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Performance Assessment of Predicted Heat Strain in High Heat Stress

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Performance Assessment of Predicted Heat Strain in High Heat Stress Exposures

by

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Dedication

I dedicate this dissertation to my wife Pam, who has supported me throughout the years both financially and emotionally and has always been there to pick me up when I was at my lowest points and who had enough faith in me to see this to the end. My children Lynn and Erik who picked up the slack at home when help was needed, thank you. I could not have done it without you.

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Abstract

Heat stress is a common physical agent associated with many occupations. The most commonly used method of assessing heat stress exposure is an empirical method using the Wet Bulb Globe Temperature Index but his method is limited in its ability to parse out individual contributors to the heat stress. The International Organization for Standardization (ISO) published a rational model called Predicted Heat Strain (PHS) in 2004, and rational methods have the advantage of separating out the individual pathways for heat exchange. The objective of this research was a performance assessment of the current PHS model. This experimental design consisted of 15 trials (3 clothing ensembles and 5 heat stress levels) involving 12 men and women. The clothing ensembles were work clothes, NexGen® (microporous) coveralls, and Tychem® QC (vapor-barrier) coveralls. The heat stress levels were 1.0 , 2.0 , 3.5 , 5.5 and 9.0 °C-WBGT above the average critical environment for each ensemble determined in prior studies. The metabolic rate was 190 W/m^2. The two outcomes of each trial were an exposure time when core temperature reached 38 °C (ET38) and a Safe Exposure Time (SET) defined as the amount of time required to reach either a core temperature (T_{re}) = 38.5 ºC, a heart rate of 85% age-estimated maximum, or fatigue.

Trial data for environment, metabolic rate and clothing were inputs to the (PHS) model to determine a predicted amount of time for the participants to reach a T_{re} = 38 ºC, which was the limiting condition in PHS for acute exposures. The first consideration was predictive validity for which PHS-Time was compared to ET38. The expectation would be that PHS-Time would predict the mean ET response. Results for predictive validity indicated a moderate agreement between ET38 and PHS-Time (r^2 of 0.34 and Intraclass Correlation Coefficient at 0.33). When the method for accounting for clothing was changed to that recommended by ISO, the PHS predicted times moved systematically toward a shorter exposure time and modest agreement (r^2 of 0.39 and Intraclass Correlation Coefficient at 0.31). Protective validity was the ability of the PHS-Time to predict an exposure time that would be safe for most people. In this case, PHS-Time was compared to SET. The PHS was protective for 73% of the cases. When it was modified to account for clothing following the ISO method, the protective outcomes were 98%.

In addition, the PHS model examined with respect to starting core temperature and fixed height and weight. Using the actual core temperature improved the outcomes somewhat, but changing from 36.8 to 37.0 would be sufficient. There is a strong tendency to over-predict PHS-Time for individuals with a low body surface area, usually short and lower than average weight.

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CHAPTER 1:

INTRODUCTION

Heat stress is common to many occupations because of the hot environment. Thermal stress is also affected by energy demands of the work and type of clothing worn. Taking into account these additional factors, occupations such as firefighters, military personnel involved in training or combat operations, miners and other workplaces involving high ambient air temperatures, radiant heat sources, high humidity, and strenuous physical activities are at risk to excessive heat exposure. (Barwood *et al*., 2009; Bricknell, 1997; Carter *et al*., 1999; Chen *et al*., 2003; Cortés-Vizcaino & Bernard, 1996) In addition, indoor occupations including manufacturing, bakeries, restaurant kitchens, industrial laundry facilities, and utility plants expose workers to heat stress problems. (Jay & Kenny, 2010; Nag *et al*., 2007)

When the human body can no longer adjust to thermal demands placed on its physiologic functions such as core body temperature and heart rate, sweating increases. (Bernard, 1996) Thermal balance is maintained when heat gains equal heat losses. However, when heat gains begin to exceed heat losses then heat strain may become excessive and these exposures may be manifested as heat cramps, heat exhaustion and heat stroke. (Kamijo & Nose, 2006) The question then becomes how we safely limit heat stress exposures.

Currently there are two types of models to assess levels of heat stress. Empirical models rely on environmental monitoring such as use of the Wet Bulb Globe Temperature (WBGT) and estimated workload based on metabolic rate. Rational models include the classic Heat Stress Index (Belding & Hatch 1955) and Predicted Heat Strain model (ISO 7933, 2004) Rational models are based on biophysical modeling of the worker to predict physiologic responses based on core body temperature, heart rate, sweat rate based on environmental conditions, energy expended and clothing worn.

Empirical Models

Empirical models for predicting risks of heat stress are based on various field experiments and the derived limits on environmental not physiological factors and rely on the environment, metabolic energy expenditure and clothing worn. (Brake and Bates, 2002) An example of the empirical model that has been used by the United States Army Research Institute for Environmental Medicine (USARIEM) is the wet bulb temperature for limiting metabolic rate based on a work/rest cycle. (Brake & Bates, 2002; Bricknell, 1997; Cadarette *et al*., 1999, Cadarette *et al*., 2006)

The United States Navy uses the WBGT to determine environmental conditions that limit outdoor activities. Other examples of empirical models include Air Cooling Power (ACP) used in South African mining operations;

Corrected Effective Temperature (CET) and Thermal Work Limit (TWL). (Brake & Bates, 2002) All of these indices use the wet bulb temperature in conjunction with the estimated metabolic rate and some level of acclimatization.

The most commonly used empirical method for predicting response to heat stress exposure is the Wet Bulb Globe Temperature. This index is based on environmental conditions to determine the possibility of developing an adverse physiological response to excessive heat exposure and thus the index must be adjusted to take into account work demands and clothing. The initial development of the WBGT was for application to United States Marine recruits during physical training in summer months. In empirically deriving the heat stress threshold, only one type of clothing was considered. (Budd, 2008) These empirical models have provided reasonable methods of determining the upper limit of exposure. The WBGT limit that provided the basis for the American Conference of Government Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) is still the currently used limit. Other types of clothing used in the current workplace can be accounted for in the empirical model with use of clothing adjustment factors. (O'Connor & Bernard, 1999; Bernard *et al*, 2005, 2008)

Rational Models

A rational model of heat stress uses a biophysical model of heat exchange between a person and the environment (Brake & Bates, 2002). These environment factors include air temperature (dry bulb reading), humidity or ambient water vapor pressure, air speed, and equivalent blackbody temperature (or radiant temperature) of the surroundings. This rational model may consist of a direct method of metabolic rate assessment, a predictive method based on the analysis of the tasks performed in either a real or hypothetical job, or established tables to look up metabolic rate data for purposes of assessment. (Malchaire *et al*., 1999; Malchaire *et al*., 2002; Malchaire & Mairiaux, 1991; and Malchaire, 2006) The United States Navy in attempting to predict heat strain found that the Heat Stress Index (HSI) was not useful for applications in shipboard uses and developed the Permissible Heat Exposure Limit (PHEL) charts based on extensive heat-stress experiments using physiologic data. (Epstein & Moran, 2006)

The publication of ISO 7933 (1989) placed emphasis on calculating the required sweat rate as a method for determining the thermal stress. It was extremely complex and as such it was poorly understood and not used in industry. (Malchaire, 2006) In 2004, the ISO 7933 standard was revised providing a method of heat strain analysis based on the calculation of the predicted heat strain (PHS). This method incorporated the methods of predicting the sweat rate and core temperature to predict the human response of working in a thermal environment. This method does not predict an individual response of a specific worker but thermal stress conditions that could cause rise in core temperatures and establishment of maximum allowable exposure times. (ISO 7933, 2004) The standard remains complex and designed to be used by expert safety and health personnel to control heat stress risks.

The purpose of this research was to examine the performance of the current ISO PHS, a rational model designed to predict physiological response to the thermal environment.

- Predictive validity is the ability of PHS to predict the time limit for an average population of exposures to acute heat stress. The predictive validity was evaluated for the PHS model with respect to an exposure time limit with comparisons to actual observed exposure times for a participant to reach a core temperature (T_{re}) of 38.0 ºC (ET38).
- Protective validity is the ability of the PHS time limit to predict a time that the least tolerant person can safely work under the heat stress conditions. To evaluate protective validity, the PHS predicted time was compared to the observed Safe Exposure Time (SET). SET was defined as the time to reach a T_{re} of 38.5 ºC, a heart rate of 85% of age-estimated maximum heart rate or fatigue.

CHAPTER 2:

LITERATURE REVIEW

Heat stress has been known to cause a rise in core temperature for over 70 years. The use of the heat balance equation was first described by Winslow, Gagge, and Herrington (1939) to determine quantitative influence of air movement upon heat loss. They theorized that the difference between the metabolic rate and evaporation should equal the sum of radiation and convection and in this case heat storage should equal zero. More specifically the heat balance equation was displayed as:

$$(M - E) = R + C$$

with the premise that heat storage (S) is zero when the difference between metabolic rate (M) and evaporation (E) is equal to the sum of radiation (R) and convection (C). Further studies over the years suggested refinements to the relationship. One of their conclusions at the time was that thermal storage could not be estimated strictly from skin or rectal temperature but more "adequately from the algebraic sum of metabolic heat production, evaporative heat loss and gain, and loss by radiation and convection" (Winslow, Gagge and Herrington, 1940).

Belding and Hatch (1955) reviewing research conducted in the 1930s and 1940s explained that the relationship between core temperature, heat storage and avenues of heat loss could be used to assess the degree of heat stress. Using results published by Winslow, Gagge, and Herrington (1939), Belding and Hatch conceptualized the relationship between heat storage and heat balance, and how physiologic responses along with environmental conditions contributed to heat loss. They pointed out that heat gain could be compensated by the human body through sweating and that evaporation of sweat resulted in maintaining heat balance. They defined the rate of evaporation required (E_{req}) to maintain heat balance as

$$\mathrm{E}_{req} = \mathrm{M} + \mathrm{R} + \mathrm{C}$$

where M is metabolic rate, R is radiative heat loss, and C is convective heat loss. Belding and Hatch also stated that for a given environment there existed a maximum amount of evaporation that could occur (E_{max}). Belding and Hatch (1955) proposed that the level of heat stress could be expressed as a ratio of E_{req} to E_{max} and called it the Heat Stress Index (HSI).

$$HSI = \frac{E_{req}}{E_{\max}} \times 100$$

The Index of Thermal Stress (ITS) reported by Givoni (1963, 1976) improved on the Heat Stress Index model. He inserted the concept of solar load (R_s) into the heat balance equation and replaced metabolic rate with metabolic heat production (H) as M-W (where W is rate of external work) accounting for external work so mathematically

$$E_{req} = H - (C+R) - R_s$$

His research indicated an important aspect to methods of heat loss which was that not all sweat is evaporated but some may drip from the body. This led to the conclusion that the required sweat rate (S_w) is related to the required evaporation rate which is affected by the body's efficiency to sweat (n_{sc}):

$$S_w = \frac{E_{req}}{n_{sc}}$$

The ITS equation was revised by McIntyre (1980) converting W m^{-2} into g h^{-1};

$$\mathrm{ITS} = \frac{[H - (C + R) - R_s]}{0.37 n_{sc}}$$

where 0.37 is the conversion factor for W m^{-2} into g h^{-1},n_{sc} is the body's efficiency to sweat; H is heat production, C + R is the sum of radiative and convective heat loss and R_s solar load.

Research in the 1960's indicated that intermittent and continuous work in moderate climates up to 27.5 °C demonstrated that rectal temperatures rose within one hour to equilibrium then remained steady. (Lind, 1962) This response was similar at 23 °C and 27 °C. However in climate settings where the effective temperature was greater than 30 °C rectal temperatures and heart rates increased with intermittent work slightly higher than that associated with continuous work. (Lind, 1962) The conclusion was that “climates within the prescriptive zone in which thermal equilibrium is dependent solely on rate of work, an extension of the exposure from 3 to 8 hours has no detrimental effects”. No detrimental effects as based on physiological responses were defined by Lind (1962) as changes in rectal temperature, pulse rate, and sweat loss. Lind (1962) in additional studies using three volunteer miners found that a similar relationship existed between pulse rate increases and Corrective Effected Temperature (CET) as did rectal temperatures and CET. Pulse rates and rectal temperature appeared to rise “slowly over a wide range of climates, and then faster in hot climates”. (Lind, 1962) In this particular study Lind (1962) indicated that within the prescriptive zone, core temperature is kept steady by adjustments of physiological mechanisms for thermoregulation. As the level of thermal stress increases, skin temperature rises and by doing so heat losses by radiation and convection are reduced, while evaporative losses from the skin increase to maintain heat balance.

Physical work or exercise causes a person to convert stored chemical energy into kinetic and thermal energy, however only 20% of this energy is used with 80% remaining as heat. (Taylor, 2006) When the work or exercise environment is hot, non-evaporative heat dissipation is impeded. If the air temperature and the skin temperature are relatively equal then the dissipation of heat by natural convection ceases and the body then becomes dependent on evaporative cooling. (Taylor, 2006) When evaporation of sweat becomes the primary way to dissipate heat in a hot environment without an increase in body temperature then the thermal compensability is based on the thermal environment. (Taylor, 2006)

Empirical Methods

The wet bulb globe temperature (WBGT) is the widely accepted environmental index for occupational heat stress exposure. Developed in the early 1950's for evaluating potential heat stress hazards to military recruits, this measurement tool has been the basis for most empirical methods of determining heat stress exposure. Lind described possible criteria to define thermal limits involving everyday exposure in a heat stress environment as the prescriptive climate. (Lind, 1960; Lind, 1963) This prescriptive climate defined the "level of bodily thermoregulation which remained steady for a given amount of work. (Lind, 1963) Based on these studies of Lind with some additional data, threshold limit values® (TLV®s) and recommended exposure limits (RELs) have been developed, relating WBGT and metabolic rate to an eight hour exposure limit. The American Conference of Government Industrial Hygienists® (ACGIH®) TLV for heat stress and strain provided a screening evaluation tool that considered the environmental conditions.

Rational Methods

The Required Sweat Rate, a rational model which calculated the amount of sweating required for heat balance was based on further development of the Index of Thermal Stress (ITS) and the Heat Stress Index (HSI). This new index Required Sweat Rate improved the heat balance equation and provided a calculated method of interpretation by comparing the amount of sweat required by the amount of sweating physiologically possible. (Vogt, *et al*, 1981; Cena & Clark, 1981; Parsons, 1993) Six parameters were used in the calculation of the required sweat rate, i.e.; air temperature (t_a), radiant temperature (t_r), relative humidity (ϕ), air velocity (v), clothing insulation (I_{cl}), metabolic rate (M) and external (W). The revised heat balance equation included heat losses due to respiratory convection (C_{res}) and respiratory evaporation (E_{res}). The improved heat balance relationship based on required evaporation (E_{req}) was expressed as the sum of metabolic rate minus external workload and methods of heat loss.

The Required Sweat Rate (SW_{req}) was derived from the required amount of evaporation and the efficiency of sweating (r) and provided that amount of sweating required to maintain thermal equilibrium in the body.(Parsons, 1993)

As part of the revision, the posture of the individual in the heat environment was also considered and effective radiation area values were assigned; 0.72 for sitting and 0.77 for standing. Parsons (1993) and Mairliaux and Malchaire (1988) reported results of extensive practical trials involving the use of the required sweat rate and validation of the model which resulted in it being accepted as an International Standard (ISO 7933) in 1990.

The Required Sweat Rate model relied on use of accepted reference values and thus provided a practical interpretation on calculated values. (Parsons, 1993) Initially three values must be predicted, the skin wettedness (w_p), evaporation rate (E_p), and predicted sweat rate (Sw_p). If the required skin wettedness value is met, then the required value becomes the predicted and thus skin wettedness (w_p) equals the required amount of sweating. (W_{req}). (Parsons, 1993) The required sweat rate and limit values (for both non-acclimated and acclimated personnel) determine the predicted sweat rate. These limit values are stated for both a warning and danger category. Thermal equilibrium in the case of this model depends on the fact that persons can achieve the required sweat rate and without causing any unacceptable water loss. (Parsons, 1993) When above conditions are met, then there is no heat exposure limit for an 8 hour shift. If these conditions are not met, then Duration Limiting Exposure (DLE) values (allowable exposure times) must be calculated. (Parsons, 1993) These values consists of two tiers; the first being the limiting exposure value based on heat storage and the second being the limit to prevent further water loss that would lead to dehydration.

After publication of ISO 7933 (1989), several papers were published critical of the Required Sweat Rate index. These published papers compared various versions of the Required Sweat Rate index against limited sets of data and issues of concern were identified. (Malchaire *et al*., 2001) Limitations identified were prediction of skin temperature and maximum allowable exposure times; influence of the clothing on convective and evaporative heat exchanges; combined effect of clothing and movement; and increase of core temperature and its link to activity. (Malchaire *et al*., 2001) In addition the Required Sweat Rate standard was rarely used in practical heat stress assessments. Limitation concerns and infrequent use led to the establishment of a joint research project by European research experts in the "field of thermal factors and sanctioned by the European Union". (Malchaire *et al*., 2001)

A study designed to establish the critical heat environments in that human test subjects would just maintain thermal equilibrium (E_{req} = E_{max}) provided additional information that was recommended for inclusion in the revision to ISO 7933 Several environments were designed to simulate: hot, dry climates; warm, humid climates; fifty-percent humidity climates; and metabolic rate, fixed climate. (Barker, *et al*., 1999) The inflection point (where body thermal equilibrium cannot be maintained) was determined for all climates. Values for the total evaporative resistance ($R_{\text{e,t}}$) were calculated for each climate and ensemble along with clothing factors. Their conclusion was that incorporating these values would increase the utility of the ISO 7933 standard. (Barker, *et al*., 1999)

Predicted Heat Strain Model

Malchaire *et al*., (2001) defined the objectives of the joint research project between main European research teams in the field of thermal factors to focus on what were conceived as major problems of ISO 7933 (1989). The objectives were geared to end users on a strategy for assessment of the stress working in hot environments, allowing practitioners to determine maximum allowable exposure duration and optimization of the hot working environment. (Malchaire *et al*., 1999) Considering variations on the prediction of heat exchanges between clothed persons and the thermal environment along with special clothing characteristics resulted in the description and validation of new algorithms involving clothing convective heat exchanges and clothing evaporative heat resistance. (Havenith *et al*., 1999; Holmer *et al*., 1999; and Malchaire *et al*., 2001) Criteria for determining maximum allowable exposure duration and specifically "inter-individual differences in sweat rate, evaporation efficiency, water loss and core temperature increases" were reviewed and reported on by Malchaire *et al*. (2000).

Mehnert *et al*. (2000) developed and validated a new model for the expression used to predict the mean skin temperature, improving the overall validity for this algorithm. In addition, other areas of ISO 7933 (1989) were reviewed pertaining to algorithms used in determining respiratory heat losses, influence of protective clothing, prediction of mean skin temperature along with exponential averaging for skin temperature and sweat rate, prediction of mean body temperature, distribution of heat storage, prediction of rectal temperature, and evaporation efficiency. (Malchaire *et al.,* 2000) Once these changes were incorporated into the model, the Required Sweat Rate index was changed to

Predicted Heat Strain (PHS) model to avoid confusion between the older versions and this new revised model. (Malchaire *et al.,* 2000)

With ISO 7933(2004) the Predicted Heat Strain model (PHS), respiratory evaporative and convective heat losses are considered as well as convective and radiative losses of the skin. The difference between the required and predicted evaporation rates determine the heat storage within this model. (Malchaire, 2001) The influence of protective clothing on the SW_{req} and rate of evaporation in PHS were considered to more accurately predict heat exchange between the environment and the exposed individual. (Malchaire, *et al*., 2001)

The PHS model incorporated a more realistic approach to convective and radiative heat transfer. Holmer, *et al*., (1999) stated that these heat transfer methods between “human body surface and the environment are the most important avenues of sensible heat exchange”. Their research concluded that present calculations of convective and radiative heat losses in ISO 7933 (1989) underestimated values associated with effects of body motion (pumping action) and wind on clothing heat transfer. (Holmer, *et al*., 1999) In addition, the clothing area factor (f_{cl}) could only be used in regards to “integrated dry heat loss”. They proposed a correction formula for clothing and convective heat transfer, differentiating between undressed and dressed. The undressed correction factor

$$I_{corr} / = I_{st}\, e^{(0.126 - 0.899x_{v} + 0.246x_{v}<2 - 0.313xw + 0.097xw<2)}$$

and for dressed

$$I_{corr} / = I_{st}\, e^{(0.043 - 0.398x_v + 0.066x_v<2 - 0.378xw + 0.094xw<2)}$$

where I_{corr} is the corrected total insulation based on the static, standing insulation value (I_{st}) which is calculated from a given I_{cl} (clothing insulation value) I_a (thermal insulation of the boundary layer on a nude person when the $v_{ar} = 0$) and v is air velocity in m s^{-1} and w is the walking speed in m s^{-1}. The value w is calculated by using the equation

$$w = 0.0052 \text{ x } (M - 58).$$

Holmer, *et al*., 1999 stated that their equations applied values of 0 to 1.84 clo, air velocity from 0.2 to 3 m s^{-1} and walking speeds up to 1.2 m s^{-1}. These equations along with applied values were incorporated into ISO 7933(2004). (Malchaire, *et al*,. 2001, Holmer, *et al*,. 1999) Related research applying the same approach to clothing evaporative heat resistance as to clothing convective heat exchange was conducted by Havenith *et al*., (1999). The definition of evaporative resistance was considered problematic when used in calculations to evaluate heat strain per ISO 7730(1989). Evaporative clothing resistance data was minimal and to measure the vapor resistance was considered too expensive and complex. In addition, when the value is known for evaporative clothing resistance, but without the value of vapor resistance, the model's validity is very limited.

