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Validation of the USF Safe Exposure Time Equation for Heat Stress

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by

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Table of Contents

List of Tables

List of Figures

Abstract

Heat stress conditions are prevalent in the working environment around the world. Often they are not readily engineered out. Administrative controls and, in extreme/toxic environments, personal protective gear are the means available to protect workers. For every combination of metabolic work rate, clothing ensemble and environmental WBGT, there is a time of exposure threshold, beyond which the worker can no longer compensate for the heat stress, and signs and symptoms of heat strain appear. Increasingly, worker environments require specialty clothing either for worker protection or to maintain a clean/sanitary environment. Prior to the publication of the USF safe exposure time equation, no simple method was available for determining safe worker exposure time based on a clothing adjustment factor. To demonstrate the validity of the USF SET equation, both direct and indirect data from different environments, metabolic rates, and clothing ensembles were collected to compare observed tolerance times to the predicted safe exposure time. Statistical analysis was performed using the Kolmogorov-Smirnov test. The USF SET equation predicted an acceptable safe exposure time, 19 % of the trials. Based upon this data, the USF safe exposure time heat stress equation over estimates safe exposure time for workers in hot environments, in various clothing ensembles at various metabolic work rates.

Introduction

Heat related injury occurs when the body is unable to maintain homeostasis between heat gain and heat loss from the body. The physiological response to environmental heat stress, which occurs beyond homeostasis, is termed heat strain. Heat strain manifests in progressive symptoms displayed by the worker beginning with fatigue, elevated heart rate, thirst, and headache progressing to mental status change and cessation of sweating and finally, loss of consciousness and death. Unacclimatized workers will display heat strain signs and symptoms quicker than acclimatized workers.

Even mild heat strain can affect worker performance. NASA research data showed that telegraph key operators made five mistakes an hour, nineteen after three hours when the temperature was just 80 °F (26.7 °C). At 95 °F (35 °C), mistakes increased to 60 per hour, 138 after three hours. Dehydration further exacerbates heat strain. Wasterlund and Chaseling showed that dehydration equaling a 1 percent body weight loss of fluid correlated to a 12 percent decrease in productivity in forestry workers. Gopinthan, et al demonstrated that a 2 percent body weight equivalent dehydration correlated to declines in visual motor tracking, short-term memory, attention and arithmetic efficiency. A 4 percent equivalent body loss dehydration correlated to a 23 percent decline in reaction time. When the environmental temperature reaches 95 °F (35 °C) or more, the only way the body can cool itself is via the transfer of core heat to the skin surfaces via blood and the subsequent evaporation of sweat. When the body is dehydrated, the efficiency of this cooling mechanism is impaired. (1)

The NCAA completed a four-year study finding that the risk of heat stress injury increases five-fold when the WBGT rises above 82 °F (27.8 °C).(2)

The total number of hospitalizations with codes for heat illness among Army soldiers was 5,246 from 1980 through 2002. There were 37 deaths due to heat illness, and the mortality rate was 0.3 per 100,000 soldiers per year during the 22-year period.(3) Environmental Health and Safety Today reported that 2,554 workers missed work in 2000 due to heat related injury.(4)

Wallace found in researching marine training that cumulative heat stress from previous day's exposure is a factor in predicting exertional heat injury for that day beyond just the current WBGT, suggesting that WBGT alone is inadequate for protecting workers/athletes from heat strain. (5)

Military epidemiological research suggests that exertional heat injury may increase long-term mortality from organ failure including kidney, heart and liver. (6).

Heat related death continues to threaten workplace safety, nationwide, especially in the agricultural industry. The CDC reported 423 worker deaths from heat stress between 1992 and 2006 translating to 0.02 deaths/100,000 workers. Farm workers had the highest death rates - 68 deaths translating to 0.39 deaths/100,000 workers and heat related illness.(7) As Figure 1 indicates, heat related deaths are actually increasing among American farm workers.

