=29) for predicting time to reach unacceptable levels of comfort of the respirator according to the heat index of the environmental condition for acceptabilities of 30, 40, and 50%.

The model equations indicated that the respirator became uncomfortable at a level of 40% at 2.85 minutes for the heat index of 55°C, at 4.26 minutes for the heat index of 37°C, at 5.22 minutes for the heat index of 28°C, and at 5.34 minutes for the heat index of 27°C. Overall, the time to reach an unacceptable level of respirator comfort decreased with an increase in the heat index of the environmental conditions, indicating that there was an effect of the condition on respirator comfort. The time at which the respirator becomes uncomfortable will provide useful information for those who set policies on the length of time at which the performance of respirator users might decline substantially.

The time to reach an unacceptable level of respirator comfort was not considered to be representative of termination time. The model may serve as a useful tool for both respirator manufacturers and employers to determine how long it takes for the respirator user to become uncomfortable in the environmental conditions. This time may be indicative of deteriorating physiological function at the worksite and decreased work efficiency. While some individuals may push through the discomfort and continue to perform, others may terminate or remove the respirator at this time.

5.4.3. User Acceptability vs. Mean Facial Skin Temperature

User acceptability was measured in the manner described in section 5.4.2. In order to compare the results obtained from the current study with those in the literature, user acceptability was graphed against mean facial skin temperature for all ten subjects at each of the four heat index values. Figure 5-7 shows this relationship. Data for mean facial skin temperature is located in Tables A2.1. to A2.4. in Appendix 2. An overall relationship between user acceptability and mean facial skin temperature was evident. It was expected that at the higher heat index values, acceptability would decrease more quickly as facial skin temperature increased, but this was not observed; however, as mean facial skin temperature increased for all four conditions, acceptability decreased.

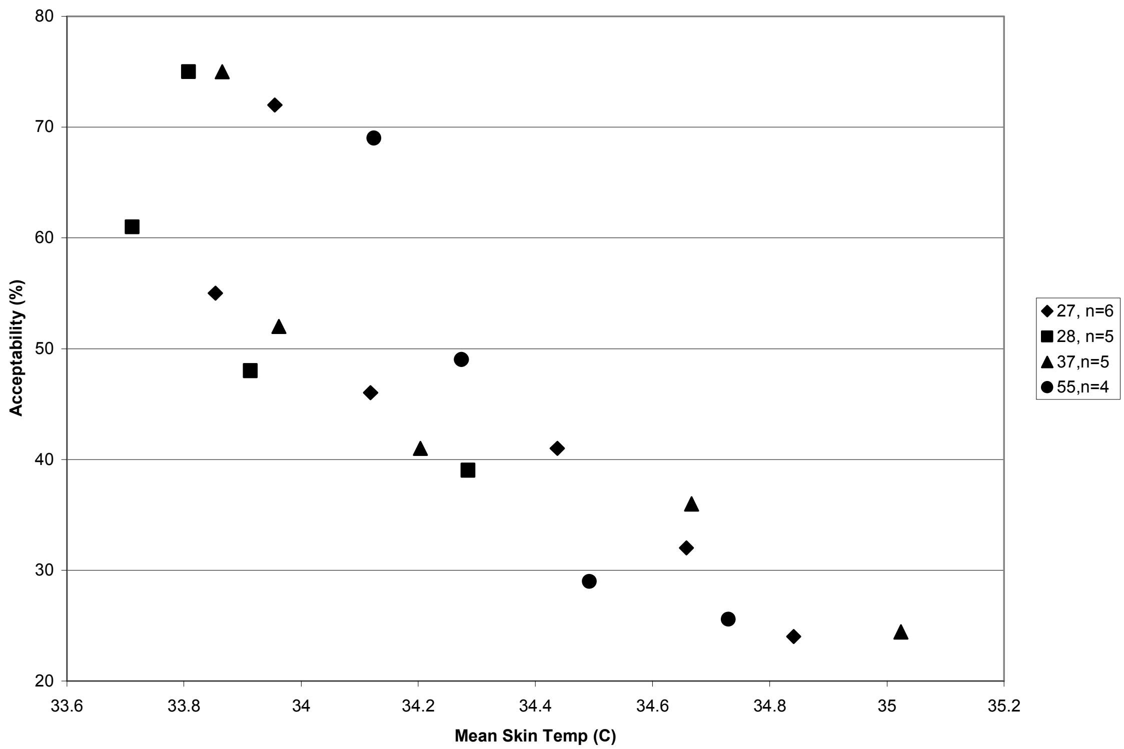

Figure 5-7. Average user acceptability (%) versus average mean facial skin temperature (°C) for all four heat index values.

In previous studies (Gwosdow et al., 1989; Dubois et al., 1990; Fox and Dubois, 1993), exercising subjects with lip skin temperatures of 31°C or less indicated that the condition was almost 100% acceptable and any temperature over this threshold became increasingly unacceptable. In the current study, a mean facial skin temperature (a weighted mean of lip, cheek, and forehead temperatures) was used instead of the lip temperature since Gwosdow et al. (1989) indicated that the cheeks and forehead are the regions most sensitive to warm stimuli.

Dubois et al. (1990) fit a linear regression through the data points representing the relationship between acceptability and mean facial skin temperature. A similar approach was taken in order to compare results obtained from the current research study to those obtained by Dubois et al. (1990). Dubois et al. (1990) obtained the following equation for unacceptability of mask conditions:

$$A=-16.6347+0.527*F \tag{5-7}$$

where A=unacceptability (%), and F=mean facial skin temperature (°C) (left nasolabial fold).

Both nonlinear and linear regression equations were fit to the data collected in the current study; however, the linear model produced the best results. The model took the following form to describe acceptability of mask conditions:

$$A=1362.5-0.2*HI-38.40*F \tag{5-8}$$

where A = acceptability (%), HI = heat index (°C), and F = mean facial skin temperature (°C). The standard error estimate of Equation 5-8 was 8.74 (standard error ratio 52%). This suggested that the model provided good accuracy. The correlation coefficient was 0.87 or 74% explained variance. These goodness of fit statistics indicated that the model provided accurate estimates of acceptability as a function of the heat index and mean facial skin temperature.

Dubois et al. (1990) concluded that acceptability began to decrease and the respirator mask became uncomfortable above mean facial skin temperatures of 34.5°C. In the current study, the threshold of acceptability was defined as a value of 40%, which corresponded to a BACS score of 4 ("fairly uncomfortable"). Table 5-5 shows that for all heat index values, the respirator became uncomfortable above facial skin temperatures of 34.5°C. Figure 5-8 illustrates this result. Beyond this temperature, acceptability fell below 40%. This result confirmed those obtained by Dubois et al. (1990).

Table 5-5. Acceptability (%) values computed from Equation 5-8 for 27°C, 28°C, 37°C, and 55°C for a range of mean facial skin temperatures.

Skin Temp (°C)	HI=27°C	HI=28°C	HI=37°C	HI=55°C
32.9	98.6	98.58	98.4	98.04
33	94.76	94.74	94.56	94.2
33.1	90.92	90.9	90.72	90.36
33.2	87.08	87.06	86.88	86.52
33.3	83.24	83.22	83.04	82.68
33.4	79.4	79.38	79.2	78.84
33.5	75.56	75.54	75.36	75
33.6	71.72	71.7	71.52	71.16
33.7	67.88	67.86	67.68	67.32
33.8	64.04	64.02	63.84	63.48
33.9	60.2	60.18	60	59.64
34	56.36	56.34	56.16	55.8
34.1	52.52	52.5	52.32	51.96
34.2	48.68	48.66	48.48	48.12
34.3	44.84	44.82	44.64	44.28
34.4	41	40.98	40.8	40.44
34.5	37.16	37.14	36.96	36.6
34.6	33.32	33.3	33.12	32.76
34.7	29.48	29.46	29.28	28.92
34.8	25.64	25.62	25.44	25.08
34.9	21.8	21.78	21.6	21.24
35	17.96	17.94	17.76	17.4
35.1	14.12	14.1	13.92	13.56
35.2	10.28	10.26	10.08	9.72
35.3	6.44	6.42	6.24	5.88
35.4	2.6	2.58	2.4	2.04

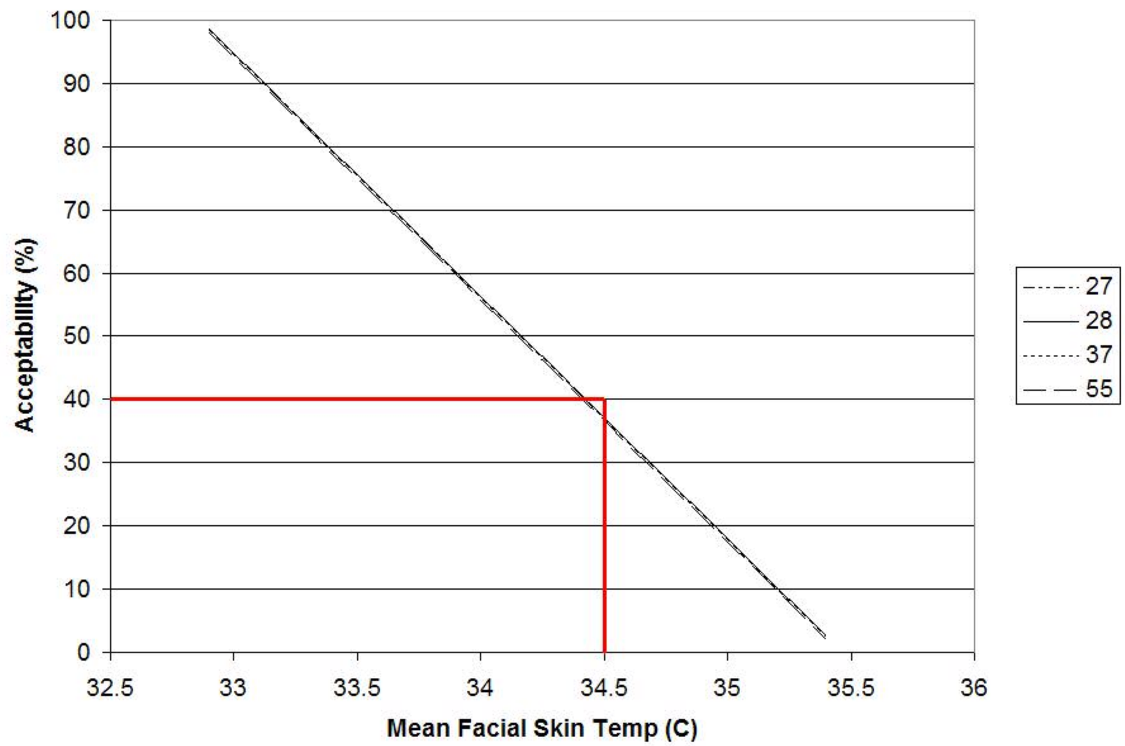

Figure 5-8. Plot of average acceptability vs. average mean facial skin temperature using data from Table 5-5 for the four heat index conditions (n=26).

The results indicated that respirator comfort decreased above a mean facial skin temperature of 34.5°C during exercise conditions, which confirmed the results of Dubois et al. (1990). This information will be useful for employers who may choose to monitor facial skin temperature as an indication of respirator comfort and ultimately, work efficiency.

5.4.4. Mean Facial Skin Temperature versus Time

Figure 5-9 shows the measured data of the mean facial skin temperature as a function of time. The data are found in Tables A2.1. to A2.4. in Appendix 2. The curves show an initial plateau or decline in facial skin temperature followed by a linearly increasing trend. The plateau or decline did not represent significant variation, but the increasing trend was meaningful. A substantial difference between each of the four conditions was not evident; however, the general relationship indicated an increase in facial skin temperature over time. At 37°C, the slope in the linear portion of the data was much higher than that of 55°C. This could be a result of lower performance times during testing at 55°C, during which the mean facial skin temperature never reached a peak.

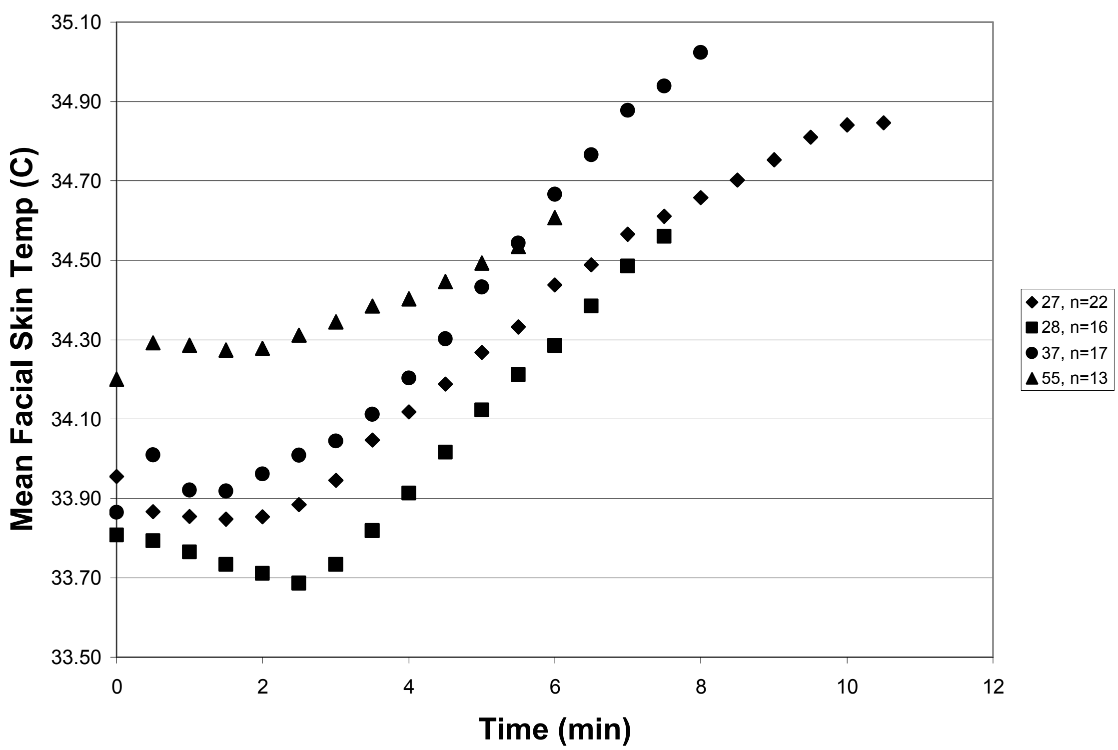

Figure 5-9. Average mean facial skin temperature (°C) vs. time (min) for all four heat index conditions.

5.4.5. Rectal Temperature vs. Mean Facial Skin Temperature

Figure 5-10 shows the fitted relationships between the mean facial skin temperature and rectal temperature. The graph was of value in characterizing the rate of increase of rectal temperature in response to the environmental stimulus. At 27°C, the rectal temperature correlated to mean facial skin temperature ($p<0.05$) with an R^2 value of 0.9775. At 28°C, rectal temperature correlated to mean facial skin temperature ($p<0.05$) with an R^2 value of 0.9139. At 37°C, rectal temperature correlated to mean facial skin temperature ($p<0.05$) with an R^2 value of 0.9472. At 55°C, rectal temperature correlated to mean facial skin temperature ($p<0.05$) with an R^2 value of 0.9395.

As the heat index increased, the temperature range decreased. This was mainly due to the fact that at the higher heat index values where performance time was shorter, less data were collected. At a heat index of 55°C, the slope of the trend was .67. At heat index values of 37°C and 28°C, the slope was .31. At a heat index of 27°C, the slope was .47. This indicated that mean facial skin temperature and rectal temperature increased independently of the environmental condition.

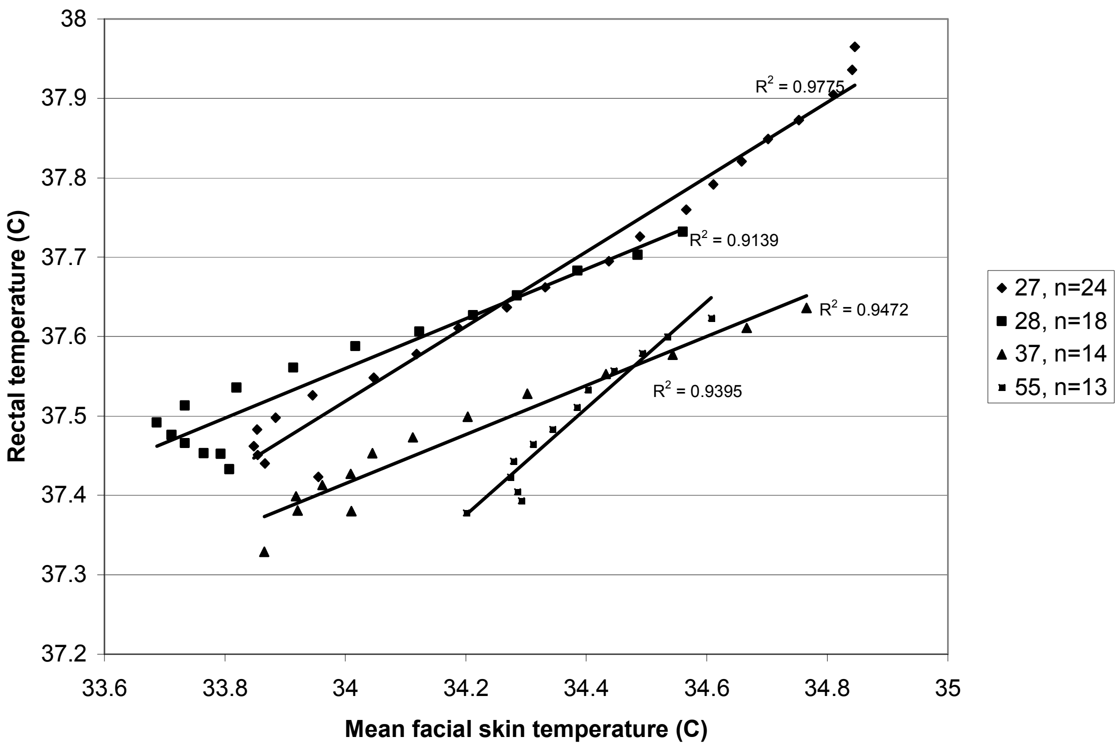

Figure 5-10. Average rectal temperature vs. average mean facial skin temperature for all four heat index values as well original data points.

5.5. *Analysis of Factors Affecting C_1*

Parameter C_1 from Equation 5-3 was found to vary among data representing different subjects and test conditions. Several surveys (section 2.8) were administered to the subjects and analysis of these surveys resulted in numerical values that varied according to the responses of the subject. Responses to the surveys are in Tables A6.1. to A6.5 in Appendix 6. In order to determine variants on which C_1 depended, a series of graphical procedures was undertaken. These plots (Figures A7.1. to A7.9) are in Appendix 7. A relationship was not evident between C_1 and all survey parameters; C_1 did have a relationship with minute volume, the sensing-intuition (SN) personality characteristic, and respirator familiarity. The relationship between C_1 and minute volume was the first of these.

5.5.1. C_1 versus Minute Volume

Minute volume for each of the subjects is located in Table A1.2. in Appendix 1. This value represents the minute volume recorded for each subject at the work rate corresponding to 65-70% of their VO_2max as determined during the VO_2max test.

Figure 5-11 shows the relationship between the C_1 and minute volume (V_e). Minute volume was essentially a measure of a person's capacity to breathe air, and it was measured in liters of air inspired per minute. Larger individuals and those individuals who were very physically active typically had higher minute volumes than those who were smaller and less physically active. Figure 5-11 indicates that females typically had lower minute volumes than the men at their particular work rate as a percentage of

VO_2max during the study, and that a slight relationship existed between C_1 and V_e for the men. The data shown in Figure 5-11 suggested an increase in C_1 with increasing V_e.