Validation of PHS Model

After publication of ISO 7933 (1989) questions arose about the predicted validity of the Required Sweat Rate. European researchers associated with eight laboratories worked in collaboration to research methods to rectify what was considered to be the main flaws associated with the Required Sweat Rate model. (Malchaire, et al., 2001) Because of this research effort the Predicted Heat Strain (PHS) model was developed. A large number of laboratory and field experiments involving (909 total experiments) used the newly developed PHS model to "predict minute by minute sweat rates and rectal temperatures". (Malchaire, *et al*., 2001) The analysis of the reported data reported the Pearson correlation coefficient between observed and predicted separately for laboratory and field experiments. Correlations for core temperature were 0.66 for laboratory experiments and 0.59 for field experiments. A further conclusion was that the sweat rate was predicted more accurately by the PHS model than by the Required Sweat Rate model. (ISO 7933,1989). (Malchaire, *et al*., 1989)

With the revision in ISO 7933(1989), the methods of estimating the static insulation characteristics of clothing involved the estimated calculations of the subject nude and clothed. The static heat resistance ($I_{tot\ st}$) is estimated for the nude subject (based on the heat exchange (C + R) taking into account no air movement or subject movement. For the clothed subject the static heat resistance ($I_{tot\ st}$) can be estimated using the clothed to unclothed surface area of the body. Insulation characteristics of clothing must be modified when activity and ventilation come in to play. The reduction of clothing insulation can be caused by wind and movement. Default values were assigned for wind speed (ν_{ar}) at 3m·sec^{-1} and the walking speed (ν_w) at 1.5 m·sec^{-1}. If the walking speed is undefined or stationary then individual calculations must be performed. To correct another issue associated with insulation properties, thermal characteristics for types of clothing had to be determined because "the rate of heat exchange between body and the environment due to radiation, convection, and evaporation" can be altered by clothing (Barker, Kini, and Bernard, 1999) To adequately determine the thermal characteristics, the principal philosophy was to establish the "critical environment conditions in which test subjects were able to maintain thermal equilibrium". (Barker, Kini, and Bernard, 1999) Their research provided estimated values for a wide range of clothing to include total insulation, (I_t) total evaporative resistance ($R_{e\text{-}t}$), and clothing factors (*CF*). The decrease in heat flow due to clothing and air insulation is represented by I_t. To account for a decrease in water vapor flow due to clothing permeability is represented by $R_{e\text{-}t}$. This research agreed with reports from other researchers in regards to the total evaporative resistance, the *CF* for dry heat exchange, and the *CF* for evaporative cooling and when pumping factors and clothing wetness were considered. (Barker, Kini, and Bernard, 1999)

Thermal insulation values (I_{cl} clo) for common clothing ensembles were defined. In addition the revised standard included reflection coefficients (F_r) for special materials and only applied to that part of the body covered by the reflective material. This standard as written did not apply to special clothing such as materials that affected the evaporative resistance influenced by the permeability to vapor pressure of the material, however a default value was provided for the static moisture permeability index (i_{mst}) equal to 0.38. (ISO 7933, 2004)

Havenith (1999) theorized that “heat transfer through clothing materials consisted mainly of conduction and radiation”. He also stated that “for most clothing materials, the volume of air enclosed is far greater than the volume of the fibers”. He thus concluded that the insulation value is more dependent on the material thickness and less on the fiber type. Havenith *et al*.,(1999) described a proposal for clothing evaporative heat resistance improvements in the various models. They described the difference between ISO 9920 and ISO 7933 in relation to determination of evaporative resistance of clothing ensembles (R_T). For ISO 7933, the use of reduction factors for vapor transfer (F_{pcl}) which is the “reduction factor for evaporative heat loss with clothing, compared to the nude person”. In ISO 9920, the use of, the permeability index of clothing (i_m) provided a relationship between evaporative resistance and dry heat resistance of clothing items or systems. Holmer *et al*., (1999) described the clothing convective heat exchange and a proposal improvement prediction in standards and models. Holmer *et al*., (1999) and Havenith *et al*., (1999) felt that present calculations in ISO 7933 underestimated the values due to insufficient consideration of the effects of body motion and wind on clothing heat transfer. They recommended correction factors for clothing and convective heat transfer. Application of the model ISO 7933(2004) after publication, resulted in researchers addressing new issues. The method on how PHS addressed the static and dynamic properties of clothing continues to be researched. Several research studies addressed personal protective clothing (PPC) and how to account for their thermal characteristics in the PHS model. Holmer (2006) looked at the effect of PPC on physiological strain due to heat stress and concluded that the ISO 7933(2004) did not account for issues associated with PPC. Holmer (2006) also recommended that the "effect of weight and bulk on metabolic rate requires consideration. Holmer (2006) concluded that the most important factor is the thickness of trapped still air layers. He also stated that the "heat gain by solar radiation is also affected by the color of the clothing".

Gonzalez *et al*., (2006) compared the work limiting effects of five protective coveralls and a semi clothed condition. Using a progressive metabolic rate protocol, concluded that air permeability was a better predictor of limiting performance by fabric work than the moisture vapor transmission rate (MVTR).

In addition to the various types of materials and fabrics used in personal protective clothing (PPC) there may be other components of the ensemble that might affect the rate of heat loss. A research study performed at the University of South Florida employing 15 participants (4 woman and 11 men) evaluated the effects of hoods as part of PPC and the effect of the critical WBGT on thermal equilibrium. A second part of the study was to compare two flame retardant fabrics against standard work clothes. For critical WBGT, the hooded ensembles had a lower critical WBGT than the non-hooded ensembles. There was no significant difference in critical WBGT between flame retardant ensembles and untreated ensembles. (Ashley & Bernard, 2008)

Recognizing that the evaporative resistance is an inherent limiting factor during heat stress exposure, it can be used to compare clothing ensembles in rational models of heat exchange. In a study at the University of South Florida, the apparent total evaporative resistance ($R_{e,T,a}$) of five clothing ensembles was estimated empirically from wear trials using a progressive heat stress protocol and from clothing insulation adjustments based on ISO 9920(2007). Using a larger number of participants than previous studies (20 men and 9 women) they found significant differences ($p > 0.0001$) among the ensembles for apparent total evaporative resistance. The Tychem® QC ensemble had the highest ($R_{e,T,a}$) at 0.033 kPa m^2 W^{-1} followed by Tyvek and work clothes with the lowest at 0.013 kPa m^2 W^{-1}. (Caravello, *et al*., (2008) Havenith (1999) concluded that while convection and radiation have a minor effect in maintaining thermal equilibrium in hot environments, evaporative resistance (R_e) was the most important factor in maintaining thermal balance. In addition evaporative cooling may be limited by clothing A relationship also exists between $R_{e,T}$ and water vapor permeability (i_m) and this reflects the ability of clothing to support evaporative cooling. Static values are assigned to $R_{e,T}$ and i_m when clothing is worn without significant air motion and movement. Air movement and activity of the wearer under certain working conditions must result in adjustment of values to reflect a realistic condition. (Caravello, *et al*., 2008; ISO 9920, 2007) Conclusions reached by researchers included that walking at a brisk pace can nearly halve the insulation of moderately thick clothes because body movements pump air in and out of the clothing. (Lotens, 1989; Havenith *et al*.,1990; Holmer *et al*., 1999) When clothing becomes wet, insulation is further reduced. (Kenney *et al*., 1993; Holmer and Nilsson, 1995; Brode *et al*., 2008; Havenith *et al*., 2008); Caravello *et al*., 2008). Caravello *et al*., (2008) reported the results of using a mixed linear model that indicated there was a linear relationship between apparent total evaporative resistance and WBGT clothing adjustment factors. To determine where the differences existed multiple *t* tests were used. Values for $R_{e,T,a}$, $R_{e,T,stat}$, $i_{m,a}$ and $i_{m,stat}$ indicated there were no differences among ensembles with the exception of NexGen and Tychem® QC both of which were different from all others. (Caravello *et al*., 2008)

The ISO 7933 (2004) has a minimum and maximum value for wind velocity. In addition, types of clothing addressed and clothing factors are limited. To address these issues, the Hong Kong Polytechnic University and Tianjin Polytechnic University in China developed a manikin, anthropologically representative of a Chinese man. Using 32 sets of clothing ensembles trials were conducted in a heat stress environment of 20 ± 0.3 ºC and a relative humidity of 50 ± 5%. Six different wind velocities (range of 0.22 to 4.04 m s^{-1}) were used in their experimental design. The styles of clothing evaluated were of the type, commonly worn by Chinese and tourists in China. The data indicated that a "general trend that clothing thermal insulation (I_{cl}) and moisture vapor resistance (R_{st} and R_s) decreases with the increase in wind velocity". (Qian & Fan, 2006). They concluded that their predicted values for I_{cl} and R_{st} and R_s varied with the ensemble and wind velocity and “were significantly affected by the air permeability of the outer fabric, fit index, and garment style as whether or not there is underwear on the body”.(Qian & Fan, 2006)

The apparent total evaporative resistance values developed by Caravello *et al*., (2008) and the USF research team concluded that the progressive heat stress protocol is considered a useful method to estimate the apparent total evaporative resistance which does not rely on the direct determination of sweat rate. These determined values would later be used in further research at USF. Determining a Safe Exposure Time (SET) based on adjusted WBGT, CAFs, and ACGIH TLV could indicate a long exposure time up to 480 minutes which is greater than the TLV of 120 minutes. During human trials at 30.8 ºC-WBGT and a metabolic rate at 180 W the SET for work clothes ensemble was greater than 120 minutes, greater than the TLV. (Bernard & Ashley, 2009)

Current Research on the Predicted Heat Strain Model

Application of the Predicted Heat Strain model has resulted in continued review for areas of improvement and better methods for utilization. Collaborative research between the Japan National Institute of Occupational Safety and Health and the University of South Florida looked at the utility of PHS model to limit short term exposures. This research looked at the comparison between the observed safe exposure time at 38.5 °C (SET), observed time at 38 ºC (ET38). predicted time from PHS model, and PHS model modified with the clothing values of ISO 9920(2007). Results indicated that the PHS model was not protective when used as a method to limit heat stress exposures in a prescriptive fashion. The PHS model modified with substituted values for core temperature and clothing values of ISO 9920(2007) for the default values of the standard PHS model appeared to be overly protective in 93% of the trials. In their conclusion, the use of PHS or PHS modified was limited in prescribing acute exposure periods. The substitution of the metabolic rate for actual walking speed led to a systematic lowering of the prescribed times and may be an area of further research. (Ueno, *et al*., 2009)

In addition to continued research on testing the protective validity, the effects of clothing ensembles on the PHS model also continues to be studied. Bernard *et al*., (2010) looked at convective transfer as another mechanism to support evaporative cooling in relation to protective clothing. Their findings indicated that "capacity to support evaporative cooling can be assessed by $R_{e,t,a}$ and critical WBGT and that clothing with lower porosity had relative higher values of $R_{e,t,a}$ and critical WBGT". Havenith *et al*., (2011) also looked at heat stress in chemical clothing with regards to porosity and vapor resistance, and concluded that the amount of air permeability increase can reduce heat stress levels which allows for better optimization of chemical protective clothing.

Researchers at Lund University in Lund, Sweden looked at prediction of heat strain responses while wearing protective clothing. The analyzed clothing ensembles consisted of firefighting clothing, high visibility clothing, and military clothing. Using six volunteers they ascertained that the PHS model was not applicable for clothing insulation values above 1 clo. In addition they recommended that the PHS model incorporate methods for handling clothing insulation values greater than 1 clo and should be amended to include individual algorithms, physical or physiological parameters and further subject studies. (Wang, *et al*., 2011)

Currently within the European Union some researchers are looking at other models for predicting physiological response to heat stress. This research is a mathematical model applied to a multi-node model of human heat transfer. (Fiala *et al*., 2011) Review of the literature involving the Universal Climate Thermal Index (UCTI) a model designed to assess human reaction to outdoor climates involving hot and cold conditions, revealed that the main method of validation were results predicted by the PHS. So far only computer modeling has been used to predict outcomes in relationship to other empirical modes such as WBGT (ISO 7243, 1989) and the rational model PHS (ISO 7933,2004). (Kampmann *et al*., 2011)

The majority of research involving a predictive method of measuring physiological response to heat stress continues to center around the PHS model. Human subject testing of this model continues to provide additional areas for research and improvement. The main obstacle for general use of the PHS model continues to be deriving a simplified method for general industry use.

CHAPTER 3:

METHODS

This research was designed to evaluate thermal characteristics over a range of protective clothing ensembles in relationship to heat stress assessment in occupational settings and to evaluate the predictive and protective properties of the current rational model. The experimental design was to sample within a range of clothing effects by choosing three ensembles representative of protective clothing used in industry worn in controlled heat stress environment.. General work clothes were designated as the reference point, two categories of protective clothing were nominated for the study. Clothing, environmental conditions, and metabolic rate contribute to heat stress exposures that are well above the upper limit of the prescriptive zone and described as uncompensable heat stress. This exposure under these conditions is time-limited. The primary objective of this research was to conduct a performance assessment of the current rational model designed to predict physiological response to the thermal environment. The secondary objective was to assess the predictive and protective validity of the Predicted Heat Strain model.

Variables

The independent variables identified in this study were three different ensembles and five different time-limited environments. The metabolic rate was controlled at 190 W/m^2, which was a moderate to high level rate.

The three different ensembles represented a range from work clothes to the most restrictive from an evaporative cooling point of view. They were:

- Work Clothes
- NexGen (microporous film)
- Tychem® QC (vapor barrier)

The five time-limited environments were selected such that relative humidity was 50%. The dry bulb temperature determined for each test ensemble was based on what would result in a WBGT that was a fixed increment above the average critical WBGT for that ensemble. This average critical WBGT was based on data collected over two years from previous research studies identified as the R5 protocol (50% relative humidity and a metabolic rate of 190 W m^{-2}). The WBGT increments (ΔWBGT) were selected starting with a value that was nominally 1 ºC WBGT higher than the critical WBGT for that clothing ensemble at 50% relative humidity for safe exposure times involving 30, 45, 60, 90, and 120 minutes. The US Navy used very similar exposure time increments that involved moderate work rates. The heat stress levels were:

- Plus 1 °C – WBGT for a time of about 120 minutes
- Plus 2 °C – WBGT for a time of about 90 minutes

- Plus 3.5 °C – WBGT for a time of about 60 minutes
- Plus 5.5 °C – WBGT for a time of about 45 minutes
- Plus 9 °C – WBGT for a time of about 30 minutes

The dependent variables determined were:

- Time to reach core temperature (T_{re}) of 38 ºC (ET38)
- Time to reach safe exposure time (SET) based on core temperature, heart rate, and fatigue.

Equipment

The experiments were conducted in a Model 7010 climate chamber designed by Forma Scientific. The internal dimensions of the chamber are 2.7 meters wide, 3.0 meters deep, and 2.2 meters high. The possible range of humidity that could be selected was 10 to 90% and the temperature range was from 4 to 60 °C. The environmental conditions selected for each trial were controlled from outside the chamber.

A Clubtrack 612 treadmill manufactured by Stairmaster© Health and Fitness Products, Inc. was used to control the metabolic rate through settings of speed and slope. Physiologic monitoring consisted of heart rate, rectal temperature, and skin temperature. The heart rate (HR) was monitored by the attachment of chest leads and cables connected to an electrocardiography system (EKG) Model E320 manufactured by Burdick Division of Kone Instruments, Inc. Rectal temperature (T_{re}) was measured using a flexible thermistor inserted 10 cm beyond the anal sphincter muscle. Skin temperature (t_{sk}) was measured using surface thermistors or thermocouples at four points (chest, upper arm, thigh, and calf). Average skin temperature was defined as (Parsons, (1993):

$$T_{sk} = 0.3T_{chest} + 0.3T_{arm} + 0.2T_{thigh} + 0.2T_{calf}$$

The flexible thermistor and surface thermistors were attached to a monitoring system outside the chamber.

Metabolic rate was determined by assessment of oxygen consumption. The measurement was made by having the subject breathe through a mouthpiece with a two-way breathing valve connected to flexible tubing that directed the expired air to a collection bag. The expired air was collected for three minutes. The volume of air expired was measured by using a dry gas meter. A small amount of the expired air was removed from the collection bag and drawn through a drying agent into an oxygen analyzer (Beckman E2 Oxygen Analyzer) to determine oxygen content and oxygen consumption was computed using standard methods.

Subjects

Twelve subjects were recruited from the Tampa Bay area (location near the university) using advertisements in local print media. The subjects were recruited for a three week period of temporary employment. The targeted age for the subject pool was between 18 and 50 years of age. For other factors such gender or race there was no preference, however the goal was to balance the ratio of men to woman. Since the metabolic rate was normalized to body surface area and heat stress levels low, differences in performance between men and women were small. (Moran *et al*., 1999; Kenney & Zeman, 2002) Review of the literature led to the conclusion that no physiologic response to heat stress would differ between races. (Fanger, 1970, 1972)

Potential subjects were interviewed by the Principal Investigator or Co-Investigators who explained the purpose and methods of the experiments performed to obtain data for the study and determined their interest and availability. Those potential individuals who were interested and available underwent a physical examination and had to be qualified by a licensed physician prior to their acceptance as a study subject. A complete medical, family, social, and work history was completed by the physician and included questions relating to recent fever and infections, obesity, cardiovascular disease, diabetes, hyperthyroidism, and impaired sweat production. The physical examination that was conducted specifically looked for any evidence of the vestibular system, pulmonary system, cardiovascular system, gastrointestinal system, genitourinary system, musculoskeletal system, and neurologic system all subjects received a resting 12-lead electrocardiogram. Those subjects who the physician considered might be compromised were either excluded or received additional testing in a follow-up examination. Any subjects whose medical history included drug or alcohol abuse and/or taking the following classes of medications: alpha and beta (sympathetic) blocking agents, anticholinergics, antidepressants (including lithium), antihistamines, calcium channel blockers, cocaine, diuretics, dopaminergics, ethanol, neuroleptics, and sympathomimetics were excluded. Female subjects were given a home pregnancy test and the results were self-reported. Those who were pregnant were excluded, and those not pregnant were asked to take precautions against pregnancy during the period of participation.

Subjects were provided with a copy of informed consent and explained to them in detail, consistent with university policy. Risks involved in this study were considered to be low however feelings of dizziness, weakness, fatigue, and thirst were possible. The risk of these symptoms occurring during these specific trials were considered to be slightly higher than previous heat stress studies but could be quickly reversed. Subjects were informed that they may withdraw at any time during the study. The informed consent documentation package was approved by the university Institutional Review Board and has been audited by them. All findings and recommendations made by IRB auditors have been implemented. All individual data collected was secured in the laboratory under the supervision of the Principal Investigator or Co-Investigators. In compliance with the university's HIPAA policy, and data collected that might be available to the public, coded identifiers have been used.

Each subject underwent a five day acclimation period consisting of two hours in the climatic chamber daily where the environmental conditions were controlled at 50 °C and 20% relative humidity (rh). After a successful acclimation period, the goal for each of the twelve subjects over a two week period was to complete a morning and afternoon trial with at least a two-hour break between trials. With this goal in mind it was anticipated that each subject would complete one trial wearing all three ensembles in each of the five time-limited environments. The order in which the subject would wear a specific ensemble in one of the five environmental conditions was randomized. A total of 45 subject-weeks were dedicated taking into account the period for acclimation and data collection. With the amount of time dedicated, the scheduling of the required number of trials was considered to be reasonable.

Ensembles

Three different clothing ensembles were used during this study. The ensembles used were: work clothes (135 g m^{-2} cotton shirt and 279 g m^{-2} cotton pants), NexGen LS417 (water-barrier, vapor-permeable coverall) , and one vapor-barrier type coverall (Tychem® QC). Subjects wore a cotton tee-shirt and gym shorts under their protective clothing and appropriate athletic shoes..

Protocol

To determine the effects of the ensembles on time-limited heat stress at a moderate work rate at 50% relative humidity, treadmill speed and grade was set to elicit a metabolic rate of approximately 190 W m^{-2}. During the first week of trials, the speed and grade was determined for each subject. Metabolic rate for each trial was determined by the average of one to three 3-minute expired air samples collected during the trial at approximately 30 minute intervals.

The trials had a time limit of 120 minutes using a relative humidity of 50%. For the time-limited, constant heat stress trials, both sweat loss and sweat evaporation were assessed from the changes in body weight dressed and semi-nude, adjusted for fluid consumption.

During each trial, subjects were allowed and encouraged to drink water or a commercial fluid replacement as desired, with a minimum fluid consumption at a rate of 750 ml h^{-1}. The levels of heat stress ranged from low to high, thus subjects were encouraged to drink more during the break between morning and afternoon and in the evening. During the minimum two-hour break between trials, subjects rested in a cool environment and consumed a light meal

Data collection consisting of heart rate, core temperature, and skin temperature was accomplished by the continuous monitoring of the subject throughout the trial (including the acclimation period) and recorded every five minutes. General data also collected included age, gender, height, and weight. Testing sessions lasted up to 3 hours unless any one of the termination criteria was met prior to the time limit. The termination criteria established and approved by the Institutional Review Board were:

- T_{re} of 39 °C or greater
- sustained heart rate greater than 90% of the age-predicted maximum heart rate
- subject wishes to stop.

Rate of heat storage was calculated as

$$S = \frac{0.97 m_b \Delta T_{re}}{A_D \Delta t}$$

Changes in time and core temperature were based on the slope of the core temperature versus time line. To ensure a margin of safety during the trials, the safe exposure time (SET) was set as the time at which the subject reached a core temperature of 38.5 °C (lower than the limit set by the IRB), reached 85% of age-predicted maximum heart rate, or volitional fatigue symptoms. Subjects were under continuous supervision during all trials and specific symptoms that could occur were identified to the subject and the staff member monitoring the trial. Subjects were free to stop a trial at any time they wished due to feelings of extreme discomfort or the first symptoms of a heat-related disorder.

Experimental Design

The basic experimental design used was a randomized block complete factorial design. This design consisted of the subjects (n=12) as the blocking factor with the ensembles (3) as the treatments and time-limited environments described as increments in WBGT (ΔWBGT)(5). The constructed design was that each subject would complete one trial each of the combinations of three ensembles and five critical WBGTs. The order of the ensembles and critical WBGTs were randomized. The philosophy was that sequence, day-of-week and time-of-day effects would be inconsequential and randomization would minimize any chance of confounding results. If a trial had to be repeated then the repeat occurred at the beginning of the fourth week. In the case of a withdrawal by a subject, the replacement by another subject would then complete the entire set of 15 trials.

Analysis of Data

The analysis consisted of a general linear mixed effects model with ensemble and heat stress level as fixed effects and participants as the random effect for metabolic rate and safe exposure time. A series of scatter plots for the two dependent variables (i.e., rate of heat storage and safe exposure time) versus ∆WBGT for each ensemble was constructed with the mean and standard deviation bars overlaid on individual data. This allowed for visual inspection of the data and identification of potential outliers. A secondary analysis was run when outliers were identified using the data minus the outlying values. In designing the analysis, time of day and gender were not expected to be significant.

A frequency distribution was conducted for reasons of termination of trials by ensemble and exposure code. A mixed 3-way ANOVA for metabolic rate (MSA) was performed with fixed effects for ensemble code and heat stress level with the participant as a random variable. The mixed 3-way ANOVA was repeated for WBGT. After censoring the data for those trials in which the starting Tre was greater than 37.5 ºC a second 3-way ANOVA was performed as above. Additional ANOVA was performed on ensemble and exposure code using the measured data for termination time (T_{re} at trial stop) and time to reach T_{re} at 38.0 ºC.(ET38)

Regression analysis was performed on censored data with ensemble code, exposure code and the interaction of ensemble code*exposure code being the independent variables and response time at termination as the dependent variable. The regression analysis was repeated using the amount of time to reach T_{re} = 38 ºC because that was the core temperature limit for the PHS model. The resulting summary of fit and fixed effect tests were reviewed The means and confidence interval for each ensemble was based on each ΔWBGT separately when the P-values were less than 0.2 when involving the values for the interactions for ensemble*ΔWBGT. For p-values greater than 0.2, the mean and confidence interval was based on the data for each ΔWBGT over all ensembles.

Any significant differences identified within the means of the main effects were judged to exist at the α=0.05 level. Wherever significant differences occurred among ensembles and metabolic rates, Tukey's honestly significant method for multiple comparisons was used.