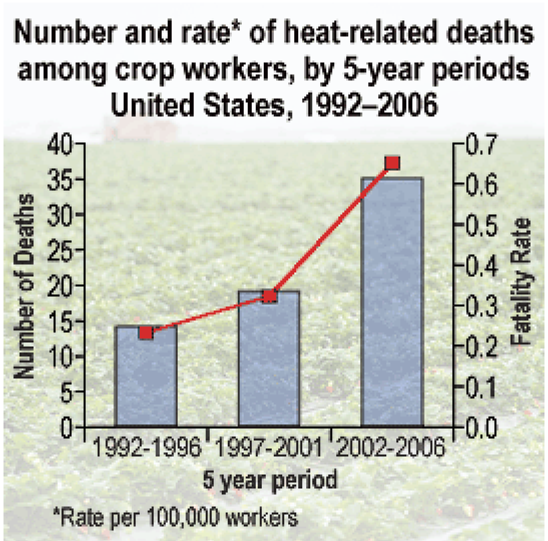

Figure 1: Farm Worker Deaths (7)

Washington state figures put the cost per heat related illness worker's compensation claim at $1,287 looking at claims between 1995 and 2004.(8) In 1973, OSHA organized a Standards Advisory Committee for Heat Stress and heat related illness. Still by 2004, there was no specific OSHA standard for heat stress; therefore, safety officials must rely upon the "general duty clause" of the OSH Act for making decisions about safe working conditions in heat stress conditions.(9) Having a viable method of predicting safe worker performance in a hot working environment gives management a means to determine if and when engineering, administrative or PPE corrections are needed for worker safety.

The problem continues in answering how heat stress can be evaluated. Wet bulb globe temperature (WBGT) is the traditional method used by the industry to set occupational exposure limits (OEL's) that include NIOSH REL, ACGIH TLV and ISO 7243. The problem occurs where working conditions are extreme, e.g. tropical and desert environments, and working any time of the day would exceed the WBGT recommendations. The problem also occurs in working environments where workers must wear special clothing, such as vapor barrier protective HAZMAT suits. These working conditions may not be tolerated for the 8 hours presumed by the usual WBGT-based exposure assessment methods.

Literature Review

Many working conditions present with a combination of environmental conditions, work demands and clothing requirements that will significantly reduce the amount of time a person can work under those conditions. The recognition of this problem has led to the pursuit of alternative assessment schemes that can predict a safe exposure time.

WBGT (wet bulb globe temperature) came out of research in the 1950's by the U.S. Navy because of significant incidences of heat related illness among Marine recruits in training. WBGT was an improvement over looking at only temperature and humidity. It incorporated temperature and humidity along with wind and sun radiation. The military further identified thresholds for WBGT based upon epidemiological studies of casualty records and additionally considered susceptible or vulnerable recruits and determined when training would be suspended or altered to reduce the incidence of heat related illness.(10) The limitations of WBGT become evident as environmental humidity increases, as compensation is needed for wear of special clothing, as individual acclimatization varies, and as the environment becomes extreme and/or the work stress becomes extreme. (11) Also, there is considerable room for variation in arriving at the WBGT depending upon equipment, conditions, operator error and interpretations of values gathered.(10)

One method based on WBGT is an approach used by most industries and formulated by ACGIH. It is a table of WBGT readings corresponding to hourly work and recovery cycles for light, medium, heavy and very heavy work. WBGT has been criticized as being too conservative a method for determining allowable work for workers who must work in extreme environments or heavy work environments such as mining in the tropics. It may indicate they should not be working in these conditions, but the fact of the matter is that they are going to work in these environments (Australia and UAE) so another method of predicting safe exposure time is needed to protect these workers. (12)

Chin Lee reported problems with ISO's WBGT approach as it requires extensive calculations and interpretation not practical for real world working. He contended that there was poor correlation of the ISO's under hot and humid conditions. Lee's studies led him to contend that heat strain indices correlate poorly with heat stress indices at high work levels.(13) Generally, methods of assessment of high heat stress may fall into two categories. Rational methods like the Belding and Hatch Heat Stress Index and the ISO Predicted Heat Strain have been used to set a prescribed work time. Alternatively, empirically based methods have also received attention.

