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Gender Differences During Heat Strain at Critical WBGT

by

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of the requirements for the degree of
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ABSTRACT

Heat stress is influenced by environmental conditions, workload and clothing. A critical environment is the upper limit of compensable heat stress for a given metabolic rate and clothing ensemble. The physiological strains associated with heat stress are core and skin temperatures, heart rate and Physiological Strain Index (PSI). Because heat dissipation mechanisms may differ between men and women, there may be gender differences in the critical environment and the associated physiological variables. Gender differences were explored between acclimated men (n = 20) and women (n = 9) at the upper limit of compensable heat stress. Participants walked on a motorized treadmill at a target metabolic rate of $160 W/m^2$ while wearing five different clothing ensembles (cotton work clothes, cotton coveralls, and three coveralls of particle barrier, liquid barrier, and vapor barrier properties). The starting air temperature (T_{db}) was 34ºC and humidity was held constant at 50%. Once thermal equilibrium was achieved, T_{db} was increased 1ºC every five minutes until loss of thermal equilibrium or termination criteria were met. Upon initial analysis, several gender differences were found. A significant difference ($p = 0.035$) was found for $WBGT_{crit}$, where values were 32.5ºC for men and 33.1ºC for women. Women had higher average heart rates (HR = 125 and 112 bpm), average skin temperatures (T_{sk} =36.4 and 36.2ºC), and PSI values (4.5 and 3.8) than men. No significant difference was found between genders for core temperature (T_{re}) ($p = 0.147$). The target metabolic rate of 160W/m^2 was not achieved and there were significant differences ($p<0.0001$) between men (172 W/m^2) and women (152 W/m^2). The effect of metabolic rate on $WBGT_{crit}$ was examined and it was discovered that the difference in $WBGT_{crit}$ could be explained by the difference in metabolic rate. The same logic was applied to the physiological responses and confirmed a difference between genders for T_{re}, HR, and PSI. The differences for T_{sk} disappeared. These findings indicate that women experienced a greater cardiovascular strain at the critical condition and also greater heat strain than men at the same heat load.

INTRODUCTION

Heat stress is influenced by work demands, environment, and clothing. To maintain thermal equilibrium, heat gains from the metabolic demands and the environment are balanced by the evaporative heat loss plus any loss due to convection or radiation. The maximum rate of evaporative heat loss is modified by the ability of the clothing to support water vapor transport and by the water vapor in the air. The greater the heat gain the greater the evaporative cooling must be to maintain equilibrium. When the person is able to maintain thermal equilibrium, the heat stress condition is considered compensable. When equilibrium cannot be maintained because the gains exceed the capacity to dissipate the heat, then the heat stress is called uncompensable.

Generally, physiological responses to heat stress include increased heart rate, skin temperatures, sweat rate, and core temperature. Personal factors such as acclimation state, fitness level, and gender affect an individual's response to heat stress. Acclimation to the heat induces physiological adaptations to improve heat tolerance. The adaptations include increased sweat rate, decreased heart rate, and increased plasma volume. Fitness level also improves the response to heat stress as long term aerobic training leads to many of the same adaptations as acclimation. Prior research demonstrates differences in physiological response to heat stress between the genders. These differences appear in studies that do not select men and women based on matching criteria; and they tend to be minimized if participants are acclimated and matched on maximum aerobic capacity.

Occupational exposure limits are based on the level of heat stress at the critical condition, or the transition point between compensable and uncompensable heat stress. Given that there are average differences in physiological responses of men and women toheat stress, it may be reasonable to suspect that critical conditions would be different. If there are no differences in the transition between compensable and uncompensable heat stress for men and women, then there may be a difference in the physiological cost at the upper limit of compensable heat stress. In summary, it is not known if exposure limits to heat stress may be influenced by gender. Further, the physiological cost of working at that limit might be different for men and women.