All recorded data were entered into an Excel spreadsheet. Using Visual Basic for applications (VBA), a macro was developed by Bernard and Ueno to compute the Predicted Heat Strain model in ISO 7933. Various T_{re} values, clothing values, and body surface area values were substituted into the model to determine safe exposure times. Those values were compared to actual observed times and different PHS outcomes to each other. Results were analyzed by scatter plots using an identity line to evaluate overall protective effect. These scatter plots were also used to assist in evaluation of the predictive ability of the PHS model. A difference in heat storage rate and safe exposure time against the five levels of heat stress, both within and among ensembles was expected.

In theory, the rate of heat storage should be the difference between the required and maximum evaporative cooling. For each combination of ensemble and ∆WBGT, the required and maximum rates of evaporative cooling were estimated using previously described biophysical models.

CHAPTER 4:

RESULTS

The purpose of this study is to compare variations of a heat stress model to data collected in the laboratory. There were 12 participants in the study and their characteristics (mean ± standard deviation) for age, height, weight, and body surface area is provided in Table 1 by men, women, and combined.

Table 1. Participant Characteristics (Mean ± Standard Deviation).

	Number	Age (yr)	Height (cm)	Weight (kg)	Body Surface Area (m^2)
Men	8	33 ± 0	181 ± 4	95 ± 10	2.15 ± 0.09
Women	4	28 ± 9	160 ± 7	66 ± 27	1.67 ± 0.33
All	12	32 ± 10	174 ± 11	85 ± 22	1.99 ± 0.30

Thermal exposure was defined as the five heat stress levels in combination with three clothing ensembles represented 15 trial conditions. With 12 participants, there were 180 possible trials. In fact, there were actually a total of 177 trials due to some participants not completing a particular trial. Because starting core temperatures greater than 37.5 °C represented an unusually high temperature and thus shorter possible exposure time, the final data set was censored to eliminate any trials where the participant had a core temperature

(T_{re}) greater than 37.5 °C at the beginning of the trial. The result was 153 uncensored trials. The number of trials for each participant by clothing ensemble and level of heat stress exposure is provided in Table 2. There were 35 empty cells over 9 participants, which was due to incomplete trials and censoring of the trial. There were eleven duplicate trials over 6 participants.

Table 2. Distribution of Trials by Heat Stress Levels and Ensembles

	Work Clothes					NexGen					Tychem® QC					
Conditions	Heat Stress Level					Heat Stress Level					Heat Stress Level					
Participants	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	Total
S1	1	1	2	2		1	2	1		1	1	1	1	1	1	16
S2	1	1		1	1	1	1	1	1	1	1	1	1	1	2	15
S3	1	1	1	1	1	1	1	1	1		1	1	1	1		13
S4	1	1	1			1	1		1	1	1	1	1	1		11
S6		1	1			1			1			1	1	1	1	8
S7	1	1	1	1	1								1		1	7
S8	1	2	1				1	1		1			1	1		9
S9	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	16
S10	1	1	1	1	2	1	2	1	1	1	1	1	1	2	1	18
S11	1	1			1	1	1	1	2		1	1	1	1	2	14
S12	1	1	1	1	1	1	1				1	1	1	1		11
S13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Totals	11	13	11	10	9	10	12	8	9	7	9	10	12	12	10	153

Table 3 is a summary of the heat stress conditions by clothing ensemble, relative metabolic rate (MSA), dry bulb temperature (T_{db}), psychometric wet bulb temperature (T_{pwb}), and water vapor pressure (P_v). A mixed 3-way ANOVA for

MSA was performed with fixed effects for ensemble code and heat stress level with the participant as a random variable. There were no significant differences among heat stress levels but there were among ensembles. Work clothing was greater than the vapor barrier ensemble (189 W m^{-2} versus 179 W m^{-2}) with NexGen ensemble in between at 184 W m^{-2}. The difference was about 6% increase for work clothes over vapor barrier. which was not considered significant.

Table 3. Trial Conditions by Ensemble and Heat Stress Level

Heat Stress Level	MSA	T_{db} (°C)	T_{pwb} (°C)	WBGT (°C)	P_v (kPa)
Work Clothes					
H1	187 ± 15	43.3 ± 0.2	32.0 ± 0.8	36.0 ± 0.6	3.99 ± 0.3
H2	183 ± 21	44.2 ± 0.2	33.2 ± 0.8	37.1 ± 0.6	4.34 ± 0.3
H3	195 ± 23	45.7 ± 0 .6	33.8 ± 0.9	38.1 ± 0.7	4.46 ± 0.3
H4	194 ± 19	47.9 ± 0.5	35.5 ± 1.0	39.9 ±0.8	4.92 ± 0.3
H5	190 ± 23	52.5 ± 1.1	39.4 ± 1.5	43.9 ± 1.2	6.27 ± 0.6
NexGen					
H1	185 ± 14	39.6 ± 0.2	29.5 ± 0.7	33.2 ± 0.5	3.44 ± 0.2
H2	188 ± 19	40.7 ± 0.2	30.9 ± 0.8	33.9 ± 0.6	3.56 ± 0.2
H3	181 ± 10	43.0 ± 0.9	31.8 ± 0.8	35.7 ± 0.7	3.94 ± 0.2
H4	182 ± 21	45.2 ± 1.2	33.6 ± 0.7	37.7 ± 0.6	4.44 ± 0.2
H5	185 ± 23	49.6 ± 0.6	36.6 ± 0.7	41.1 ± 0.5	5.29 ± 0.3
Tychem® QC					
H1	180 ± 16	35.2 ± 0.1	26.0 ± 0.5	29.4 ± 0.4	2.74 ± 0.1
H2	175 ± 17	36.4 ± 0.2	26.6 ±1.4	30.1 ± 1.0	2.84 ± 0.4
H3	182 ± 22	38.6 ± 0.3	27.9 ± 1.3	32.0 ± 1.5	3.01 ± 0.4
H4	180 ± 24	40.6 ± 0.4	30.0 ± 0.7	33.8 ± 0.6	3.54 ± 0.2
H5	184 ± 18	45.6 ± 1.3	33.1 ± 1.4	37.4 ± 1.1	4.25 ± 0.5

The mixed 3-way ANOVA was repeated for WBGT. As expected from the experimental design, there were significant differences for ensemble (p<.0001) and heat stress level (p<.0001). The decrease in WBGT from work clothes to NexGen was 2.5 °C-WBGT which confirmed the goal of the experimental design.

The decrease in work clothes to vapor-barrier was 6.4 °C-WBGT, which again compared well to the designed difference of 6.5.

The research protocol established three criteria for a safe exposure time (SET). SET was set to the time at which the first of the following occurred: (1) 85% of maximum heart rate (220-age); (2) when the core temperature (T_{re}) reached 38.5 °C; or (3) if the participant expressed desire to stop. A trial would also be stopped at 120 minutes. Table 4 is a summary of the reasons for termination of the trials. The most frequent reason for SET was the participant reaching a T_{re} of 38.5 °C, followed by participants reaching 85% of their maximum heart rate. Only seven participants reached the trial time limit of 120 minutes and these were associated with NexGen at Heat Stress Levels 1 and 2.

Table 4. Reasons for Trial Termination

Ensemble	H1	H2	H3	H4	H5	All
			T_{re} = 38.5			
Work clothes	8	10	8	6	3	35
NexGen	5	4	5	5	4	23
Tychem® QC	6	6	9	8	5	34
All	19	20	22	19	12	92
			HR ≥ 85% Max			
Work clothes	2	3	2	4	5	16
NexGen	1	2	2	3	3	11
Tychem® QC	3	4	3	3	5	18
All	6	9	7	10	13	45
			Subject Fatigue			
Work clothes	1	0	1	0	1	3
NexGen	2	1	1	1	0	5
Tychem® QC	0	0	0	1	0	1
All	3	1	2	2	1	9
			Trial Time Limit			
Work clothes	0	0	0	0	0	0
NexGen	4	3	0	0	0	7
Tychem® QC	0	0	0	0	0	0
All	4	3	0	0	0	7

Table 5 provides the mean and standard deviation for the observed safe exposure times by ensemble and heat stress level. The results indicated a decrease in SET from Heat Stress Level 1 through Heat Stress Level 5 for all ensembles with the exception of Heat Stress Level1 and Heat Stress 2 for NexGen ensemble.

Table 5. Safe Exposure Time (SET) by Ensemble and Heat Stress Level (Mean and Standard Deviation).

	Work Clothes	NexGen	Tychem® QC
Exposure Code	SET (Mean ± Standard Deviation)		
H1	76 ± 17	80 ± 31	76 ± 15
H2	61 ± 19	96 ± 26	70 ± 15
H3	57 ± 17	50 ± 12	55 ± 12
H4	38 ± 5	39 ± 8	46 ± 5
H5	25 ± 7	28 ± 9	32 ± 7

A 3-way ANOVA using a mixed model where heat stress level and ensemble were fixed effects and the random effect was participants. There were significant differences among heat stress levels, ensembles, and the interaction of heat stress level and ensemble. Figure 1 illustrates the safe exposure times by heat stress level for each ensemble. It is clear that the significant interaction was due to NexGen at heat stress level 2.

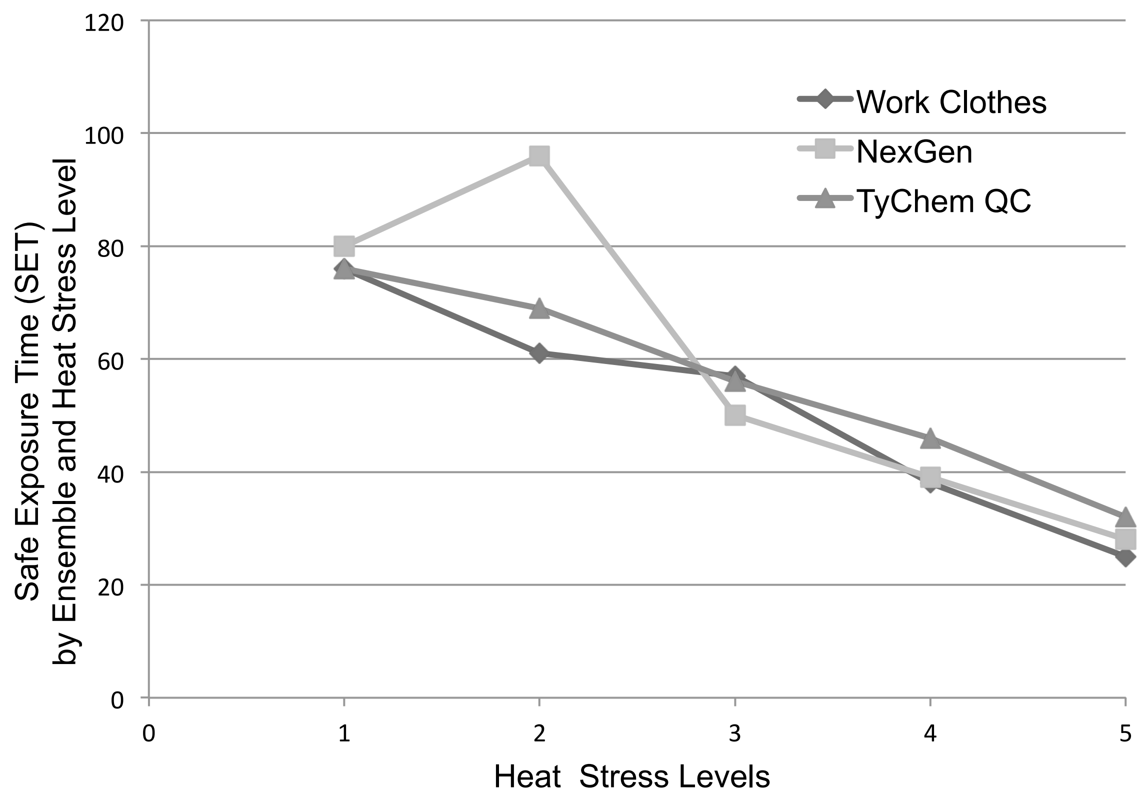

Figure 1. Safe Exposure Time (SET) by Ensemble and Heat Stress Level.

Because the Predicted Heat Strain model uses a criterion T_{re} = 38 °C, this study looked at the actual time for a person to reach T_{re} = 38 °C (ET38) (See Table 6). The mean and standard deviation of observed time is reported in the table and the mean limiting times by ensemble and heat stress levels are illustrated in Figure 2. A three-way mixed model ANOVA where the fixed effects of ensemble and heat stress level, and participants as a random factor indicated significant effects due to ensembles and heat stress level, but no significant interaction. Work Clothes were different from Tychem® QC ensemble and NexGen.

Table 6. Time in Minutes to T_{re} = 38 °C (ET38) (Mean ± Std Dev) by Ensemble and Heat Stress Level

Exposure Code	Work Clothes	NexGen	Tychem® QC
H1	53 ± 15	61 ± 27	60 ± 12
H2	43 ± 17	57 ± 14	60 ± 23
H3	45 ± 13	44 ± 11	44 ± 11
H4	31 ± 4	31 ± 12	40 ± 10
H5	23 ± 7	30 ± 14	49 ± 31

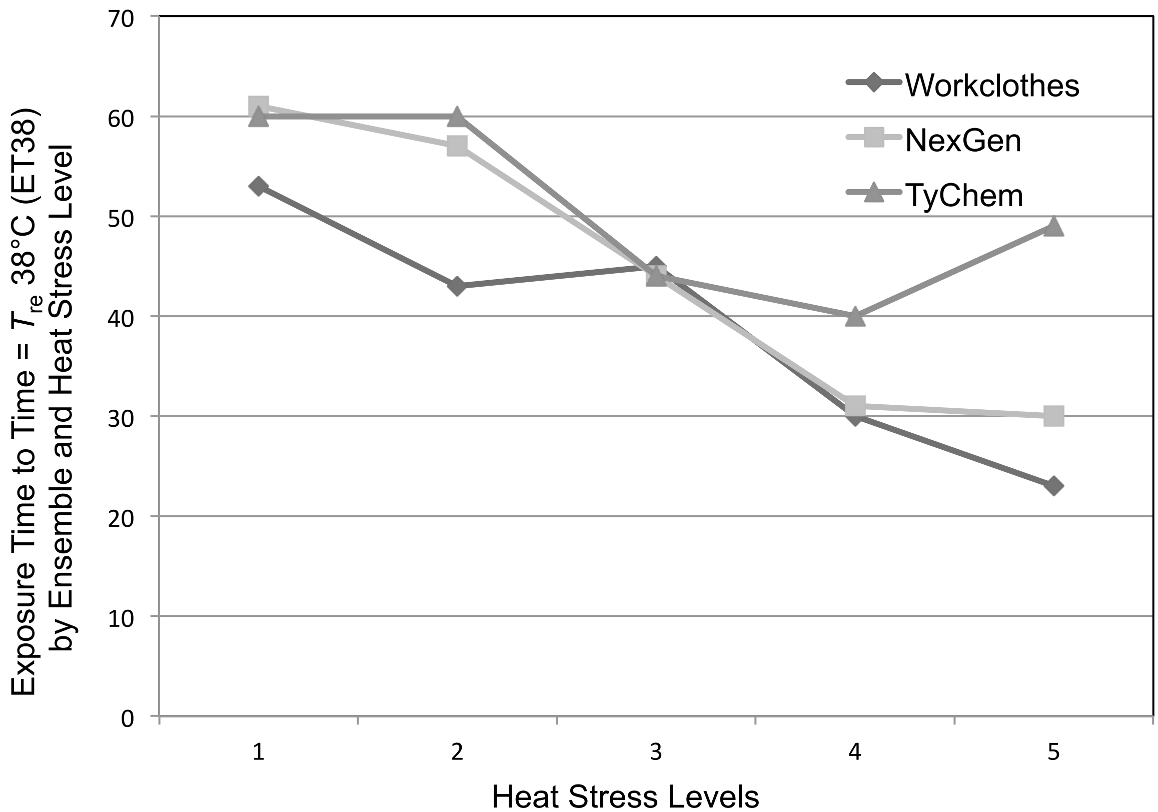

Figure 2. Exposure Time to T_{re} 38 °C (ET38)by Ensemble and Heat Stress Level

Predicted Heat Strain Model

The Predicted Heat Strain model is a method for evaluating thermal stress conditions that could result in elevated body core temperatures that might result in adverse health effects. PHS was based on a limit of T_{re} = 38 °C for short-term exposures (ISO 7933, 2004). Adjustments to the clothing insulation and evaporative resistance were developed for the PHS model. The predictive validity of the PHS model can be examined by comparing the PHS times to the observed time limit at T_{re} = 38 °C (ET38). Another way to examine the usefulness of PHS is to examine the relationship between PHS time limit and the observed safe exposure time based on the criteria mentioned above. This might be called the protective validity.

Predictive Validity of PHS

The first step in assessing the predictive validity was to compare the PHS Standard (PHS_{Std}) time directly to the observed time at ET38. This relationship is shown in Figure 3. The pattern seen in Figure 3 is possibly contributed to the actual starting value of T_{re} rather than using the PHS default fixed value of 36.8 °C.

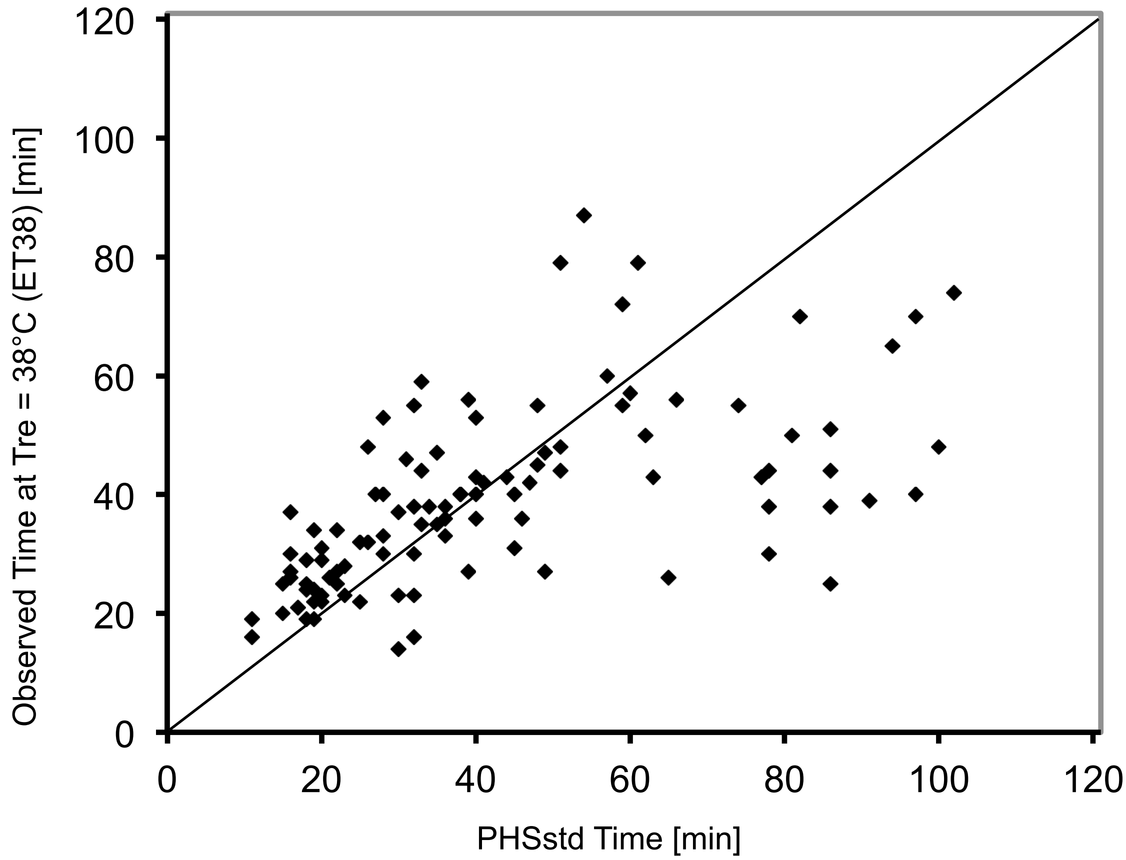

Figure 3. Relationship between PHS Standard Time Limit and the Observed Time at T_{re} = 38 °C (ET38).

Figure 4 shows the relationship between PHS with adjusted initial T_{re} versus the observed time to ET38. The overall effect was to shift predicted times to the left (shorter times).

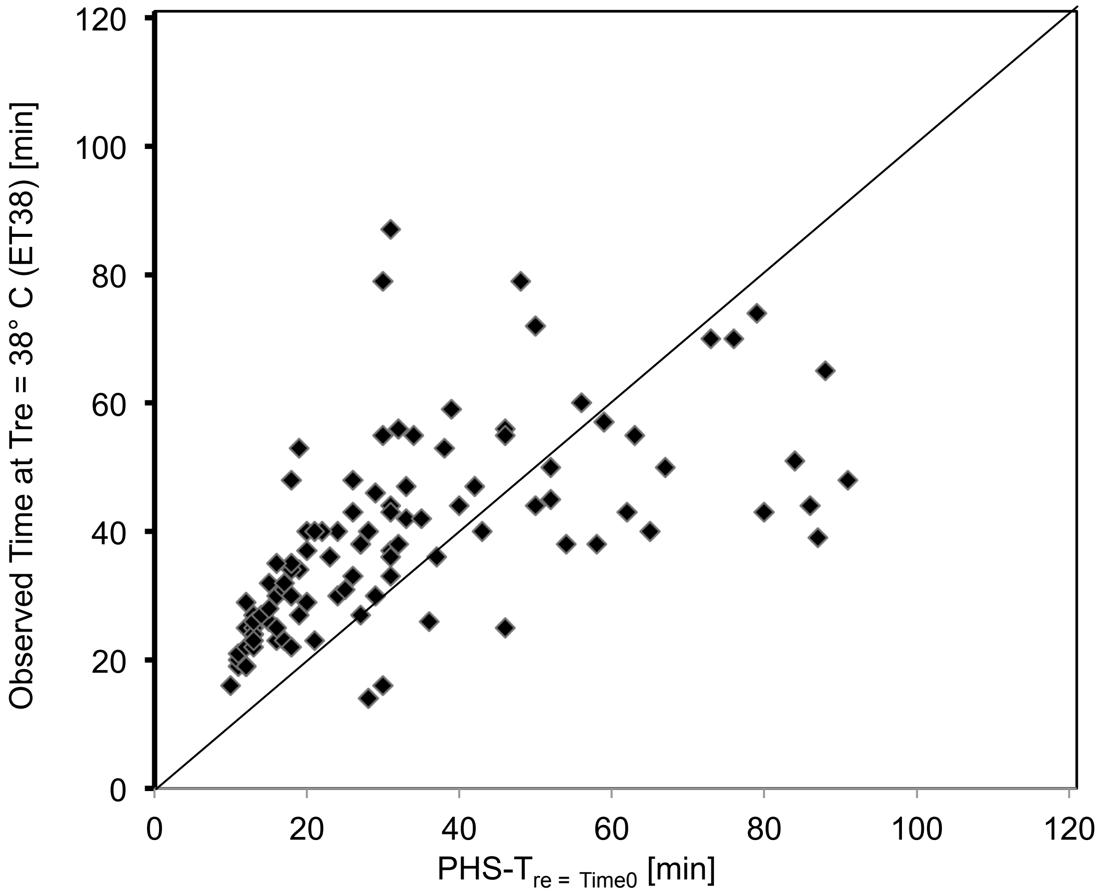

Figure 4. Relationship between PHS Time Limit Based on Initial T_{re} and the Observed Time at T_{re} = 38 °C (ET38).