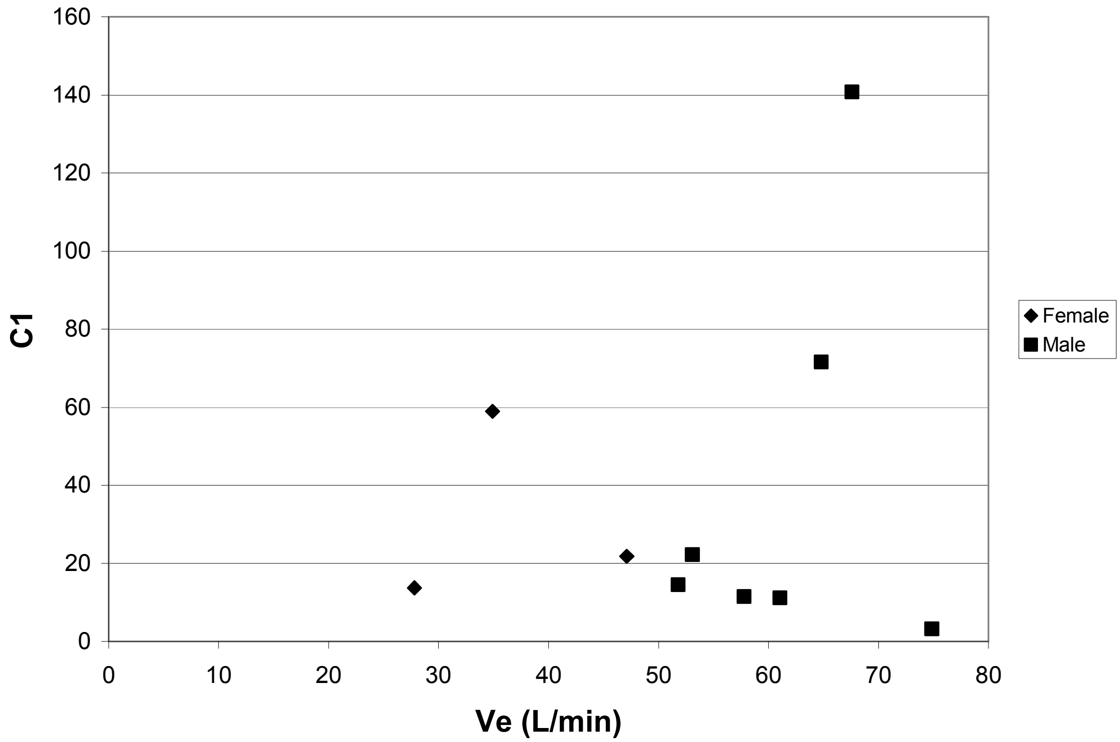

Figure 5-11. C_1 (from Equation 5-3) vs. V_e for female and male subjects (n=10).

5.5.2. C_1 versus SN

Figure 5-12 shows the relationship between C_1 and the Sensing-Intuition (SN) parameter from the MBTI assessment. The results indicated that those with higher C_1 values also exhibited a lower tendency to have sensing characteristics, and instead had higher intuitive characteristics.

According to Figure 5-12, having more intuitive characteristics should increase the propensity of that individual to fit the initial PT-HI model (Equation 5-3); however, the opposite result was expected. When modeled collectively (Equation 5-9), C_1 and SN showed a positive relationship instead of a negative one.

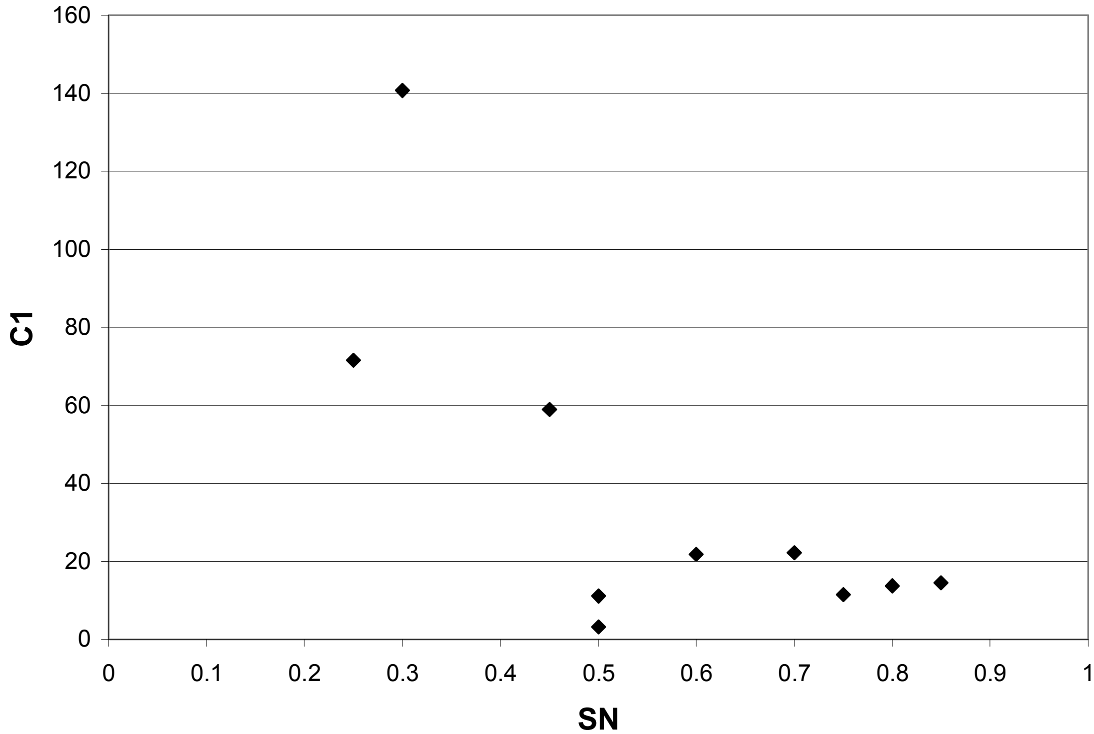

Figure 5-12. The relationship between the model coefficient C_1 (from Equation 5-3) and SN for all subjects (n=10).

The negative relationship of this bivariate plot was misleading because other more dominant variables also influenced the value of C_1.

5.5.3. C_1 vs. Respirator Familiarity

Respirator familiarity was quantified as the number of times an individual had worn the respirator while performing manual labor prior to the research study. Figure 5-13 shows the relationship between C_1 and respirator familiarity. As an individual became more familiar with the respirator, they were also more inclined to have a better fit with the PT-HI model, which was indicated by a higher C_1 value.

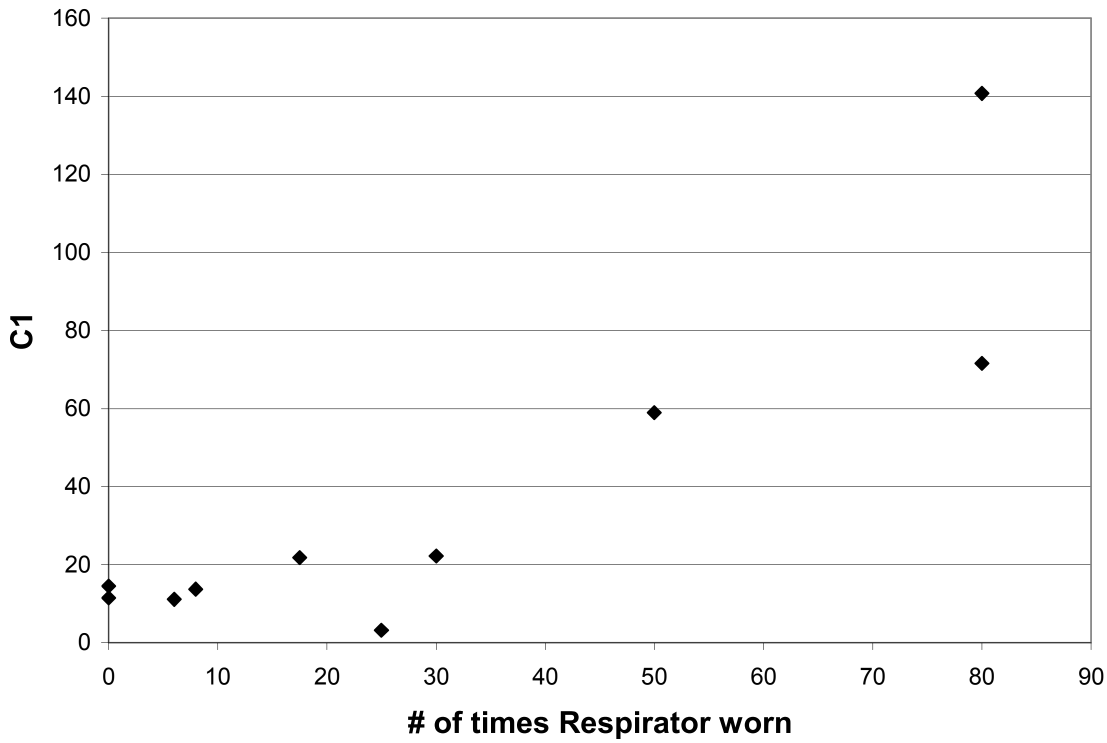

Figure 5-13. The relationship between the model coefficient C_1 (from Equation 5-3) and Respirator Familiarity for all subjects (n=10).

5.6. *Collective PT-HI model*

In reviewing the fitted coefficients of the original model (Equation 5-3) and knowing the subjects, it was evident that variations of the coefficients were related to characteristics of the subject. In order to assess this variation, a number of parameters were analyzed, three of which showed strong correlations with the original model coefficients. These parameters included psychological type, respirator familiarity, and minute volume.

The performance time-heat index model was modified to include the sensing-intuition (SN) psychological parameter, the number of times the respirator was worn prior to the study (RF), and the minute volume (V_e). This collective model accounted for the variations in performance times among each of the subjects and provided accurate reproductions of the performance time.

In order to predict performance time according to the heat index of environmental conditions, an empirical model was fit to the data collected from each testing session using the numerical least squares technique. Graphing the data indicated that the structure of the model was nonlinear and that performance time was negatively correlated with the heat index of the environmental condition. A significant amount of variation existed between the subjects as evidenced from the differences between C_1 from Equation 5-3. Thus, in order to obtain an accurate model for performance time, several parameters were evaluated using surveys to determine how each affected the performance time. The parameters chosen that affected C_1 were minute volume (V_e), the Sensing-Intuition characteristic (SN), the number of times the respirator was worn (RF), and the heat index (HI). The general form of the model is as follows, and model results are in Table 5-6:

$$PT = \alpha_1 V_e^{\alpha_2} e^{\alpha_3 * SN} e^{\alpha_4 * RF} e^{\alpha_5 * HI} \qquad (5\text{-}9)$$

where PT=performance time (min), α_1, α_2, α_3, α_4, and α_5 are model coefficients, V_e=minute volume (L/min), SN=sensing-intuition parameter, RF= number of times the respirator was worn, and HI=heat index (°C)

Table 5-6. Performance time model results from Equation 5-9.

n	e/y	S_e	S_e/S_y	R	α_1	α_2	α_3	α_4	α_5
40	-0.004	4.15	0.6141	0.8161	14.86	-0.1243	1.293	0.01624	-0.0198

(n= sample size, e/y = bias, S_e = standard error of the estimate, S_e/S_y = prediction accuracy, R = correlation coefficient, α_1, α_2, α_3, α_4, and α_5 are model coefficients)

In reviewing the residuals of the model, the prediction accuracy and goodness of fit statistics were improved over those shown in Table 5-3 from Equation 5-3. While the goodness of fit statistics were not as good as they could be, they indicated that a collective model to include all subjects as well as other significant parameters was a good representation of the PT-HI process.

Some of the subjects had performance times that did not vary greatly with a change in the heat index of the environmental conditions. Initially, the majority of subjects had poor goodness of fit statistics, with Se/Sy values above 1.0 and correlation values close to zero. However, when the subjects were modeled collectively as a function of V_e, SN, RF, and HI, the explained variation rose substantially.

The individual effects of each variable are shown in Table 5-7. Performance time was calculated over a range of each variable while holding the other variables at mean values.

Table 5-7. Performance time (min) predictions from Equation 5-9 for values of V_e (L/min), SN (ratio), RF (number of times respirator worn), and HI (°C)

Ve	PT (min)
20	16.08
30	15.29
40	14.75
50	14.35
60	14.03
70	13.76
80	13.53

SN	PT (min)
0.2	8.47
0.3	9.64
0.4	10.97
0.5	12.49
0.6	14.21
0.7	16.17
0.8	18.41
0.9	20.95

RF	PT (min)
0	8.73
10	10.27
20	12.08
30	14.21
40	16.72
50	19.67
60	23.13
70	27.21
80	32.01

HI	PT (min)
25	19.51
30	17.67
35	16.01
40	14.50
45	13.13
50	11.89
55	10.77

To show the effect of each variable, the model (Equation 5-9) was used to develop plots of each variable. The values of the four variables were varied over the approximate range of the measured data. The range of the computed values of performance time shown in the graphs suggested the importance of that variable. Figures 5-14 through 5-17 include estimations of performance time for each parameter listed in Table 5-7.

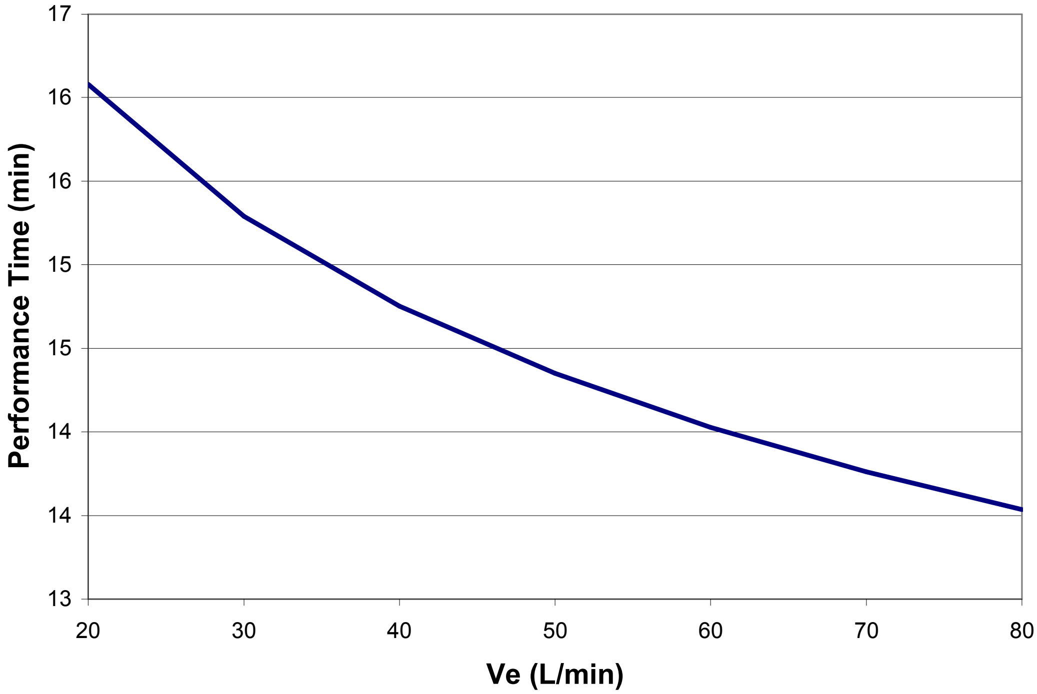

Figure 5-14. Performance time (minutes) vs. V_e (L/min) computed from Equation 5-9.

Performance time decreased with an increase in an individual's minute volume (V_e). This may be explained by differences in size, sex, and level of physical activity. Minute volume is the amount of air an individual inhales per minute. Typically, a person who is of smaller stature has a lower minute volume since their lung capacity and need for air are smaller. Furthermore, larger individuals may have different heat transfer characteristics from their bodies than someone who is of smaller stature. Thus, someone with a smaller minute volume probably is not going to feel the effects of an extreme environmental condition as intensely as a person who inhales a great deal of air per breath.

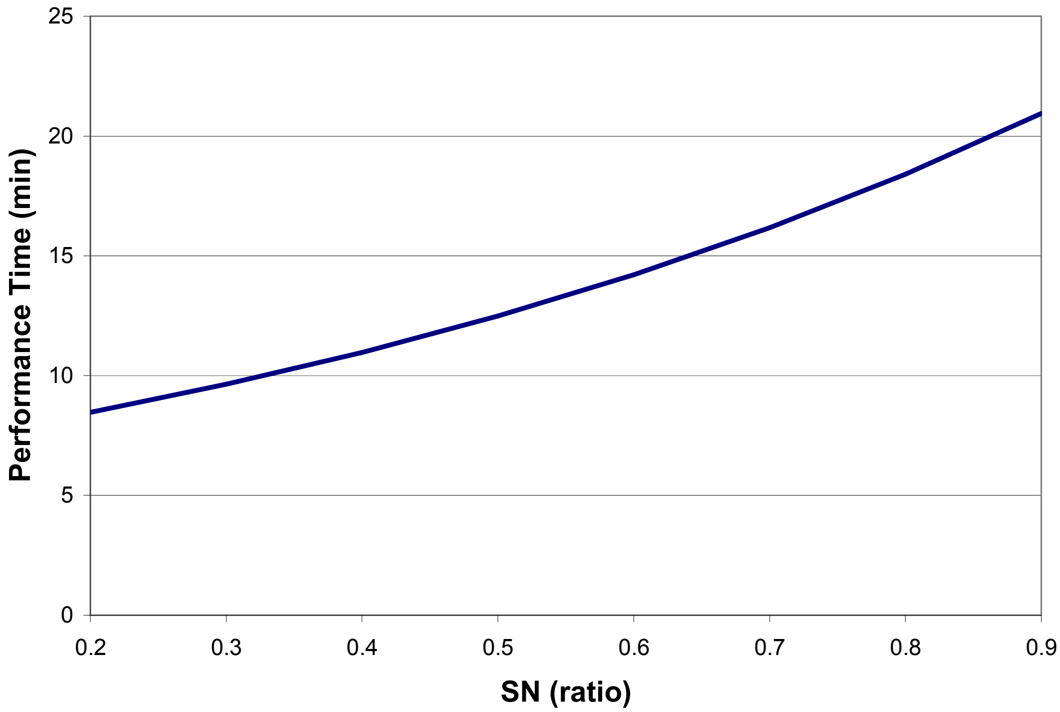

Figure 5-15. Performance time (minutes) vs. the sensing-intuition (SN) parameter computed from Equation 5-9.

When modeled collectively in Equation 5-9, SN showed a positive relationship with performance time. Performance time increased with an individual's propensity to a higher SN ratio as determined from the MBTI assessment. A person with a high ratio of SN possessed more sensing (S) characteristics as compared to intuition (N) characteristics. This individual is likely to deal in facts and has an attitude that places emphasis on the present, rather than the future. This individual tends to focus on activities at hand. Because the N-type person is generally a daydreamer, they lack focus on activities in the present. Therefore, performance time was expected to increase with an increase in values of SN, and the model coefficient related to SN showed the expected trend. This relationship seems rational, since a person who thinks about current activities is more likely to stay focused on their performance and tends to have a longer performance time than a person who is already thinking about their next task.

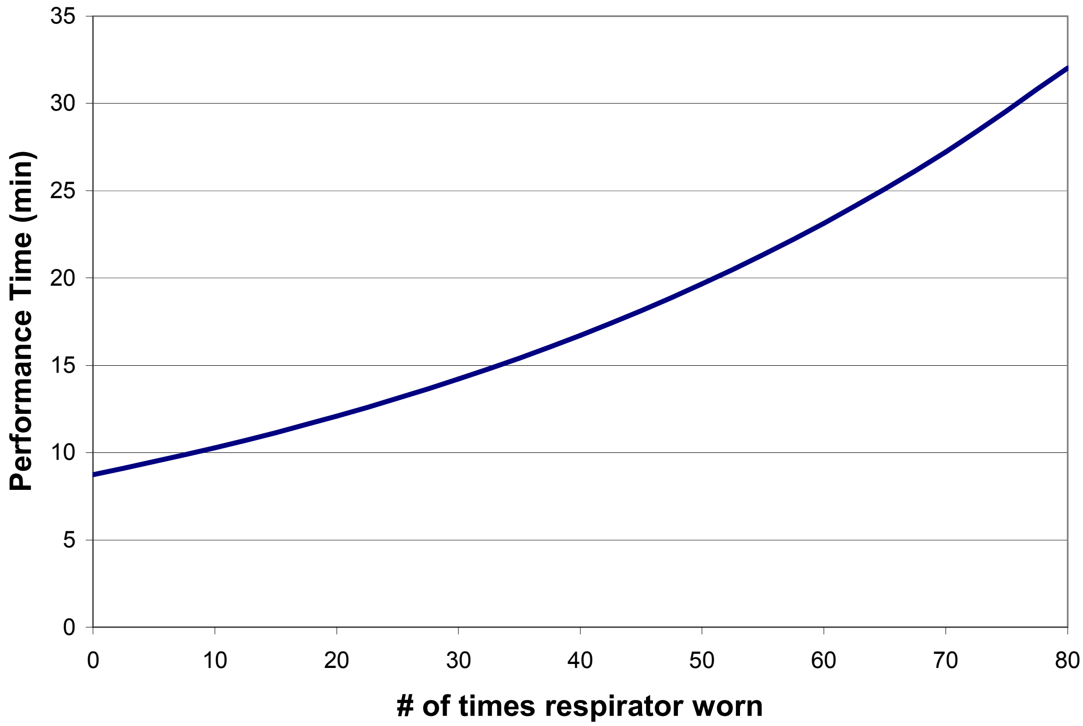

Figure 5-16. Performance time (min) vs. the number of times of the respirator was worn during manual labor prior to the current study computed from Equation 5-9.