LITERATURE REVIEW

Heat stress assessment follows traditional industrial hygiene exposure assessment methods such as the Threshold Limit Value (TLV)(1). The exposure assessment is commonly accomplished by setting a wet bulb globe temperature (WBGT) limit based on the work demands and clothing requirements. Heat strain is the collective physiological response to heat stress, and represents the individual cost of the heat stress exposure. The underlying assumption of using heat stress exposure limits is that the heat strain is then managed.

Critical Heat Stress Condition

WBGT-based exposure assessment has its roots in the work of Lind (2) in 1963, when he proposed the Upper Limit of the Prescriptive Zone (ULPZ). Fundamentally, the ULPZ is the critical conditions or the upper bound on compensable heat stress. Lind's ULPZ forms the basis for the NIOSH Recommended Exposure Limit (REL) (3) and the ACGIH TLV for heat stress and strain (1).

Belding and Kamon (4), Kenney, Mikita, Havenith, Puhl, and Crosby (5), and Barker, Kini, and Bernard (6) have developed progressive heat stress exposure protocols that shorten the time needed to identify the critical conditions or the upper bound on compensable heat stress. While not used to set occupational exposure limits, these protocols have been used to examine the effects of humidity, air speed, and clothing on the critical conditions and to explore differences in physiological responses for acclimation, gender and fitness as described later.

Metabolic Rate

Because the level of heat stress and the level of physiological strain depend on the metabolic rate, it is worthwhile mentioning some of the interactions. For any individual in a thermally neutral environment, steady-state core temperature and heart rate increases with the metabolic rate. To make comparisons of core temperature and heart rate among individuals, it is customary to make those comparisons with reference to aerobic capacity. That is, as a first approximation, the core temperature and heart rate is the same across individuals working at the same fraction of their maximum aerobic capacity. Below the critical conditions of heat stress for the individual, the core temperature is not expected to change, and will be that of the thermally neutral conditions. The heart rate is expected to be elevated to accommodate the added blood flow to the skin as the critical condition is approached.

On the other hand, level of heat stress depends on the actual metabolic rate, because it represents the rate of heat generation that must be removed to maintain thermal equilibrium. Because the heat exchange surface is nominally the body surface area, there is a convention to report metabolic rate adjusted to body surface area, or normalized metabolic rate. As the normalized metabolic rate increases, the environmental conditions must be come more favorable to heat loss by evaporation, which means the absolute humidity is lower or the WBGT is lower. For heat stress exposure assessment, the ISO (7) method uses normalized metabolic rate while the NIOSH (3) and ACGIH (1) recommend absolute metabolic rate. In either case, the level of heat stress is expressed as the combination environmental conditions (e.g., WBGT) and metabolic rate, without reference to fitness.

This interaction of metabolic rate with heat stress and physiological response leads to a quandary that requires a careful statement of the research question. For instance, if the central research question is physiological response to heat stress due to gender, then both the heat stress level and relative metabolic demands must be matched simultaneously. This is accomplished by matching the participants by aerobic capacity and the setting the metabolic rate as a percent of the capacity at a fixed environmental condition. Recognizing that there are differences in the population of men and women for aerobic capacity, this masks the population effects (8). If the absolute metabolic rates are not used, then the level of heat stress is matched but the core temperatures and heart rates may be biased high for women who have a lower average aerobic capacity.

Clothing

Clothing provides a barrier against harmful chemical and physical agents, but in turn, can hinder heat dissipation. When unclothed, thermal exchange can occur directly across the skin. When clothed, an air layer or microenvironment is formed between the skin and the environment. When multiple layers of clothing are worn, multiple microenvironments are formed between the layers. Metabolically generated heat must pass through each microenvironment before being dissipated to the ambient environment (9). For this reason, thermal properties of different clothing ensembles such as insulation, ventilation, and permeability greatly influence heat dissipation from the skin to the environment. For example, water barrier and vapor barrier clothing decrease permeability, hindering evaporative heat loss (10). Progressive heat stress protocols are used to evaluate the total insulation and the total evaporative resistance of clothing ensembles (6,11,12). In addition, this protocol is used to recommend clothing adjustment factors by comparing the mean critical conditions for work clothes to the mean critical conditions for the clothing ensemble of interest. Numerous studies reported clothing adjustment vapor barrier clothing at a value of around 9 to 11ºC (11,12,13,14). In contrast, cotton work clothes or coveralls have a much lower adjustment factor ranging from 0 to 4ºC; other types of clothing to be considered include water barrier, vapor-transmitting ensembles (0 to 5.5ºC) and particle barrier ensembles (1.5 to 2.0ºC) (10). Also, the layering of any combination of fabrics or ensembles increases the effects of heat stress (10).