Figure 5 illustrates the change to the ISO9920 method for clothing within the PHS method. When using the ISO 9920 values in the PHS model, the predicted times became shorter. The results indicated that there was a substantial shift of points to above the identity line into a more protective zone.

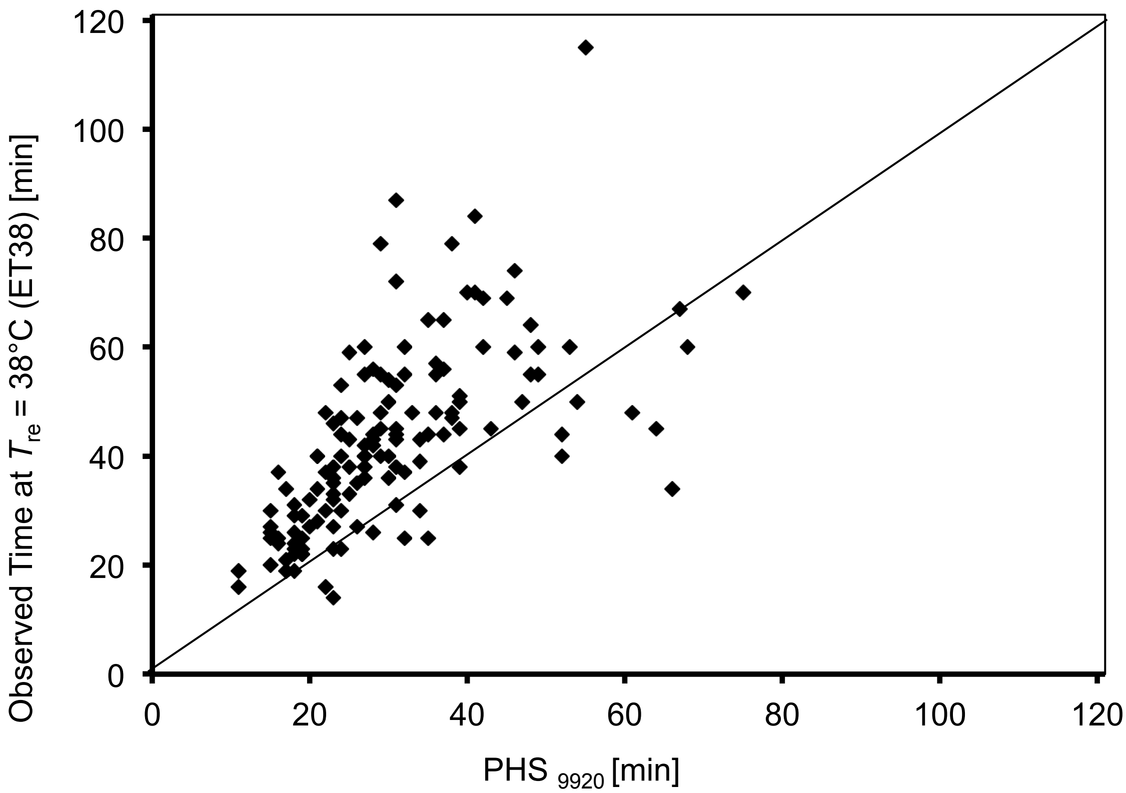

Figure 5. Relationship between PHS Time Limit Based on ISO9920 Methods for Clothing and the Observed Time at T_{re} = 38 °C (ET38).

Figures 3 through 5 demonstrate qualitatively varying degrees of predictive validity. To further examine the performance, pairs of data with either observed or predicted values of 120 were deleted from the dataset to avoid problems with arbitrary time assignment. Table 7 provides the mean values for the observed and PHS times, the slope and intercept of the least squares straight line fit, the coefficient of determination (r^2) and the intraclass correlation coefficient (ICC) for the three comparisons. There were at least 100 pairs of data available for analysis, where the PHS_{9920} had substantially more at 135 pairs. The mean observed exposure time was 39 minutes for the PHS_{Std} and PHS_{Tre} and increased to 43 for PHS_{9920}. This means that the analysis with PHS_{9920} had a larger number of paired data with longer times. The predicted times for PHS_{Std} were greater than those for $PHS_{Tre=Time0}$ and PHS_{9920}, suggesting a systematic shift of the pairs to the left and therefore above the identity line. Looking to the best fit line, ideally, the slope would be 1.0 and the intercept 0. In fact, the slopes ranged from 0.37 to 0.84 with significant intercepts of 23 to 17 minutes. The coefficient of determination and intraclass correlations were similar and in the vicinity of 0.3 to 0.4, which indicated fair agreement between the observed time to ET38 and the three PHS methods. The PHS_{9920} appeared to provide the stronger predictive capability with some improvement for accounting for the actual starting core temperature.

Table 7. Comparison of PHS_{Std}, $PHS_{Tre = Time0}$, and PHS_{9920} to Observed Time for T_{re}= 38 ºC by means (Time), Correlation Coefficient and Intraclass Correlation Coefficient

	PHS_{Std}	$PHS_{Tre = Time0}$	PHS_{9920}
Number	102	106	135
Slope	0.37*	0.44*	0.84*
Intercept	23	24	17
Coefficient of determination (r^2)	0.34	0.40	0.39
Intraclass Correlation Coefficient	0.33	0.40	0.31
Wilcoxon Sign Test p > lzl	0.7901	<.0001	<.0001
Wilcoxon Sign Test p > z	0.3951	1.000	1.000
Wilcoxon Sign Test p < z	0.6049	<.0001	<.0001

* p < 0.001

Protective Validity of PHS

Protective validity changes the utility perspective for PHS. In this case, the PHS would be used to predict a safe time limit for most exposures. The better comparison point for observations is the observed safe exposure time (SET) based on the first occurrence of the individual trial exposure limits; that is, a somewhat higher heat strain threshold than T_{re} = 38 °C (ET38).

The first logical comparison is the PHS (PHS_{Std}) versus SET. From the predictive validity results described above, it is clear that a starting T_{re} of 36.8 ºC is too low by results of the Wilcoxon Rank Sign Test. For this comparison, a starting value of 37.0 °C was used and the predicted time is called $PHS_{Tre=37^{\circ}C}$. See Figure 6 for the results. This comparison indicates that the predicted exposure time tends to be protective but there are 16 pairs that are to the right of the identity line (not protective).

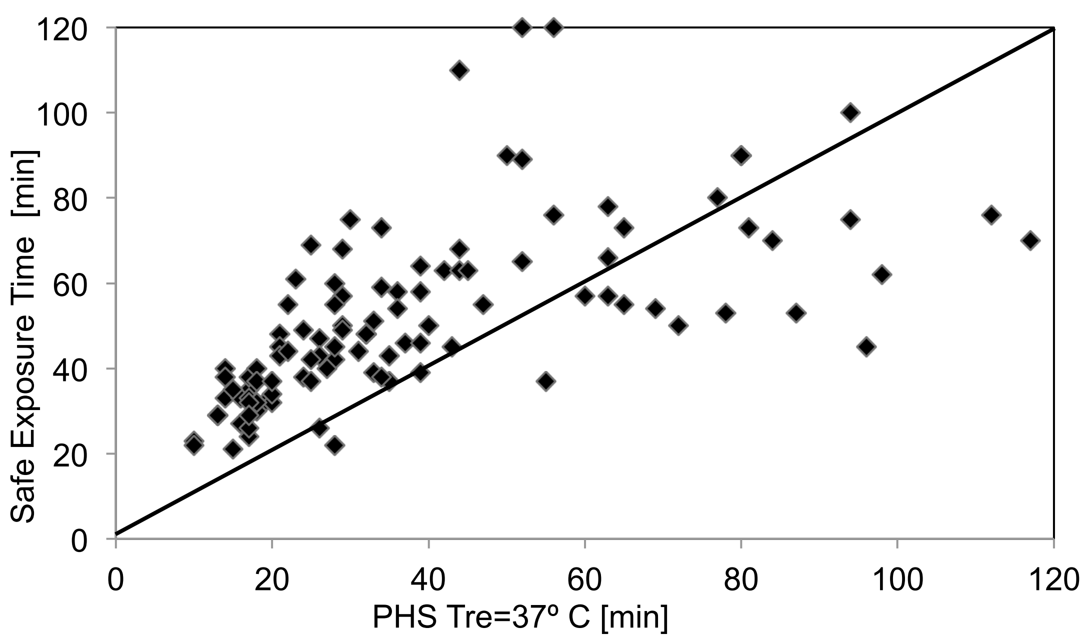

Figure 6. Relationship between $PHS_{Tre = 37^{\circ}C}$ at Start and the Safe Exposure Time (SET).

Trial results for actual T_{re} were re-entered into the PHS model as the second comparison. Figure 7 provides a plot of the relationship between $PHS_{Tre = Time0}$ and the Safe Exposure Time. As expected, this resulted in a general shift of the pairs to the left with 13 pairs still to the right.

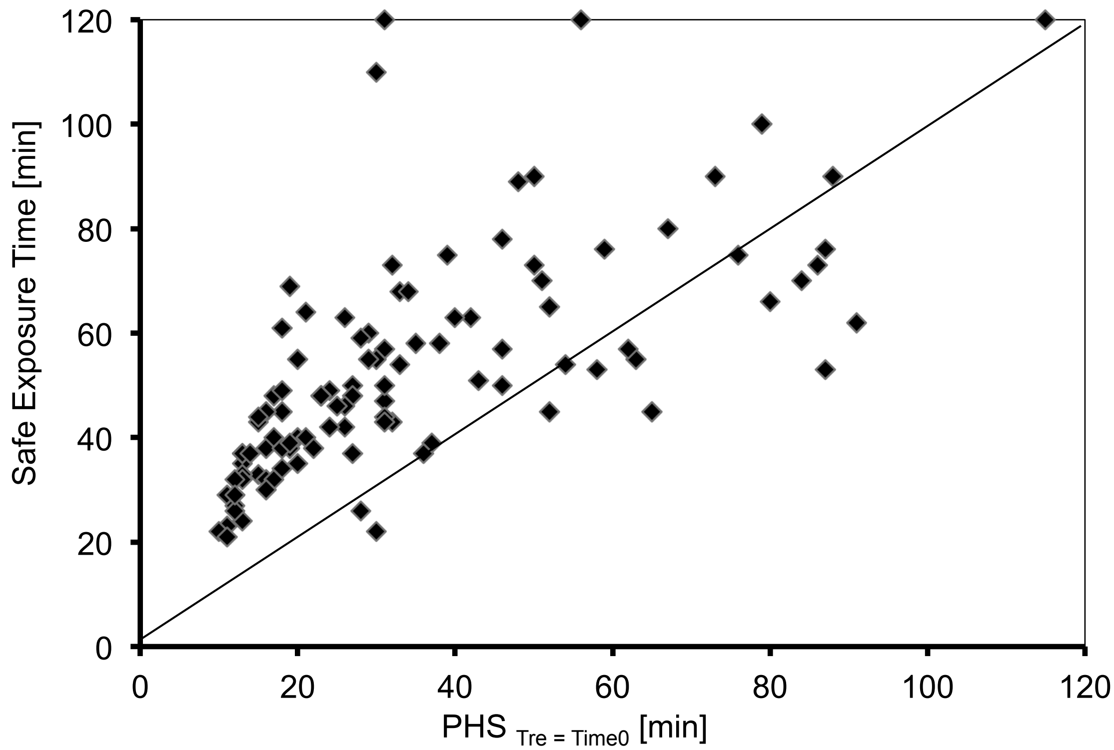

Figure 7. Relationship between $PHS_{Tre = Time0}$ and the Safe Exposure Time (SET).

The third comparison looking at protective validity involved the standard PHS model modified with inserted clothing values of ISO 9920 (PHS_{9920}) and the SET. (See Figure 8). With PHS_{9920}, all but one of the data pairs were above the identity line and thus protective.

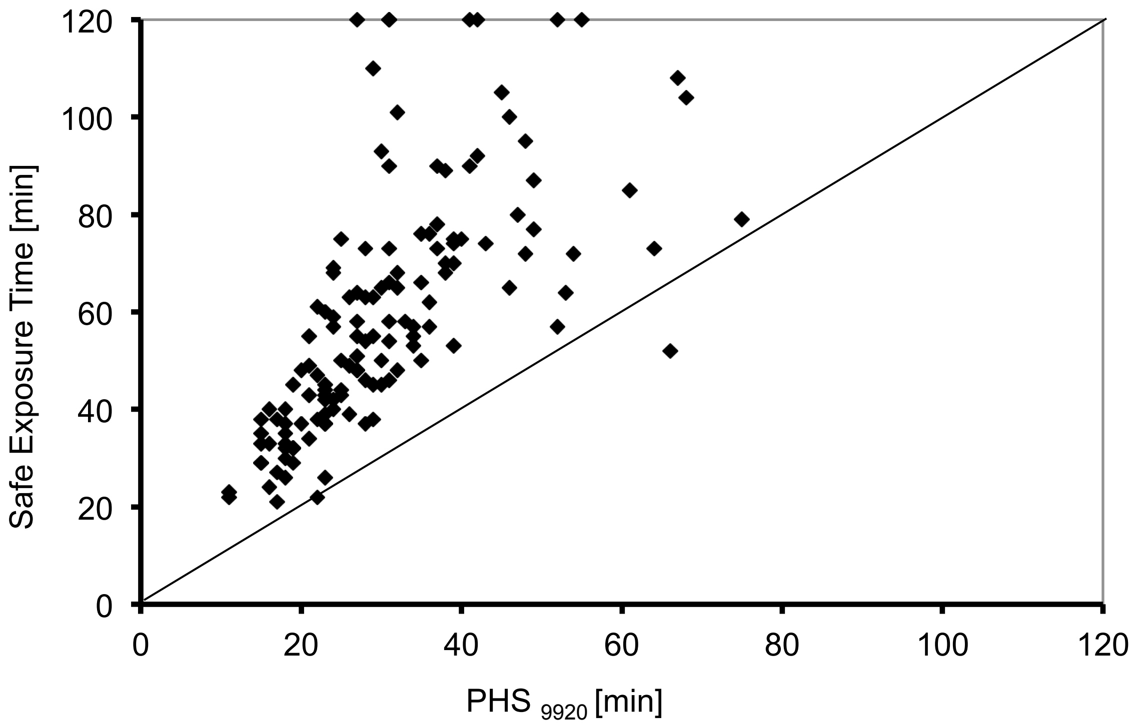

Figure 8. Relationship between PHS Standard modified with ISO 9920 Clothing Values (PHS_{9920}) and Safe Exposure Time (SET).

The fourth comparison of the PHS model to SET involves substituted values for resultant total clothing insulation ($I_{T,r}$) based on ISO 9920 and apparent total evaporative resistance ($R_{e,T,a}$) reported by Caravello *et al*., (2008) for the three ensembles used in the trials. The relationship between SET and $PHS_{37\text{-}IT,r;Re,T,a}$ is presented in Figure 9. Virtually all the pairs represent a protective outcome.

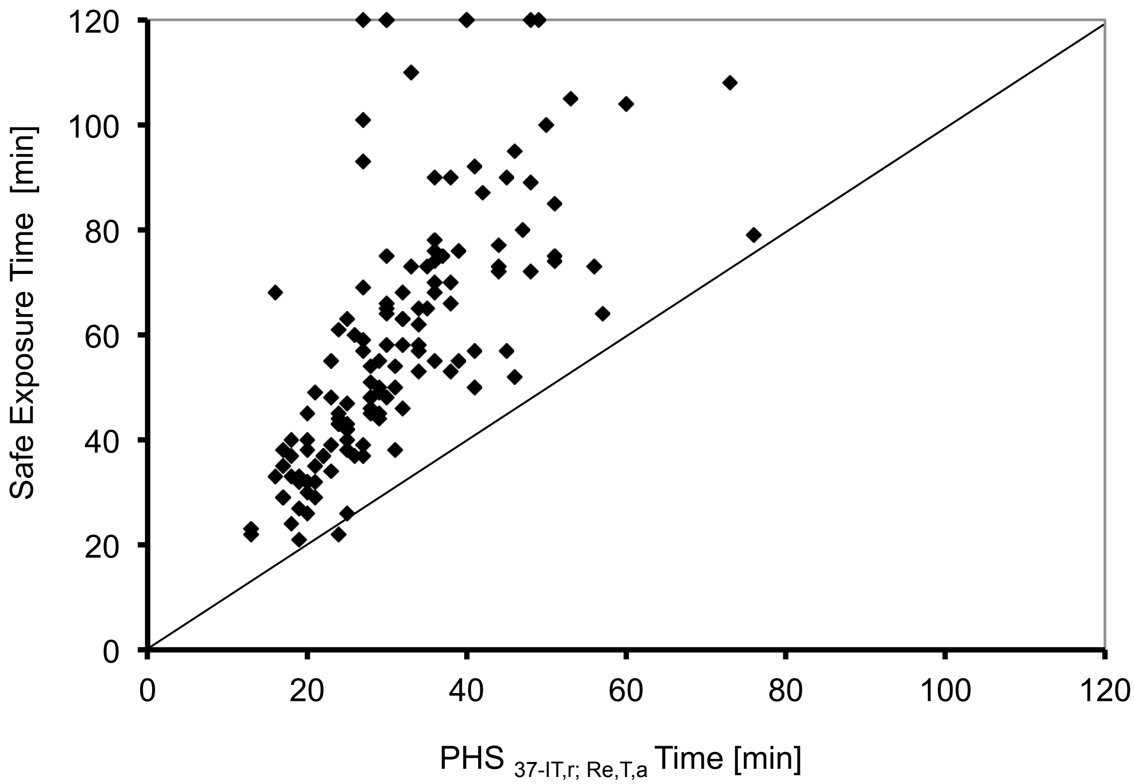

Figure 9 Relationship between PHS37 with $I_{T,r}$ and $R_{e,T,a}$ and Safe Exposure Time.

Figures 6 through 9 demonstrate qualitatively varying degrees of protective validity. To further examine the protective performance, pairs of data with either observed or predicted values of 120 minutes were deleted from the dataset to avoid problems with arbitrary time assignment. Table 8 provides the number of observed pairs for the analysis, the mean values for observed Safe Exposure Time and the PHS times, and the coefficient of determination (r^2). All data pairs were used for the Wilcoxon Sign Test and the results for the four comparisons are also reported in Table 8.

Table 8. Summary of bivariate statistics for protective validity between Observed SET and $PHS_{Tre=37\ °C}$, PHS_{Tre}, PHS_{9920} , and $PHS_{37\text{-}IT,r;Re,T,a}$

PHS modified variables	$PHS_{Tre=37°C}$	PHS_{Tre}	PHS_{9920}	$PHS_{37\text{-}IT,r,Re,T,a}$
Number of Pairs	102	103	128	128
Coefficient of determination (r^2)	0.66	0.68	0.72	0.75
Wilcoxon Sign Test Prob > z	1.0000	1.0000	1.0000	1.0000
Wilcoxon Sign Test Prob< z	<0.0001	<0.0001	<0.0001	<0.0001
Protective Outcomes (n = 135)				
False Negative SET<0.9PHS	37	33	3	1
False Positive SET >1.1PHS	84	84	128	129
True Positive 0.9PHS>SET<1.1PHS	14	18	4	5
% Protective	73	76	98	99

When the mean observed Safe Exposure Time based on 102 observations was compared to 128 number of observations, the mean time increased by 5 minutes indicating that longer exposure times were brought into the analysis although not significant. The coefficient of determination (r^2) increased from 0.66 to 0.75 with the number of included pairs. For all comparisons, the Wilcoxon Sign Test was very significant ($p<0.0001$) in the direction of protective outcomes (PHS less than SET). When accounting for either a fixed at 37 °C or variable starting $T_{re\ =\ Time0}$, the number of False Positives was 84 and the protective ratio (TP+FP/n) was about 75%. When clothing was used to modify PHS (either with ISO9920 or observed values), there were 128 False Positives with a protective percentage of 98%.

The initial comparison of the Safe Exposure Time and PHS_{Std} model used the actual height and weight of each participant and the protective effect did not appear to differ. When a fixed height and weight was used in the PHS model, the protective effect appeared to be slightly more with the SET.

Intra-PHS Comparisons

It is clear from the above analysis of predictive and protective validity that starting T_{re} and clothing adjustments are important factors in the outcomes. In addition the role of anthropometry is worth exploring. Looking at the relationships between a standard PHS and modified PHS using the trial data to generate comparison pairs is a useful exercise. As done in assessing the predictive validity, any PHS computed times greater than 120 minutes were deleted from the dataset to prevent any arbitrarily time assignments. The following factor analyses were performed:

- Fixed T_{re} at 36.8 °C (PHS_{Std}) versus fixed T_{re} at 37 °C
- Fixed T_{re} at 37 °C versus actual T_{re}
- PHS_{Std} versus PHS_{9920}
- PHS_{Std} versus $PHS_{37-\ IT,r,Re,T,a}$
- PHS_{Std} versus PHS with fixed anthropometry($PHS_{Fixed\ Ht/Wt)}$

The first comparison is the PHS_{Std} model with a default value of 36.8 ºC for T_{re} compared to a PHS model with a higher T_{re} value of 37 °C ($PHS_{Tre\ =\ 37º\ C}$). Figure 10 shows the comparison. As expected, the predicted times became systematically lower because the allowed heat storage was lower.