Rational Methods

The most current rational model of heat stress analysis is ISO7933: Ergonomics of the thermal environment -- Analytical determination and interpretation of heat stress using calculation of the predicted heat strain (PHS).(14) Under circumstances in which the body cannot maintain sufficient levels of heat loss, a safe exposure time is based on the time to reach a predicted body core temperature of 38 °C. For longer exposures where there is a risk of dehydration, the ISO standard also provides a time limit. This model has been validated and most body core temperatures will be below 38.5 °C.(15)

An alternative method is TWL, thermal work limit, developed in Australia and elaborated upon by Graham Bates at Curtin University, Perth, Australia in his Ph.D. dissertation in 2002. (16). This equation evolved out of the need for the industry to develop a "standard" for heat stress in the workplace that was better fitted to the extreme work environments of the Australian mining industry and the UAE construction industry. Brake and colleagues recognized that under high heat stress conditions, people reduce their work demands to maintain thermal equilibrium. Brake monitored heat stress responses in mine workers in Australia and subsequently developed the Thermal Work Limit (TWL) as an index of thermal stress, which is fundamentally a rational model but interesting in the work-limiting thought process.(16) The result of the analysis is an average rate of work that can be sustained. It has been used in the extreme conditions encountered by miners in Australia and construction workers in the United Arab Emirates. Miller and Bates stated, "TWL was a more appropriate and realistic index than WBGT, which was found to be excessively conservative."(17) As evaluated, workers wore standard cotton work clothing.

Empirical Methods

The occupational exposure limits based on WBGT are empirical limits to heat stress that assume that the exposures will be repeated throughout an 8-hour day. Developing work/rest cycles that limit the overall time-weighted average to the exposure limit is a method of setting an exposure time limit. These methods are straightforward but potentially over-protective. For this reason, alternative empirical methods have been explored.

An early, lab based research approach for determining "safe exposure of men to severe heat" was developed by Bell, et al. in the mid-1960's. This method resulted in a rectangular hyperbolic curve with $y=b+c/x-a$ with $x=p(db) + (1-p)(wb)$; y is tolerance time; a, b, and c are constants and x the weighted sum of the wet- and dry-bulb temperatures. It was developed by studying test subjects in the lab under heat conditions and work until an observer determined that heat strain collapse was imminent and the trial was ended and data recorded. A safety factor was taken using the 95th percentile confidence limit.(18) The corresponding hyperbolic curves predict maximum tolerance time under various wet and dry bulb conditions for workers with primary activities of sitting, standing or working. Bell's equations were based on standard work clothes. The maximum worker tolerance was defined as near complete collapse. Bell claimed his equation allowed for a margin of safety based on individual differences. This claim is belied by a table in his paper that showed the predicted time was often greater than the mean observed tolerance time. Further, collapse as a criterion was too aggressive to be used for occupational exposures. The small range of activities and aggressive criterion eliminated consideration of Bell's approach to setting exposure limits.

The US Navy has many locations for which the environmental conditions would limit the amount of work time. For this reason, Dasler developed empirical limits called physiological heat exposure limits (PHELs).(19) The environmental conditions were represented by WBGT and there were six separate curves for light to moderate metabolic rates. The clothing was the utilities uniform. The time limits were based on a body core temperature reaching 39 °C. Other than a higher body core temperature than is usually considered as a target for occupational exposures, the PHEL charts have been useful for setting acceptable work times for up to six hours. It is interesting to note that the six hour limits were lower than the commonly accepted WBGT limits for eight hours at the same metabolic rates.

Bernard and Ashley (2009) developed the USF safe exposure time equation with the intent of using WBGT as the environmental index and the well-established Clothing Adjustment Factors (CAFs). This equation includes WBGT adjusted for metabolic work rate and CAF. It does assume short sustained exposures of 120 minutes or less.(20) The following is their formulation of a safe exposure time (SET).

$$\text{SET [min]} = 26000/(\text{AdjWBGT}[^{o}\text{C-WBGT}] - \text{TLV})^{3} + 10$$

$$= 26000/(\text{WBGT}_{\text{measured}} + \text{CAF} - 0.02(365 - \text{M[W]}) - (56.7\text{-}11.5\log_{10}\text{M}))^{3} + 10$$

The purpose of this effort is to validate the USF safe exposure time (SET) model with independent data.

Methods

In order to validate the USF SET equation independent data are needed. The validation process can be done in two ways: collecting direct data from relevant laboratory or field trials and collecting indirect data inferred from the literature. Both types of data were collected and used in this validation process.