Personal Factors

External influences of heat stress include environment, clothing, and MR. Interpersonal differences in response to heat stress may be attributed to acclimation status, cardiovascular fitness, and gender.

Acclimation

Acclimatization is repeated exposure to heat, which induces physiological adaptations to improve heat tolerance. When this improved tolerance is achieved by exercise in a controlled environmental chamber, it is called acclimation. For the purposes of this paper, the effects of heat acclimation and acclimatization are similar and the process will be referred to as acclimation.

Physiological effects of acclimation include decreased HR (15,16,17,18,19,20,26,28,31,33,36), decreased T_{re} (15,16,17,19,26,28,33,36), decreased T_{sk} (15,16,20,26,31,33,36), and lower T_{re} at the onset of sweating (21,22,26,36). There is also increased plasma volume (21,22,23,24,25,26,31,36), reduced sodium chloride in sweat (27,31), and increased sweat rate (15,16,17,18,19,20,31). Pandolf (28) and Cheung (15) reported decreased ratings of perceived exertion and thermal sensation as well.

The development of acclimation occurs by exposing workers to a hot environment for increasing time. Traditional acclimation protocols use low exercise intensities (40-60% VO_{2max}) for 1-2 hours per day over 6-10 days (28,29,30). Hot-dry and hot-wet environments are equally sufficient to induce physiological changes of improved heat tolerance (16,28,31,32).

Gill and Sleivert (33) studied the differences in acclimation of daily versus intermittent exposure to heat. Fourteen competitive rowers were randomly assigned to either an intermittent (10 sessions over 3 weeks) or a consecutive (10 days) acclimation group. They found that T_{re} decreased significantly with intermittent exposure, but found a significantly larger decrease with consecutive day heat exposure. HR, T_{sk}, and ratings of perceived exertion also decreased significantly with consecutive acclimation, but not with intermittent acclimation. The investigators concluded that some adaptation occurs with intermittent heat exposure, but daily heat exposure is a more effective acclimation strategy.

The changes induced by acclimation develop quickly over the first few days and are essentially complete after two weeks. Acclimation is said to be complete when there is a plateau in the physiological adaptations including decreased HR and T_{re} and increased SR (34). HR and plasma volume adaptations occur in the first few days, while T_{re} and sweating adjustments take place after about six days of acclimation (23). As HR can be affected by other variables unrelated to thermal load, an increase in T_{re} is a better predictor of exhaustion from heat stress (32). For this reason, a plateau in T_{re} is most often used as the major criteria for complete acclimation (16).

Fitness

Habitual exercise or long-term aerobic training leads to similar physical adaptations as acclimation especially in cardiovascular efficiency (15). Plasma volume increases by about 20%, which leads to an increase in stroke volume, due to greater venous return and a greater end diastolic volume. The increase in stroke volume results in a reduced HR and an increase in muscle blood flow (35). In addition, there is an enhanced sweating response at a given percentage of maximal effort. Overall, there is a decrease in physiological strain and energy cost for a given submaximal workload (36).

Aerobic capacity is expressed as maximal oxygen uptake (VO_{2max}). The average for women is 2.0L/min and 3.5L/min for men. When adjusted for body weight, VO_{2max} is 33 and 40ml/kg respectively (23,37). In industrial settings, men and women generally do similar jobs. As men have a higher VO_{2max}, women work at a higher percentage of aerobic capacity than men in general. As a result, women have higher HRs, higher body temperatures, greater perceived stress, and quicker onset of fatigue during exercise (8).