Each of the subjects was asked to disclose the number of times he or she had previously worn the respirator while performing manual labor prior to participation in the current study. This number was used to quantify an individual's level of familiarity with the respirator. According to the results from Figure 5-16, an increase in respirator familiarity increased a person's performance time at any given environmental condition.

An individual's confidence in a test condition directly influences their performance. An individual's familiarity with the respirator mask imparts confidence in their ability to perform while wearing a mask. Respirator masks are uncomfortable due to the design components necessary for adequate protection; a person who is familiar with this discomfort likely performs better than a person who is not familiar with the respirator. The novice can be overwhelmed by the discomfort and has uncertain expectations. This lack of confidence likely leads to a lower level of performance. Someone who has worn the respirator repeatedly while performing physical labor will likely push through the discomfort and only terminate because of the limitations the environmental condition placed upon them.

Performance time decreased with an increase in the heat index of an environmental condition. The decay coefficient of the heat index component of the model exhibited the expected direction.

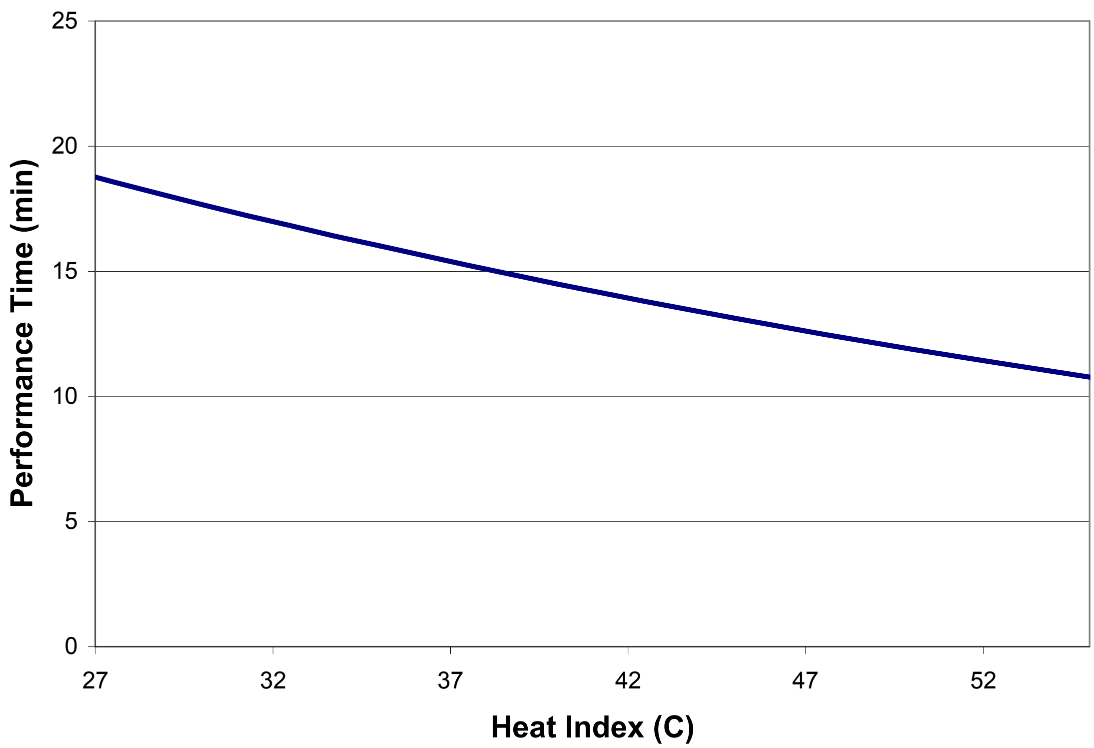

Figure 5-17. Performance time (minutes) as a function of the heat index (°C) of the environmental condition computed from Equation 5-9.

Figure 5-17 shows the range of PT for a range of heat indices while holding the other variables at their means. This result was expected since exercising in a very warm, humid environment compared to one that was cooler and less humid stressed the subject on a number of levels, forcing them to terminate sooner. Inside the respirator mask, evaporation was inhibited, leading to a build-up of saturated air from the respiratory system. This increased facial skin temperature, making the subject feel unbearably warm. Furthermore, breathing humid air in comparison to air that was less humid put a strain on the respiratory system, perhaps forcing labored breathing and a feeling of suffocation. All subjects felt as though they were hyperventilating and were not getting enough air during the warmest condition, citing difficult breathing as the reason for termination.

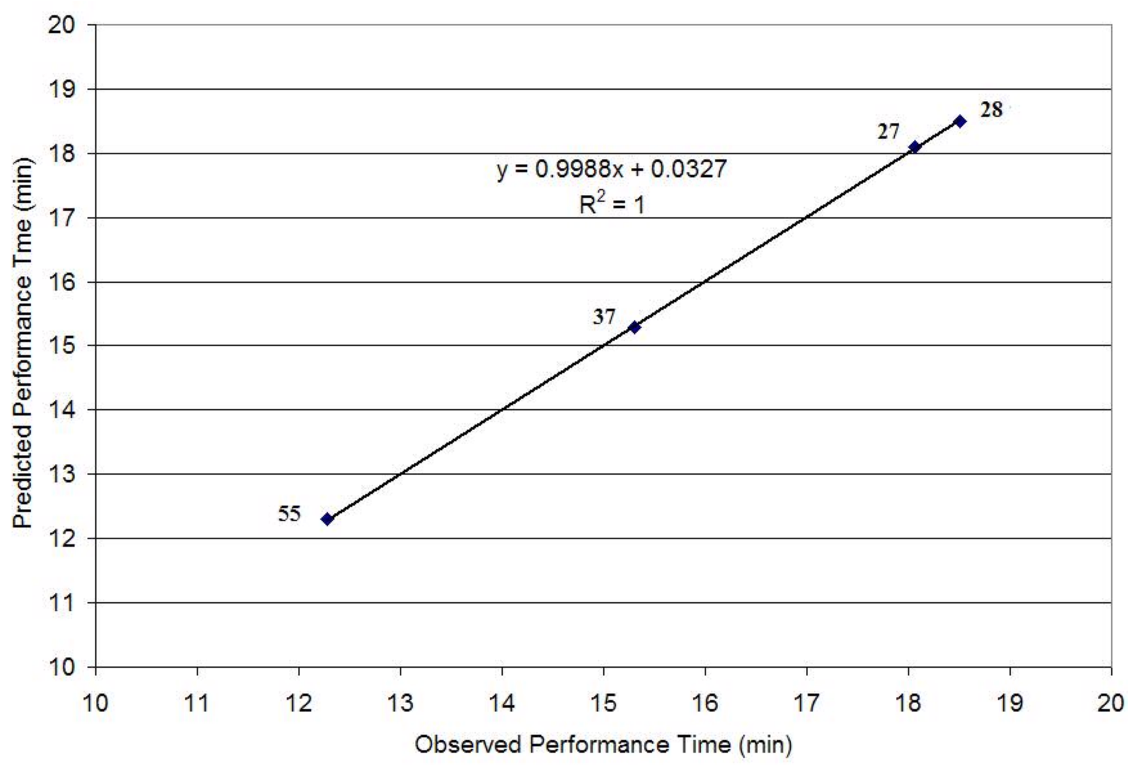

Figure 5-18. Predicted performance time (n=4) vs. observed performance time (n=4) at the four heat index conditions. Each observed performance time is an average of the performance times for ten subjects.

Figure 5-18 shows the trend for predicted performance times from the model (Equation 5-9) versus average values of the observed performance times. The R^2 value was 1.0 indicating a good linear relationship. The slope was 0.99, indicating that the model predicts performance time well. Table 5-8 displays the observed and predicted values for performance time.

Table 5-8. Predicted performance time values (min) and observed average performance time values (min) for ten subjects.

HI (°C)	Predicted PT (min)	Observed PT (min)
27	18.1	18.1
28	18.5	18.5
37	15.3	15.3
55	12.3	12.3

The model (Equation 5-9) will be useful for manufacturers because it can help them to design respirators appropriate for the locations and environments under which they will be used. This may include attaching motorized blowers with more efficient filters to lower the humidity inspired by the user or designing masks with enhanced evaporative cooling.

Such a model would be useful for employers to determine the factors that contribute to the detriment of performance time as the inspired air conditions become warmer and more humid. Employers may use the model for pre-screening purposes and for determining how long they can expect their employees to perform efficient work. Knowledge of an individual's V_e, familiarity with the respirator, and/or SN-type personality, can allow employers to gauge the performance time of workers under a variety of environmental conditions.

The PT-HI model (Equation 5-9) predicts performance time across a range of heat indices; however, the performance time values are all less than 20 minutes. While an individual may not stop working after this time, they may remove the respirator, exposing them to toxic substances. Employers must be aware that this is occurring, and thus they may choose to allocate their human resources more effectively.

Furthermore, the model would be useful in respirator training programs to help illustrate expected performance. Ultimately, the model can result in increased comfort of respirators, better work efficiency, and less injury and heat related illness of respirator users.

The PT-HI model (Equation 5-9) should be used with some caution. The R value was 0.82, meaning that performance time can not always be accurately predicted from V_e, RF, SN, or HI. An R value closer to 1.0 would be indicative of a better model; including more parameters to better explain the variation among subjects would likely achieve this. However, the collective model (Equation 5-9) had better prediction accuracy than the original model that included only the heat index as evidenced in Table 5-3. This is an indication that data relative to individual subject characteristics must be collected in order to explain the performance of individuals performing work in warm, humid environments.

5.6.1. Sensitivity Analysis of the PT-HI model (Equation 5-9)

The performance time model of Equation 5-9 included four variables, each representing a different characteristic of the system. The four predictor variables represented the environmental conditions (HI) of the test, the experience (RF) of the subject, the physiological stature (V_e) of the subject, and the psychological nature (SN) of the subject. To assess the importance of these four factors, a relative sensitivity analysis of the PT-HI model (Equation 5-9) was made. The four relative sensitivity functions are as follows:

$$\delta PT/\delta V_e * V_e/PT = \alpha_2 \quad (5\text{-}10)$$

$$\delta PT/\delta SN * SN/PT = \alpha_3 SN \quad (5\text{-}11)$$

$$\delta PT/\delta R * RF/PT = \alpha_4 RF \quad (5\text{-}12)$$

$$\delta PT/\delta HI * HI/PT = \alpha_5 HI \quad (5\text{-}13)$$

where the coefficients α_2, α_3, α_4, and α_5 are the values given in Equation 5-9.

While the relative sensitivity functions can be evaluated at any level of a variable, the mean values are most commonly used. Based on the data for the ten subjects of this research, the results of a sensitivity analysis are summarized in Table 5-8. The results showed that the environmental (HI) and psychological (SN) factors were the most important, with relative sensitivities of more than 80%. Experience with the respirator (RF) was less important, but a 1% increase in respirator use will lead to about a 0.5% increase in PT. The physiological factor (V_e) was the least important, but it was still important, with a relative sensitivity of about 30%. The relative sensitivities appeared to give rational indications of the relative importance of the four predictors and general intent of the effects.

Table 5-9. Relative sensitivity analysis of the PT-HI model (Equation 5-9).

Variable	Mean	PT Model Coefficient	Model form	Relative Sensitivity Function	Relative Sensitivity
SN	0.57	1.561	exponential	α_3SN	0.89
HI	36.75	-0.0231	exponential	α_5HI	-0.849
R	29.65	-0.0183	exponential	α_4RF	0.542
V_e	54.08	-0.315	power	α_2	-0.3165

Chapter 6: Conclusions

- Performance time correlated strongly with V_e, SN, RF, and HI. Physiological variables such as rectal temperature and facial skin temperature did not vary significantly with the change in the environmental conditions.
- A sensitivity analysis of the PT-HI model indicated that the most important predictors of performance were the heat index and personality type, followed by respirator familiarity, then minute volume.
- Individual subject characteristics were more important than physiological variables as predictors of performance times.
- The respirator became uncomfortable above a mean facial skin temperature of 34.5°C
- Times to reach various levels of acceptability at the environmental conditions were determined

Chapter 7: Recommendations for Further Research

7.1 Equipment

During the course of the research several problems with the environmental chambers arose. Because they were several years old, the compressors and chillers failed repeatedly and this forced testing to be delayed for several months. A solution to this problem would be to design a suitable environmental chamber that could supply warm humid air to the respirator mask and obtain equipment that would perform properly.

The humidity chamber could be constructed similar to the device (Figure 2-1) built by Gwosdow et al. (1989), with some modifications made to enhance the ability of the air to become saturated more quickly. Furthermore, the device should be capable of supplying the subject with the appropriate flow rates conducive to moderate intensity exercise. According to Wilmore (2004), the maximum peak flow rate of large men is on the order of 100 L/min, although the average flow rate is around 24 L/min.

A Plexiglas chamber would be filled with the volume of water needed to supply the specified humidity and air temperature within the chamber. A heating component capable of controlling the temperature of the system would consist of several coils. Insulated tubing would connect the outlet of the humidity chamber with the inlet of the respirator mask in order to minimize heat losses. A fan system should be used to push air into the chamber, which would pass through a series of grids on the lid of the chamber to allow the air to pass through slowly, and thus, allow for maximum saturation to occur.

The outlet of the chamber should be connected directly to an insulated hose, which in turn, connects to the inspiratory valve of the respirator. A suitable system designed to deliver warm humid air to the respirator mask would be another suitable method for subject testing considering the equipment problems experienced with the commercial environmental chambers used for this research.

The temperature and humidity sensors used to monitor expired air inside the respirator masks were not sufficiently quick to display instantaneously the temperature and humidity. However, the sensor did reflect a relative change in temperature and humidity over the course of the testing session. A sensor capable of displaying breath by breath changes in temperature and humidity would be preferred in order to separate and calculate heat losses from the face and respiratory system.

7.2 Subject Effort

Performance time was directly related to subject effort, which may be a function of several variables. Since performance time was the independent variable in the model, it was necessary to attempt to explain the variables that may influence subject effort. The inability to control the subject effort can introduce significant errors into the data collected. Subject effort variables include, but are not limited to, subject motivation, familiarity with the respirator, level of physical fitness, emotional state prior to testing, and personality type. If each of these variables could be controlled, a more accurate model could be developed.

Subject motivation may arguably be the strongest predictor for how well a person is able to perform work; however, it is also the hardest to quantitatively measure.

Existing indices are purely subjective and may be a function of the person's mood, overall attitude, physical health, stress level, and diet. A questionnaire could be administered to measure a person's motivation based on the aforementioned factors, but it is likely to change on a daily basis and thus must be administered before each testing session. A quantitative score should be given to each subject for each testing session completed in order to measure their personal motivation for performing the work. It may also be necessary to administer a second test immediately after testing to determine if the subject's motivation has waned, as it may for an intuitive (N) personality type.

Four out of the 10 subjects tested for this study were unfamiliar with wearing the respirator. In other words, they had worn a respirator less than 10 times while performing physical labor. Because a respirator is uncomfortable to begin with, a person who is not familiar with this feeling may be more inclined to terminate because of this discomfort before the effects of the environmental condition can be felt. Furthermore, one of the subjects tested was very familiar with the respirator. He was a member of the armed forces for 7 years, and frequently donned the respirator for several hours at a time in extreme environmental conditions. During this time, regardless of the discomfort, he was unable to remove the respirator and was forced to endure the condition. Therefore, during testing he pushed through each of the conditions with relative ease and did not cite the conditions as his reason for termination.

The remaining five subjects had worn the respirator several times while exercising in previous studies in the lab and were, therefore, moderately familiar with the discomfort of wearing a respirator. Attempting to quantify the familiarity with wearing a respirator may help to explain the performance time of each individual. Therefore, research is needed to more accurately quantify respirator mask familiarity as a predictor.

A third factor that may be related to subject effort is the level of physical fitness. The body temperature of a person who is out of shape may increase more rapidly. The person may become dehydrated more quickly and may be inclined to terminate sooner than someone who is more physically fit. A quantitative measure of a person's physical fitness level would help to explain differences in performance time under each of the testing conditions. This measure may include the duration and frequency of exercise and type of exercise performed.

7.3. Research Methods

It is imperative to obtain an accurate representation of the population when performing a research study. The number of subjects affects the accuracy of conclusions made from the measured data, with accuracy increasing with the sample size. However, it is also important to ensure that subjects show variability in the important factors. Both the sample size and the variability inherent to the data collected determine knowledge gained from the data analysis. While only ten subjects were tested in this research, the subjects varied in physical fitness, personality type, aerobic capacity, and mask familiarity. This enabled the research to identify important relationships. However, more knowledge about the population could be gained by testing more subjects. These subjects should include equal numbers of men and women, they should represent all levels of physical fitness, and represent both subjects who are familiar with wearing a respirator and those who are unfamiliar with wearing a respirator. By including subjects with diverse characteristics the analyses are more likely to detect the true effects of the inputs. Furthermore, in order to validate the model, more tests on the ten subjects who participated in the study are needed.

Since each subject has a different VO_2max, V_e, and tidal volume (V_t), it is possible that the amount of oxygen utilized and amount of air intake per minute could help to explain why some subjects terminate sooner than others at each of the testing conditions. For example, some of the larger subjects seemed to be affected by the conditions more so than some of the smaller subjects. This could be a direct function of how much air is being utilized per minute. The larger subjects were perhaps feeling the warm humid conditions sooner and more intensely than the smaller subjects because they were breathing in a larger volume of air per breath. If continuously expired air data were monitored during each testing session, this could provide the researcher with more information regarding the relationship between such parameters as minute volume (V_e) and tidal volume (V_t) to performance time under the environmental conditions.

In order to gain a better understanding of each subject's attitude prior to each testing session, a state anxiety test could be administered. This test would give the researcher information on how the subject is feeling that day, and a quantitative score is reported. A low score indicates low anxiety and a high score indicates high anxiety. Since a person feels differently day to day, this score could provide some insight on why a subject performs particularly well on one day, and poorly on the next day, especially when the difference is not related to the change in the environmental condition. Such inconsistency in performance introduces error into the measured data. Such error could mask effects or suggest significant effects that are not accurate.

The performance time – heat index model was developed from exercise in neutral-warm conditions. In order to develop a more accurate model capable of explaining how performance time could be predicted for exercise in cooler environments, three to four cool, dry conditions should be added to the protocol, and the analyses repeated. The model developed indicates a negative correlation between performance time and the heat index of the condition; however, a more accurate indication of the underlying function could be obtained with a wider variation in the data. A parabolic function may be observed if the cooler conditions were included in the protocol.