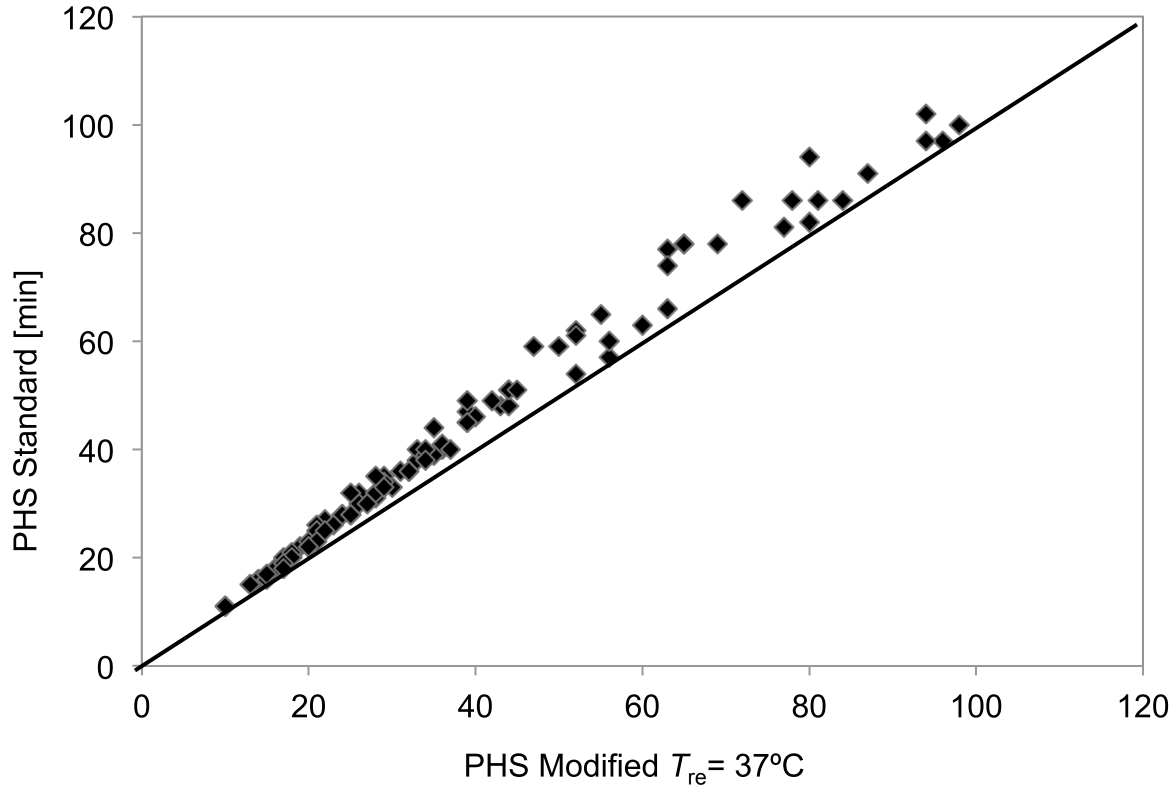

Figure 10. Comparison of PHS Standard (starting T_{re} = 36.8 ºC) to the PHS Standard modified with a Starting T_{re} = 37 ºC.

Figure 11 provides the results of comparing PHS $_{Tre= 37ºC}$ to the PHS model modified with the actual T_{re} at the starting time (PHS$_{Tre = Time0}$). It remains clear that the starting value of core temperature played an important role in predicting a PHS time.

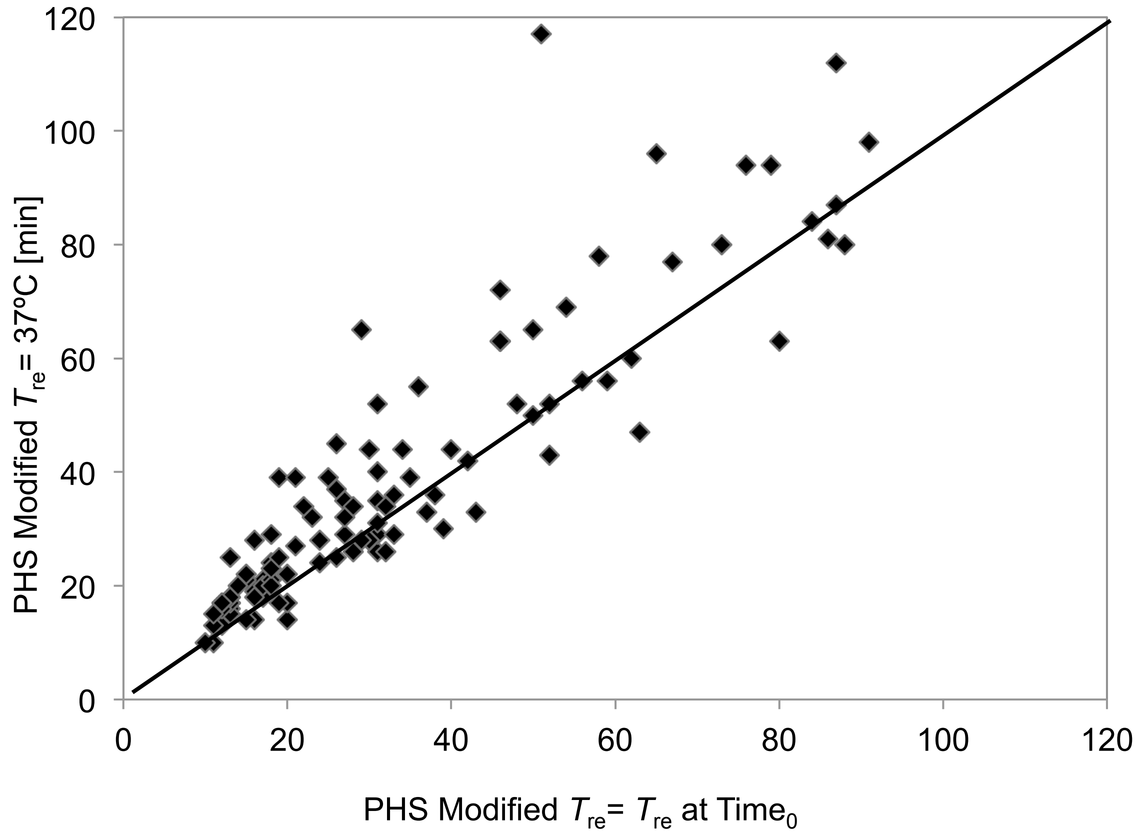

Figure 11. Comparison of PHS Standard modified with an inserted value of fixed T_{re} = 37 ºC to PHS Standard modified with the actual T_{re} at $Time_0$.

In addition to the starting core temperature, the PHS model was sensitive to thermal characteristics of the clothing. Figure 12 is a comparison of the PHS Standard model to the PHS model modified with clothing values from ISO 9920. It was clear that PHS_{Std} appeared more protective.

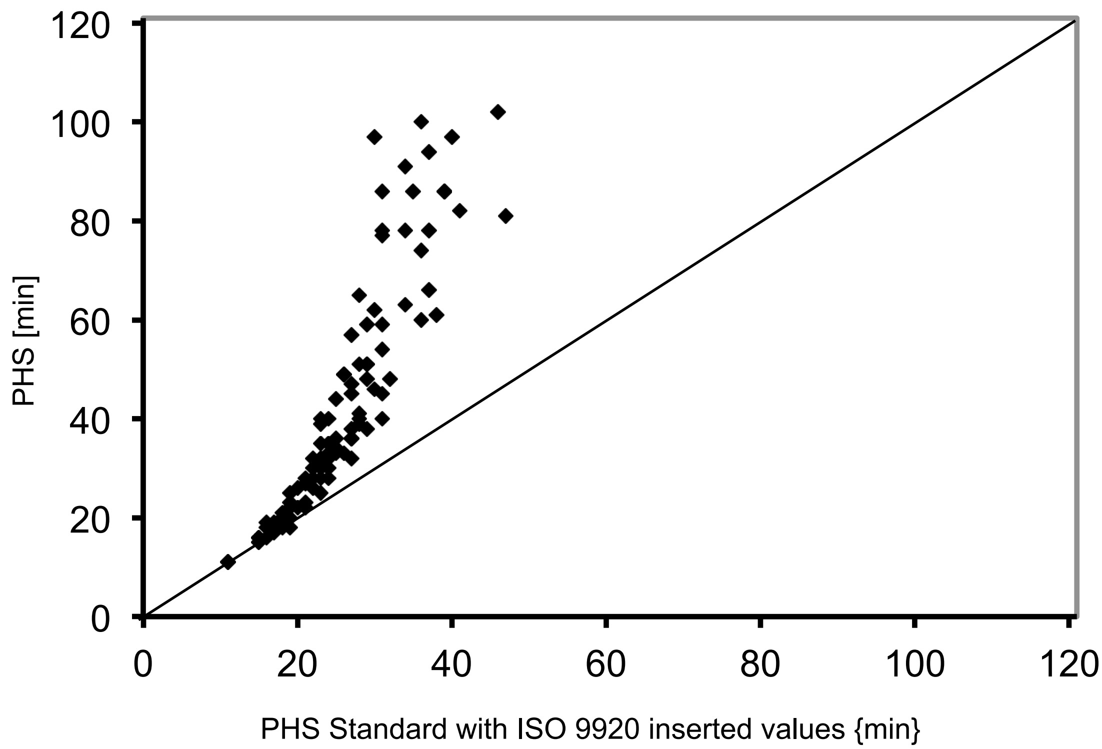

Figure 12. Comparison of PHS Standard modified with inserted value of ISO 9920 values ($PHS_{9920)}$ compared to the PHS Standard Model (PHS_{Std}).

Alternatively to the ISO9920 factors for clothing, empirical factors were compared to the standard PHS. By inserting substituted values for resultant total clothing insulation ($I_{T,r}$) based on ISO 9920 and apparent total evaporative resistance ($R_{e,T,a}$) reported by Caravello *et al*.,(2008) there is a significant shift to shorter predicted times for the model with empirical values for the clothing (see Figure 13).

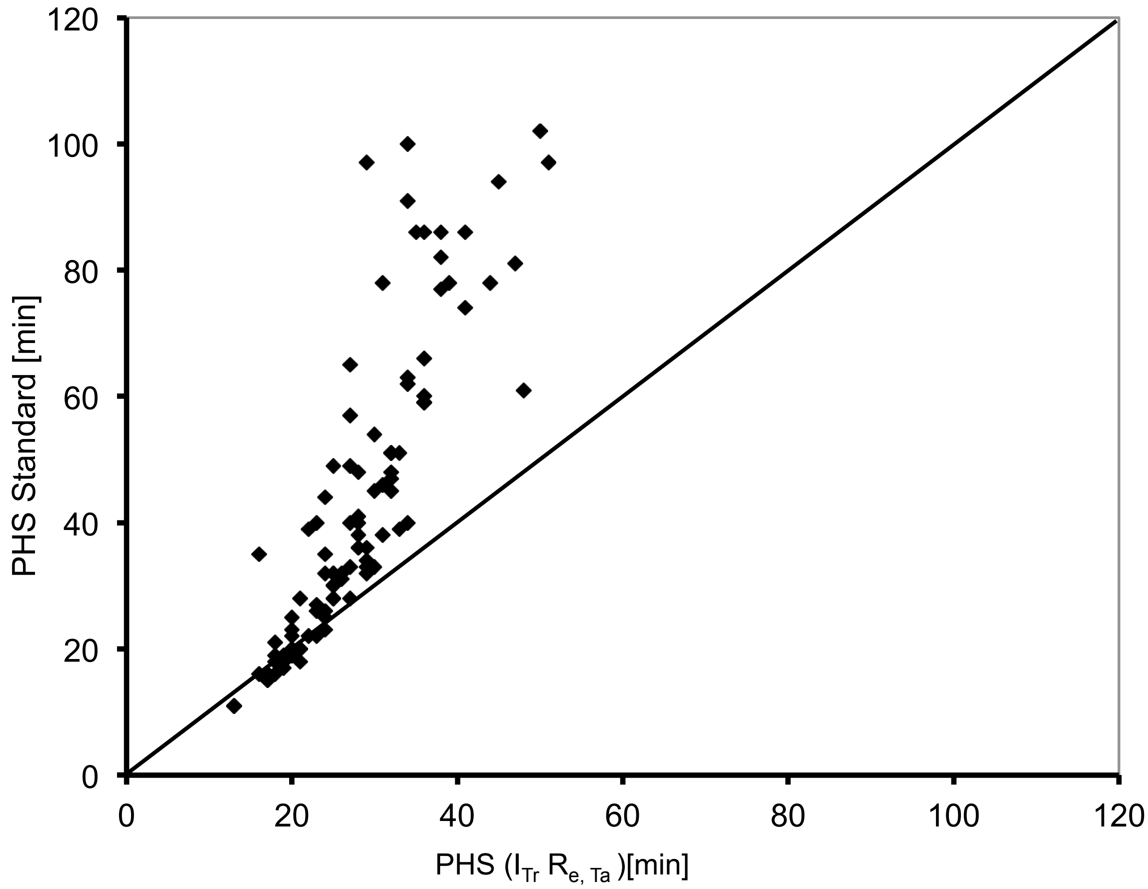

Figure 13. Comparison of PHS Standard model to the PHS Standard modified with inserted clothing values $I_{T,r}$ and $R_{e,Ta}$.

The next comparison involves participant height and weight. The standard PHS model (PHS_{Std}) considered individual anthropometry while there is value in assuming a fixed anthropometry. Figure 14 is the relationship between PHS_{Std} and $PHS_{Fixed\ Ht/Wt}$ for the participants set at the average values for the participant population in the current study. There were two distinct groups. The group with fewer observations all had body surface areas less than 1.6 m^2, while those in the other group had body surface areas greater than 2.0 m^2. The PHS model with fixed anthropometry over-predicted the time for those with the lower body surface area.

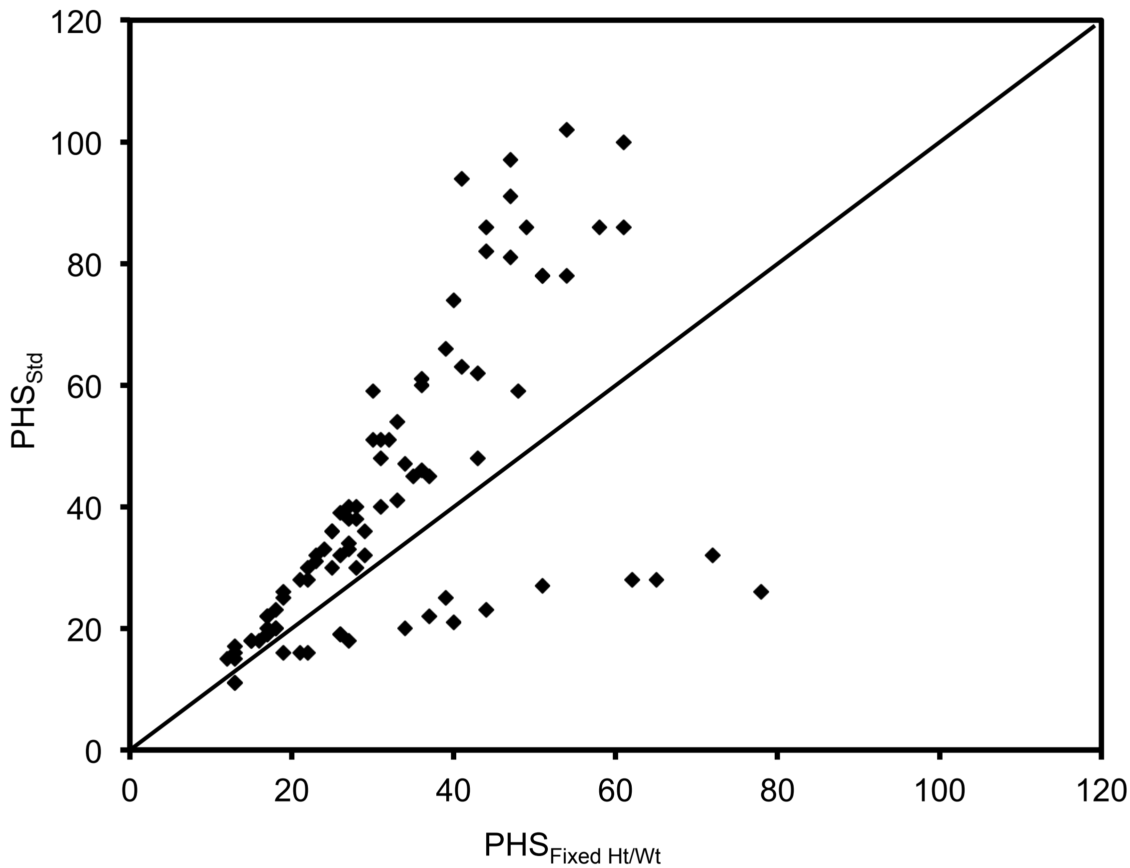

Figure 14. Relationship of the PHS Standard to PHS Standard with fixed height and weight for participants.

The overall effect of clothing adjustment factors show a shift towards more protective. To evaluate the difference in overall effect PHS$_{9920}$ was compared to PHS($I_{T,r}$,$R_{e,Ta}$). Figure 15 shows the relationship between the two modified PHS models with substituted clothing adjustment factors.

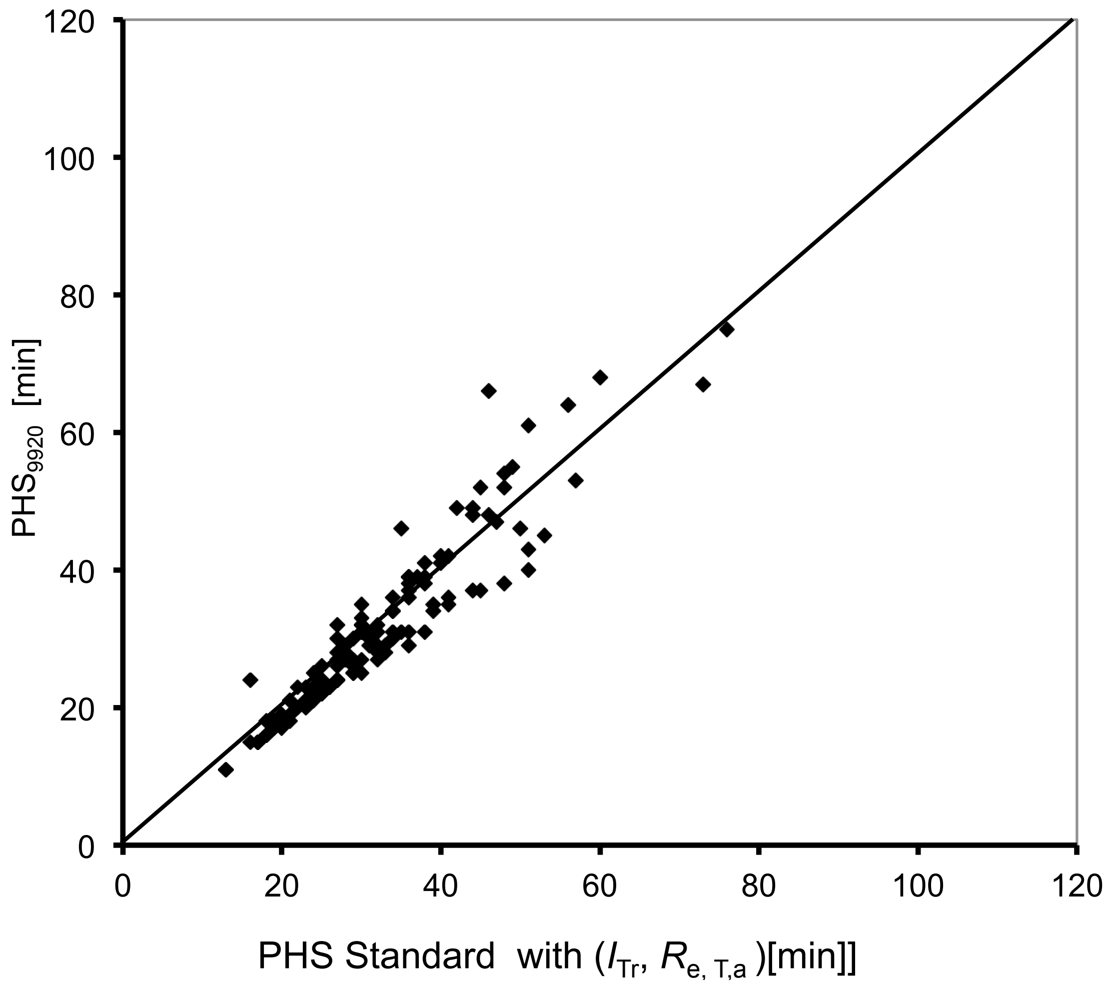

Figure 15. Comparison of PHS standard modified with substituted clothing values from ISO 9920 (2007) to the PHS standard modified with substituted ISO 9920 value for I_{Tr} and $R_{e,T,a}$ from Caravello et.al.

The results indicated a more linear effect similar to that involving substituted core temperature, however, the PHS model with substituted values from ISO 9920 tended to push most datasets slightly below the identity line.

CHAPTER 5:

DISCUSSION

The predictive and protective validity of the Predicted Heat Strain (PHS) model was assessed by used of 3-way mixed ANOVA, linear regression and utilization of Wilcoxon's Rank Sign Test. Using descriptive data available comparisons of heat stress level to exposure time were performed.

Descriptive Data

Twelve participants were included in the study of high heat stress. Because metabolic rate was considered part of the experimental control and not a treatment, the first concern was whether the metabolic rate (MSA) was the same across ensembles and heat stress levels. The mixed effects ANOVA indicated a statistically significant difference in MSA of 10 W m^{-2} between work clothes and Tychem® QC with NexGen in between. The difference is less than 6% of the mean and not important for the analysis. There were no significant differences in MSA among heat stress levels

There were intentional differences in the critical WBGTs for the ensembles and for heat stress levels, and these were confirmed. In the experimental design a difference in WBGT between the change from work clothes to NexGen of 2.5 ºC-WBGT was expected and 6.5 ºC-WBGT from the change between work clothes and a vapor barrier (Tychem® QC).

Regarding reasons for ending trial and establishing SET; 60% of the trials were terminated because the participant reached a T_{re} of 38.5 ºC followed by reaching the maximum heart rate at 29%. Seven participants were stopped after 120 minutes while wearing the NexGen ensemble at heat stress levels 1 (4) and 2 (3). Nine trials were terminated because the participants expressed fatigue or other subjective type reason. These results indicated that the SET decreased from heat stress level 1 through heat stress level 5. One exception was noted in that at heat stress level 2 while wearing the NexGen ensemble an increase in SET from heat stress level 1 was shown, where a decrease should have been noted. The same anomaly was noted for the same data in a paper by Bernard and Ashley (2009). A 3 way ANOVA mixed using a mixed model (Heat Stress Level and Ensemble were fixed effects and participants as random effect) was performed for MSA and WBGT. Results indicated significant differences among heat stress levels, ensembles and the interaction of heat stress level and ensembles. When the mean SET by ensemble code was plotted against heat stress levels, it is clear that the interaction is due to NexGen at heat stress level 2. These results were also reported by Bernard and Ashley (2009) which included the results of a Tukey HSD multiple comparison test ($\alpha = 0.05$) and indicated “that all five heat stress levels were different from each other for safe exposure time”.

The time to reach a core temperature of 38 °C is another dependent variable. As expected the times were shorter than SET. The time decreased with heat stress level, but the patterns were not as consistent as those for SET.

Predictive Validity

Malchaire *et al*. (2001) published their analysis of the predictive validity of PHS based on laboratory and field trials. They concluded that the PHS model predicted the mean response for core temperature well. For comparison, the observed time to reach a core temperature of 38 °C (ET38), which was the PHS criterion point, was compared to the time predicted by PHS. Figure 4 in Chapter 4 demonstrated a general agreement with considerable spread in the data. Notably the best-fit line had a slope of 0.37 and a significant intercept (23), which weakened the practical utility of the prediction. In addition the interclass correlation coefficient was modest at 0.33.

To see if the predictive validity could be improved and noting the number of starting core temperatures in excess of 36.8 ºC (the PHS starting point), the starting core temperature in the PHS model was set to the starting core temperature values observed in the trial. The results are seen in Figure 5 of Chapter 4. There is some improvement in the interclass correlation coefficient (0.40), but the significant intercept (24) along with a shallow slope (0.44) remained. So overall, there was not an important change in the predictive validity.