Gender

Generally it is believed that women are at a disadvantage in hot environments. First, women have a smaller muscle mass to fat ratio, which leads to less efficient work and more heat production. Next, a smaller blood volume coupled with a larger surface area-to-mass ratio leads to a greater effect of dehydration. Sweat initiation occurs at a higher T_{re} and T_{sk} causing more heat storage at sweat onset. Also, T_{sk} is usually higher in women in hot environments because they rely more on convective heat loss, allowing less heat conductance (38). Women have a lower SR than men of equal fitness, size, and acclimation state. This may be a disadvantage in hot dry environments where men can dissipate more heat through evaporative cooling (39).

However, in hot-wet environments women may be at an advantage as they depend more on convective rather than evaporative heat loss (39). Shapiro, Pandolf, Avellini, Pimental, and Goldman (40) studied 10 men and 9 women after acclimation in hot wet, hot dry, and comfortable environments. During the hot wet protocols, women had lower T_{sk}, T_{re}, and less sweat loss. Here a larger surface area to mass ratio led to more evaporative heat loss. The opposite was true in the hot-dry experiments. Men were at a physiological advantage producing lower T_{re} and T_{sk}, lower HR, and lower heat storage. Men and women tended to react similarly in the comfortable environments, indicating that the physiological advantages/disadvantages were related to the type of climate, specifically whether it was wet or dry.

Gender differences in physiological response to heat stress may be reduced if fitness level, and acclimation state are standardized (38,39). Paolone, Wells, and Gerard

(41) found physically fit women were capable of working in the heat about as well as men when workload is relative to individual maximal capacities.

Physiological Response and Gender

General physiological responses to heat stress include an increase in HR, SR, and T_{re}. There is also an increase in T_{sk} due to increased peripheral blood flow. Conflicting evidence exists regarding gender differences in physiological responses to exercise. In addition to examining these physiological responses, a physiological strain index (PSI) can be used as a tool to evaluate heat stress.

Skin Temperature

Most studies found no difference in T_{sk} between genders when matched on fitness (41, 42,43,44, 45,46,51). However, a few found that women tended to have higher T_{sk} than men when participants were not matched on fitness (47,45) or during exercise in hot dry environments (40,48). Moran, Shapiro, Laor, Izraeli, and Pandolf (45) looked at three groups of acclimated participants. The first two groups were of similar fitness and included nine women and eight men with maximal aerobic capacities of 46.1 and 43.6 ml/kg, respectively. The third group consisted of eight men who were significantly more fit ($P<0.0001$) than the first two groups with maximal aerobic capacity of 59.1 ml/kg. All groups worked at an equivalent workload. Each completed nine trials in comfortable, hot wet, and hot dry environments at low, moderate, and high exercise intensities. There was no difference in T_{sk} when men and women were matched on fitness, but a significant difference ($p<0.005$) was found when comparing fit men to women. McLellan (47) also found a higher average T_{sk} for women than men (0.1-0.2°C) while performing light intermittent exercise at equivalent absolute metabolic rate. These participants were not matched on fitness and were not acclimated.

Yousef, Dill, Vitez, Hillyard, and Goldman (48) and Shapiro et al. (40) both found women to have higher T_{sk} in hot dry environments. Yousef et al. (48) studied 57 men and 60 women all between the ages of 17 and 31 walking for three one-hour trials in desert heat at 40% of VO2max. Women had a significantly higher average T_{sk} than men ($p<0.05$). Shapiro et al. (40) examined 9 women and 10 men under hot wet, mild wet, and hot dry conditions. T_{sk} for women was higher in the hot dry conditions but lower in the hot wet conditions. Men rely more on evaporative heat loss and women rely more on convective heat loss. Using this reasoning, it is not surprising that men had higher T_{sk} in mild wet and hot wet conditions.