Appendix 1 (Subject Excel Data)

Table A1.1 Subject Demographics

Subject	Age	Height (in)	Weight (lb)	Sex
001	43	68	205	M
145	35	70	209	M
343	21	70	190	M
358	24	66	142	F
359	26	70	180	M
379	23	65	135	F
401	25	64	110	F
405	21	69	175	M
419	21	68	148	M
420	21	67	165	M
Average	**26**	**67.7**	**165.9**	
St. Dev	**7.3**	**2.2**	**32**	

Table A1.2. VO_2max data

Subject	VO_2 (ml/m/kg)	Ve (L/min)	Vt (L)
145	28.7	67.61	1.64
420	34.2	51.86	1.9
001	25.53	64.79	1.31
419	29.27	51.85	1.28
359	29.26	53.09	1.64
358	22.9	34.93	1.04
379	18.09	27.8	1.02
343	36.42	74.85	1.86
401	36.57	47.12	1.24
405	30.65	61.04	1.27
Average	**29.2**	**53.5**	**1.4**
St. Dev	**5.8**	**14.5**	**0.3**

Table A1.3. Performance Time data

	Condition (ºC)	Performance Time (min)
Subject 001	27	24.12
	28	31.22
	37	15.75
	55	11.75
Subject 145	27	31.75
	28	29.88
	37	18.58
	55	6.5

	Condition (ºC)	Performance Time (min)
Subject 358	27	25.25
	28	26.42
	37	17.17
	55	11.92
Subject 359	27	19.7
	28	23.40
	37	21.20
	55	20.75
Subject 379	27	12.5
	28	13.53
	37	14.25
	55	12.56
Subject 419	27	11.43
	28	10.50
	37	10.11
	55	10.40
Subject 420	27	15
	28	12.56
	37	13.75
	55	13.22
Subject 405	27	10.65
	28	7.63
	37	8.22
	55	7.63
Subject 401	27	18.67
	28	18.58
	37	16.12
	55	15.75
Subject 343	27	11.57
	28	11.32
	37	17.85
	55	

Appendix 2 (Mean Facial Skin Temperature Data)

Table A2.1. Mean facial skin temperature in °C (recorded every 30 seconds) for each subject at a heat index of 27°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	Average
33.50	35.21	34.47	33.16	33.93	33.61	34.83	33.82	32.70	34.32	**33.95**
33.57	35.04	34.53	32.74	33.29	33.74	34.81	34.04	32.80	34.11	**33.87**
33.54	35.06	34.61	32.68	33.18	33.74	34.75	34.06	32.80	34.12	**33.85**
33.52	35.07	34.72	32.66	33.05	33.73	34.72	34.06	32.82	34.14	**33.85**
33.40	35.11	34.89	32.59	32.98	33.73	34.71	34.06	32.92	34.15	**33.85**
33.36	35.13	35.08	32.52	32.91	33.72	34.72	34.07	33.01	34.33	**33.88**
33.39	35.15	35.23	32.49	32.94	33.72	34.73	34.18	33.14	34.50	**33.95**
33.46	35.22	35.39	32.62	32.92	33.78	34.74	34.30	33.31	34.72	**34.05**
33.65	35.26	35.51	32.37	32.90	33.82	34.79	34.35	33.55	34.98	**34.12**
33.88	35.28	35.57	32.28	32.85	33.93	34.83	34.38	33.72	35.17	**34.19**
34.17	35.28	35.69	32.28	32.83	34.01	34.84	34.47	33.82	35.29	**34.27**
34.47	35.30	35.69	32.28	32.83	34.06	34.88	34.54	33.93	35.34	**34.33**
34.78	35.30	35.92	32.39	32.82	34.21	34.89	34.64	34.03	35.39	**34.44**
34.99	35.22	35.89	32.47	32.76	34.30	34.92	34.76	34.14	35.44	**34.49**
35.18	35.17	35.94	32.61	32.73	34.49	34.96	34.87	34.23	35.49	**34.57**
35.32	35.14	35.96	32.71	32.70	34.63	34.94	34.86	34.35	35.49	**34.61**
35.44	35.10	35.97	32.53	32.69	34.88	34.97	35.03	34.44	35.53	**34.66**
35.52	35.18	35.97	32.54	32.65	35.05	35.00	35.14	34.43	35.52	**34.70**
35.57	35.25	36.02	32.53	32.67	35.19	35.05	35.21	34.50	35.53	**34.75**
35.60	35.39	36.04	32.59	32.70	35.34	35.08	35.23	34.56	35.56	**34.81**
35.62	35.44	36.09	32.66	32.75	35.43	34.92	35.27	34.60	35.63	**34.84**
35.63	35.51	36.13	32.56	32.70	35.45	34.75	35.33	34.70	35.69	**34.85**
35.66	35.53	36.16	32.54	32.77	35.60	34.61		34.70	35.83	**34.82**
35.69	35.58		32.58	32.85	35.74	34.52		34.69	35.93	**34.70**
35.72	35.67		32.64	32.83	35.84	34.46			36.00	**34.74**
35.76	35.75		32.54	32.88	35.90	34.31			36.07	**34.74**
35.79	35.83		32.54	32.96		34.30			36.11	**34.59**
35.86	35.95		32.65	32.95		34.30			36.12	**34.64**
35.91	35.97		32.64	32.98		34.41			36.21	**34.69**
35.92	36.03		32.70	33.02		34.36			36.26	**34.71**
35.96	36.03		32.80	33.09		34.30				**34.43**
35.87	36.08		32.72	33.27		34.20				**34.43**
35.87	36.10		32.82	33.31		34.13				**34.44**
35.97	36.11		32.88	33.43		34.13				**34.50**

Subject Number										
001	145	343	358	359	379	401	405	419	420	Average
36.02	36.19		32.98	33.27		34.10				**34.51**
36.01	36.22		32.98	33.42		34.09				**34.55**
35.93	36.32		33.00	33.44		34.14				**34.57**
35.99	36.36		32.96	33.40						**34.68**
36.06	36.40		33.08	33.52						**34.77**
36.06	36.44		33.13	33.54						**34.79**
36.06	36.47		33.21							**35.25**
35.92	36.48		33.21							**35.20**
35.95	36.48		33.27							**35.23**
35.90	36.51		33.35							**35.25**
35.98	36.57		33.47							**35.34**
35.96	36.64		33.55							**35.38**
35.99	36.65									**36.32**
35.75	36.69									**36.22**
35.66	36.70									**36.18**
	36.71									**36.71**
	36.71									**36.71**
	36.71									**36.71**
	36.72									**36.72**
	36.73									**36.73**
	36.78									**36.78**
	36.82									**36.82**
	36.83									**36.83**
	36.86									**36.86**
	36.89									**36.89**
	36.91									**36.91**
	36.96									**36.96**
	36.95									**36.95**
	37.00									**37.00**
	36.96									**36.96**

Table A2.2. Mean facial skin temperature in °C (recorded every 30 seconds) for each subject at a heat index of 28°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
32.50	34.90	33.94	32.49	34.23	34.39	34.81	33.79	32.97	34.05	**33.81**
32.64	34.93	33.73	32.70	34.01	34.13	34.82	34.00	32.85	34.10	**33.79**
32.63	34.94	33.65	32.66	33.90	34.03	34.80	34.03	32.92	34.10	**33.76**
32.58	34.92	33.58	32.62	33.79	33.92	34.81	34.08	32.95	34.09	**33.73**
32.53	34.91	33.55	32.61	33.70	33.81	34.81	34.11	32.97	34.11	**33.71**
32.49	34.92	33.43	32.56	33.55	33.76	34.81	34.14	32.99	34.22	**33.69**
32.47	34.97	33.64	32.48	33.40	33.72	34.81	34.26	33.12	34.47	**33.73**
32.55	34.99	33.75	32.49	33.44	33.75	34.79	34.38	33.36	34.70	**33.82**
32.71	35.05	33.81	32.44	33.33	33.80	34.78	34.55	33.83	34.85	**33.91**
33.07	35.12	34.07	32.30	33.27	33.88	34.74	34.66	34.04	35.03	**34.02**

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
33.36	35.17	34.24	32.26	33.24	33.99	34.73	34.80	34.24	35.19	**34.12**
33.62	35.19	34.52	32.20	33.22	34.15	34.72	34.93	34.29	35.27	**34.21**
33.89	35.18	34.40	32.39	33.26	34.32	34.74	34.97	34.38	35.33	**34.28**
34.10	35.18	34.60	32.45	33.37	34.44	34.74	35.02	34.54	35.40	**34.39**
34.30	35.27	34.69	32.59	33.43	34.58	34.76	35.11	34.65	35.49	**34.49**
34.48	35.29	34.73	32.80	33.39	34.71	34.77	35.15	34.72	35.57	**34.56**
34.65	35.33	34.69	32.91	33.58	34.84	34.82		34.69	35.63	**34.57**
34.85	35.37	34.72	32.71	33.64	34.89	34.85		34.73	35.69	**34.60**
35.00	35.38	34.87	33.05	33.64	35.03	34.88		34.83	35.76	**34.71**
35.07	35.34	34.95	33.16	33.72	35.16	34.91		34.87	35.86	**34.78**
35.23	35.38	34.95	33.08	33.81	35.33	34.94		34.93	35.98	**34.85**
35.35	35.48	35.13	33.03	33.80	35.46	34.97		35.01	36.06	**34.92**
35.42	35.48	35.06	33.14	33.77	35.64	35.01				**34.79**
35.48	35.49		33.21	33.81	35.75	35.01				**34.79**
35.57	35.56		33.27	33.86	35.88	35.00				**34.86**
35.59	35.58		33.27	33.88	35.92	34.92				**34.86**
35.67	35.60		33.23	33.94	36.07	34.76				**34.88**
35.76	35.62		33.38	33.99	36.14	34.89				**34.96**
35.77	35.62		33.36	34.06		34.95				**34.75**
35.78	35.61		33.24	34.21		34.73				**34.72**
35.79	35.63		33.33	34.30		34.62				**34.73**
35.84	35.67		33.40	34.46		34.55				**34.78**
35.88	35.69		33.58	34.50		34.52				**34.83**
35.93	35.70		33.45	34.51		34.55				**34.83**
35.95	35.74		33.34	34.57		34.53				**34.82**
35.94	35.78		33.40	34.64		34.82				**34.92**
35.89	35.79		33.57	34.58		34.84				**34.94**
35.85	35.83		33.58	34.69		34.88				**34.97**
35.86	35.86		33.52	34.70						**34.99**
35.89	35.85		33.59	34.80						**35.03**
35.96	35.78		33.67	34.79						**35.05**
35.99	35.78		33.82	34.92						**35.13**
36.05	35.79		33.65	34.84						**35.08**
36.13	35.83		33.87	34.85						**35.17**
36.18	35.77		33.85	34.85						**35.16**
36.21	35.78		33.85	34.86						**35.18**
36.23	35.74		33.89	34.93						**35.20**
36.25	35.87		33.72							**35.28**
36.26	35.90		33.76							**35.31**
36.25	35.96		33.90							**35.37**
36.25	35.95		33.95							**35.38**
36.24	35.97		34.04							**35.42**
36.26	35.92		34.19							**35.46**
36.29	36.00									**36.15**
36.35	36.09									**36.22**
36.34	36.09									**36.22**
36.36	36.11									**36.23**
36.38	36.18									**36.28**

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
36.40	36.20									**36.30**
36.39	36.18									**36.28**
36.39										**36.39**
36.35										**36.35**
36.32										**36.32**
36.36										**36.36**
36.32										**36.32**
36.37										**36.37**
36.41										**36.41**

Table A2.3. Mean facial skin temperature in °C (recorded every 30 seconds) for each subject at a heat index of 37°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
32.66	34.81	33.13	34.47	33.81	34.01	34.47	33.59	33.66	34.05	**33.87**
32.81	34.82		34.59	33.60	34.15	34.46	33.81	33.69	34.17	**34.01**
32.81	34.90	33.14	34.47	33.50	34.10	34.47	33.90	33.69	34.20	**33.92**
32.80	34.97	33.03	34.43	33.41	34.06	34.52	34.02	33.74	34.21	**33.92**
32.77	35.08	33.40	34.40	33.30	33.98	34.54	34.20	33.77	34.18	**33.96**
32.75	35.17	33.78	34.32	33.19	33.94	34.54	34.43	33.75	34.22	**34.01**
32.73	35.29	33.98	34.27	33.05	33.85	34.57	34.61	33.81	34.28	**34.05**
32.72	35.36	34.10	34.27	33.02	33.70	34.60	34.85	33.97	34.52	**34.11**
32.87	35.46	34.31	34.26	32.90	33.67	34.62	35.04	34.11	34.78	**34.20**
33.03	35.55	34.55	34.27	32.78	33.70	34.61	35.12	34.31	35.11	**34.30**
33.31	35.60	34.76	34.52	32.73	33.81	34.57	35.22	34.48	35.33	**34.43**
33.63	35.65	34.73	34.74	32.72	33.90	34.55	35.35	34.61	35.57	**34.54**
33.92	35.71	34.83	34.94	32.72	34.08	34.57	35.43	34.81	35.65	**34.67**
34.16	35.76	35.00	35.03	32.71	34.32	34.59	35.51	34.87	35.71	**34.77**
34.42	35.77	34.99	35.22	32.83	34.59	34.61	35.61	34.95	35.79	**34.88**
34.61	35.78	34.92	35.27	32.92	34.78	34.57	35.66	35.06	35.82	**34.94**
34.79	35.79	35.15	35.30	32.99	34.94	34.58	35.74	35.11	35.84	**35.02**
34.85	35.87	35.15	35.31	33.06	35.10	34.53		35.17	35.84	**34.99**
34.99	35.94	35.13	35.34	33.15	35.19	34.53		35.23	35.87	**35.04**
35.17	36.02	35.20	35.36	33.27	35.37	34.47		35.29	35.90	**35.12**
35.34	36.11	35.45	35.41	33.34	35.49	34.31		35.31	35.93	**35.19**
35.42	36.17	35.08	35.45	33.40	35.56	34.26			35.98	**35.17**
35.58	36.24	34.91	35.52	33.45	35.65	34.42			36.07	**35.23**
35.66	36.28	35.09	35.60	33.52	35.70	34.43			36.21	**35.31**
35.72	36.33	35.20	35.66		35.75	34.42			36.35	**35.63**
35.74	36.35	35.21	35.79		35.86	34.33			36.50	**35.68**
35.81	36.39	35.20	35.78		35.95	34.24			36.56	**35.70**
36.16	36.40	35.11	35.86		36.03	34.28			36.62	**35.78**
36.09	36.42	35.33	35.89		36.16	34.27				**35.69**
	36.43	35.69	35.94			34.20				**35.56**
	36.44	35.73	35.99			34.06				**35.56**
	36.47	35.73	35.81			34.06				**35.52**
	36.49	35.68	35.87			34.08				**35.53**
	36.53	35.75	36.00							**36.09**

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
	36.57	35.61	36.14							**36.11**
	36.61	35.43								**36.02**
	36.62									**36.62**
	36.45									**36.45**

Mean facial skin temperature in °C (recorded every 30 seconds) for each subject at a heat index of 55°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
33.39	34.77	34.33	34.46	34.42	34.43	34.31	34.37	33.61	33.92	**34.20**
33.61	34.93	34.37	34.50	34.42	34.50	34.36	34.39	33.69	34.15	**34.29**
33.56	34.94	34.41	34.47	34.35	34.47	34.36	34.33	33.81	34.17	**34.29**
33.44	34.95	34.47	34.44	34.31	34.42	34.34	34.30	33.91	34.17	**34.27**
33.28	34.97	34.41	34.41	34.27	34.38	34.36	34.27	34.09	34.34	**34.28**
33.12	35.00	34.58	34.41	34.26	34.34	34.32	34.25	34.23	34.59	**34.31**
32.94	35.01	34.75	34.42	34.20	34.26	34.32	34.19	34.53	34.83	**34.34**
32.88	35.00	34.74	34.40	34.13	34.30	34.30	34.16	34.81	35.12	**34.38**
32.89	35.03	34.91	34.36	33.98	34.24	34.29	34.04	34.92	35.35	**34.40**
33.00	35.06	34.97	34.31	33.92	34.34	34.26	34.02	35.10	35.49	**34.45**
33.04	35.14	35.05	34.26	33.91	34.46	34.28	34.03	35.20	35.56	**34.49**
33.26	35.13	35.00	34.15	33.91	34.52	34.35	34.06	35.31	35.65	**34.53**
33.52	35.09	35.04	34.19	33.95	34.59	34.41	34.10	35.45	35.74	**34.61**
33.82		35.11	34.26	33.99	34.71	34.46	34.16	35.52	35.85	**34.65**
34.14		35.14	34.33	34.05	35.06	34.51	34.27	35.57	35.94	**34.78**
34.37		35.17	34.44	34.13	35.27	34.55	34.36	35.66	35.98	**34.88**
34.58		35.25	34.54	34.19	35.47	34.55		35.71	36.08	**35.05**
34.68		35.33	34.50	34.23	35.62	34.51		35.76	36.10	**35.09**
34.78		35.40	34.54	34.30	35.76	34.38		35.82	36.16	**35.14**
34.74		35.46	34.45	34.35	35.90	34.36		35.90	36.19	**35.17**
34.83			34.36	34.42	36.00	34.32		35.96	36.28	**35.17**
			34.22	34.39	36.12	34.26		36.06	36.34	**35.23**
			34.20	34.44	36.17	34.27			36.36	**35.09**
				34.51	36.25	34.28			36.46	**35.38**
				34.56	36.32	34.29			36.48	**35.41**
				34.63	36.48	34.31			36.54	**35.49**
				34.68		34.29			36.62	**35.19**
				34.77		34.28				**34.53**
				34.82		34.34				**34.58**
				34.93		34.44				**34.68**
				34.99		34.47				**34.73**
				35.08		34.48				**34.78**
				35.15						**35.15**
				35.22						**35.22**
				35.33						**35.33**
				35.37						**35.37**
				35.45						**35.45**
				35.55						**35.55**
				35.67						**35.67**

				Subject Number						
001	145	343	358	359	379	401	405	419	420	**Average**
				35.70						**35.70**
				35.77						**35.77**

Appendix 3 (Acceptability Data)

Table A3.1. Acceptability (%) data (recorded every 2 minutes) for each subject at a heat index of 27°C

Subject Number										
001	**145**	**343**	**358**	**359**	**379**	**401**	**405**	**419**	**420**	**Average**
80	100	80	50	70	80	60	60	80	60	**72**
40	60	60	50	60	60	40	50	80	50	**55**
50	20	60	50	60	20	40	40	70	50	**46**
50	0	60	40	60	20	30	30	70	50	**41**
40	0	30	40	60	10	20	20	60	40	**32**
30	0	10	40	40	0	10	10	60	40	**24**
20	0	20	40	30	0	0	10	60	40	**22**
20	0		30	20		0			40	**18**
20	0		30	10		0				**12**
20	0		30	10		0				**12**
20	0		30	10						**17**
10	0		20							**10**
10	0		20							**10**
	0		20							**20**
	0									
	0									
	0									

Table A3.2. Acceptability (%) data (recorded every 2 minutes) for each subject at a heat index of 28°C

Subject Number										
001	**145**	**343**	**358**	**359**	**379**	**401**	**405**	**419**	**420**	**Average**
80	80	80	60	60	100	60	70	90	70	**75**
60	60	80	50	40	60	60	60	80	60	**61**
60	20	60	50	40	40	60	40	60	50	**48**
60	0	50	50	40	20	40	30	60	40	**39**
60	0	30	50	30	20	40	20	50	20	**32**
60	0	30	50	20	0	40		50	10	**29**
60	0		50	20	0	20			0	**21**
50	0		40	20		0				**22**
40	0		40	10		0				**18**
40	0		30	10		0				**16**
40	0		30	0						**18**
40	0		20	0						**20**
40	0		10	0						**17**
30	0		10							**13**
20	0									**10**

Subject Number										
001	**145**	**343**	**358**	**359**	**379**	**401**	**405**	**419**	**420**	**Average**
20										**20**
20										**20**
20										**20**

Table A3.3. Acceptability (%) data (recorded every 2 minutes) for each subject at a heat index of 37°C

Subject Number										
001	**145**	**343**	**358**	**359**	**379**	**401**	**405**	**419**	**420**	**Average**
80	80	100	50	60	90	60	70	90	70	**75**
60	40	60	50	40	60	40	40	70	60	**52**
60	20	50	40	40	40	40	20	60	40	**41**
60	20	50	40	40	20	20	10	60	40	**36**
60	0	50	30	30	0	10	10	50	30	**24**
50	0	50	20	20	0	0		60	20	**24**
40	0	50	20	20	0	0			0	**16**
30	0	30	20	10	0	0			0	**13**
	0	30	0	10		0				**8**
	0			10						**5**

Table A3.4. Acceptability (%) data (recorded every 2 minutes) for each subject at a heat index of 55°C

Subject Number										
001	**145**	**343**	**358**	**359**	**379**	**401**	**405**	**419**	**420**	**Average**
70	80	100	50	60	80	60	60	70	60	**69**
10	60	100	50	40	40	40	40	60	50	**49**
0	0	30	50	40	20	40	20	50	40	**29**
0	0		50	40	10	40	10	50	30	**26**
0			40	40	0	40	0	60	20	**25**
0			40	20	0	20		60	10	**21**
			40	20	0	0			0	**12**
				0		0				**0**
				0						**0**
				0						**0**

Table A3.5. Acceptability (%)for each heat index (°C) condition over time (min) calculated from Equation 5-5.