There may be problems with the way that PHS handles the thermal effects of clothing. For instance, Holmer *et al*., (2006) indicated that by using the clothing corrections in ISO 7933(2004) for insulation and evaporative resistance for encapsulating clothing, the observed time for exposure to the thermal environment was less than the predicted time. To consider the effect of clothing insulation and evaporative resistance on the predictive validity of the PHS model, the default clothing values of PHS_{Std} were changed to the ISO9920 method for clothing values. By substituting the ISO9920 values, all but 16 data pairs were shifted to the left of the identity line (to shorter predicted times). There was no improvement in the interclass correlation coefficient (0.39) but the slope tended closer to 1.0 at 0.84, but there was a significant intercept at 17. In the trial results reported by Malchaire (2001), only 37% (N=248) involved clothed individuals and 63% (N=424) of the results involved nude participants. This could explain the associated problems in the way that PHS handles thermal effects when various types of clothes are tested with I_{cl} greater than 1 clo.

Results summarized in this section used a time based protocol on reaching a core temperature of 38 °C (ET38). There were effects due to the starting core temperature and the clothing adjustment algorithms. Overall, the predictive validity of PHS falls short of the initial reports of Malchaire *et al* (2001).

Protective Validity

The starting T_{re} for the ISO 7933 (2004) computer model algorithm was 36.8 ºC. Epstein and Moran (2006) noted that "an essential requirement for continued normal body function" requires a core temperature "maintained within a very narrow limit of 1 ºC around the acceptable resting T_{re} of 37 ºC. The generally accepted value for core body temperature, measured rectally, by the medical community and sports physiologist is 37 ºC. (Casa *et al*., 2007; Gilbert *et al*., 2004; Jette *et al*.,1995; Muir *et al*.,2001). The mean T_{re} for the twelve participants in this study was 37.2º C. For the current study, a fixed value of 37 °C was used (PHS modified with a T_{re} of 37 ºC and referred to PHS_{37}).

Safe Exposure Time (SET) was the trial time at which one of the following criteria is first reached: (1) reaching a T_{re} of 38.5 ºC; (2) reaching an HR of 85% of the age adjusted maximum HR; (3) when the length of trial reached 120 minutes and; (4) the participant expressing a desire to stop. SET was used to test the protective validity of the PHS model and some variations. These model modifications involved changes to starting core temperature, changes in relation to how PHS handles clothing adjustment factors, and body surface area. The second phase of these comparisons was to compare the PHS_{Std} to the other PHS models that were modified with different variables.

The first comparison was to substitute the value of 37 ºC in place of T_{re} = 36.8 ºC in the PHS model. This modified PHS model designated as $PHS_{Tre=37ºC}$ and the exposure times generated by this model and the Safe Exposure Times

(SET) were plotted against each other. Figure 7 from Chapter 4 indicated that the predicted exposure times tended to be protective with 16 data pairs below the identity line and not protective. There were 14 true positive outcomes and 84 false positive (protective) outcomes with a protective percentage of 73%.

In this next comparison the PHS_{Std} was modified by substituting the participant's actual starting T_{re} in place of the default value. This modified PHS model was designated $PHS_{Tre=Time0}$. Figure 8 from Chapter 4 is the relationship between the two data sets, which indicated in a general shift to the left (above the identity line) with 13 data pairs still to the right of the identity line. There were 18 true positive outcomes and 84 false positive (protective) outcomes with a protective percentage of 76%. Using the actual starting core temperatures had a modest improvement in predictive validity.

To look at the protective validity and utility of the PHS model, the clothing values of ISO 9920 were inserted in the PHS model in place of original methods (PHS_{9920}). The predicted exposure times from this model and the observed SET are seen in Figure 9 from Chapter 4. All but one of the data pairs were shifted above the identity line. There were only 4 true positive outcomes and 128 false positive (protective) outcomes with a protective percentage of 98%. This represented a significant increase in protection.

The fourth comparison of the PHS model to Safe Exposure Time performed involved substituting values for resultant total clothing insulation ($I_{T,r}$) based on ISO 9920 and apparent total evaporative resistance ($R_{e,T,a}$) reported by

Caravello *et al*.,(2008) in addition to using the T_{re} = 37 ºC for the three ensembles used in the trials. The results of these changes are seen in Figure 10 of Chapter 4. There were 5 true positive outcomes and 129 false positive (protective) outcomes with a protective percentage of 99%.

There was little difference in the outcomes for the two modifications for the thermal effects of clothing. Whether the ISO9920 or the apparent values were used, the results were virtually the same. This was confirmed by comparing the results of Figures 12, 13 and 15 of Chapter 4.

Intra-PHS Comparisons

From the comparisons of SET and PHS it became clear that the starting T_{re} and adjustments made to clothing values were a significant factor in the predictive and protective validity outcomes. To evaluate other relationships within PHS and PHS modified using the trial data, other comparisons were performed. These included:

- Fixed T_{re} at 36.8 °C (PHS_{Std}) versus fixed T_{re} at 37 °C
- Fixed T_{re} at 37 °C versus actual T_{re}
- PHS_{Std} versus PHS_{9920}
- PHS_{Std} versus $PHS_{37-\ IT,r,Re,T,a}$
- PHS_{Std} versus PHS with fixed anthropometry($PHS_{Fixed\ Ht/Wt)}$

The first comparison that was completed within PHS was modifications that involved PHS_{Std} (default T_{re} = 36.8 ºC) to $PHS_{Tre=37ºC}$. In Figure 11 of Chapter

4, all data pairs fell above the identity line. As was expected the predicted times were systematically lowered when the starting core temperature was 37 °C versus 36.8 °C because the allowed heat storage was lower.

The next comparison involving core temperature was $PHS_{Tre=37°C}$ to $PHS_{Tre=Time0}$ (fixed T_{re} to T_{re} using actual participants core temperatures). The data pairs were plotted and approximately 30 data pairs were pushed below the identity line. The results re-enforced that value of T_{re} can change the predictive validity and protective effect.

The effect of clothing has shown to play a significant role in performance of the PHS model. When results from PHS_{Std} are plotted against PHS_{9920} the distribution pattern changed significantly (see Figure 12, Chapter 4). All of data pairs were shifted above the identity line with the bulk of data pairs positioned below 60 minutes. To further evaluate the performance of PHS, PHS_{Std} was plotted against $PHS_{37-\ IT,r,Re,T,a}$. The results in Figure 13 displayed a similar pattern. That is, changing the method for accounting for thermal characteristics of insulation and evaporative resistance has a major effect on PHS.

When PHS_{Std} was compared to $PHS_{Fixed\ Ht/Wt}$, the average value of the participant was inserted into the PHS_{Std} mode. Figure 14, Chapter 4, revealed two distinct groups. The group with fewer observations and below the identity line all had body surface areas of at or less than 1.6 m^2. The group with data pairs above the identity line and with the greater number of observations had a body surface area greater than 2.0 m^2. The PHS model with fixed anthropometry over predicted the time for those with lower body surface area. Because none of the participants had an average body surface between 1.6 m^2 and 2.0 m^2 the primary average body surface that causes this bifurcation in the scatter plot was not demonstrated. According to ISO 8996 (2004), the average man has a nude body surface area of 1.8 $m^{2.}$ That value also happens to be the default value for body surface area in the PHS model. When dressed in clothing, the body surface area is expanded and heat exchange at the body surface area must be corrected by adjusted clothing factors I_{cl} either measured or calculated. (Homer, 2006).

CHAPTER 6:

CONCLUSIONS

There were several important observations with respect to predictive validity. These results were not supportive of the past reports of predictive validity such as Machaire *et al*.,(2001). Expecting to find a moderate to strong agreement, instead based our human trials compared to PHS predicted times, we found a modest at best agreement. (Intraclass correlation coefficient at 0.33) Starting body core temperature is an important effect on PHS. By introducing the value for core body temperature of the actual participants T_{re} (mean value 37.2 ºC) we saw some improvement in the interclass correlation coefficient to 0.40 but the best fit line's intercept and slope were still relatively close in value thus not an important change in the predictive validity.

Clothing factors such as I_{cl}, i_{mst} and $R_{e,T}$ affect the outcomes of the PHS model and values from ISO 9920 substantially shifts the results to left of the identity line indicating shorter predicted times. Although no significant change in interclass correlation coefficient was noted (0.39) however, the slope of the best fit line increased in value closer to 1 (0.84) but still a significant intercept at 17.

In summary, there were effects due to starting T_{re} and clothing adjustment factors in the PHS model algorithms. The predictive validity of PHS falls short of the initial reports of Malchaire *et al*., (2001).

There were several important observations with respect to protective validity. PHS in its current form is not protective. When compared to the observed SET to reach a T_{re} = 38 ºC (ET38), PHS showed significantly more times right of the identity line indicating less protection.

Starting body core temperature is an important effect that improves somewhat the protective validity. Higher starting temperatures shortened the predicted time for exposure to thermal stress. Increasing the T_{re} to 37ºC reduced the number of datasets right of the identity line to approximately 16 data pairs. This indicated a greater protective effect by reducing the predicted amount of exposure time. This resulted in a protective outcome of 73%.

Clothing effects are substantial by increasing the evaporative resistance and thus reducing the models heat loss and shortening the predicted amount of exposure time By modifying the clothing algorithm in the PHS model by insertion of ISO 9920 values, the protective percentage was increased to 98%.

A second comparison of modifying the PHS model clothing algorithm with the ISO 9920 based resultant evaporative resistance $I_{T,r}$ and apparent total evaporative resistance ($R_{e,\ t,a}$) reported by Caravello *et al*., (2008). This slightly improved the protective outcome to 99%.

Another comparison involved various PHS modifications between clothing factors and $T_{re.}$ Modified PHS models with different T_{re}'s were plotted against the PHS model indicated the modified PHS models were more protective. PHS modified models inserted with different clothing values were significantly more protective When the two modified PHS models involving clothing value substitutions were compared to each other, the dataset distribution among the identity line appeared to be rather linear.

PHS standard model modified with fixed anthropometry and plotted against the PHS standard model indicated that those with body surface areas above 2.0 m^2 were to the left of the identity line .The participants who had a body surface of 1.6 m^2 or less were to the right of the identity line and were under protective. Unfortunately we had no participants who had body surfaces between 1.6 and 1.9 to actually determine the threshold for the shift.

Previously reported research involving the validation of the PHS model in regards to predictive and protective times for exposure to thermal stress was limited to a lower T_{re} than that accepted by the medical community as normal or average. The laboratory and field experiments reported by Malchaire (2001) involving 909 trials were more focused on the predictive validity for required sweat rate. Clothing adjustment factors were narrow in scope because in 63% of reported results involving core temperature, the participants were nude. This impacted the predictive and protective validity involving clothing and would have had an effect on the rate in rise of core body temperature. This research demonstrated that by using higher core body temperatures and clothing adjustment factors involving a larger range for thermal insulation values would provide a more realistic application of the Predicted Heat Strain.

CHAPTER 7:

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Appendices

Appendix A: Statistics Data Printouts

Response WBGT

Summary of Fit

RSquare	0.963361
RSquare Adj	0.959644
Root Mean Square Error	0.783075
Mean of Response	35.75399
Observations (or Sum Wgts)	153

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper
Subject	0.1144218	0.0701642	0.0514583	-0.030694	0.1710224
Residual		0.6132063	0.076832	0.4866369	0.7967703
Total		0.6833705			

-2 LogLikelihood = 388.97519787

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Ens Code	2	2	130.6	882.4426	<.0001*
Exp Code	4	4	128.9	439.6195	<.0001*
Ens Code*Exp Code	8	8	129.7	0.8258	0.5813

Effect Details

Ens Code

Least Squares Means Table

Level	Least Sq Mean	Std Error
A	38.997032	0.13286738
D	36.296870	0.14272740
E	32.553330	0.13386943

LSMeans Differences Tukey HSD

$\alpha = 0.050$

Level				Least Sq Mean
A	A			38.997032
D		B		36.296870
E			C	32.553330

Levels not connected by same letter are significantly different.

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Pct of Total
10.267
89.733
100.000

Next Page: Appendix A

Response WBGT

Effect Details

Exp Code

Least Squares Means Table

Level	Least Sq Mean	Std Error
T120	32.851677	0.16407549
T30	40.775245	0.17546081
T45	37.126106	0.16249795
T60	35.274487	0.16273415
T90	33.717872	0.15442132

LSMeans Differences Tukey HSD

$\alpha = 0.050$

Level						Least Sq Mean
T30	A					40.775245
T45		B				37.126106
T60			C			35.274487
T90				D		33.717872
T120					E	32.851677

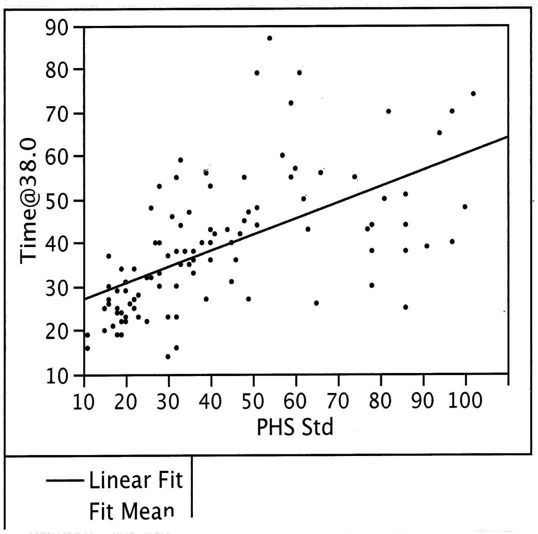
Levels not connected by same letter are significantly different.

Ens Code*Exp Code

Subject

Next Page: Appendix A

Bivariate Fit of Time@38.0 By PHS Std



Linear Fit

Time@38.0 = 23.362589 + 0.3695538*PHS Std

Summary of Fit

RSquare	0.339638
RSquare Adj	0.333034
Root Mean Square Error	12.44315
Mean of Response	39.06863
Observations (or Sum Wgts)	102

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
				2.0418
Lack Of Fit	50	10393.072	207.861	**Prob > F**
Pure Error	50	5090.117	101.802	0.0065*
Total Error	100	15483.189		**Max RSq**
				0.7829

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	7963.331	7963.33	51.4321
Error	100	15483.189	154.83	**Prob > F**
C. Total	101	23446.520		<.0001*

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Input: Fit Y by X of Time@38.0 by PHS Std

Bivariate Fit of Time@38.0 By PHS Std

Linear Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	23.362589	2.512803	9.30	<.0001*
PHS Std	0.3695538	0.05153	7.17	<.0001*

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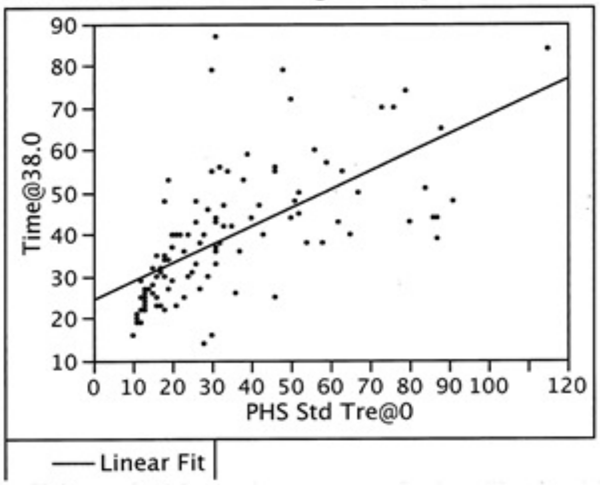
Bivariate Fit of Time@38.0 By PHS Std Tre@0



Linear Fit

Time@38.0 = 24.440725 + 0.4368245*PHS Std Tre@0

Summary of Fit

RSquare	0.403606
RSquare Adj	0.397872
Root Mean Square Error	12.15138
Mean of Response	39.49057
Observations (or Sum Wgts)	106

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
				1.0424
Lack Of Fit	54	8132.340	150.599	Prob > F
Pure Error	50	7223.898	144.478	0.4423
Total Error	104	15356.237		Max RSq
				0.7194

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	10392.253	10392.3	70.3815
Error	104	15356.237	147.7	Prob > F
C. Total	105	25748.491		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	24.440725	2.147354	11.38	<.0001*
PHS Std Tre@0	0.4368245	0.052069	8.39	<.0001*

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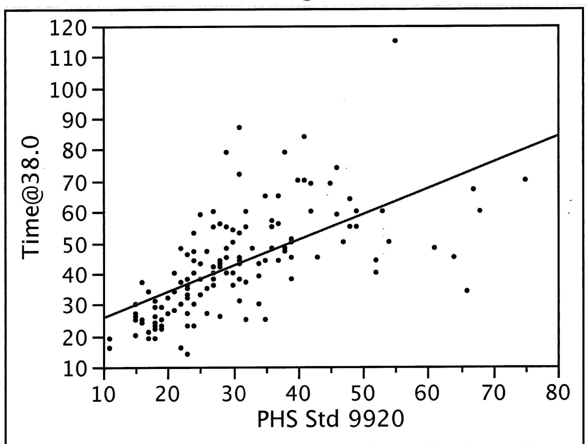
Input: Fit Y by X of Time@38.0 by PHS Std 9920

Bivariate Fit of Time@38.0 By PHS Std 9920



Linear Fit

Time@38.0 = 17.29115 + 0.8363514*PHS Std 9920

Summary of Fit

RSquare	0.388248
RSquare Adj	0.383649
Root Mean Square Error	13.26184
Mean of Response	43.00741
Observations (or Sum Wgts)	135

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
				2.5387
Lack Of Fit	43	12821.125	298.166	**Prob > F**
Pure Error	90	10570.419	117.449	0.0001*
Total Error	133	23391.544		**Max RSq**
				0.7236

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	14845.448	14845.4	84.4085
Error	133	23391.544	175.9	**Prob > F**
C. Total	134	38236.993		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.29115	3.022849	5.72	<.0001*
PHS Std 9920	0.8363514	0.091032	9.19	<.0001*

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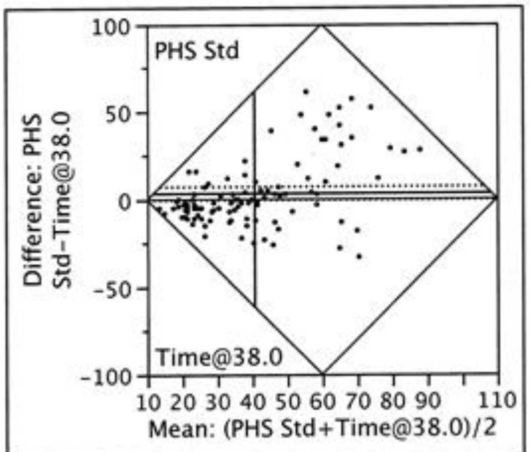
Input: Matched Pairs of Time@38.0, PHS Std

Matched Pairs

Difference: PHS Std-Time@38.0



PHS Std	42.5	t-Ratio	1.771345
Time@38.0	39.0686	DF	101
Mean Difference	3.43137	Prob > |t|	0.0795
Std Error	1.93716	Prob > t	0.0398*
Upper95%	7.27417	Prob < t	0.9602
Lower95%	-0.4114		
N	102		
Correlation	0.58278		

Wilcoxon Sign-Rank

	PHS Std-Time@38.0
Test Statistic	74.500
Prob > |z|	0.7901
Prob > z	0.3951
Prob < z	0.6049

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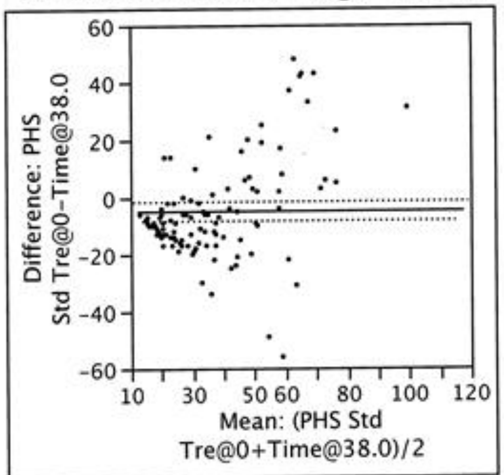
Matched Pairs

Difference: PHS Std Tre@0-Time@38.0



PHS Std Tre@0	34.4528	t-Ratio	-2.94222
Time@38.0	39.4906	DF	105
Mean Difference	-5.0377	Prob > |t|	0.0040*
Std Error	1.71222	Prob > t	0.9980
Upper95%	-1.6427	Prob < t	0.0020*
Lower95%	-8.4328		
N	106		
Correlation	0.6353		

Wilcoxon Sign-Rank

	PHS Std Tre@0-Time@38.0
Test Statistic	-1185.0
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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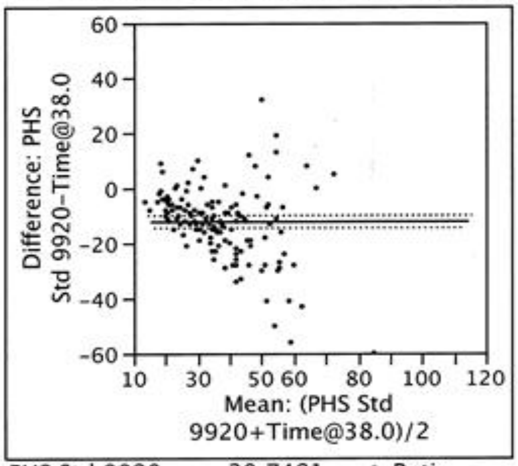
Input: Matched Pairs of Time@38.0, PHS Std 9920 Page 1 of 1

Matched Pairs

Difference: PHS Std 9920−Time@38.0



PHS Std 9920	30.7481	t-Ratio	−10.6522
Time@38.0	43.0074	DF	134
Mean Difference	−12.259	Prob > |t|	<.0001*
Std Error	1.15086	Prob > t	1.0000
Upper95%	−9.9831	Prob < t	<.0001*
Lower95%	−14.535		
N	135		
Correlation	0.6231		

Wilcoxon Sign-Rank

	PHS Std 9920−Time@38.0
Test Statistic	−3727.0
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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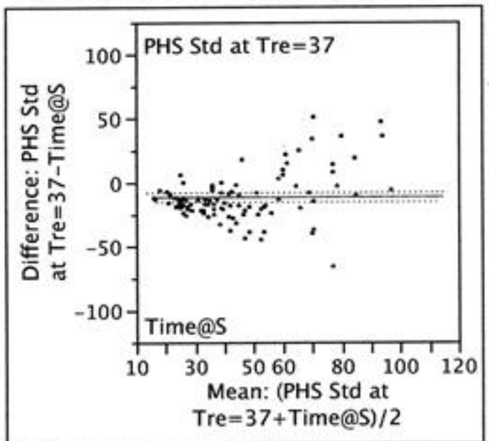
Matched Pairs

Difference: PHS Std at Tre=37-Time@S



PHS Std at Tre=37	38.9608	t-Ratio	-6.36042
Time@S	50.7549	DF	101
Mean Difference	-11.794	Prob > |t|	<.0001*
Std Error	1.8543	Prob > t	1.0000
Upper95%	-8.1157	Prob < t	<.0001*
Lower95%	-15.473		
N	102		
Correlation	0.66064		