Sweat Rate

Most studies report a higher sweat rate (SR) in men (42,40,41,44,46,47,48, 49,50,51). Shapiro et al. (40) studied gender related differences in ten men and nine women under several different hot wet and hot dry conditions. Men sweated more than women in all climates. The most significant difference was during hot wet exposures, where men sweated 25-40% more than women. The average sweat rates were 557 and 423 $g \cdot m^{-2} \cdot h^{-1}$, respectively.

Conversely, some studies report no difference in SR between men and women. Moran et al. (45) found no difference between men and women with similar aerobic capacities at the same exposure. The group of fit men had a significantly higher SR than women at the high exercise intensity (650 W). In addition, Frye and Kamon (42) studied four men and four women of similar fitness levels pre and post acclimation. There was no difference in post-acclimation SR. These results coupled with those from Moran et al. (45) infer that the acclimation process and the matching of participants on fitness can reduce gender differences in SR.

Heart Rate

Generally, there is an increase in heart rate (HR) as the level of heat stress increases. Research on the gender difference in HR during heat stress is conflicting. Avellini, Kamon and Krajewski (51) examined responses of physically fit men (n=4) and women (n=4) with comparable maximal aerobic capacities (64.2 and 65.7 ml/kg, respectively) and equal body surface areas to acclimation to humid heat. Participants underwent a three-hour heat stress test ($T_{db} = 36°C$, $T_{wb} = 30°C$, $VO_2 = 1.0$ L/min) before and after a ten-day acclimation to humid heat. Before acclimation, men and women began experiments with similar resting HR values. However, men had higher HR values than women during 30, 60, and 90 minutes of exercise. When expressed as a percentage of resting HR, there were no differences between genders in exercising HR. Post acclimation, men had significantly greater HRs than women at 90 min as well as a significantly higher HR during the 3rd hour of the experiments. This could have been caused by a high SR during the experiment that could not be replaced through ad libitum water ingestion or a reduction in SR since women rely more on convective heat loss. In this same study, no post-acclimation differences in HR were found between men and women during the first 1.5 hours of the experiment.

Paolone et al. (41) and Keatisuwan, Tadakatsu, and Tochihara (44) found higher HRs in men during heat stress experiments. Keatisuwan et al. (44) exposed men and women to hot dry (T_{db} = 40ºC, RH = 30%) and hot wet (T_{db} = 31ºC, RH = 80%) environments while performing work rest cycles. During work, participants pedaled on a bicycle ergometer at 40% VO2max. Paolone had subjects work at 50% VO2max in neutral (T_{db} = 25ºC, T_{wb} = 18ºC), warm (T_{db} = 32ºC, T_{wb} = 34ºC), and hot environments (T_{db} = 40ºC, T_{wb} = 31ºC) where RH was held to 50-55%. Environmental exposures were two hours divided into work, rest, and recovery. The higher HRs for men in both studies could be explained by the fact that participants were not matched on fitness and that the men had a greater level of heat stress with an elevated need for skin blood flow.

In several studies, when participants were matched on fitness, there were no differences between genders in HR (42,42,44,45,51). However, when participants are not matched on fitness and exercise at an equivalent absolute workload, the women are working at a higher relative workload resulting in a higher HR (49,47,45). Kamon, Avellini, and Krajewski (49) reported a higher heart rate for women ($P<0.05$) at the critical condition, the point between compensable and uncompensable heat stress. McLellan (47) also found higher HRs in women under conditions of compensable heat stress. As discussed in a previous section, Moran et al. (45) examined three groups of participants while exercising under controlled conditions of compensable heat stress. No difference was found in HR between the men and women matched on fitness. However, the women had a significantly higher ($P<0.05$) HR than the fit men. Yousef et al. (48) and Shapiro et al. (40) both conducted experiments with participants of different fitness levels in hot dry environments and reported a higher HR in women. A hot dry environment can emphasize the effect of different fitness levels due a lower rate of evaporative heat loss in women, leading again to higher HR.