Direct Data

For the direct data source, individual tolerance times were taken from trials performed at USF for DuPont under DOD contract and for MSA and Scott Paper Company. In addition, there were two trials performed at NASA. These data were not published, but were available in the study records. The direct data provided assessment opportunities using different clothing ensembles in different heat stress environments. These data are summarized by study and clothing ensemble in Table 1. The summary data were then used to calculate the predicted safe exposure time using the USF SET equation and also reported in Table 1.

Table 1. Summary of direct data by study, clothing ensemble and environment.

Trial Information	WBGT (°C-WBGT)	CAF (°C-WBGT)	Metabolic Rate (W)	Mean Obs.Time (min)	Predicted SET (min)
DuPont 1					
Control, DI N=25	28.8	3	344	62±12	> 120
Control, DII N=8	23.9	3	338	105.9±16	> 120
Control, J N=8	28.1	3	374	112.8±12	> 120
BaseSPM, DI N=8	28.8	11	353	31.2±4.9	25
BaseSPM, DII N=8	23.9	11	357	55.8±10.5	75
BaseSPM, J N=8	28.1	11	350	96.2±28	28
PropSPM, DI N=8	28.8	3.5	379	33±4	> 120
PropSPM, DII N=8	23.9	3.5	343.7	75.4±26.6	> 120
PropSPM, J N=8	28.1	3.5	360	102±16.5	> 120
DuPont II					
Control, DI N=8	28.8	3	334	61±9	>120
SPMA, DI N=8	28.8	11	333	42.75±9.9	27
SPMB, DI N=8	28.8	3.5	331.5	46.75±4.3	> 120
SPMC, DI N=8	28.8	3.5	338	36	>120
DuPont III					
Control, DI N=8	28.8	3	367	63±15	>120
AB-A, DI N=8	28.8	3.5	351	47±6	>120
AB-A, J N=4	28.8	3.5	323	78±24	>120
AB-B, DI N=8	28.8	3.5	350	45±8	>120
MSA Phase I					
Vapor Barrier N=5	32	11	271±71	31±8	24
MSA Phase 2					
Vapor Barrier, N=5	32	11	276±62	31±12	23
Scott Study					
ComfortGard I N=5	32	-1	254±39	80±28	>120
ComfortGard II N=5	32	4	262±56	72±17	>120
ComfortGard III N=2	32	4	262±25	72±5	>120
Tyvek 1422A N=5	32	2	275±70	50±12	>120
NASA					
NASA Vapor Barrier N=2	37.05	11	300	44	14

General Description of USF Studies

The combinations of clothing and heat stress level were assigned to participants in random order; the schedule for each participant was random as well. Participants were monitored for rectal temperature and heart rate while walking on a Burdick T500 treadmill between 2.5 and 3.0 mph with no grade at about 190 W/m^2. Metabolic rate was calculated from oxygen consumption, sampled at approximately 30-minute intervals. Trial termination criteria were when 1) rectal temperature reached 38.5 °C, 2) maximum age-predicted heart rate (0.85*[220-Age]) was reached, 3) participant asked to stop, or 4) participant accomplished 120 minutes on the treadmill without reaching any of the other termination criteria.

DuPont Studies

All the DuPont/DOD studies were similar in that they examined potential chemical protective ensembles (sometimes known as MOPP gear). The studies used similar environments and metabolic rates but differed in the clothing. Three environments, distinguished by the relative humidity with no radiant heat source, were selected for the study. The environmental conditions were:

- Jungle: 35 °C at 50% relative humidity (Vp = 2.81 kPa)
- Desert I: 49 °C at 20% relative humidity (Vp = 2.35 kPa)
- Desert II: 40 °C at 30% relative humidity (Vp = 2.21 kPa)

DuPont 1

In the first study the following three clothing ensembles and three environments (Jungle, Desert I and Desert II) were examined in a full factorial design with eight participants.

The primary ensembles based on fabric were:

- Control: The current standard (Saratoga Hammer) ensemble
- Base SPM Fabric
- Proprietary SPM Fabric

The summary information including tolerance times is reported in Table 1.

DuPont 2

In the second DuPont study the following four clothing ensembles and one environment (Desert I) were examined in a full factorial design with eight participants.