Time	A(27)	A(28)	A(37)	A(55)
0	70.89	74.45	72.99	61.39
0.5	67.29	70.71	68.19	57.37
1.5	60.63	63.79	59.50	50.10
2.5	54.63	57.54	51.93	43.75

Time	A(27)	A(28)	A(37)	A(55)
3.5	49.23	51.91	45.31	38.21
4.5	44.36	46.83	39.54	33.37
5.5	39.97	42.24	34.51	29.14
6.5	36.01	38.10	30.12	25.45
7.5	32.45	34.37	26.28	22.23
8.5	29.24	31.01	22.93	19.41
9.5	26.34	27.97	20.01	16.95
10.5	23.74	25.23	17.47	14.80
11.5	21.39	22.76	15.24	12.93
12.5	19.27	20.53	13.30	11.29
13.5	17.36	18.52	11.61	9.86
14.5	15.65	16.71	10.13	8.61
15.5	14.10	15.07	8.84	7.52
16.5	12.70	13.60	7.71	6.57
17.5	11.45	12.27	6.73	5.73
18.5	10.31	11.06	5.87	5.01
19.5	9.29	9.98	5.13	4.37
20.5	8.37	9.00	4.47	3.82
21.5	7.54	8.12	3.90	3.34
22.5	6.80	7.33	3.41	2.91
23.5	6.13	6.61	2.97	2.54
24.5	5.52	5.96	2.59	2.22
25.5	4.97	5.38	2.26	1.94
26.5	4.48	4.85	1.98	1.69
27.5	4.04	4.38	1.72	1.48
28.5	3.64	3.95	1.50	1.29
29.5	3.28	3.56	1.31	1.13
30.5	2.95	3.21	1.15	0.99
31.5	2.66	2.90	1.00	0.86
32.5	2.40	2.61	0.87	0.75
33.5	2.16	2.36	0.76	0.66
34.5	1.95	2.13	0.66	0.57
35.5	1.75	1.92	0.58	0.50
36.5	1.58	1.73	0.51	0.44
37.5	1.42	1.56	0.44	0.38
38.5	1.28	1.41	0.39	0.33
39.5	1.16	1.27	0.34	0.29
40.5	1.04	1.15	0.29	0.25
41.5	0.94	1.03	0.26	0.22
42.5	0.85	0.93	0.22	0.19
43.5	0.76	0.84	0.20	0.17
44.5	0.69	0.76	0.17	0.15
45.5	0.62	0.68	0.15	0.13
46.5	0.56	0.62	0.13	0.11
47.5	0.50	0.56	0.11	0.10

Time	A(27)	A(28)	A(37)	A(55)
48.5	0.45	0.50	0.10	0.09
49.5	0.41	0.45	0.09	0.08
50.5	0.37	0.41	0.08	0.07
51.5	0.33	0.37	0.07	0.06
52.5	0.30	0.33	0.06	0.05
53.5	0.27	0.30	0.05	0.04
54.5	0.24	0.27	0.04	0.04
55.5	0.22	0.24	0.04	0.03
56.5	0.20	0.22	0.03	0.03
57.5	0.18	0.20	0.03	0.03
58.5	0.16	0.18	0.03	0.02
59.5	0.14	0.16	0.02	0.02
60.5	0.13	0.15	0.02	0.02
61.5	0.12	0.13	0.02	0.01
62.5	0.11	0.12	0.01	0.01
63.5	0.09	0.11	0.01	0.01
64.5	0.09	0.10	0.01	0.01
65.5	0.08	0.09	0.01	0.01
66.5	0.07	0.08	0.01	0.01
67.5	0.06	0.07	0.01	0.01
68.5	0.06	0.06	0.01	0.01
69.5	0.05	0.06	0.01	0.01
70.5	0.05	0.05	0.00	0.00
71.5	0.04	0.05	0.00	0.00
72.5	0.04	0.04	0.00	0.00
73.5	0.03	0.04	0.00	0.00
74.5	0.03	0.03	0.00	0.00
75.5	0.03	0.03	0.00	0.00
76.5	0.02	0.03	0.00	0.00
77.5	0.02	0.03	0.00	0.00
78.5	0.02	0.02	0.00	0.00
79.5	0.02	0.02	0.00	0.00
80.5	0.02	0.02	0.00	0.00
81.5	0.01	0.02	0.00	0.00
82.5	0.01	0.02	0.00	0.00
83.5	0.01	0.01	0.00	0.00
84.5	0.01	0.01	0.00	0.00
85.5	0.01	0.01	0.00	0.00
86.5	0.01	0.01	0.00	0.00
87.5	0.01	0.01	0.00	0.00
88.5	0.01	0.01	0.00	0.00
89.5	0.01	0.01	0.00	0.00
90.5	0.01	0.01	0.00	0.00
91.5	0.01	0.01	0.00	0.00
92.5	0.00	0.01	0.00	0.00

Time	A(27)	A(28)	A(37)	A(55)
93.5	0.00	0.00	0.00	0.00
94.5	0.00	0.00	0.00	0.00
95.5	0.00	0.00	0.00	0.00
96.5	0.00	0.00	0.00	0.00
97.5	0.00	0.00	0.00	0.00
98.5	0.00	0.00	0.00	0.00
99.5	0.00	0.00	0.00	0.00

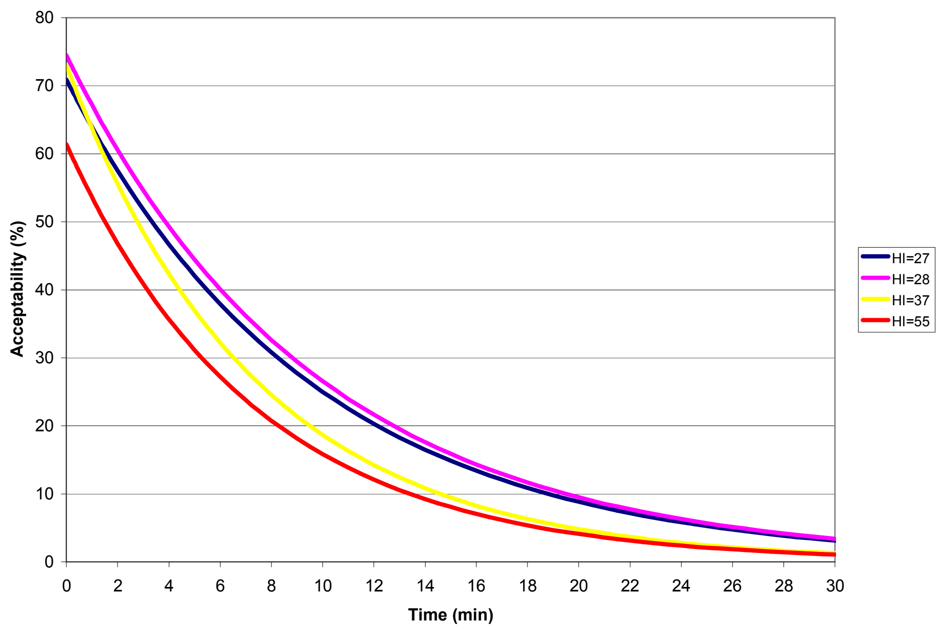

Figure A3.1. Average acceptability (%) vs. time (min) for all heat index conditions. Data taken from Table A3.5.

Table A3.6. Time (min) to reach acceptability levels (30%, 40%, and 50%) at various heat indices calculated from Equation 5-6

Heat Index (°C)	30%	40%	50%
27	8.20	5.34	3.47
28	8.06	5.22	3.38
29	7.93	5.10	3.28
30	7.80	4.99	3.19
31	7.67	4.88	3.10
32	7.54	4.77	3.02
33	7.41	4.66	2.94
34	7.29	4.56	2.85
35	7.17	4.46	2.78
36	7.05	4.36	2.70
37	6.93	4.26	2.62
38	6.82	4.17	2.55
39	6.70	4.08	2.48
40	6.59	3.99	2.41
41	6.48	3.90	2.35

Heat Index (°C)	30%	40%	50%
42	6.37	3.81	2.28
43	6.27	3.73	2.22
44	6.16	3.65	2.16
45	6.06	3.57	2.10
46	5.96	3.49	2.04
47	5.86	3.41	1.98
48	5.76	3.33	1.93
49	5.67	3.26	1.88
50	5.57	3.19	1.82
51	5.48	3.12	1.77
52	5.39	3.05	1.72
53	5.30	2.98	1.68
54	5.21	2.91	1.63
55	5.12	2.85	1.59

Appendix 4 (Rectal Temperature Data)

Table A4.1. Rectal temperature in °C (recorded every 30 seconds) for each subject at a heat index of 27°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
37.16	37.62	37.7	37.4	37.4	37.31	37.21	37.49	37.29	37.69	**37.423**
37.17	37.63	37.7	37.4	37.4	37.31	37.24	37.52	37.34	37.7	**37.44**
37.19	37.64	37.7	37.4	37.4	37.31	37.26	37.54	37.36	37.72	**37.451**
37.21	37.64	37.7	37.4	37.4	37.31	37.28	37.56	37.38	37.74	**37.462**
37.26	37.65	37.7	37.4	37.4	37.32	37.31	37.6	37.4	37.76	**37.483**
37.26	37.66	37.7	37.4	37.4	37.33	37.33	37.62	37.42	37.78	**37.498**
37.3	37.67	37.8	37.5	37.4	37.36	37.36	37.66	37.45	37.82	**37.526**
37.32	37.68	37.8	37.5	37.5	37.38	37.39	37.69	37.47	37.84	**37.548**
37.36	37.7	37.8	37.5	37.5	37.4	37.43	37.74	37.5	37.88	**37.578**
37.39	37.71	37.8	37.5	37.5	37.44	37.48	37.78	37.54	37.89	**37.611**
37.43	37.72	37.9	37.5	37.5	37.46	37.51	37.83	37.57	37.92	**37.637**
37.45	37.75	37.9	37.6	37.6	37.49	37.56	37.87	37.6	37.93	**37.662**
37.48	37.78	37.9	37.6	37.6	37.52	37.57	37.92	37.63	37.96	**37.695**
37.51	37.81	37.9	37.6	37.6	37.55	37.61	37.97	37.66	37.98	**37.726**
37.54	37.82	38	37.7	37.7	37.59	37.65	38.01	37.71	38.01	**37.76**
37.57	37.85	38	37.7	37.7	37.62	37.68	38.07	37.76	38.02	**37.792**
37.59	37.88	38	37.7	37.7	37.66	37.69	38.1	37.81	38.06	**37.821**
37.63	37.89	38	37.7	37.7	37.69	37.7	38.15	37.84	38.11	**37.849**
37.63	37.91	38	37.8	37.8	37.73	37.72	38.19	37.87	38.12	**37.873**
37.67	37.93	38.1	37.8	37.8	37.78	37.72	38.24	37.89	38.16	**37.905**
37.68	37.95	38.1	37.8	37.9	37.81	37.73	38.29	37.94	38.19	**37.936**
37.72	37.97	38.1	37.8	37.9	37.85	37.74	38.33	37.98	38.22	**37.965**
37.74	37.99	38.2	37.8	37.9	37.89	37.77		38.02	38.26	
37.79	38.01		37.8	37.9	37.93	37.82		38.05	38.29	
37.82	38.04		37.9	38	37.97	37.84			38.32	
37.84	38.06		37.9	38	37.99	37.87			38.34	
37.87	38.07		37.9	38		37.91			38.37	
37.89	38.08		37.9	38.1		37.93			38.39	
37.9	38.1		37.9	38.1		37.96			38.41	
37.92	38.12		37.9	38.1		37.98			38.43	
37.92	38.15		38	38.1		37.99				
37.92	38.17		38	38.1		38.02				
37.92	38.21		38	38.2		38.04				
37.92	38.22		38	38.2		38.07				

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
37.92	38.24		38	38.2		38.09				
37.96	38.27		38.1	38.2		38.11				
37.96	38.29		38.1	38.2		38.13				
37.98	38.32		38.1	38.2						
37.98	38.34		38.1	38.3						
37.99	38.35		38.1	38.3						
38	38.37		38.2							
38.01	38.38		38.2							
38.01	38.39		38.2							
38.02	38.44		38.2							
38.04	38.44		38.2							
38.12	38.46		38.2							
38.31	38.47		38.3							
38.64	38.5		38.3							
38.74	38.51		38.3							
	38.54		38.3							
	38.57		38.3							
	38.57									
	38.59									
	38.62									
	38.63									
	38.66									
	38.68									
	38.69									
	38.73									
	38.74									
	38.76									
	38.79									
	38.82									
	38.84									

Table A4.2. Rectal temperature in °C (recorded every 30 seconds) for each subject at a heat index of 28°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
37.67	37.63	37.41	37.5	37.37	37.32	37.43	37.45	37.32	37.23	**37.433**
37.68	37.67	37.42	37.53	37.4	37.34	37.43	37.48	37.32	37.25	**37.452**
37.68	37.67	37.42	37.53	37.37	37.33	37.44	37.49	37.34	37.26	**37.453**
37.68	37.67	37.44	37.53	37.39	37.35	37.46	37.51	37.35	37.28	**37.466**

Subject Number

001	145	343	358	359	379	401	405	419	420	Average
37.67	37.67	37.46	37.54	37.41	37.37	37.46	37.53	37.36	37.29	37.476
37.67	37.69	37.49	37.55	37.43	37.38	37.49	37.55	37.37	37.3	37.492
37.7	37.69	37.54	37.57	37.43	37.41	37.51	37.57	37.4	37.31	37.513
37.77	37.7	37.56	37.59	37.46	37.43	37.52	37.58	37.42	37.33	37.536
37.83	37.71	37.58	37.6	37.47	37.47	37.54	37.61	37.45	37.35	37.561
37.87	37.73	37.61	37.64	37.49	37.5	37.57	37.64	37.47	37.36	37.588
37.88	37.74	37.64	37.66	37.51	37.53	37.59	37.66	37.48	37.37	37.606
37.89	37.74	37.66	37.7	37.52	37.55	37.61	37.69	37.52	37.39	37.627
37.91	37.75	37.7	37.72	37.53	37.6	37.63	37.72	37.54	37.42	37.652
37.96	37.76	37.73	37.75	37.57	37.63	37.68	37.74	37.58	37.43	37.683
37.98	37.77	37.73	37.78	37.58	37.66	37.7	37.78	37.61	37.44	37.703
38	37.78	37.79	37.82	37.59	37.7	37.72	37.81	37.64	37.47	37.732
38.03	37.79	37.81	37.84	37.62	37.73	37.74		37.68	37.48	
38.07	37.81	37.84	37.87	37.66	37.77	37.77		37.72	37.49	
38.12	37.82	37.88	37.9	37.66	37.81	37.79		37.75	37.52	
38.16	37.83	37.9	37.93	37.69	37.85	37.83		37.78	37.54	
38.21	37.84	37.94	37.94	37.7	37.9	37.84		37.82	37.57	
38.28	37.87	37.96	37.98	37.72	37.94	37.87		37.85	37.58	
38.29	37.88	38	37.99	37.75	37.97	37.9			37.61	
38.3	37.89		38.02	37.78	38.02	37.93			37.64	
38.3	37.91		38.04	37.78	38.05	37.93			37.66	
38.3	37.93		38.05	37.82	38.08	37.94			37.68	
38.25	37.94		38.07	37.85	38.15	37.94				
38.18	37.96		38.08	37.86	38.18	37.94				
38.01	37.99		38.09	37.87		37.94				
	38.01		38.12	37.91		37.94				
	38.02		38.13	37.93		37.93				
	38.05		38.14	37.98						
	38.07		38.17	38						
	38.09		38.18	38.03						
	38.11		38.21	38.06						
	38.13		38.22	38.08						
	38.14		38.23	38.12						
	38.16		38.24	38.14						
	38.18		38.27	38.18						
	38.19		38.28	38.19						
	38.22		38.29	38.25						
	38.25		38.32	38.29						
	38.27		38.33	38.31						

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
	38.29		38.35	38.33						
	38.32		38.36	38.35						
	38.34		38.38	38.39						
	38.36		38.4	38.43						
	38.39		38.43							
	38.41		38.44							
	38.43		38.46							
	38.45		38.47							
	38.47		38.51							
	38.5		38.53							
	38.53									
	38.56									
	38.58									
	38.62									
	38.65									
	38.66									
	38.68									

Table A4.3. Rectal temperature in °C (recorded every 30 seconds) for each subject at a heat index of 37°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
37.56	37.55	37.63	37.55	37.38	37.24	37.2	37.6	37.18	36.4	**37.329**
37.58	37.58	37.63	37.66	37.43	37.34	37.2	37.61	37.24	36.5	**37.38**
37.64	37.59	37.63	37.67	37.44	37.24	37.3	37.61	37.25	36.5	**37.381**
37.72	37.6	37.66	37.67	37.46	37.26	37.3	37.62	37.27	36.5	**37.399**
37.78	37.61	37.67	37.68	37.46	37.28	37.3	37.62	37.27	36.5	**37.413**
37.79	37.63	37.69	37.69	37.48	37.29	37.3	37.63	37.29	36.5	**37.427**
37.81	37.64	37.76	37.73	37.49	37.31	37.3	37.64	37.33	36.5	**37.453**
37.84	37.66	37.77	37.75	37.5	37.36	37.4	37.66	37.32	36.5	**37.473**
37.87	37.67	37.81	37.78	37.53	37.38	37.4	37.66	37.35	36.5	**37.499**
37.9	37.69	37.86	37.79	37.55	37.42	37.5	37.68	37.38	36.6	**37.528**
37.93	37.71	37.89	37.82	37.57	37.45	37.5	37.69	37.41	36.6	**37.553**
37.96	37.73	37.92	37.83	37.58	37.49	37.5	37.71	37.43	36.6	**37.577**
38.01	37.76	37.98	37.84	37.6	37.51	37.6	37.73	37.5	36.6	**37.611**
38.06	37.78	37.99	37.85	37.64	37.54	37.6	37.74	37.52	36.6	**37.636**
	37.81	38.02	37.87	37.65	37.57	37.7	37.77	37.56	36.7	
	37.82	38.04	37.88	37.69	37.63	37.7	37.78	37.59	36.7	
	37.84	38.07	37.91	37.71	37.63	37.7	37.8	37.62	36.7	

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
	37.87	38.09	37.93	37.73	37.66	37.7		37.67	36.7	
	37.88	38.12	37.94	37.77	37.67	37.8		37.71	36.7	
	37.9	38.14	37.96	37.79	37.71	37.8		37.75	36.7	
	37.93	38.17	37.97	37.82	37.75	37.8		37.78	36.7	
	37.96	38.19	38	37.84	37.77	37.8			36.7	
	37.97	38.21	38.02	37.87	37.81	37.9			36.7	
	37.99	38.24	38.04	37.91	37.83	37.9			36.7	
	38.01	38.26	38.06	37.94	37.87	37.9			36.8	
	38.02	38.28	38.08	37.97	37.95	37.9			36.8	
	38.03	38.3	38.09	37.99	37.99	38			36.8	
	38.04	38.32	38.12	38.03	38.03	38			36.8	
	38.07	38.34	38.14	38.07	38.11	38				
	38.09	38.37	38.16	38.09		38				
	38.1	38.39	38.18	38.13		38				
	38.12	38.41	38.19	38.16		38				
	38.15	38.45	38.22	38.18		38.1				
	38.17	38.48	38.25	38.23						
	38.19		38.27	38.26						
	38.24			38.28						
	38.24			38.33						
	38.24			38.36						
				38.4						
				38.43						
				38.46						
				38.51						
				38.54						

TableA4.4. Rectal temperature in °C (recorded every 30 seconds) for each subject at a heat index of 55°C