Core Temperature

Most investigators found no difference in core temperature (T_{re}) between genders when matched on fitness (42,42,45,51) or when exercising at an equivalent MR (42,41,44,52). However, in hot dry environments, T_{re} tends to be higher in women due to their physiologic preference to dissipate heat through convective means (40,48). The female participants in the study by Yousef et al. (48) had higher T_{re} than the men.

Comparably, Shapiro et al. (40) found that while exercising in hot wet environments, men tend to have higher T_{re} due to the decreased ability to dissipate heat through sweat evaporation. In conclusion, differences between genders in physiological responses tend to disappear when subjects are matched on fitness, body size, acclimation state, and ambient environment in which exercise takes place are standardized.

Physiological Strain Index

A physiological strain index (PSI) developed by Moran, Shitzer, and Pandolf (53) is based upon Tre and HR as "representative of the combined strain reflected by the thermoregulatory and cardiovascular systems (45)." The index rates physiological strain on a scale of 0-10 and is calculated as follows (53):

$$PSI = 5(T_{ret} - T_{re0}) \bullet (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \bullet (180 - HR_0)^{-1} \qquad [3]$$

Where T_{ret} and HR_t are simultaneous measurements taken at any time during exposure and Tre_0 and HR_0 are the initial measurements.

Moran et al. (45) examined the ability of PSI as a tool to assess differences between genders during heat strain at various exercise intensities and climates. As discussed previously, three groups of acclimated participants exercised at low, moderate, and high intensities in comfortable, hot wet, and hot dry environments. The participant groups consisted of eight men (M) matched on fitness to a group of nine women (W), and a group of eight men (MF) that were more fit than the first two groups. In general, PSI values increased with exercise intensity and heat load. No significant difference in PSI was found between M and F at the same exposure. However, MF had a significantly lower strain than the matched groups. Specifically, significant differences between M and MF were found during moderate exercise in the hot wet ($PSI_M = 6$ and $PSI_{MF} = 4$) and hot dry ($PSI_M = 5$ and $PSI_{MF} = 4$) climates. During high intensity exercise, there were significant differences between M and MF in all three environments. When PSI was applied from the beginning to the end of experiments across all three environments, ranking was as follows: low exercise intensity – little to low strain with values of 2-4, moderate exercise intensity – little to moderate strain with values of 2-6, and high exercise intensity – low to very high strain with values of 2-9 (45).

Hypothesis

The purpose of this study was to examine gender differences in response to heat stress at critical WBGT across a range of clothing ensembles. There were two null hypotheses to be tested. In the first, the null hypothesis is that there are no differences in $WBGT_{crit}$ between women and men among five clothing ensembles. If there is a failure to reject the first hypothesis, suggesting that the levels of heat stress are the same, then differences in physiological response can be attributed to population characteristics based on gender. Thus the second null hypothesis is that there are no differences between women and men in their physiological response to heat stress at $WBGT_{crit}$ across clothing ensembles.

METHODS

The purpose of this project was to population differences in heat stress and strain attributable to gender. The progressive experimental protocol fixed metabolic demand and level of relative humidity (RH). Determination of the point of transition from compensable to uncompensable heat stress was the critical condition.

Participants

The study included twenty-nine adults (nine women and twenty men). Their physical characteristics can be found in Appendix A and means and standard deviations of their physical characteristics by gender are provided in Table 1. A subset of participants included 15 adults (four women and eleven men) from the main study. Subset participant physical characteristics are provided in Appendix A. Means and standard deviations of their physical characteristics by gender are provided in Table 2.

All participants were recruited from the Tampa Bay area using local print media and campus advertising at the University of South Florida. They were employed for three weeks and compensated on a per experiment basis. Participants were first interviewed by an investigator for the purpose of explaining the study and to determine interest and availability. A physician conducted a physical examination and written consent was obtained before participants could begin experiments. Women self reported results of a home pregnancy test.