Wilcoxon Sign-Rank

	PHS Std at Tre=37-Time@S
Test Statistic	-1657.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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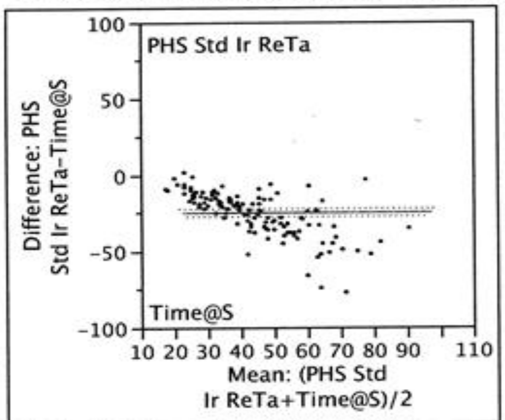
Comparison Data 20110425: Matched Pairs of Time@S, PHS Std Ir ReTa

Page 1 of 1

Matched Pairs

Difference: PHS Std Ir ReTa-Time@S



PHS Std Ir ReTa	31.1719	t-Ratio	-19.4485
Time@S	56.1406	DF	127
Mean Difference	-24.969	Prob > |t|	<.0001*
Std Error	1.28384	Prob > t	1.0000
Upper95%	-22.428	Prob < t	<.0001*
Lower95%	-27.509		
N	128		
Correlation	0.75186		

Wilcoxon Sign-Rank

	PHS Std Ir ReTa-Time@S
Test Statistic	-4125.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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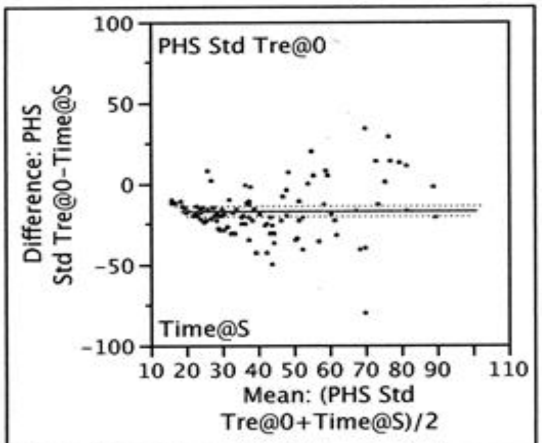
Matched Pairs

Difference: PHS Std Tre@0-Time@S



PHS Std Tre@0	33.4951	t-Ratio	-10.7421
Time@S	50.7282	DF	102
Mean Difference	-17.233	Prob > |t|	<.0001*
Std Error	1.60425	Prob > t	1.0000
Upper95%	-14.051	Prob < t	<.0001*
Lower95%	-20.415		
N	103		
Correlation	0.67875		

Wilcoxon Sign-Rank

	PHS Std Tre@0-Time@S
Test Statistic	-2252.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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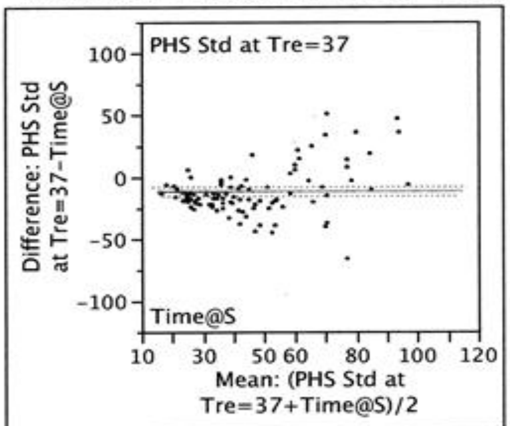
Comparison Data 20110425: Matched Pairs of Time@S, PHS Std at Tre=37

Matched Pairs

Difference: PHS Std at Tre=37-Time@S



PHS Std at Tre=37	38.9608	t-Ratio	-6.36042
Time@S	50.7549	DF	101
Mean Difference	-11.794	Prob > |t|	<.0001*
Std Error	1.8543	Prob > t	1.0000
Upper95%	-8.1157	Prob < t	<.0001*
Lower95%	-15.473		
N	102		
Correlation	0.66064		

Wilcoxon Sign-Rank

	PHS Std at Tre=37-Time@S
Test Statistic	-1657.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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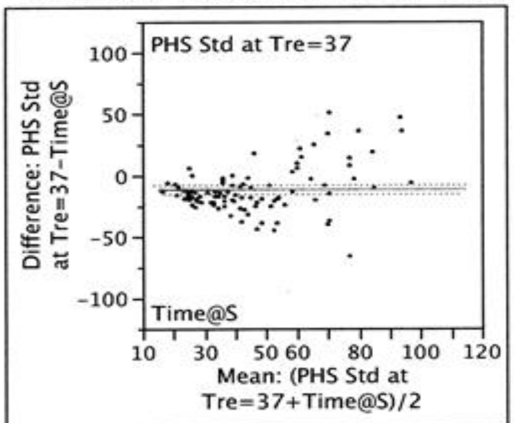
Matched Pairs

Difference: PHS Std at Tre=37-Time@S



PHS Std at Tre=37	38.9608	t-Ratio	-6.36042
Time@S	50.7549	DF	101
Mean Difference	-11.794	Prob > |t|	<.0001*
Std Error	1.8543	Prob > t	1.0000
Upper95%	-8.1157	Prob < t	<.0001*
Lower95%	-15.473		
N	102		
Correlation	0.66064		

Wilcoxon Sign-Rank

	PHS Std at Tre=37-Time@S
Test Statistic	-1657.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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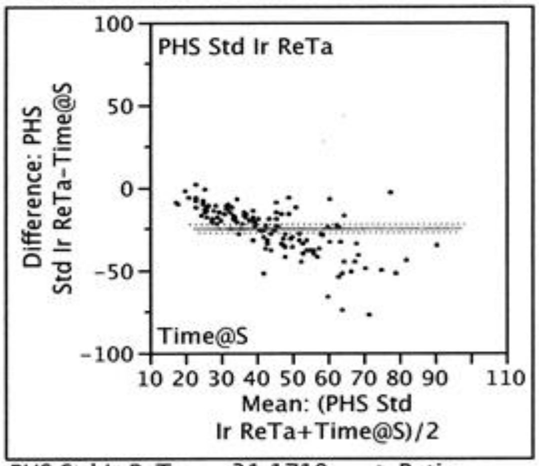
Matched Pairs

Difference: PHS Std Ir ReTa-Time@S



PHS Std Ir ReTa	31.1719	t-Ratio	-19.4485
Time@S	56.1406	DF	127
Mean Difference	-24.969	Prob > |t|	<.0001*
Std Error	1.28384	Prob > t	1.0000
Upper95%	-22.428	Prob < t	<.0001*
Lower95%	-27.509		
N	128		
Correlation	0.75186		

Wilcoxon Sign-Rank

	PHS Std Ir ReTa-Time@S
Test Statistic	-4125.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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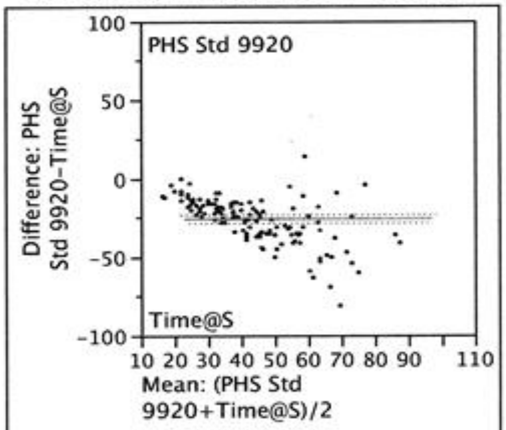
Comparison Data 20110425: Matched Pairs of Time@S, PHS Std 9920 Page 1 of 1

Matched Pairs

Difference: PHS Std 9920–Time@S



PHS Std 9920	30.25	t-Ratio	-19.7732
Time@S	56.1406	DF	127
Mean Difference	-25.891	Prob > |t|	<.0001*
Std Error	1.30938	Prob > t	1.0000
Upper95%	-23.3	Prob < t	<.0001*
Lower95%	-28.482		
N	128		
Correlation	0.72118		

Wilcoxon Sign-Rank

	PHS Std 9920–Time@S
Test Statistic	-4040.0
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

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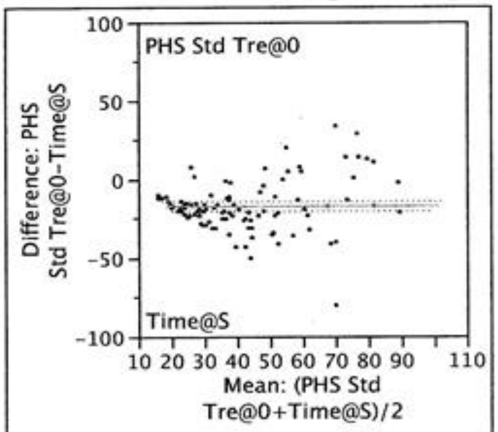
Comparison Data 20110425: Matched Pairs of Time@S, PHS Std Tre@0

Matched Pairs

Difference: PHS Std Tre@0-Time@S



PHS Std Tre@0	33.4951	t-Ratio	-10.7421
Time@S	50.7282	DF	102
Mean Difference	-17.233	Prob > |t|	<.0001*
Std Error	1.60425	Prob > t	1.0000
Upper95%	-14.051	Prob < t	<.0001*
Lower95%	-20.415		
N	103		
Correlation	0.67875		

Wilcoxon Sign-Rank

	PHS Std Tre@0-Time@S
Test Statistic	-2252.5
Prob > |z|	<.0001*
Prob > z	1.0000
Prob < z	<.0001*

Appendix B: Final Censored Data Set

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Subject	Date	Gender	Height	Weight	BSA	Ens Code	Exp Code	Vair	Ir	Re,T,a	M	MSA	Vwalk	Tdb	Tg	Tpwb	WBGT
104	S3	3/6/2007	F	160	50	1.50	E	T90	0.50	0.12	0.032	219	146	1.48	36.5	36.3	26.6	29.51
105	S4	5/16/2007	M	175	91	2.03	D	T90	0.50	0.12	0.018	355	175	1.12	40.5	40.3	29.8	33.65
106	S8	8/1/2007	M	175	88	2.03	D	T90	0.50	0.12	0.018	372	183	1.12	40.8	40.6	30.6	34.3
107	S10	11/4/2007	M	183	89	2.10	A	T30	0.50	0.12	0.013	363	173	1.16	50.0	50.2	37.2	41.8
108	S12	1/1/2008	M	180	105	2.24	A	T120	0.50	0.12	0.013	446	199	1.03	43.5	43.4	33.1	36.89
109	S12	12/27/2007	M	180	105	2.24	A	T60	0.50	0.12	0.013	459	205	1.03	46.6	46.5	35.1	39.22
110	S12	12/31/2007	M	180	105	2.24	E	T90	0.50	0.12	0.032	433	193	1.03	36.5	36.3	27.1	30.56
111	S12	12/31/2007	M	180	105	2.24	E	T45	0.50	0.12	0.032	439	196	1.03	40.5	40.4	29.7	33.61
112	S13	2/20/2008	M	180	104	2.23	A	T90	0.50	0.12	0.013	362	162	1.03	44.3	44.0	35.5	38.75
113	S13	1/30/2008	M	180	104	2.23	D	T120	0.50	0.12	0.018	389	174	1.03	39.6	39.5	30.3	33.76
114	S13	2/3/2008	M	180	104	2.23	D	T90	0.50	0.12	0.018	442	198	1.03	40.5	40.3	29.7	33.58
115	S13	1/24/2008	M	180	104	2.23	E	T60	0.50	0.12	0.032	490	220	1.03	38.5	38.3	28.8	32.35
116	S3	3/5/2007	F	160	50	1.50	A	T90	0.50	0.12	0.013	283	189	1.48	44.4	44.1	32.3	36.54
117	S3	2/28/2007	F	160	50	1.50	D	T120	0.50	0.12	0.018	300	200	1.48	39.5	39.5	28.9	32.78
118	S4	5/6/2007	M	175	91	2.06	A	T120	0.50	0.12	0.013	362	176	1.12	43.3	43.1	31.6	35.75
119	S4	5/13/2007	M	175	91	2.06	D	T30	0.50	0.12	0.018	353	171	1.12	49.6	49.2	36.8	41.22
120	S4	4/29/2007	M	175	91	2.06	E	T120	0.50	0.12	0.032	349	169	1.12	35.4	35.3	26.0	29.49
121	S7	8/27/2007	M	182	107	2.28	A	T45	0.50	0.12	0.013	408	179	1.03	48.7	48.4	36.2	40.56
122	S7	9/10/2007	M	182	107	2.28	E	T30	0.50	0.12	0.032	397	174	1.03	44.8	44.5	33.7	37.64
123	S8	8/19/2007	M	175	88	2.04	A	T120	0.50	0.12	0.013	348	171	1.12	43.4	43.4	32.7	36.61
124	S8	9/12/2007	M	175	88	2.04	A	T90	0.50	0.12	0.013	398	195	1.12	44.4	43.7	33.4	37.19
125	S8	8/23/2007	M	175	88	2.04	D	T60	0.50	0.12	0.018	344	169	1.12	42.4	41.0	31.3	34.91
126	S8	8/14/2007	M	175	88	2.04	D	T30	0.50	0.12	0.018	352	173	1.12	50.3	49.2	36.4	40.94
127	S8	8/21/2007	M	175	88	2.04	E	T60	0.50	0.12	0.032	310	152	1.12	39.5	48.7	29.3	35.82
128	S8	8/15/2007	M	175	88	2.04	E	T45	0.50	0.12	0.032	303	149	1.12	40.1	40.6	30.6	34.3
129	S10	11/11/2007	M	183	89	2.10	E	T30	0.50	0.12	0.032	424	202	1.16	47.8	46.2	34.4	38.64
130	S11	11/6/2007	F	170	107	2.16	A	T30	0.50	0.12	0.013	390	181	0.85	53.2	52.9	39.0	43.87
131	S12	1/3/2008	M	180	105	2.24	A	T90	0.50	0.12	0.013	471	210	1.03	44.1	43.9	32.9	36.9
132	S12	12/24/2007	M	180	105	2.24	A	T45	0.50	0.12	0.013	462	206	1.03	49.0	48.3	36.1	40.46
133	S12	12/24/2007	M	180	105	2.24	D	T120	0.50	0.12	0.018	417	186	1.03	39.6	39.4	30.6	33.94
134	S12	12/30/2007	M	180	105	2.24	D	T90	0.50	0.12	0.018	498	222	1.03	41.0	40.6	30.9	34.51
135	S13	2/11/2008	M	180	104	2.23	D	T45	0.50	0.12	0.018	361	162	1.03	44.6	44.3	33.6	37.51
136	S13	2/18/2008	M	180	104	2.23	D	T30	0.50	0.12	0.018	358	161	1.03	49.0	48.8	37.8	41.8

	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
1	Pv	HR@0	HR@5	Tre@0	Time @38.0	HR@S	Tre@S	Time @S	Reason	Note	PHS Std	PHS Std Tre@0	PHS Std 9920	PHS Std Ir ReTa	PHS Std Fixed Ht Wt	PHS Std at Tre=37	PHS Std 9920 Fixed Ht Wt
104	2.56	97	93.0	37.4	34	154	38.5	52	T		121	121	66	46	121	121	121
105	3.48	84	89.0	37.4	44	122	38.2	120	P		121	121	52	48	121	121	39
106	3.71	102	93.0	37.4	45	126	38.5	75	T		121	121	39	37	108	121	32
107	5.48	111.7	89.0	37.4	19	135	38.4	27	T		16	12	17	19	16	16	16
108	4.36	77	80.0	37.4	79	128	38.5	110	T		51	30	29	33	31	44	21
109	4.88	71	88.0	37.4	48	132	38.4	61	T		26	18	22	24	19	23	17
110	2.95	70	89.0	37.4	56	130	38.5	78	T		66	46	37	36	39	63	26
111	3.44	98	108.0	37.4	36	143	38.5	48	T		36	23	27	28	25	32	20
112	5.19	98	108.0	37.4	53	167	38.3	69	H		28	19	24	27	21	26	19
113	3.69	115	111.0	37.4	64	162	38.5	95	T		121	121	48	46	91	121	32
114	3.44	112	109.0	37.4	69	167	38.4	92	H		121	121	42	41	70	121	28
115	3.02	110	116.0	37.4	43	167	38.2	46	H		40	26	28	28	27	37	21
116	4.02	94	114.0	37.5	23	169	38.7	37	H	T,H	32	13	23	26	121	25	39
117	3.27	116	107.0	37.5	25	134	38.3	48	T		121	23	32	30	121	121	105
118	3.86	99	100.0	37.5	45	120	38.5	74	T		121	121	43	51	121	121	34
119	5.35	90	104.0	37.5	19	129	38.5	26	T		19	12	18	20	17	17	16
120	2.73	90	95.0	37.5	40	124	38.5	57	T		121	121	52	45	121	121	41
121	5.17	91	101.0	37.5	26	128	38.5	43	T		23	15	21	24	18	21	16
122	4.48	94	97.0	37.5	32	139	38.4	44	T		25	15	23	24	19	22	17
123	4.23	89	103.0	37.5	30	127	38.5	55	T		78	29	34	39	54	65	28
124	4.40	96	102.0	37.5	40	129	38.5	64	T		45	21	27	30	35	39	23
125	3.82	96	97.0	37.5	48	143	38.4	70	T		121	51	38	38	78	117	32
126	5.14	100	106.0	37.5	22	144	38.5	32	T		20	13	19	21	18	18	17
127	3.39	86	87.0	37.5	35	131	38.4	49	T		33	18	26	29	27	29	23
128	3.75	94	98.0	37.5	31	146	38.5	46	T		45	25	31	32	37	39	27
129	4.54	91	97.0	37.5	22	162	38.4	32	T		19	12	18	19	17	17	16
130	6.04	105	123.0	37.5	21	168	38.0	21	H		17	11	17	19	13	15	13
131	4.25	80	93.0	37.5	48	135	38.4	63	T		51	26	29	32	30	45	21
132	5.11	90	108.0	37.5	27	141	38.5	37	T		22	14	20	22	17	20	15
133	3.79	78	83.0	37.5	84	119	38.3	120	P		121	115	41	40	56	121	28
134	3.79	83	86.0	37.5	87	126	38.1	120	P		54	31	31	30	33	52	22
135	4.46	98	106.0	37.5	40	167	38.0	38	H		38	22	29	31	27	34	22
136	5.80	102	102.0	37.5	29	167	38.0	29	H		18	12	19	21	15	17	15