Subject Number										
001	145	343	358	359	379	401	405	419	420	**Average**
	37.36	37.26	37.58	37.12	37.57	37.41	37.48	37.34	37.28	**37.38**
	37.38	37.26	37.59	37.12	37.57	37.41	37.49	37.36	37.36	**37.39**
	37.39	37.26	37.59	37.13	37.58	37.42	37.51	37.39	37.37	**37.40**
	37.41	37.26	37.59	37.14	37.6	37.44	37.56	37.42	37.39	**37.42**
	37.43	37.26	37.59	37.14	37.61	37.45	37.59	37.46	37.46	**37.44**
	37.46	37.26	37.61	37.16	37.63	37.48	37.61	37.48	37.49	**37.46**
	37.46	37.28	37.62	37.18	37.64	37.5	37.63	37.52	37.52	**37.48**
	37.48	37.31	37.63	37.23	37.66	37.54	37.66	37.54	37.55	**37.51**

Subject Number

001	145	343	358	359	379	401	405	419	420	**Average**
	37.49	37.33	37.64	37.21	37.69	37.57	37.7	37.58	37.59	**37.53**
	37.51	37.36	37.67	37.21	37.7	37.61	37.73	37.61	37.61	**37.56**
	37.53	37.38	37.69	37.22	37.71	37.64	37.77	37.64	37.63	**37.58**
	37.53	37.39	37.73	37.23	37.73	37.67	37.81	37.67	37.64	**37.60**
	37.55	37.41	37.75	37.24	37.76	37.7	37.84	37.7	37.66	**37.62**
		37.43	37.78	37.25	37.78	37.73	37.89	37.74	37.68	
		37.46	37.82	37.28	37.79	37.75	37.92	37.77	37.69	
		37.49	37.84	37.29	37.81	37.79	37.96	37.82	37.7	
		37.52	37.88	37.31	37.83	37.81		37.84	37.71	
		37.55	37.9	37.33	37.85	37.83		37.88	37.75	
		37.58	37.93	37.36	37.87	37.84		37.93	37.77	
		37.61	37.95	37.38	37.89	37.86		37.97	37.79	
			37.97	37.41	37.9	37.89		38	37.81	
			37.99	37.43	37.93	37.9		38.06	37.83	
			38.01	37.46	37.94	37.92			37.84	
			38.02	37.49	37.96	37.93			37.86	
			38.04	37.53	37.97	37.95			37.89	
				37.55	38.01	37.97			37.89	
				37.58		37.98			37.94	
				37.61		38.01				
				37.64		38.02				
				37.67		38.04				
				37.7		38.06				
				37.72		38.08				
				37.76						
				37.77						
				37.81						
				37.84						
				37.88						
				37.88						
				37.91						
				37.95						
				37.97						
				38						

Appendix 5 (Performance Time – Heat Index Model)

Table A5.1. Performance time (PT) values (min) for each subject at various heat indices (°C)

HI	PT (001)	PT(145)	PT(358)	PT(359)	PT(379)	PT(419)	PT(420)	PT(405)	PT(401)	PT(343)
27	27.23	31.73	25.76	21.51	13.35	10.83	13.81	9.12	18.34	11.19
28	26.28	30.03	24.98	21.48	13.34	10.81	13.78	9.06	18.23	11.73
29	25.35	28.42	24.23	21.46	13.32	10.79	13.76	8.99	18.11	12.29
30	24.46	26.89	23.50	21.43	13.31	10.76	13.74	8.93	18.00	12.87
31	23.60	25.45	22.79	21.41	13.29	10.74	13.71	8.86	17.88	13.48
32	22.77	24.08	22.10	21.38	13.28	10.72	13.69	8.80	17.77	14.13
33	21.97	22.79	21.43	21.35	13.26	10.69	13.67	8.74	17.65	14.80
34	21.20	21.57	20.79	21.33	13.25	10.67	13.64	8.67	17.54	15.50
35	20.45	20.41	20.16	21.30	13.23	10.65	13.62	8.61	17.43	16.24
36	19.73	19.31	19.55	21.28	13.22	10.62	13.60	8.55	17.32	17.02
37	19.04	18.28	18.96	21.25	13.21	10.60	13.58	8.49	17.21	17.83
38	18.37	17.30	18.39	21.22	13.19	10.58	13.55	8.43	17.10	18.67
39	17.72	16.37	17.83	21.20	13.18	10.56	13.53	8.37	16.99	19.56
40	17.10	15.49	17.29	21.17	13.16	10.53	13.51	8.31	16.88	20.50
41	16.50	14.66	16.77	21.15	13.15	10.51	13.49	8.25	16.77	21.47
42	15.92	13.87	16.26	21.12	13.13	10.49	13.46	8.19	16.66	22.49
43	15.36	13.13	15.77	21.09	13.12	10.46	13.44	8.13	16.56	23.56
44	14.82	12.42	15.30	21.07	13.10	10.44	13.42	8.07	16.45	24.69
45	14.30	11.76	14.84	21.04	13.09	10.42	13.40	8.01	16.35	25.86
46	13.79	11.13	14.39	21.02	13.08	10.40	13.37	7.96	16.24	27.09
47	13.31	10.53	13.95	20.99	13.06	10.38	13.35	7.90	16.14	28.38
48	12.84	9.96	13.53	20.97	13.05	10.35	13.33	7.84	16.04	29.74
49	12.39	9.43	13.12	20.94	13.03	10.33	13.31	7.79	15.93	31.15
50	11.95	8.92	12.73	20.92	13.02	10.31	13.29	7.73	15.83	32.64
51	11.53	8.44	12.34	20.89	13.01	10.29	13.26	7.68	15.73	34.19
52	11.13	7.99	11.97	20.86	12.99	10.26	13.24	7.62	15.63	35.82
53	10.74	7.56	11.61	20.84	12.98	10.24	13.22	7.57	15.53	37.52
54	10.36	7.16	11.26	20.81	12.96	10.22	13.20	7.51	15.43	39.31
55	10.00	6.77	10.92	20.79	12.95	10.20	13.17	7.46	15.33	41.18

Appendix 6 (Survey Data)

Table A6.1. Perceived Effort and Reward Questionnaire Results

Subject	Score
359	0.00
405	1.00
419	0.21
420	0.51
343	0.64
379	0.21
145	0.41
401	0.54
001	0.49
358	0.21

Table A6.2. Claustrophobia Questionnaire Results

Subject	Score
359	0.00
405	0.92
419	0.65
420	0.50
343	0.58
379	0.42
145	0.81
401	1.15
001	1.04
358	0.75

Table A6.3. Physical Activity Questionnaire Results

Subject	kcal/wk
359	4396
405	5108
419	6316
420	5928
343	22624
379	3262
145	2078
401	3878
001	28616
358	3768

Table A6.4. Respirator User Questionnaire Results. Frequency represents the number of times the respirator had been worn prior to taking part in the study.

Subject	Frequency
359	30
405	6
419	0
420	0
343	25
379	8
145	80
401	17.5
1	80
358	50

Table A6.5. MBTI Personality Type Questionnaire Results

			EI			SN			TF			JP
Subject	**E**	**I**	**EI**	**S**	**N**	**SN**	**T**	**F**	**TF**	**J**	**P**	**JP**
001	4	6	0.40	5	15	0.25	5	5	0.50	16	4	0.80
145	9	1	0.90	6	14	0.30	5	15	0.25	11	9	0.55
358	10	0	1.00	9	11	0.45	7	13	0.35	9	11	0.45
359	4	6	0.40	14	6	0.70	3	17	0.15	13	7	0.65
405	1	9	0.10	10	10	0.50	5	15	0.25	11	9	0.55
419	6	4	0.60	15	5	0.75	15	5	0.75	16	4	0.80
420	9	1	0.90	17	3	0.85	7	13	0.35	7	13	0.35
343	5	5	0.50	10	10	0.50	7	3	0.70	11	9	0.55
379	3	7	0.30	16	4	0.80	11	9	0.55	13	7	0.65
401	3	7	0.30	12	8	0.60	2	18	0.10	12	8	0.60

Appendix 7 (C_1 graphs)

All C_1 values are from Equation 5-3.

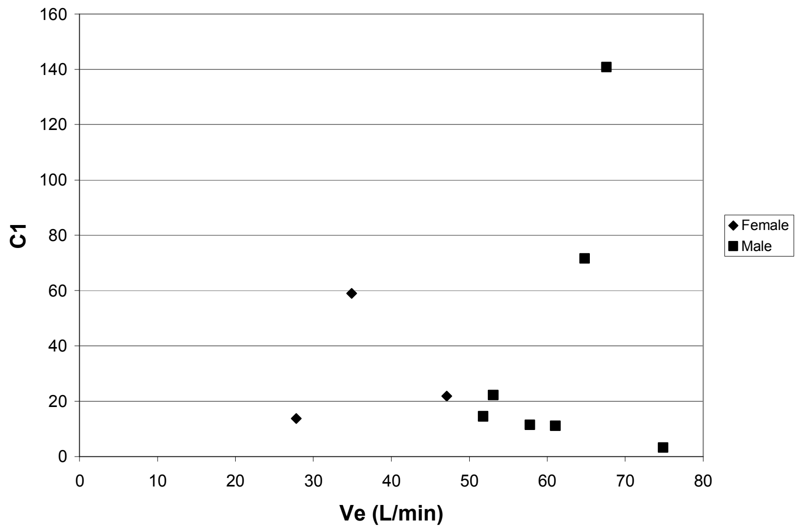

Figure A7.1. C_1 vs. V_e from Table A1.2. for each subject (n=10).

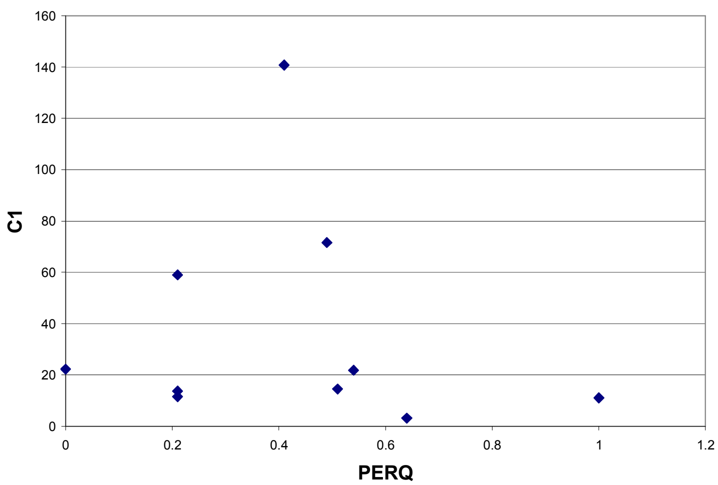

Figure A7.2. C_1 vs. Perceived Effort and Reward Questionnaire results from Table A6.1. for each subject (n=10).

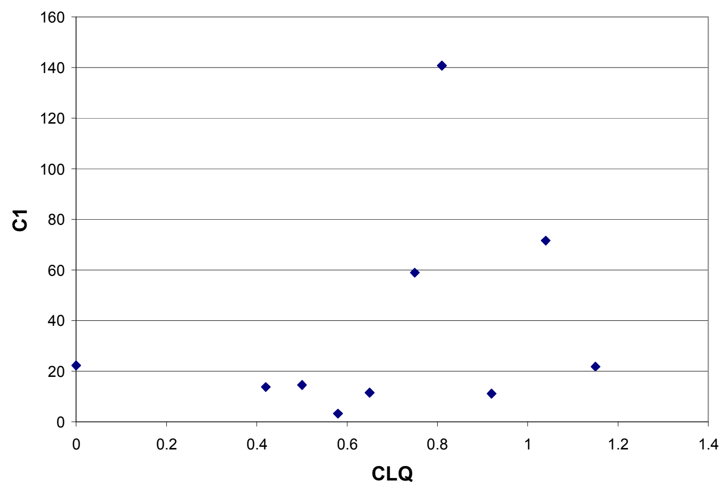

Figure A7.3. C_1 vs. Claustrophobia Questionnaire results from Table A6.2. for each subject (n=10).

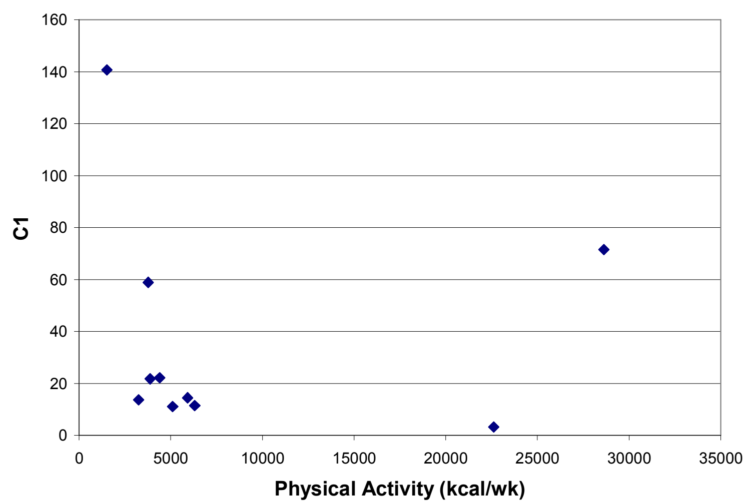

Figure A7.4. C_1 vs. level of physical activity results from Table A6.3. for each subject (n=10).

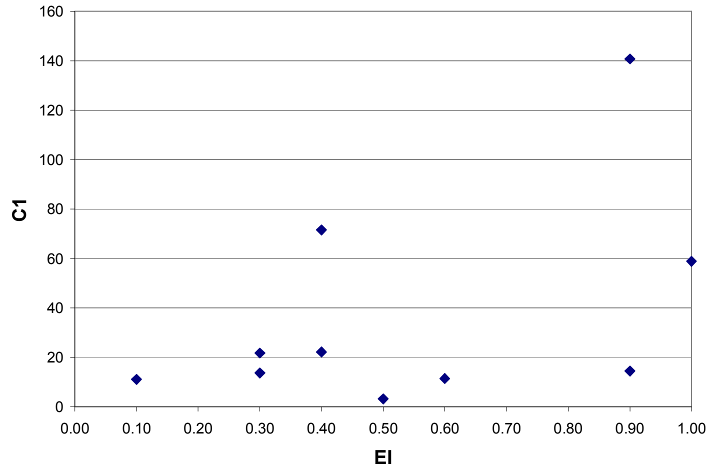

Figure A7.5. C_1 vs. Extroversion/Introversion personality characteristic from Table A6.5. for each subject (n=10).

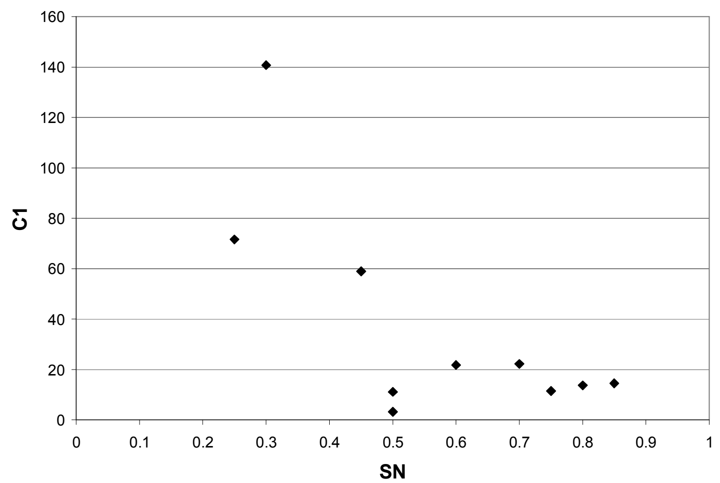

Figure A7.6. C_1 vs. Sensing/Intuition personality characteristic from Table A6.5. for each subject (n=10).

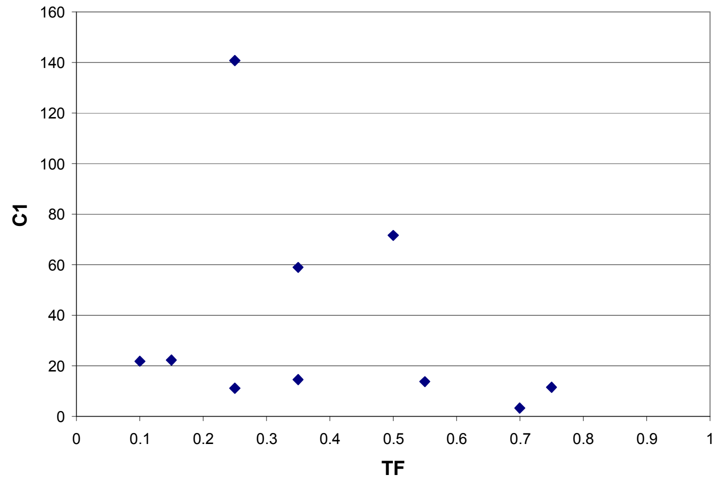

Figure A7.7. C_1 vs. Thinking/Feeling personality characteristic from Table A6.5. for each subject (n=10).

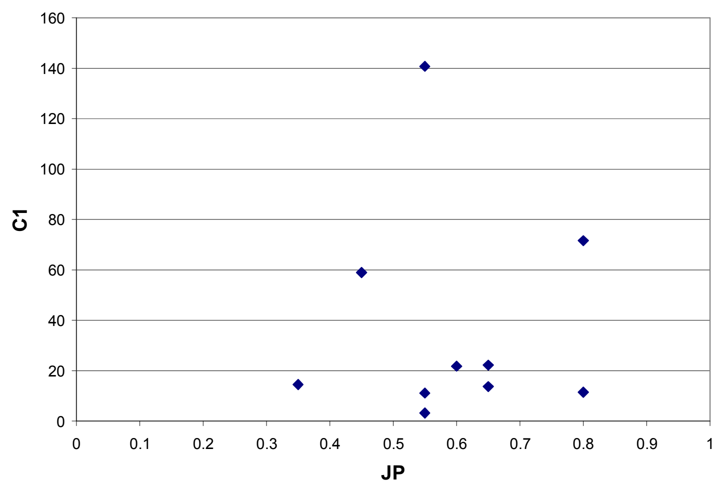

Figure A7.8. C_1 vs. Judging/Perception personality characteristic from Table A6.5. for each subject (n=10).

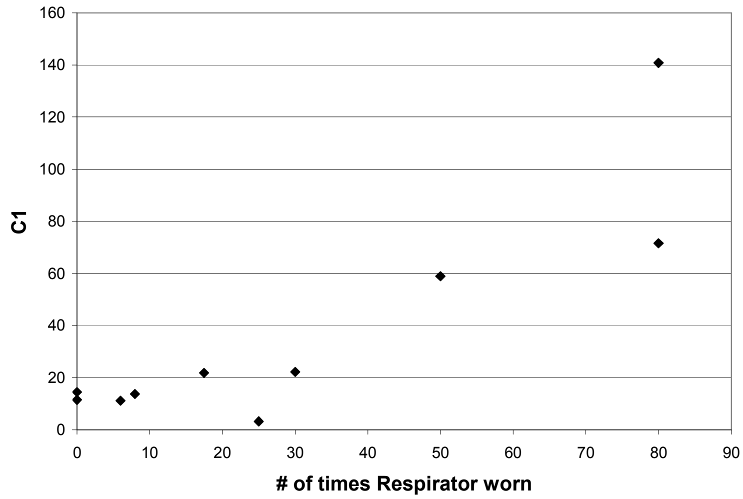

Figure A7.9. C_1 vs. Respirator Familiarity from Table A6.4. for each subject (n=10).