The primary ensembles based on fabric were:

- Control: The current standard (Saratoga Hammer) ensemble
- SPM-A
- SPM-B
- SPM-C

The order of the ensembles was balanced to minimize the effects of order. A cotton tee-shirt and gym shorts were worn under the clothing as the base ensemble.

The summary information including tolerance times is reported in Table 1.

DuPont 3

In the third DuPont study the following five clothing ensembles and one environment (Desert I) were examined in a full factorial design with eight participants. In addition a sub-study with one ensemble (AB-A) in the Jungle environment was examined with four participants.

The primary ensembles based on fabric were:

- Control: The current standard (Saratoga Hammer) ensemble
- AB-A (Internal Control using standard SPM)
- AB-B (No porosity)
- AB-C (Porosity 1)
- AB-D (Porosity 2)

The order of the ensembles was balanced to minimize the effects of order. A cotton tee-shirt and gym shorts were worn under the clothing as the base ensemble.

The summary information including tolerance times is reported in Table 1.

Mine Safety Appliances Company (MSA)

The MSA studies were performed in two phases to test different cooling systems against a no-cooling control. The no-cooling control was a vapor-barrier ensemble with hood and respirator. The environment for both phases was representative of the Gulf Coast in the summer time with T_{db} = 35 °C and rh = 55% (WBGT = 32 °C-WBGT)

The summary information including tolerance times is reported in Table 1.

Scott Paper Company

The Scott Paper Company studies, conducted with three clothing ensembles in one environment (Gulf Coast) were examined in a full factorial design with five participants with a sub-study for one clothing ensemble (Tyvek).

The primary ensembles based upon fabric were:

Comfort-Gard I

Comfort-Gard II

Comfort-Gard III

The order of the ensembles was balanced to minimize the effects of order. A cotton tee-shirt and gym shorts were worn under the clothing as the base ensemble.

The summary information including tolerance times is reported in Table 1.

NASA Trials

Two individual trials at NASA were observed. Termination criteria for the NASA trial was 38.9 °C so work times were standardized to 38.5 °C core body temperature using a factor of 0.8.(21) The correction factor of 0.8 was calculated by taking 38.5 minus 36.8 divided by 39.0 minus 36.8 yielding 0.773 rounded to 0.8.

The summary information for the two NASA trials including tolerance times is reported in Table 1.

Indirect Data

The indirect data was taken from data reported in studies providing clothing description, metabolic work rate, WBGT, observed working times and trial termination criteria that could be standardized to 38.5 °C core body temperature. Mean values were either given or calculated for each study and a 5th percentile time was calculated that was 95 percent protective. The descriptive data from the reported studies are provided in Table 2. The assigned data were then used to calculate the predicted safe exposure time using the USF SET equation and reported in Table 2.

Table 2: Derived literature Data

Study	WBGT	CAF	Work(W)	Obs. Work time	Ave. Time Std	Protective Work Time	Predicted SET
Zhang N=10	30	0	465	74±26	50	24	132
Bishop N=14	26	11	430	135±11.9	95	55	233
Bell 1	37.4	0	325	55.1±9.8	45	31	48
Bell 2	40.9	0	325	31.4±5.3	22	15.4	24
Bell 3	43.9	0	325	19.6±2.1	14	12	17
Bell 4	46.9	0	325	15.2±2.1	9	7	14
Bell 5	51.8	0	325	9.9±2.2	9	5.4	12
Muir 1	18	11	450	109.2±19.6	98	70	293
Muir 2	23	11	450	62.3±7.7	56	51	40
Muir 3	28	11	450	42.5±6.1	39	34	19
Hostler	18.45	11	355	45	41	17	121

Zhang, et al.

Zhang, et al. conducted a trial with 10 individuals to test the effectiveness of a carbon dioxide cooling device imbedded in the work clothing.(22) He conducted a non-cooling control trial, which was the trial of interest. Extracting the data from Zhang's graph of rectal temperature and exposure time, 38.5 °C corresponded to 50 minutes exposure time at 465 W of metabolic work in cotton shirts and pants. The CAF was taken to be 0. Adjusting the exposure time plot by 1.65 Z-score correlating to the 95% safety factor equated to 24 minutes as the safe exposure time.