Next Pages: Appendix B

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
1	Subject	Date	**Gender**	Height	Weight	BSA	Ens Code	Exp Code	Vair	Ir	Re,T,a	M	MSA	Vwalk	Tdb	Tg	Tpwb	WBGT	Pv	HR@0	HR@5	Tre@0	Time @38.0	HR@S	Tre@S	Time @S	Reason	Note	PHS Std	PHS Std Tre@0	PHS Std 9920	PHS Std Ir ReTa	PHS Std Fixed Ht Wt	PHS Std at Tre=37	PHS Std 9920 Fixed Ht Wt
53	S9	7/31/2007	F	157	55	1.55	A	T90	0.50	0.12	0.013	303	195	1.34	44.4	44.1	33.5	37.38	4.44	116	118.0	37.1	40	167	38.1	55	T		27	20	21	23	51	22	28
54	S9	9/5/2007	F	157	55	1.55	D	T90	0.50	0.12	0.018	309	199	1.34	40.9	40.1	31.6	34.85	4.02	98	114.0	37.1	43	169	38.0	43	H		44	31	25	24	121	35	36
55	S10	11/6/2007	M	183	89	2.10	A	T60	0.50	0.12	0.013	377	180	1.16	45.9	46.0	33.3	37.81	4.27	86	86.0	37.1	42	145	38.5	58	T		47	35	27	32	34	39	23
56	S10	11/23/2007	M	183	89	1.90	A	T45	0.50	0.12	0.013	400	211	1.16	48.7	48.1	36.3	40.54	5.21	116	92.0	37.1	31	158	38.4	40	T		20	17	18	20	18	18	16
57	S10	10/10/2007	M	183	89	2.10	D	T90	0.50	0.12	0.018	337	160	1.16	40.9	40.6	29.5	33.53	3.36	76	75.0	37.1	45	108	38.4	73	T		121	121	64	56	121	121	47
58	S10	11/21/2007	M	183	89	2.11	E	T90	0.50	0.12	0.032	371	176	1.16	36.4	36.3	27.3	30.7	3.02	82	78.0	37.1	50	125	38.5	74	T		121	121	39	36	73	121	32
59	S10	10/15/2007	M	183	89	2.10	E	T60	0.50	0.12	0.032	370	176	1.16	38.5	38.1	27.4	31.31	2.90	81	85.0	37.1	48	148	38.3	62	T		100	91	36	34	61	98	30
60	S10	10/3/2007	M	183	89	2.10	E	T45	0.50	0.12	0.032	361	172	1.16	40.1	40.3	30.1	33.86	3.60	*	78.0	37.1	42	131	38.4	54	T		41	33	28	28	33	36	24
61	S11	11/5/2007	F	170	107	2.16	A	T90	0.50	0.12	0.013	341	158	0.85	44.0	43.8	33.0	36.94	4.29	99	99.0	37.1	79	167	38.3	89	H		61	48	38	48	36	52	26
62	S11	10/25/2007	F	170	107	2.16	A	T60	0.50	0.12	0.013	451	209	0.85	44.5	44.9	33.0	37.27	4.26	105	104.0	37.1	56	146	38.4	73	T		39	32	28	33	26	34	20
63	S2	3/14/2007	F	154	52	1.47	A	T90	0.50	0.12	0.013	304	207	1.43	44.3	44.2	32.9	36.99	4.24	90.0	100.0	37.2	32	129	38.4	48	T		26	17	20	23	78	21	31
64	S2	3/4/2007	F	154	52	1.47	A	T45	0.50	0.12	0.013	336	229	1.43	48.2	47.2	34.7	39.15	4.62	93.0	107.0	37.2	25	142	38.5	33	T		18	13	16	18	27	16	21
65	S2	2/26/2007	F	154	52	1.47	E	T60	0.50	0.12	0.032	329	223	1.43	38.4	38.2	28.1	31.83	2.75	107	104.0	37.2	27	129	38.5	37	T		39	27	23	22	121	35	38
66	S2	3/6/2007	F	154	52	1.47	E	T30	0.50	0.12	0.032	278	189	1.43	45.1	44.3	30.8	35.55	3.48	103	111.0	37.2	25	145	38.5	32	T		22	16	19	20	37	19	25
67	S3	3/14/2007	F	160	50	1.50	D	T45	0.50	0.12	0.018	279	186	1.48	45.1	44.7	33.5	37.56	4.39	88	100.0	37.2	23	150	38.8	32	T		23	17	19	20	44	20	27
68	S4	6/19/2007	M	175	91	2.06	A	T90	0.50	0.12	0.013	324	157	1.12	44.3	44.1	32.8	36.855	4.20	88	88.0	37.2	44	125	38.5	73	T		78	50	37	44	51	65	30
69	S4	12/31/2007	M	175	91	2.06	D	T120	0.50	0.12	0.018	364	177	1.12	39.6	39.4	29.6	33.24	3.47	95	94.0	37.2	50	142	38.7	72	T		121	121	54	48	121	121	41
70	S4	5/8/2007	M	175	91	2.06	E	T45	0.50	0.12	0.032	364	177	1.12	40.6	40.3	30.8	34.35	3.78	92	93.0	37.2	38	131	38.5	48	T		36	27	27	28	29	32	23
71	S7	9/17/2007	M	182	107	2.28	A	T120	0.50	0.12	0.013	434	190	1.03	43.5	42.4	31.3	35.33	3.75	87	97.0	37.2	69	113	38.4	105	T		121	121	45	53	75	121	28
72	S8	9/11/2007	M	175	88	2.04	A	T60	0.50	0.12	0.013	449	220	1.12	45.5	44.4	33.3	37.33	4.30	92	102.0	37.2	40	138	38.4	59	T		40	28	24	27	31	34	21
73	S9	7/26/2007	F	157	55	1.55	A	T45	0.50	0.12	0.013	260	168	1.34	49.0	48.6	37.0	41.18	5.47	112	131.0	37.2	27	175	38.3	35	H		16	13	15	17	19	15	18
74	S9	9/4/2007	F	157	55	1.55	D	T120	0.50	0.12	0.018	302	195	1.34	39.7	39.6	30.3	33.79	3.68	111	117.0	37.2	40	155	38.1	45	F		97	65	30	29	121	96	54
75	S9	8/1/2007	F	157	55	1.55	E	T45	0.50	0.12	0.032	331	214	1.34	41.6	40.8	30.4	34.22	3.59	87	116.0	37.2	22	169	38.2	45	T		25	18	19	20	39	21	25
76	S10	11/13/2007	M	183	89	2.10	A	T120	0.50	0.12	0.013	365	174	1.16	43.1	42.9	32.5	36.32	4.18	75	76.0	37.2	44	134	38.4	76	T		121	87	35	39	66	112	29
77	S10	10/9/2007	M	183	89	2.11	A	T30	0.50	0.12	0.013	368	174	1.16	51.8	51.5	39.6	43.87	6.40	116	111.0	37.2	25	163	38.5	29	H	T,H	15	12	15	17	13	13	14
78	S10	11/15/2007	M	183	89	2.11	D	T60	0.50	0.12	0.018	389	184	1.16	42.7	42.6	31.5	35.53	3.87	86	89.0	37.2	38	135	38.4	54	T		78	54	31	31	51	69	26
79	S10	11/7/2007	M	183	89	2.11	D	T45	0.50	0.12	0.018	375	178	1.16	45.0	44.6	33.8	37.74	4.51	85	89.0	37.2	30	129	38.4	42	T		32	24	24	25	26	28	21
80	S10	11/12/2007	M	183	89	2.10	D	T30	0.50	0.12	0.018	365	174	1.16	49.1	49.0	36.4	40.88	5.22	82	104.0	37.2	23	162	38.4	30	H		20	16	18	20	17	18	16
81	S10	11/14/2007	M	183	89	2.10	E	T120	0.50	0.12	0.032	365	174	1.16	35.2	35.1	26.0	29.43	2.74	81	75.0	37.2	60	130	38.4	87	T		121	121	49	42	121	121	39
82	S11	10/22/2007	F	170	107	2.16	A	T120	0.50	0.12	0.013	416	193	0.85	43.1	42.7	31.5	35.56	3.84	101	98.0	37.2	70	156	38.1	75	F		97	76	40	51	47	94	27
83	S11	10/14/2007	F	170	107	2.16	D	T120	0.50	0.12	0.018	335	155	0.85	39.5	39.4	29.5	33.17	3.45	97	103.0	37.2	67	154	38.4	108	F		121	121	67	73	121	121	42
84	S11	10/24/2007	F	170	107	2.16	D	T90	0.50	0.12	0.018	353	163	0.85	40.6	40.5	30.7	34.34	3.75	107	102.0	37.2	74	157	38.3	100	F		102	79	46	50	54	94	31
85	S11	10/11/2007	F	170	107	2.16	E	T120	0.50	0.12	0.032	374	173	0.85	35.2	35.1	26.5	29.78	2.88	119	119.0	37.2	50	152	38.5	80	T		81	67	47	47	47	77	32
86	S11	10/23/2007	F	170	107	2.16	E	T30	0.50	0.12	0.032	394	182	0.85	48.0	46.2	35.0	39.06	4.75	114	118.0	37.2	34	167	38.0	34	H		22	18	21	23	17	20	16
87	S12	12/25/2007	M	180	105	2.24	E	T120	0.50	0.12	0.032	425	190	1.03	35.2	35.1	26.8	29.99	2.96	71	77.0	37.2	70	126	38.5	90	T		82	73	41	38	44	80	28
88	S2	2/25/2007	F	154	52	1.47	D	T120	0.50	0.12	0.018	295	201	1.43	39.7	39.5	29.1	32.92	3.32	93.0	93.0	37.3	37	128	38.6	65	T		121	121	32	30	121	121	101
89	S3	3/7/2007	F	160	50	1.50	A	T60	0.50	0.12	0.013	228	152	1.48	46.2	45.5	34.4	38.43	4.65	83	94.0	37.3	30	166	38.8	38	H	T,H	28	18	22	25	62	24	30
90	S3	2/26/2007	F	160	50	1.50	E	T60	0.50	0.12	0.032	248	165	1.34	38.6	38.5	28.9	32.445	3.33	116	92.0	37.3	26	152	38.5	37	T		65	36	28	27	121	55	45
91	S4	1/1/2008	M	175	91	2.06	D	T45	0.50	0.12	0.018	375	182	1.12	44.5	44.4	34.0	37.82	4.61	97	103.0	37.3	23	146	38.4	40	H		30	21	24	25	25	27	20
92	S4	5/2/2007	M	175	91	2.06	E	T60	0.50	0.12	0.032	322	156	1.12	38.3	38.3	28.5	32.14	3.23	94	96.0	37.3	38	129	38.4	53	T		86	58	39	38	61	78	32
93	S8	9/4/2007	M	175	88	2.04	A	T90	0.50	0.12	0.013	348	171	1.12	44.0	43.8	32.5	36.59	4.12	116	108.0	37.3	25	145	38.5	50	T		86	46	35	41	58	72	29
94	S9	8/7/2007	F	157	55	1.55	A	T60	0.50	0.12	0.013	354	228	1.34	46.4	46.0	34.9	38.93	4.82	112	136.0	37.3	24	169	38.1	24	H		19	13	16	18	26	17	20
95	S10	11/19/2007	M	183	89	2.11	D	T120	0.50	0.12	0.018	375	178	1.16	40.0	39.8	28.9	32.87	3.24	81	78.0	37.3	48	124	38.5	85	T		121	121	61	51	121	121	45
96	S10	10/31/2007	M	183	89	2.10	E	T45	0.50	0.12	0.032	331	158	1.16	40.8	40.6	30.1	33.95	3.55	63	75.0	37.3	36	131	38.4	50	T		46	31	30	31	36	40	26
97	S12	1/1/2008	M	180	105	2.24	A	T30	0.50	0.12	0.013	480	214	1.03	53.2	52.5	40.1	44.52	6.53	97	120.0	37.3	20	149	38.5	29	T		15	11	15	17	12	13	12
98	S12	12/23/2007	M	180	105	2.24	E	T60	0.50	0.12	0.032	425	190	1.03	38.8	38.4	28.5	32.17	3.20	83	85.0	37.3	55	147	38.5	68	T		48	34	32	32	31	44	23
99	S13	2/13/2008	M	180	104	2.23	A	T120	0.50	0.12	0.013	364	163	1.03	43.3	43.1	33.1	36.8	4.37	126	115.0	37.3	55	167	38.1	57	H		74	46	36	41	40	63	26
100	S1	3/13/2007	M	180	98	2.17	D	T30	0.50	0.12	0.018	409	188	1.07	49.5	49.2	37.0	41.36	5.43	91.0	96.0	37.4	24	138	38.5	33	T		18	13	18	19	15	17	15
101	S2	3/1/2007	F	154	52	1.47	D	T60	0.50	0.12	0.018	272	185	1.43	42.9	42.5	31.0	35.15	3.69	100.0	101.0	37.4	27	133	38.3	39	T		49	19	26	27	121	39	47
102	S2	3/12/2007	F	154	52	1.47	D	T45	0.50	0.12	0.018	342	233	1.43	45.1	44.7	32.7	37	4.11	101.0	109.0	37.4	26	145	38.5	37	T		21	13	18	18	40	18	25
103	S3	3/19/2007	F	160	50	1.50	D	T60	0.50	0.12	0.018	293	195	1.48	42.7	42.4	31.2	35.26	3.77	93	102.0	37.4	35	151	38.6	45	T		35	16	23	24	121	28	39

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
1	Subject	Date	Gender	Height	Weight	BSA	Ens Code	Exp Code	Vair	Ir	Re,T,a	M	MSA	Vwalk	Tdb	Tg	Tpwb	WBGT	Pv	HR@0	HR@5	Tre@0	Time @38.0	HR@S	Tre@S	Time @S	Reason	Note	PHS Std	PHS Std Tre@0	PHS Std 9920	PHS Std Ir ReTa	PHS Std Fixed Ht Wt	PHS Std at Tre=37	PHS Std 9920 Fixed Ht Wt
2	S7	9/19/2007	M	182	107	2.28	A	T30	0.50	0.12	0.013	398	175	1.03	53.5	52.2	39.3	43.87	6.15	103	105.0	36.2	37	143	38.1	40	F		16	20	16	18	13	14	13
3	S1	3/6/2007	M	180	98	2.17	E	T45	0.50	0.12	0.032	432	199	1.07	40.4	40.2	29.2	33.2	3.30	76.0	85.0	36.4	40	134	38.5	51	T		38	43	27	28	28	33	21
4	S3	3/1/2007	F	160	50	1.50	A	T120	0.50	0.12	0.013	297	198	1.48	43.7	43.3	30.6	35.11	3.51	98	95.0	36.4	59	168	38.5	75	H	T,H	33	39	25	30	121	30	59
5	S6	4/29/2007	M	188	79	2.05	E	T60	0.50	0.12	0.032	379	185	1.07	38.4	38.2	28.1	31.83	3.11	96	105.0	36.5	45	167	37.9	45	H		48	52	29	28	43	43	27
6	S6	4/30/2007	M	188	79	2.05	A	T60	0.50	0.12	0.013	358	175	1.07	46.0	45.0	32.5	36.95	3.98	111	112.0	36.6	55	166	38.0	55	H		59	63	29	36	48	47	28
7	S9	7/23/2007	F	157	55	1.55	A	T120	0.50	0.12	0.013	271	175	1.21	43.4	43.3	31.5	35.74	3.82	113	125.0	36.6	43	155	38.3	66	T		77	80	31	38	121	63	57
8	S1	3/19/2007	M	180	98	2.17	A	T120	0.50	0.12	0.013	447	206	1.07	43.4	43.1	32.3	36.24	4.09	88.0	87.0	36.7	44	129	38.5	73	T		86	86	31	35	44	81	24
9	S1	3/27/2007	M	180	98	2.17	A	T45	0.50	0.12	0.013	433	200	1.25	48.0	47.8	34.9	39.47	4.71	87.0	91.0	36.7	37	143	38.4	47	T		30	31	22	25	22	26	18
10	S1	3/7/2007	M	180	98	2.17	D	T90	0.50	0.12	0.018	371	171	1.07	40.7	40.2	28.9	32.99	3.19	81.0	82.0	36.7	60	114	38.5	104	T		121	121	68	60	121	121	43
11	S2	3/15/2007	F	154	52	1.47	E	T120	0.50	0.12	0.032	305	207	1.43	35.1	34.9	25.8	29.23	2.70	96	96.0	36.7	60	130	38.5	101	T		121	121	32	27	121	121	66
12	S1	4/5/2007	M	180	98	2.17	D	T120	0.50	0.12	0.018	411	189	1.07	39.5	39.3	28.8	32.65	3.24	87.0	90.0	36.8	115	126	37.9	120	P		121	121	55	49	121	121	38
13	S1	3/14/2007	M	180	98	2.17	E	T120	0.50	0.12	0.032	395	182	1.07	35.1	35.0	25.3	28.91	2.57	82.0	86.0	36.8	55	121	38.5	77	T		121	121	49	44	112	121	35
14	S2	3/5/2007	F	154	52	1.47	D	T30	0.50	0.12	0.018	301	205	1.43	49.9	49.3	35.4	40.27	4.77	75.0	103.0	36.8	30	144	38.5	38	T		16	16	15	17	22	14	19
15	S3	3/20/2007	F	160	50	1.50	A	T45	0.50	0.12	0.013	266	177	1.48	47.9	47.7	34.6	39.23	4.61	106	113.0	36.8	29	167	38.5	35	H	T,H	20	20	18	21	34	17	25
16	S3	3/15/2007	F	160	50	1.50	A	T30	0.50	0.12	0.013	317	211	1.48	53.1	52.4	38.8	43.58	5.96	96	114.0	36.8	19	164	38.3	23	H		11	11	11	13	13	10	14
17	S4	6/21/2007	M	175	91	2.06	E	T90	0.50	0.12	0.032	330	160	1.12	36.4	36.2	27.2	30.6	2.99	86	85.0	36.8	55	128	38.4	72	T		121	121	48	44	121	121	38
18	S9	8/22/2007	F	157	55	1.55	A	T45	0.50	0.12	0.013	310	200	1.34	48.1	47.5	34.9	39.38	4.70	114	125.0	36.8	34	169	38.3	38	H		19	19	17	20	26	17	22
19	S9	8/27/2007	F	157	55	1.55	D	T45	0.50	0.12	0.018	262	169	1.34	46.0	45.0	32.6	37.02	4.02	104	112.0	36.8	38	169	38.3	43	H		32	32	23	25	72	26	32
20	S1	4/12/2007	M	180	98	2.17	A	T60	0.50	0.12	0.013	445	205	1.07	46.0	45.4	34.1	38.19	4.55	86.0	88.0	36.9	44	146	38.5	57	T		33	31	24	27	24	29	19
21	S1	3/28/2007	M	180	98	2.17	D	T90	0.50	0.12	0.018	443	204	1.07	40.6	40.5	30.0	33.85	3.53	94.0	93.0	36.9	47	130	38.4	68	T		121	121	38	36	67	121	27
22	S1	3/5/2007	M	180	98	2.17	E	T60	0.50	0.12	0.032	409	188	1.07	38.5	38.1	27.4	31.31	2.90	83.0	87.0	36.9	43	131	38.6	57	T		63	62	34	34	41	60	26
23	S1	2/26/2007	M	180	98	2.17	E	T30	0.50	0.12	0.032	384	177	1.07	46.0	45.4	31.6	36.44	3.68	79.0	86.0	36.9	33	128	38.5	42	T		28	26	23	25	22	25	19
24	S2	3/7/2007	F	154	52	1.47	A	T120	0.50	0.12	0.130	309	210	1.43	43.1	42.8	31.5	35.59	3.84	97.0	94.0	36.9	47	126	38.5	68	T		35	33	24	16	121	29	43
25	S2	3/18/2007	F	154	52	1.47	D	T90	0.50	0.12	0.018	306	208	1.43	40.6	40.4	29.8	33.68	3.47	82.0	97.0	36.9	60	128	38.0	120	P		57	56	27	27	121	56	58
26	S2	3/20/2007	F	154	52	1.47	E	T30	0.50	0.12	0.032	321	218	1.43	44.7	44.6	34.4	38.16	4.75	107	115.0	36.9	26	150	38.5	33	T		16	15	15	16	21	14	19
27	S3	2/27/2007	F	160	50	1.50	E	T120	0.50	0.12	0.032	264	176	1.48	35.3	34.5	25.5	28.9	2.61	91	106.0	36.9	59	164	38.2	65	H		121	121	46	35	121	121	121
28	S3	3/4/2007	F	160	50	1.50	E	T45	0.50	0.12	0.032	281	187	1.48	40.6	39.4	28.5	32.47	3.08	91	98.0	36.9	36	165	38.1	39	H		40	37	23	23	121	33	37
29	S6	5/6/2007	M	188	79	2.05	A	T90	0.50	0.12	0.013	433	211	1.07	44.1	44.0	33.5	37.35	4.46	110	113.0	36.9	16	166	38.3	22	T		32	30	22	24	29	28	21
30	S6	5/2/2007	M	188	79	2.05	D	T45	0.50	0.12	0.018	346	169	1.07	44.8	45.0	33.6	37.72	4.45	97	108.0	36.9	14	159	38.4	26	T		30	28	23	25	28	26	22
31	S7	8/28/2007	M	182	107	2.28	A	T90	0.50	0.12	0.013	379	166	1.03	44.2	44.2	32.7	36.85	4.17	89	91.0	36.9	65	120	38.4	90	T		94	88	37	45	41	80	26
32	S9	7/30/2007	F	157	55	1.55	E	T120	0.50	0.12	0.032	302	195	1.34	35.0	35.0	26.0	29.4	2.76	109	104.0	36.9	65	169	38.0	66	H		121	121	35	30	121	121	63
33	S9	8/23/2007	F	157	55	1.55	E	T90	0.50	0.12	0.032	277	179	1.34	36.5	35.9	27.5	30.72	3.07	100	113.0	36.9	48	169	38.0	58	H		121	121	33	30	121	121	55
34	S11	10/16/2007	F	170	107	2.16	D	T60	0.50	0.12	0.018	383	177	0.85	42.6	42.3	32.7	36.28	4.28	112	112.0	36.9	53	155	38.1	58	F		40	38	31	34	28	36	23
35	S11	10/17/2007	F	170	107	2.16	D	T45	0.50	0.12	0.018	376	174	0.85	43.8	43.3	34.0	37.49	4.66	100	100.0	36.9	55	144	37.9	55	F		32	30	27	29	23	28	20
36	S11	11/1/2007	F	170	107	2.16	E	T60	0.50	0.12	0.032	355	164	0.85	38.5	38.3	24.2	29.13	2.06	98	101.0	36.9	60	167	38.1	64	H		121	121	53	57	67	121	35
37	S7	9/18/2007	M	182	107	2.28	E	T60	0.50	0.12	0.032	410	180	1.03	38.6	38.0	28.0	31.7	3.07	91	94.0	36.9	57	118	38.4	76	T		60	59	36	36	36	56	25
38	S1	3/25/2007	M	180	98	2.17	A	T60	0.50	0.12	0.013	448	206	1.07	46.5	45.9	34.3	38.445	4.59	88.0	88.0	36.9	46	113	38.4	60	F		31	29	23	26	23	28	19
39	S1	3/8/2007	M	180	98	2.17	A	T45	0.50	0.12	0.013	426	196	1.07	47.8	47.6	33.9	38.71	4.36	98.0	91.0	37.0	33	142	38.5	44	T		36	31	25	29	25	31	20
40	S1	3/1/2007	M	180	98	2.17	D	T60	0.50	0.12	0.018	416	192	1.07	42.7	42.5	31.0	35.15	3.71	96.0	88.0	37.0	39	122	38.5	53	T		91	87	34	34	47	87	25
41	S1	4/3/2007	M	180	98	2.17	E	T90	0.50	0.12	0.032	407	188	1.07	36.1	36.0	26.9	30.33	2.93	86.0	83.0	37.0	51	135	38.4	70	T		86	84	39	36	49	84	29
42	S2	2/28/2007	F	154	52	1.47	A	T30	0.50	0.12	0.013	321	218	1.43	53.2	52.9	40.8	45.13	6.86	86.0	116.0	37.0	16	150	38.5	22	T		11	10	11	13	13	10	14
43	S2	3/11/2007	F	154	52	1.47	E	T45	0.50	0.12	0.032	288	196	1.43	40.7	40.5	30.0	33.85	3.52	94	92.0	37.0	40	138	38.5	49	T		28	24	21	21	65	24	30
44	S7	9/12/2007	M	182	107	2.27	A	T60	0.50	0.12	0.013	429	189	1.03	46.3	46.0	33.0	37.6	4.14	94	99.0	37.0	72	121	38.4	90	T		59	50	31	36	30	50	22
45	S9	7/24/2007	F	157	55	1.55	E	T60	0.50	0.12	0.032	291	188	1.34	38.5	38.3	28.2	31.93	3.13	100	120.0	37.0	47	150	38.4	63	T		49	42	26	25	121	42	39
46	S10	10/11/2007	M	183	89	2.37	A	T90	0.50	0.12	0.013	370	156	1.16	44.0	43.8	33.1	37.01	4.33	80	84.0	37.0	50	116	38.4	65	T		62	52	30	34	43	52	25
47	S10	11/5/2007	M	183	89	2.10	D	T90	0.50	0.12	0.018	371	177	1.16	40.9	40.6	30.4	34.16	3.64	81	78.0	37.0	60	117	38.2	120	P		121	121	42	40	121	121	33
48	S11	10/29/2007	F	170	107	2.16	E	T90	0.50	0.12	0.032	346	160	0.85	36.5	36.1	22.8	27.49	1.86	104	108.0	37.0	70	167	38.0	79	H		121	121	75	76	121	121	46
49	S1	2/28/2007	M	180	98	2.17	A	T90	0.50	0.12	0.013	424	195	1.07	44.1	44.1	33.2	37.17	4.35	85.0	80.0	37.1	44	120	38.5	63	T		51	40	28	32	32	44	22
50	S2	3/25/2007	F	154	52	1.47	E	T90	0.50	0.12	0.032	292	199	1.43	36.1	36.0	26.7	30.19	2.87	78	94.0	37.1	54	130	38.5	93	T		121	121	30	27	121	121	57
51	S3	3/13/2007	F	160	50	1.50	D	T90	0.50	0.12	0.018	291	194	1.48	40.2	40.0	29.3	33.175	3.34	93	96.0	37.1	45	150	38.9	120	P		121	121	31	30	121	121	93
52	S4	6/25/2007	M	175	91	2.06	A	T60	0.50	0.12	0.013	355	172	1.12	46.4	46.5	34.4	38.73	4.63	97	102.0	37.1	38	140	38.5	50	T		34	27	25	29	27	29	21

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Ronald E. Long was born in Concord, North Carolina and earned an A.S. Degree in Radiologic Technology from George Washington University; a B.S. Degree in Health Studies from Charter Oak College; and a M.S. Degree in Occupational Health and Safety from National University. He was an Adjunct Instructor at George Washington University from 1987-1989. He retired from the United States Navy after 28 years as a Lieutenant Commander in the Medical Service Corps in 2001, serving as a Radiation Specialist. During his tour of duty in the military, he has served as a special lecturer in Radiological Physics and Radiation Safety for Radiology, Orthopedics, Cardiology, and Family Practice Graduate Medical Education programs at Naval Hospitals San Diego, California; Jacksonville, Florida; and Pensacola, Florida. He was awarded the Meritorious Service Medal, four Navy and Marine Corps Commendation Medals, and 4 Navy and Marine Corps Achievement Medals while in the United States Navy. From 1981-1983 LCDR Long completed 5 deterrent war patrols while assigned to a nuclear fleet ballistic missile submarine. He is a Licensed Radiological Physicist in the State of Florida.