Appendix 8 (Research Surveys)

PERQ

Please rate the following on a 0 to 4 scale to indicate how true each sentence is for you:

		not at all	slight-ly	modera-tely	very	comp-letely
1.	I often predict that I will not enjoy experiences I used to enjoy	0	1	2	3	4
2.	Even "fun" activities don't seem like much fun at all	0	1	2	3	4
3.	It seems like the costs outweigh the benefits for most tasks that I think about doing in the future	0	1	2	3	4
4.	I know that if I persist when things are difficult, I will always get some kind of pay-off	0	1	2	3	4
5.	It seems like most activities in my daily life take a great deal of effort to complete	0	1	2	3	4
6.	Other people find it easier to start things than I do	0	1	2	3	4
7.	If I were more active, I would enjoy things more	0	1	2	3	4
8.	There are very few activities that seem worth the effort	0	1	2	3	4
9.	I often feel too tired to initiate an activity	0	1	2	3	4
10.	It's so hard to decide what things are worth my time and effort that it is easier to just do nothing	0	1	2	3	4
11.	As I approach a task, it seems as if there are too many obstacles involved in doing things I need to/ would like to do	0	1	2	3	4
12.	I avoid making future plans because it is difficult to predict how much effort things will take	0	1	2	3	4
13.	When I think about beginning a task or activity, I usually decide not to do it because it will take too much effort	0	1	2	3	4
14.	Other people get better rewards for their efforts than me	0	1	2	3	4
15.	Things in life don't seem very enjoyable	0	1	2	3	4
16.	I feel worthless because it seems like I can't even manage to get the simplest things done	0	1	2	3	4
17.	When I really think about it, "the glass" is more "half-full" than "half empty"	0	1	2	3	4
18.	It's hard to find positive reasons for doing things	0	1	2	3	4
19.	I feel hopeless because it seems as if I will never enjoy life the way I used to	0	1	2	3	4
20.	When weighing the costs against the benefits, I am often confused about what to do	0	1	2	3	4
21.	If I enjoyed things more, I would be more active	0	1	2	3	4
22.	If things were easier to do, I would be more active	0	1	2	3	4

Note: Item 4 and 17 should be scored as reverse items.

		not at all	slight-ly	modera-tely	very	comp-lately
23.	It seems like I really need to invest a great deal of time and effort in a task in order to complete it successfully	0	1	2	3	4
24.	I often don't bother putting in effort to do some things I should because it just doesn't seem worth it	0	1	2	3	4
25.	It seems like the rewards from completing an activity I need / want to do are never worth the effort required	0	1	2	3	4
26.	It seems like doing daily tasks (e.g., household chores, running errands, etc.) takes a lot of energy and effort	0	1	2	3	4
27.	I find it hard to make decisions because doing something to make me feel better often takes a lot of work	0	1	2	3	4
28.	It seems as if most of my efforts in life will not pay off	0	1	2	3	4
29.	The world is a cruel place for me because it seems like nothing will turn out the way I want it to	0	1	2	3	4
30.	People falsely assume that I will enjoy things as much as they will	0	1	2	3	4
31.	I feel as if I can't be bothered doing most things I need / want to do	0	1	2	3	4
32.	I have problems making decisions because things that used to be fun don't seem fun anymore	0	1	2	3	4
33.	It seems like a hassle to become involved in a task	0	1	2	3	4
34.	I feel as if don't have the energy needed to complete most things I need to / would like to do	0	1	2	3	4
35.	Even the thought of starting something new makes me feel overwhelmed by how much effort would be involved	0	1	2	3	4
36.	If I were more active, things would become easier over time	0	1	2	3	4
37.	Other people find it easier than I do to get things done	0	1	2	3	4
38.	I avoid making future plans because it is difficult to predict how enjoyable things will be	0	1	2	3	4
39.	It takes a lot of work to get things done.	0	1	2	3	4

Paffenbarger Physical Activity Questionnaire
Scoring Worksheet

1. Energy expenditure associated with stairclimbing

    ____ stairs climbed/day * 7 days/week = ___ stairs climbed/wk

    _____ stairs climbed/week * 8 kcal/20 stairs =

    _______ **kcal energy expended/week stairclimbing**

2. Energy expenditure associated with walking

    _____ blocks walked/day * 7 days/week = ___ blocks walked/week

    _____ blocks walked/week * 8 kcal/block =

    _______ **kcal energy expended/week walking**

3. Energy expenditure associated with light sport or recreational activities

    _______ total minutes of light sport/recreational activities/week

    * 5 kcal/minute =

    ______ **kcal expended/week in light sport/recreational activities**

4. Energy expenditure associated with vigorous sport or recreational activities

    _______ total minutes of vigorous sport/recreational

    activities/week * 10 kcal/minute =

    ______ **kcal expended/week vigorous sport/recreational activities**

5. Total sport, leisure, and recreational energy expenditure per week

    kcal/wk stairclimbing __________

    kcal/wk walking __________

    kcal/wk light sport/recreational __________

    kcal/wk vigorous sport/recreational __________

    Total kcal/wk expended ______________

CLQ

How <u>anxious</u> would you feel in the following places or situations? *Circle* the most appropriate number:

S S

	Not at all anxious	Slightly anxious	Mod-erately anxious	Very anxious	Extrem-ely anxious
1. Swimming while wearing a nose plug	0	1	2	3	4
2. Working under a sink for 15 minutes	0	1	2	3	4
3. Standing in an elevator on the ground floor with the doors closed	0	1	2	3	4
4. Trying to catch your breath during vigorous exercise	0	1	2	3	4
5. Having a bad cold and finding it difficult to breathe through your nose	0	1	2	3	4
6. Snorkeling in a safe practice tank for 15 minutes	0	1	2	3	4
7. Using an oxygen mask	0	1	2	3	4
8. Lying on a bottom bunk bed	0	1	2	3	4
9. Standing in the middle of the 3rd row at a packed concert realizing that you will be unable to leave until the end	0	1	2	3	4
10. In the centre of a full row at a cinema	0	1	2	3	4
11. Working under a car for 15 minutes	0	1	2	3	4
12. At the furthest point from an exit on a tour of an underground mine shaft.	0	1	2	3	4
13. Lying in a sauna for 15 minutes	0	1	2	3	4
14. Waiting for 15 minutes in a plane on the ground with the door closed	0	1	2	3	4

RS

	Not at all anxious	Slightly anxious	Mod-erately anxious	Very anxious	Extrem-ely anxious
1. Locked in a small DARK room without windows for 15 minutes	0	1	2	3	4
2. Locked in a small WELL LIT room without windows for 15 minutes	0	1	2	3	4
3. Handcuffed for 15 minutes	0	1	2	3	4
4. Tied up with hands behind back for 15 minutes	0	1	2	3	4
5. Caught in tight clothing and unable to remove it	0	1	2	3	4
6. Standing for 15 minutes in a straitjacket	0	1	2	3	4
7. Lying in a tight sleeping bag enclosing legs and arms, tied at the neck, unable to get out for 15 minutes	0	1	2	3	4
8. Head first into a zipped up sleeping bag able to leave whenever you wish	0	1	2	3	4
9. Lying in the trunk of a car with air flowing through freely for 15 minutes	0	1	2	3	4
10. Having your legs tied to an immovable chair	0	1	2	3	4
11. In a public washroom and the lock jams	0	1	2	3	4
12. In a crowded train which stops between stations	0	1	2	3	4

The Keirsey Temperament Sorter II

Check either (a) or (b) answers and transfer check marks to scoring form when finished.

1 When the phone rings do you
__(a) hurry to get to it first
__(b) hope someone else will answer

2 Are you more
__(a) observant than introspective
__(b) introspective than observant

3 Is it worse to
__(a) have your head in the clouds
__(b) be in a rut

4 With people are you usually more
__(a) firm than gentle
__(b) gentle than firm

5 Are you more comfortable in making
__(a) critical judgments
__(b) value judgments

6 Is clutter in the workplace something you
__(a) take time to straighten up
__(b) tolerate pretty well

7 Is it your way to
__(a) make up your mind quickly
__(b) pick and choose at some length

8 Waiting in line, do you often
__(a) chat with the others
__(b) stick to business

9 Are you more
__(a) sensible than ideational
__(b) ideational than sensible

10 Are you more interested in
__(a) what is actual __(b) what is possible

11 In making decisions do you go more by
__(a) data __(b) desires

12 In sizing up others do you tend to be
__(a) objective and impersonal
__(b) friendly and personal

13 Do you prefer contracts to be
__(a) signed, sealed, and delivered
__(b) settled on a handshake

14 Are you more satisfied having
__(a) a finished product
__(b) work in progress

15 At a party, do you
__(a) interact with many, even strangers
__(b) interact with a few friends

16 Do you tend to be more
__(a) factual than speculative
__(b) speculative than factual

17 Do you like writers who
__(a) say what they mean
__(b) use metaphors and symbolism

18 Which appeals to you more:
__(a) consistency of thought
__(b) harmonious relationships

19 In disappointing someone are you
__(a) frank and straightforward
__(b) warm and considerate

20 On the job do you want your activities
__(a) scheduled
__(b) unscheduled

21 Do you more often prefer
__(a) final, unalterable statements
__(b) tentative, preliminary statements

22 Does interacting with strangers
__(a) energize you
__(b) tax your reserves

23 Facts are more likely to
__(a) speak for themselves
__(b) illustrate principles

24 Do you find visionaries and theorists
__(a) somewhat annoying
__(b) rather fascinating

25 In a heated discussion, do you
__(a) stick to your guns
__(b) look for common ground

26 Is it better to be
__(a) just
__(b) merciful

27 At work, is it more natural for you to
__(a) point out mistakes __(b) try to please

28 Are you more comfortable
__(a) after a decision __(b) before a decisi

29 Do you tend to
__(a) say right out what's on your mind
__(b) keep your ears open

30 Common sense is
__(a) usually reliable
__(b) frequently questionable

31 Children often do not
__(a) make themselves useful enough
__(b) exercise their fantasy enough

32 When in charge of others are you
__(a) firm and unbending
__(b) forgiving and lenient

33 Are you more often
__(a) a cool-headed person
__(b) a warm-hearted person

34 Are you prone to
__(a) nailing things down
__(b) exploring the possibilities

35 In most situations are you more
__(a) deliberate
__(b) spontaneous

36 Do you think of yourself as
__(a) outgoing __(b) private

37 Are you more frequently
__(a) a practical sort of person
__(b) a fanciful sort of person

38 Do you speak more in
__(a) particulars than generalities
__(b) generalities than particulars

39 Which is more of a compliment:
__(a) "There's a logical person"
__(b) "There's a sentimental person"

40 Which rules you more
__(a) your thoughts
__(b) your feelings

41 When finishing a job, do you like to
__(a) tie up all the loose ends
__(b) move on to something else

42 Do you prefer to work
__(a) to deadlines
__(b) just whenever

43 Are you the kind of person who
__(a) is rather talkative
__(b) doesn't miss much

44 Are you inclined to take what is said
__(a) more literally
__(b) more figuratively

45 Do you more often see
__(a) what's right in front of you
__(b) what can only be imagined

46 Is it worse to be
__(a) a softy __(b) hard-nosed

47 In hard circumstances are you sometimes
__(a) too unsympathetic
__(b) too sympathetic

48 Do you tend to choose
__(a) rather carefully
__(b) somewhat impulsively

49 Are you inclined to be more
__(a) hurried than leisurely
__(b) leisurely than hurried

50 At work do you tend to
__(a) be sociable with your colleagues
__(b) keep more to yourself

51 Are you more likely to trust
__(a) your experiences
__(b) your conceptions

52 Are you more inclined to feel
__(a) down to earth
__(b) somewhat removed

53 Do you think of yourself as a
__(a) tough-minded person
__(b) tender-hearted person

54 Do you value more in yourself being
__(a) reasonable __(b) devoted

55 Do you usually want things
__(a) settled and decided
__(b) just penciled in

56 Would you say you are more
__(a) serious and determined
__(b) easy going

57 Do you consider yourself
__(a) a good conversationalist
__(b) a good listener

58 Do you prize in yourself
__(a) a strong hold on reality
__(b) a vivid imagination

59 Are you drawn more to
__(a) fundamentals
__(b) overtones

60 Which seems the greater fault:
__(a) to be too compassionate
__(b) to be too dispassionate

61 Are you swayed more by
__(a) convincing evidence
__(b) a touching appeal

62 Do you feel better about
__(a) coming to closure
__(b) keeping your options open

63 Is it preferable mostly to
__(a) make sure things are arranged
__(b) just let things happen naturally

64 Are you inclined to be
__(a) easy to approach __(b) reserved

65 In stories do you prefer
__(a) action and adventure
__(b) fantasy and heroism

66 Is it easier for you to
__(a) put others to good use
__(b) identify with others

67 Which do you wish more for yourself
__(a) strength of will
__(b) strength of emotion

68 Do you see yourself as basically
__(a) thick-skinned
__(b) thin-skinned

69 Do you tend to notice
__(a) disorderliness
__(b) opportunities for change

70 Are you more
__(a) routinized than whimsical
__(b) whimsical than routinized

Respirator User Questionnaire

Please answer all questions to the best of your ability.

A. Using your respirator.

1. For how many years have you been wearing respirators? ________
2. How many times have you worn a respirator while performing manual labor? ____________
3. If you have worn a respirator before for how long at a time do you wear a respirator? ______________

B. In this particular study, the respirator became a burden. What were the reasons for terminating the test (circle all that apply)?

- TOO HOT
- TOO SWEATY
- TOO HEAVY
- TOO TIGHT
- DIFFICULT SEEING
- DIFFICULT BREATHING
- DIFFICULT MOVING
- DIFFICULT TO DO THE JOB
- FELT AWKWARD OR CLUMSY
- FELT SELF-CONSCIOUS
- FELT ANXIOUS OR CLAUSTROPHOBIC
- OTHER (please specify) ___________________________

C. Rate your attitude toward respirator masks:

Unfavorable		Neutral	Favorable	
1	2	3	4	5

D. Respirators and work.

1. Rate how hard you think the following activities are WITHOUT wearing a respirator mask. (Circle one for each activity).

	Very easy		Moderate		Very hard
Running to catch a bus	1	2	3	4	5
Machine working, welding	1	2	3	4	5
Writing	1	2	3	4	5

Walking through deep snow	1	2	3	4	5
Climbing stairs	1	2	3	4	5
Running fast	1	2	3	4	5
Walking while carrying a heavy load	1	2	3	4	5
Sweeping floors	1	2	3	4	5
Washing clothes	1	2	3	4	5
Shoveling fast	1	2	3	4	5

2. Answer these questions according to how you felt on average during each testing session.

WHEN I USE MY RESPIRATOR:	Totally disagree		Neutral		Totally agree
The respirator does not interfere with my vision.	1	2	3	4	5
I stay cool. I don't sweat because of my respirator.	1	2	3	4	5
I can breathe easily. The respirator doesn't interfere with my breathing.	1	2	3	4	5
The respirator is not heavy.	1	2	3	4	5
The respirator harness straps are comfortable.	1	2	3	4	5
I feel O.K. inside the mask.	1	2	3	4	5
Wearing the respirator does not interfere with my work.	1	2	3	4	5

Appendix 9 (Acceptability Scales)

RPE

6

7 very, very light

8

9 very light

10

11 fairly light

12

13 somewhat hard

14

15 hard

16

17 very hard

18

19 very, very hard

20

BACS

10 very, very comfortable

8 comfortable

6 fairly comfortable

4 fairly uncomfortable

2 uncomfortable

0 very, very uncomfortable

FT/OT

1 very cold

2 cold

3 slightly cool

4 neutral

5 slightly warm

6 hot

7 very hot

Appendix 10 (IRB 05-0245)

INV.

UMCP IRB Application and Instructions rev. 4/05 COPY

UNIVERSITY OF MARYLAND, COLLEGE PARK
Institutional Review Board
Initial Application for Research Involving Human Subjects

Please complete this cover page AND provide all information requested in the attached instructions.

Name of Principal Investigator (PI) or Project Faculty Advisor Arthur T. Johnson **Tel. No** 5-1184
(NOT a student or fellow; must be UMD employee)

Name of Co-Investigator (Co-PI) ______ **Tel. No** ______

Department or Unit Administering the Project Biological Resources Engineering

E-Mail Address of PI ajl6@umail.umd.edu **E-Mail Address of Co-PI** ______

Where should the IRB send the approval letter? Bldg. 142 Attn: Erica Francis

Name of Student Investigator Erica Francis **Tel. No.** 301-405-1186

Student Identification No. & E-Mail Address 177-68-7681 ebicks@msn.com

Check here if this is a student master's thesis ☒ **or a dissertation research project** ☐

Project Duration (mo/yr – mo/yr) 05/05 – 05/06

Project Title The Effect of Inspiratory Air, Humidity, and Temperature on Performance Time While Wearing A Respirator

Sponsored Project Data **Funding Agency** ______ **ORAA Proposal ID Number** ______

(PLEASE NOTE: Failure to include data above may result in delay of processing sponsored research award at ORAA.)

Conflict of Interest: Investigators ☐ do ☒ do not have a real or potential COI. Refer to question #7 on page 2.
Members of Health Center: Investigators ☐ are ☒ are not members of the Health Center. Refer to question #8 on page 2.

Vulnerable Population: The proposed research will involve the following (Check all that apply): pregnant women ☐, human fetuses ☐, neonates ☐, minors/children ☐, prisoners ☐, students ☐, individuals with mental disabilities ☐, individuals with physical disabilities ☐

Exempt or Nonexempt (Optional): You may recommend your research for exemption or nonexemption by completing the appropriate box below. For exempt recommendation, list the numbers for the exempt category(s) that apply. Refer to page 4 of this document.
☐ **Exempt----List Exemption Category Numbers** ______ ***Or*** ☒ **Non-Exempt**

If exempt, briefly describe the reason(s) for exemption. Your notation is a suggestion to the IRB Manager and IRB Co-Chairs.

5/9/05 Arthur T Johnson
Date **Signature of Principal Investigator or Faculty Advisor** *(PLEASE NOTE: Person signing above accepts responsibility for project, even when data collection is performed by other investigators)*

Date **Signature of Co-Principal Investigator**

5/9/05 Erica Francis
Date **Signature of Student Investigator**

5-10-05 Marc Rogers
Date **REQUIRED** Signature of the Departmental Human Subjects Review Committee Chairperson or Designee OR For Departments and Units without an HSRC: Department Head (Chairperson) or Designee or Unit Head (Director) or Designee

Name ______, **Title** ______

(PLEASE NOTE: When HSRC Chairperson or Unit Head is also a project investigator or the Student Investigator's advisor, this line should be signed by Designee)

***PLEASE ATTACH THIS COVER PAGE TO EACH SET OF COPIES**

The Effect Of Inspiratory Air Humidity And Temperature On Performance Time While Wearing A Respirator

Statement of Age of Subject: I, ______________________________, state that I am over 18 years of age, in good physical health, and wish to participate in a program of research being conducted by Arthur T. Johnson, Ph.D., William H. Scott Jr., M.A., and Erica Francis, at the University of Maryland at College Park.

Purpose: The purpose of this project is to measure comfort levels, performance times, and facial skin temperatures during exercise at a moderate work rate under different environmental conditions.

Procedures: The research will consist of three stages: obtain consent and orientation, perform the VO_{2max} graded exercise test, and 65-70% VO_{2max} testing under three different conditions. The initial analysis suggests that a total of 15 subjects will be needed for the study.

The first stage is to obtain consent and give a brief orientation to the subjects to describe what their participation requires. The subjects will receive no course credit for their participation in the study. The subjects may or may not be familiar with wearing a face mask; therefore, each subject will be fully advised as to the requirements of their participation. The subjects will read and sign the informed consent document and fill out a brief medical history questionnaire. This session provides the subject with a detailed description of their rights, and it provides the investigators with information about the subjects' health and ability to partake in vigorous activity. Any demographic or experimental data collected will remain confidential and correspond only to a subject number.

The second stage of research consists of a graded exercise test (VO_{2max} test) that will be used to determine the subject's maximal aerobic capacity. The graded exercise test consists of 3 minute stages; exercise intensity is increased after each stage. This test provides valuable information necessary for determining each subject's work rate during each of the testing sessions, along with information regarding each subject's critical end point values, including maximal heart rate, maximal oxygen consumption, and rating of perceived exertion (RPE) at termination. Participants will be asked to warm-up and stretch for approximately ten minutes prior to the start of the test. The mask used during the test is a half mask equipped with one-way inhalation and exhalation valves. Heart rate measurements will be assessed using sensors that will be placed on the body with the leads connected to a Patient Monitoring System. The sensors will placed on the upper part of the chest and one on the abdomen. In order to determine VO_{2max}, the subject will participate in a graded exercise test to exhaustion. The work rate will be adjusted every three minutes until the participant becomes fatigued, fails to display a rise in oxygen consumption in accordance with the increase in work rate, or reaches a maximal heart rate.