Bishop, Nunneley and Constable

Bishop, Nunneley and Constable conducted a trial with 14 individuals to test the effectiveness of intermittent cooling in emergency response workers wearing chemical protective clothing.(23) The non-cooling control trial data was used in this study. Extrapolating from non-cooling graph data by determining the standard deviation of the data times the 1.65 Z-score corresponding to the 9th percentile protective factor gives us 55 minutes of exposure time corresponding to 38.5 °C core temperature termination criteria. Trial conditions included WBGT of 26 °C, metabolic work rate of 430 W and a clothing factor of 4.

Bell et al.

Bell, et al. conducted a trial with eight men in various different environments and metabolic work rates from sitting, standing and working.(18) Data was taken only from the working trials with WBGT's of 37.4 to 51.8 °C at a working metabolic rate of 325 W and a clothing adjustment factor of 0 for cotton boiler suites. Since Bell used oral temperatures, 0.5 °C was added to approximate the body core temperatures. For each trial, a time adjustment factor was done to standardize the calculated core body temperatures to 38.5^{o}C as the termination point for the trials. This was needed as Bell continued the trials almost to the point of participant collapse. Standardization was done by taking 38.5-36.5 divided by the calculated core body temperature for the trial minus 36.8. For the 37.4 WBGT trial this equated to 38.5 – 36.5 divided by 38.9 -36.5 which equaled 0.8. Bell's average time for this trial was 55 minutes which; multiplied by 0.8 equaled 45 minutes, average. Taking the standard deviation of 9.8 for this trial multiplied times 1.65 equaled 16; subtracted from 55 gives 39, multiplied by the temperature standardization factor of 0.8 gave 31 minutes protected time. Each trial was adjusted/standardized accordingly to arrive at both the average times worked until core body temperatures reached 38.5 °C and the safe work times to the 95th percentile.

Muir, Bishop, and Ray

Muir, Bishop and Ray conducted a trial with 6 male participants to test a new ice cooling system for impermeable protective clothing having a clothing adjustment factor of 11.(24) Data from the control trial was extracted for 18 °, 23 °, and 28 °C WBGT at a metabolic work rate of 450 W. Rectal temperatures were recorded and were adjusted from Muir's threshold of 38.7 to 38.5 in like manner as the data from Bell.

Hostler, et al.

Hostler, et al. conducted a study with ten male participants varying participant hydration status using a control and a test with hyperhydration via intravenous fluid replacement.(25) The control data was used from this study. The clothing adjustment factor was 11 for the chemical-resistant enclosed clothing ensemble and air-purifying respirator. Exposure times were adjusted to reflect standardized maximum heart rates giving an adjustment factor of 0.9; multiplied times the average exposure time of 45 minutes gave 41 minutes average exposure time for the trial. Taking the standard deviation and adjusting it to the 95th percentile safety factor gave 17 minutes of protected exposure time.

Combined Data Analysis

Tables 1 and 2 summarized the representative data points for WBGT, clothing adjustment factor, and metabolic work rate. These values were then used for the USF SET equation to predict a safe exposure time. If the computed time was greater than 120 minutes, the predicted time was set to 121 minutes. In comparing the predicted to observed time, if the observed time was less than or equal to the predicted time the outcome of the decision was “OK”. For an observed value less than the predicted, the decision was “NOT”. Data were analyzed using the Kolmogorov-Smirnov test.

Results

The purpose of this study was to validate the USF Safe Exposure Time (SET) equation using direct data from DuPont, MSA, Scott Paper and NASA studies and indirect data from the literature.

Figure 2 displays the relationship between the predicted and observed time for the direct data. An identity line was provided in the figure for a reference point such that data to the right and below the line represent protective ("OK") decisions. Of all the observations, 30 of 160 or 19% of direct data points fell below the line, in contrast to 120 or 81% of direct data points above the line.