Table 1

Summary of Participant Characteristics

		Age	Height (cm)	Weight (kg)	BSA (m^2)
Women (n = 9)	Mean	28	163	63.7	1.74
	Std Dev	8	7	16.6	0.29
Men (n = 20)	Mean	29	179	88.7	2.07
	Std Dev	9	34	23.2	0.41
Both (n = 29)	Mean	29	174	80.9	1.97
	Std Dev	8	12	20.2	0.28

Table 2

Summary of Sub-Study Participant Characteristics

		Age	Height (cm)	Weight (kg)	BSA (m^2)
Women (n = 4)	Mean	23	165	64.2	1.70
	Std Dev	5	6	18.0	0.22
Men (n = 11)	Mean	28	176	81.7	1.98
	Std Dev	10	11	12.0	0.47
Both (n = 15)	Mean	27	173	77.0	1.91
	Std Dev	9	11	15.4	0.22

Clothing

Five clothing ensembles were evaluated.

1. Work clothes: 4oz/yd cotton long sleeve shirt, 8oz/yd cotton pants
2. Cotton coveralls: 10oz/yd2
3. Particle barrier coveralls (limited use): Tyvek 1424 or Tyvek 1427
4. Water barrier, vapor permeable coveralls (limited use): NexGen LS417

5. Vapor barrier coveralls (limited use): Tychem QC, polyurethane coated Tyvek

The non-woven coveralls had a zipper closure in the front, elastic cuffs and ankles. Athletic shoes and socks, shorts, underwear, cotton t-shirt, and sports bra for women were worn underneath all ensembles.

Equipment

Each experiment was conducted in a Forma Scientific 7010 climatic chamber. The dimensions inside the chamber were 2.7 meters wide x 3.0 meters deep x 2.2 meters high. The temperature and humidity range capabilities of the chamber were 4 to 60° C and 10 to 90% RH. Air speed could also be controlled.

Participants walked on a motorized treadmill (Stair Master Club Track) on which metabolic rate (MR) was controlled through speed and slope. Heart rate (HR) was monitored using a Polar Electro Heart Rate Monitor. Rectal temperature was measured using a flexible thermister (YSI 401AC) inserted 10cm past the anal sphincter muscle. T_{sk} was monitored at four sites (chest, upper arm, thigh, calf) using YSI 409A thermisters. Average T_{sk} was computed using the following equation (need reference):

$$T_{sk} = 0.3T_{chest} + 0.3T_{arm} + 0.2T_{thigh} + 0.2T_{calf}. \quad [4]$$

Calibration of thermisters was performed prior to each experiment using a hot water bath.

MR was assessed every half hour during experiments by measuring the volume and composition of expired air. Expired gases were collected by having the participant breathe through a two-way valve into a Douglas bag for 2-3 minutes. The collected volume of air was then measured using a dry gas meter and the oxygen content was measured using an oxygen analyzer (Beckman E2), which was calibrated before each experiment. Oxygen consumption was determined using the following equation (54).

$$VO_2 = V_E \cdot \Delta O_2/100 \cdot CF \qquad [5]$$

Where V_E = expired air flow rate (L/min)

ΔO_2 = difference in percent of oxygen between inspired and expired air

CF = correction factor to convert volume to STDP

Protocols

Acclimation

Each participant underwent a five-day acclimation period consisting of two hours in the climatic chamber per day. The environment in the chamber was held at 50˚C and 20% RH. Participants walked on the treadmill at a speed that would elicit a metabolic rate normalized to body surface area (MSA) of approximately 160W/m^2. Acclimation trials lasted two hours or until one of the termination criteria was met.

Experimental Sessions

Experiments were conducted in each of the five ensembles in a moderate environment, initially held constant at 34ºC and 50% RH. Treadmill speed and grade were set to elicit a MSA of approximately 160 W/m^2. When the participants reached thermal equilibrium (no change in HR or T_{re} for 15 minutes), T_{db} was increased 1ºC every 5 minutes.

T_{re}, HR, and ambient conditions were monitored continuously and recorded every five minutes. T_{sk} at four sites was recorded every ten minutes. Participants were allowed to drink water or a commercial fluid replacement beverage as desired.