The third stage of research consists of actual subject testing in an environmental chamber. Each session will be conducted at 65-70% of the participant's maximal oxygen consumption using a treadmill. All sessions will utilize a full facepiece mask, which covers the entire face including the cheeks and forehead. The subject will exercise at a constant work rate throughout all three sessions. Furthermore, each of the subjects will dress similarly and wear the same mask

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throughout all sessions. Before exercise, the subject will complete a five minute warm-up on the treadmill followed by five minutes of stretching. The subject will don a heart rate monitor, rectal probe for monitoring core body temperature, and three surface temperature sensors on the face. The sensors will be placed on the mid-forehead, right cheekbone, and upper lip under the left nostril. The rectal probe will be inserted by the subject, who will be given lubricant to ease in insertion of the rectal probe. The lab assistant will explain the insertion technique, which will be to insert the tip gradually into the sphincter approximately the length of the palm of the subject's hand (approximately 2 inches). The subject will be asked to dress in standard military fatigues and tennis shoes. A full facepiece face mask will be fitted to the subject for a comfortable, but snug fit. The outlet of the face mask will be connected via a hose to monitor continuous expired airflow, and the inspiratory valve will be connected to the outlet of the humidity chamber. The subject will begin to exercise at a treadmill speed and grade set at a work rate below 65-70% VO_{2max}; the speed and grade will be increased for approximately 90 seconds before the speed and grade corresponding to 65-70% VO_{2max} is reached. At this work rate, the subject will be asked to exercise until he or she reaches exhaustion, which he or she will indicate with a thumbs down sign. Prior to the commencement of each testing session, communication signals between the lab assistant and the subject will be reviewed. The subject will be exercising in various environmental conditions. During each testing session, the subject will exercise in an environmental chamber that will remain at 30°C and 40% humidity. The respirator will be supplied with the following four combinations of temperature and humidity: 27°C-50% humidity, 27°C-70% humidity, 32°C-60% humidity,37°C-70% humidity. At the lower temperature and humidity conditions, the testing session is likely to last up to one hour. At higher temperature and humidity conditions, the testing session is likely to last up to 30 minutes. During testing, the subject will not be exercising at a high intensity, but the subject will become fatigued, hot, and sweaty due to the environmental conditions inside the mask. A 5 minute cool down period will follow the testing session.

The orientation and consent session will last approximately 15 minutes, depending on the number of questions the subject has. The VO_2max session will last approximately 45 minutes. Each testing session may last anywhere between 1 hour and 1.5 hours, depending on the condition. Total participation in the study requires 5 to 7 hours.

A lab assistant while be present during subject testing to monitor for signs of distress. Heart rate, facial skin temperature, and core body temperature will be monitored; Rating of Perceived Exertion (RPE), and the Breathing Apparatus Comfort Scales (BACS) will be recorded each minute. The RPE (6-20) and BACS (0-8) scales will be used to assess fatigue and comfort levels of the subject. A high RPE value indicates that the subject has reached exhaustion, and a low BACS value indicates that the subject views the mask conditions as uncomfortable. Both facial thermal and whole body thermal sensation values will be recorded. The RPE and BACS scales give the lab assistant an indication of how the subject feels during the testing session.

Risks: Possible risks to the subject include heat stress, severe exhaustion, or injury due to falling off of the treadmill. A lab assistant will be present throughout all testing sessions, and at any time during the testing, if a subject begins to show signs of extreme discomfort, or expresses

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extreme discomfort, the testing session will be terminated. Due to the possibility of dehydration or heat stress, water will be available for the subject's use at any time during testing.
As protection against heat stroke, core body temperature will be monitored throughout the study. Core body temperature will be monitored through a rectal probe connected to a computerized temperature monitoring system, after dressing has been completed. Testing will be terminated is rectal temperature reaches 103°F. Insertion of rectal probes could cause some minor discomfort. The tips are round and should not hurt the subject.

Benefits and Freedom to Withdraw: You will receive a copy of your test results. This information will provide you with performance under various temperature and humidity conditions, which may be used to construct optimal environmental situations.
You may withdraw from this investigation at anytime without incurring a penalty.
This request may be expressed through either verbal or written communication to an investigator.
There are no direct benefits to the subjects for their participation in this study.

Confidentiality: All personal information will remain confidential and will be stored in the co-investigator's office. This data will be accessible only to individuals directly involved in this investigation. No personal references attributed to your file will be presented in publications or conferences.

Rights: I understand that University of Maryland does not provide any medical or hospitalization insurance coverage for participants in this research study nor will the University of Maryland pay any medical expenses or provide any compensation for injury sustained as a result of participation in this research study except as required by law.

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If you have questions about your rights as a subject or wish to report a research-related injury, please contact: **Institutional Review Board Office**
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(Subject Signature) (Date)

Initials______________ 3 of 3

(Witness Signature) (Date)

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1. Abstract:

Respirators are worn in the workplace in order to protect the individual from toxic airborne substances; however, respirators are worn in only about 20-30% of the appropriate circumstances due to several factors. The primary importance for the proposed research is to study the thermal effects due to increased temperature and humidity of inspired air. An environmental chamber will be utilized for simulation of various ambient conditions, and a heating unit will supply various air conditions to the respirator. Subjects will don a full face piece respirator and exercise at 65-70% of their VO2max at three previously determined conditions. A mathematical model will be developed that correlates performance time with temperature and humidity to provide manufacturers with a useful tool for designing masks with favorable characteristics that are appropriate for optimal performance.

2. Subject Selection:

a. Who will the Subjects be? How will you recruit them? If you plan to advertise for subjects, include a copy of the advertisement.
The subjects will be students at the University of Maryland. They will be recruited from willing and able volunteers at the university, specifically, within the Department of Biological Resources Engineering. The subjects will receive no course credit for their participation. Twenty total subjects will be recruited via announcements at the conclusion of Biological Resources Engineering class periods. The studies will be conducted at the University of Maryland.

b. Will the subjects be selected for any specific characteristics (e.g. age, sex, race, ethnic origin, religion or any social or economic qualifications)?
No; however, the subjects will be screened prior to testing when the informed consent document is completed to ensure that they are in good physical health.

c. State why the selection will be made on the basis or base given in 2(b).
The purpose of the study is to determine comfort level of the respirator, and not whether or not it corrects a specific problem. For this reason, any and all volunteers will be selected.

d. How many subjects will participate in this protocol?
15 subjects

3. Procedures Section:

What precisely will be done to the subjects? Explain in detail your methods and procedures in terms of what will be done to subjects. How many subjects will be recruited? What is the total investment of time of the subjects. If subjects will complete surveys and/or other Instruments on more than one occasion, state this in the procedures

section. If you are using a questionnaire or handout, include a copy within each set of application documents. If you are conducting a focus group, include a list of the questions for the focus group.
The research will consist of three stages: obtain consent and orientation, perform the VO2max graded exercise test, and 65-70% VO2max testing under three different conditions. The initial analysis suggests that a total of 20 subjects will be needed for the study.

The first stage is to obtain consent and give a brief orientation to the subjects to describe what their participation requires. The subjects may or may not be familiar with wearing a respirator; therefore, each subject will be fully advised as to the requirements of their participation. The subjects will read and sign the informed consent document and fill out a brief medical history questionnaire. This session provides the subject with a detailed description of their rights, and it provides the investigators with information about the subjects" health and ability to partake in vigorous activity. Any demographic or experimental data collected will remain confidential and correspond only to a subject number.

The second stage of research consists of a graded exercise test (VO2max test) that will be used to determine the subject's maximal aerobic capacity. This test provides valuable information necessary for determining each subject's work rate during each of the testing sessions, along with information regarding each subject's critical termination values such as heart rate and maximum oxygen consumption. Participants will be asked to warm-up and stretch for approximately ten minutes prior to the start of the test. The mask used to collect gases during the test is a half face mask equipped with one-way inhalation and exhalation valves. Heart rate measurements will be assessed using a standard ECG electrode configuration with the leads connected to a Patient Monitoring System. In order to determine VO2max, the subject will partake in a graded exercise test to exhaustion. The work rate will be adjusted every three minutes until the participant becomes fatigued, fails to display a rise in oxygen consumption in concurrence with the increase in work rate, or reaches a maximal heart rate.

The third stage of research consists of actual subject testing in an environmental chamber. Each session will be conducted at 65-70% of the participant's maximal oxygen consumption using a treadmill. All sessions will utilize a full face piece mask, which covers the entire face including the cheeks and forehead. The subject will exercise at a constant work rate throughout all three sessions. Furthermore, each of the subjects will dress similarly and wear the same mask throughout all sessions. Before exercise, the subject will complete a five minute warm-up on the treadmill followed by five minutes of stretching. The subject will don a heart rate monitor, rectal probe for monitoring core body temperature, and three surface temperature sensors on the face. The sensors will be placed on the mid-forehead, right cheekbone, and upper lip under the left nostril. The rectal probe will be inserted by the subject, who will be given lubricant to ease in insertion of the rectal probe. The human monitor will explain the insertion technique, which will be to insert the tip gradually into the sphincter approximately the length of the palm of the subject's hand (approximately 2 inches). The subject will be asked to dress in standard military fatigues and tennis shoes. A full face piece respirator will be fitted to the subject for a comfortable, but snug fit. The outlet of the respirator will be connected via a hose to monitor continuous expired airflow, and the inspiratory valve will be connected to the outlet of the humidity chamber. The subject will begin to exercise at a treadmill speed and grade set at a work rate below 65-70% VO2max; the speed and grade will be increased for approximately 90 seconds before the speed and grade corresponding to 65-70% VO2max is reached. At this work rate, the subject will be asked to exercise until he or she reaches volitional fatigue. A 5 minute cool down period will follow the testing session.

A human monitor while be present during subject testing to monitor for signs of distress. Heart rate, facial skin temperature, and core body temperature will be monitored; Rating of Perceived Exertion (RPE), and the Breathing Apparatus Comfort Scales (BACS) will be recorded each minute. The RPE (6-20) and BACS (0-8) scales will be used to assess fatigue and comfort levels of the subject. A high RPE value indicates that the subject has reached exhaustion, and a low BACS value indicates that the subject views the mask conditions as uncomfortable. Both facial thermal and whole body thermal sensation values will be recorded.

A participant is free to withdraw from this project at anytime without incurring a penalty. This request may be expressed to an investigator through either verbal or written communication.

4. Risks and Benefits:

Are there any risks to the subjects? If so, what are these risks? What are the benefits? If there are known risks associated with the subject's participation in the research, what potential benefits will accrue to justify taking these risks?

Possible risks to the subject during the maximum oxygen consumption test are minimal and including tripping, falling off of the treadmill, and heat stress, though these risks are not anticipated.

Possible risks to the subject include heat stress, severe exhaustion, or injury due to falling off of the treadmill. A human monitor will be present throughout all testing sessions, and at any time during the testing, if a subject begins to show signs of extreme discomfort, or expresses extreme discomfort, the testing session will be terminated. Due to the possibility of dehydration or heat stress, water will be available for the subject’s use at any time during testing.

As protection against heat stroke, core body temperature will be monitored throughout the study. Testing will be terminated if rectal temperature reaches 103ºF. High rectal temperature is indicative of heat generated in the active muscles, and if this reaches the critical value, the person may become incapacitated. As a result of normal exercise, core body temperature generally rises to about 101ºF; however, heat stroke occurs at core body temperatures of 106ºF; therefore, in order to avoid approaching symptoms of heat stroke, the cut-off temperature will be 103ºF (McArdle, 1996).Core Body temperature will be monitored through a rectal probe connected to a computerized temperature monitoring system, after dressing has been completed. Insertion of rectal probes could cause some minor discomfort. The tips are round and will not hurt the subject. The rectal probes will be disposed off using biohazard disposal methods used in the laboratories.

The study is not designed to help the subjects. Participants will receive a copy of their test results and this information may be of interest to those individuals interested in duplicating optimal environmental conditions. No monetary benefits will be provided. There are no direct benefits to the subjects for their participation in this study.

The risks associated with this project are minimal and reversible with adequate rest. The benefits are specific to those persons responsive to heat stimulus and therefore will be of interest to this group. This benefit will not be transferred to other individuals; however, the minimal risk encountered makes this project feasible for this population.

5. Confidentiality

Adequate provisions must be made to protect the privacy of subjects and to maintain confidentiality of identifiable information. Explain how our procedures accomplish this objective, including such information as the means of data storage, data location and duration, description of persons with access to the data, and method of destroying the data when completed. If the research involves audiotaping, videotaping or digital recordings, state who will have access to the tapes or recordings, where the tapes or recordings will be kept, and state the final disposition of the tapes or recordings (i.e. Will the tapes or recordings be destroyed? If so, when will the tapes or recordings be destroyed?).
The results of each subject will be stored under a number relating only to the order in which they were tested. Subjects willing to be reached for further questions and comments will have a chance to give us their contact information. Statistical information used in reports concerning this project will in no way be linked to any participants of the study.
6. Information and Consent Forms

State specifically what information will be provided to the subjects about the investigation. Is any of this information deceptive? State how the subject's informed consent will be obtained. Include a final draft of the consent form that you propose to use. Include a description of the data storage methods which will be used to ensure confidentiality within the consent form.
Each subject will read and sign the consent form and questions regarding the study will be answered at this time. Prior to the study, the subject will receive the attached information, including a description of the purpose of the study, the questionnaire, and consent form. Only subjects who have signed the consent forms will be allowed to participate in the study.
7. Conflict of Interests

Describe the potential conflict of interest, including how such a conflict would affect the level of risk to the study participants.
This is not required

McArdle, W.D., Katch, F.I., and Katch, V.L., "Exercise Physiology," Williams and Winkins: Baltimore, MD, 1996.

Bibliography

Culp, G. and A. Smith. 2001. Understanding Psychological Type to Improve Project Team Performance. *Journal of Management in Engineering* 17(1): 24-33.

DuBois, A.B., Harb, Z.F., and Fox, S.H. 1990. Thermal Discomfort of Respiratory Protective Devices. *American Industrial Hygiene Association Journal*, 51(10): 550-554.

Fox, S.H., and DuBois, A.B. 1993. The Effect of Evaporative Cooling of Respiratory Protective Devices on Skin Temperature, Thermal Sensation, and Comfort. *American Industrial Hygiene Association Journal*, 54(12): 705-710.

Gwosdow, A.R., Nielsen, R., Berglund, L.G., DuBois, A.B., and Tremml, P.G. 1989. Effect of Thermal Conditions on the Acceptability of Respiratory Protective Devices on Humans at Rest. *American Industrial Hygiene Association Journal*, 50(4): 188-195.

Harber, P., Brown, C.L., and Beck, J.G. 1991. Respirator Physiology Research: Answers in Search of the Question. *Journal of Occupational Medicine*, 33(1): 38-43.

James, R., Dukes-Dobos, F., and Smith, R. 1984. Effects of Respirators Under Heat/Work Conditions. *American Industrial Hygiene Association Journal*, 45(6): 399-404.

Johnson, A.T. 1991. Biomechanics and Exercise Physiology [online book]. Available www: http://www.bre.umd.edu/johnbooks.html.

Johnson, A.T., Koh, F.C., Scott, W.H., Mackey, K.M., Chen, K.Y.S., Rehak, T. 2005. Inhalation Flow Rates During Strenuous Exercise. *Journal of the International Society for Respiratory Protection*, 22: 79-96.

Johnson, A.T., Scott, W.H., Caretti, D.M. 2003. Do Respirators Stress the Cardiovascular System? *Journal of the International Society for Respiratory Protection*, 26-36.

Johnson, A.T., Scott, W.H., Coyne, K.M., Sahota, M.S., Benjamin, M.B., Rhea, P.L. Martel, G.F., and Dooly, C.R. 1997. Sweat Rate Inside a Full-Face piece Respirator. *American Industrial Hygiene Association Journal*, 58: 881-894.

Johnson, A.T., Scott, W.H., Koh, F., Phelps, S.J. 2005. Exercise Performance While Wearing a Tight-Fitting PAPR with Limited Flow. *Journal of Occupational and Environmental Hygiene*, 2: 368-373.

Klemm, F.K. and Hall, J.F. 1972. Utility of Heat Stress Indices and Effect of Humidity and Temperature on Single Physiological Strains. *Journal of Applied Physiology*, 33: 436-440.

Koh, F. 2004. The Correlation Between Psychological Type and Performance Time While Wearing a Respirator. Masters Thesis, University of Maryland, College Park.

Laird, I.S., Goldsmith, R., Pack R.J., and Vitalis A. 2002. The Effect on Heart Rate and Facial Skin Temperature of Wearing Respiratory Protection at Work. *Annals of Occupational Hygiene,* 46(2): 143-148.

Lekeux, A.T. 1988. Effect of Environmental Temperature and Relative Humidity on Breathing Pattern and Heart Rate in Ponies During and After Standardized Exercise. *Veterinary Record*, 123(11): 295-299.

Louhevaara, V., Tuomi, T., Korhonen, O., and Jaakkola, J. 1984. Cardiorespiratory Effects of Respiratory Protective Devices During Exercise in Well-trained Men. *European Journal of Applied Physiology*, 52: 340-345.

McCann, D.J., and Adams, W.C. (1997). Wet Bulb Globe Temperature Index and Performance in Competitive Distance Runners. *Medicine and Science in Sports and Exercise*, 29(7): 955-961.

McCuen, R.H. 1993. Microcomputer Applications in Statistical Hydrology. Prentice-Hall, Inc., Upper Saddle River, NJ.

McCuen, R.H. 2003. Modeling Hydrologic Change. CRC Press, Boca Raton, FL.

McCuen, R.H. 1985. Statistical Methods for Engineers. Prentice-Hall Inc., Upper Saddle River, NJ.

National Weather Service 2005. Heat Index. [online]. Available www: http://www.nws.noaa.gov.

Nielsen, R., Gwosdow, A.R., Berglund, L.G., and DuBois, A.B. 1987. The Effect of Temperatures and Humidity Levels in a Protective Mask on User Acceptability During Exercise. *American Industrial Hygiene Association Journal*, 48(7): 639-645.

Nunneley, S.A. 1989. Heat Stress in Protective Clothing. *Scandinavian Journal of Work and Environmental Health*, 15(1): 52-57.

Ott, R.L. and Longnecker, M. 2001. An Introduction to Statistical Methods and Data Analysis. Woodsworth Group. Pacific Grove, CA.

Payne, W.R., Portier, B., Fairweather, I., Zhou, S., and Snow, R. 1994. Thermoregulatory Response to Wearing Encapsulated Protective Clothing During Simulated Work in Various Thermal Environments. *American Industrial Hygiene Association Journal*, 55(6): 529-536.

Pulket, C., Henschel, A., Burg, W.R., Saltzman, B.E. 1980. A Comparison of Heat Stress Indices in a Hot-Humid Environment. *American Industrial Hygiene Association Journal*, 41(6): 442-448.

Radomsky, A.S., Rachman, S., Thordarson, D.S., McIsaac, H.K., Teachman, B.A. 2001. The Claustrophobia Questionnaire. *Anxiety Disorders,* 15: 287-297.

Raffenbarger RS, Wing AL, Hyde RT. 1978. Physical activity as an index of heart attach risk in college alumni. *American Journal of Epidemiology*,108: 161-175.

Ramanathan, N.L. and Belding, H.S. 1973. Physiologic Evaluation of the WBGT Index for Occupational Heat Stress. *American Industrial Hygiene Association Journal*, 34(9): 375-383.

Roscoe, J.T. 1969. Fundamental Research Statistics for the Behavioral Sciences. Holt Reinhart and Winston Inc., New York, NY.

Selkirk, G.A. and McLellan, T.M. 2004. Physical Work Limits for Toronto Firefighters in Warm Environments. *Journal of Occupational and Environmental Hygiene*, 1(4): 199-212.

Tremblay, S., Radomsky, A.S., Dussault, D., Newth, S., & Brown Tesolin, S. 2002. The Prediction of Effort and Reward Questionnaire. Poster presented at the Association for the Advancement of Behavior Therapy Conference, Reno, NV.

Turner, N., Parker, J., and Hudnall, J. 1992. The Effect of Dry and Humid Hot Air Inhalation on Expired Relative Humidity During Exercise. *American Industrial Hygiene Association*, 53(4): 256-260.

White, M.K and Hodous, T.K. 1987. Reduced Work Tolerance Associated with Wearing Protective Clothing and Respirators. *American Industrial Hygiene Association Journal*, 48(4): 304-310.

White, M.K., Hodous, T.K., and Vercruyssen, M. 1991. Effects of Thermal Environment and Chemical Protective Clothing on Work Tolerance, Physiological Responses, and Subjective Ratings. *Ergonomics*, 34(4): 445-457.

White, M.K., Vercruyssen, M., and Hodous, T.K. 1989. Work Tolerance and Subjective Responses to Wearing Protective Clothing and Respirators During Physical Work. *Ergonomics*, 32(9): 1111-1123.

Wilmore, J.H. and Costill, D.L. 2004. Physiology of Sport and Exercise. Human Kinetics. Hong Kong, China.