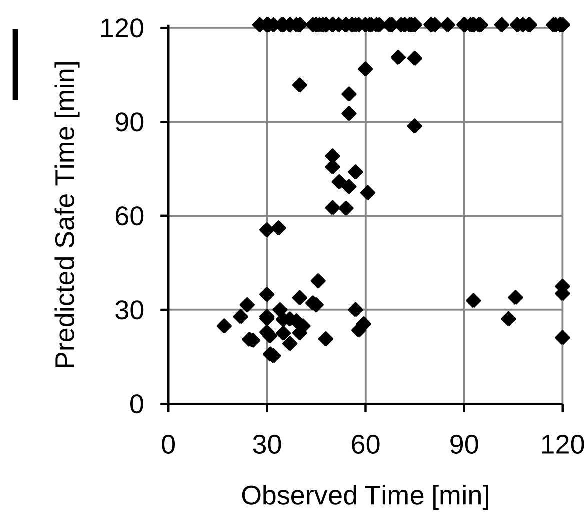

Figure 2. Comparison of observed to predicted time for the direct data. Observations to the right of the identity line are protective predictions.

In a similar fashion, Figure 3 represents the comparison between predicted and observed for the indirect data. Though several points are near or below the line, adding the 5th percentile safety factor places 9/11 data points above the line. The two points below the line correspond to a CAF of 11.

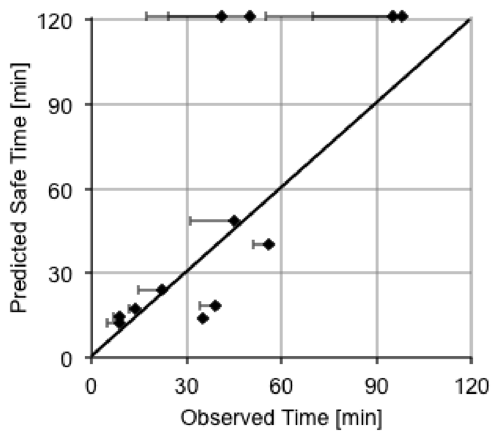

Figure 3. Comparison of observed to predicted time for the indirect data (mean with whisker for 5th percentile). Observations to the right of the identity line are protective predictions.

Discussion

Though there exists several methods for determining worker exposure under conditions of heat stress, none is universally accepted for extreme conditions. The USF SET equation was an attempt to consider environmental conditions through the widely accepted WBGT, the work demands through metabolic rate, and clothing effects through the Clothing Adjustment Factor (CAF). While the equation was based on extensive data over five levels of heat stress and three clothing ensembles, the work demands were limited to a narrow range around 380 W. The method was not validated against other data. That was the purpose of the current study.

It was clear from Figures 1 and 2 that there were extensive under predictions of a safe exposure time compared to the observed times. That is, direct data collected in the same laboratory over a 10-year period with different participants produced much different results. This was further supported by the indirect data gathered from reports in the literature. While there might be errors in how the data were extracted and interpreted from the literature, the overall pattern was similar. Using 171 individual trial data points from both the direct and indirect data, 32 of 171 times the USF SET equation predicted a safe exposure time that was less than either the actual observed tolerance time of the worker in the trial or the protective time attributed to the trial, or about 19% of the time.

The USF SET equation was based on metabolic rates near 380 W. The average metabolic rate for the direct data was 335 W and it was 377 W for the indirect data. Given the overall closeness of the average metabolic rates among the SET, direct and indirect data, metabolic rate might have been a contributor through wider variations from the mean. There was some indication that the further the lower the metabolic rate, the greater the loss of protection. This suggested that the SET equation is too sensitive to changes in metabolic rate from 380 W.

Looking at high CAF clothing, 20 of the 30 points falling below the line corresponded to a CAF of 11 °C-WBGT. It was interesting to note that the ensembles assigned a CAF of 11 °C-WBGT were the same or similar to the vapor-barrier ensemble used in the USF SET study, but the design of the study used a much lower CAF (6.5 °C-WBGT) knowing that the value of 11 °C-WBGT would be protective. The reason for the difference was due to the sensitivity of vapor-barrier clothing to the prevailing water vapor pressure. This observation about the differences between observed and predicted would suggest that the USF SET does not handle the clothing differences very well and that much higher values are required to obtain necessary protection.

Thus far, the USF SET over estimates safe exposure time in heat stress conditions and for this reason, its use should be limited and double checked against another form of assigning safe exposure time. Additional research is needed to determine what changes or adjustments to the USF safe exposure time equation will produce protective predicted safe exposure times using this equation.

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