Trials lasted approximately 120 minutes unless termination criteria were met. Termination criteria included successful completion of the trial (determination of critical conditions), a T_{re} above 39°C, a HR of 90% age-predicted max, or by request of the participant.

The order in which the five ensembles were worn during trials was randomized, with any necessary repeats completed at the end of the three-week period.

Critical Conditions

WBGT exposure limits are based upon an inflection point, or the point at which the body can no longer maintain thermal equilibrium. The critical condition was determined for each experiment by noting the chamber conditions 5 minutes before a significant increase (0.1°C or more) in T_{re}. The critical WBGT was then computed using O'Connor and Bernard's method (10).

$$WBGT_{crit} = 0.7\,(T_{pwb} + 1.0) + 0.3T_g \qquad [6]$$

Statistical Analysis

Data were analyzed using a mixed model analysis of variance. Level of significance was set at 0.05. From a complete data set, we extracted trials of one metabolic level ($160W/m^2$) and one environmental condition (50%RH). Analysis included ANOVA evaluating the differences in MR, MSA, $WBGT_{crit}$, and physiological responses by gender and by ensemble. Subjects were nested within gender for all analyses. The interaction of gender and ensemble was also examined. From the subset of data, ANOVA evaluated differences in $WBGT_{crit}$, MSA, and physiological responses

(T_{re}, HR, T_{sk}, and PSI) by metabolic level, by gender, and by ensemble. Subjects were nested within gender. The interaction of gender and ensemble was examined followed by the interaction of gender and metabolic level.

RESULTS

The current study included a primary population of 20 men and 9 women described in Table 1, and a sub-study population from the main group that included 11 men and 4 women (Table 2).

Level of Heat Stress

The study design called for a target metabolic rate of 160 W/m^2. Table 3 gives the absolute (MR) and normalized metabolic rates (MSA) by gender for the group average and standard deviation. A two-way analysis of variance (ANOVA) (subjects nested in gender by ensemble) revealed a significant gender difference ($p < .0001$) for MR, and for MSA ($p < .0001$). MR was greater for men than for women (347 W and 270 W, respectively). Men had a significantly greater MSA than women (172 W/m^2 and 152 W/m^2, respectively). There were no differences in MSA ($p = 0.519$) or MR ($p = 0.372$) among ensembles.

Results critical WBGT (WBGTcrit) as mean and standard deviation by gender and ensemble are reported in Table 4. Figure 1 illustrates the mean WBGTcrit values by ensemble. A two-way ANOVA (subjects nested in gender by ensemble) was used to determine statistical significance for gender and ensemble as well as the interaction. There were significant differences ($p = 0.035$) between genders for $WBGT_{crit}$ where the mean values were 32.5°C for men and 33.1°C for women. There was also a significant difference for $WBGT_{crit}$ among ensembles ($p<0.0001$). Tychem, the vapor barrier ensemble was the lowest at 27.3°C. Work clothes (34.8ºC) and cotton coveralls (34.9°C) produced the highest WBGT_{crit}.

Table 3

Means and Standard Deviations of Metabolic Rate

		MR (W)	MSA (W/m^2)
Women	Mean	270	152
	Std Dev	68	34
Men	Mean	347***	172***
	Std Dev	58	30
Both	Mean	322	165
	Std Dev	71	32

*** Significant difference from Women (P<.0001)

Table 4

Critical WBGT (WBGT_{crit} °C) for Men, Women, and Both Wearing All Ensembles

		Work Clothes	Cotton Coveralls	Tyvek	NexGen	Tychem	All
Women	Mean	34.9	35.5	34.1	32.9	27.9	33.1
	Std Dev	1.6	1.7	0.8	1.6	1.9	3.1
Men	Mean	34.8	34.7	34.1	32.1	27.1	32.5***
	Std Dev	2.1	1.4	1.5	1.3	1.6	3.3
Both †	Mean	34.8^a	34.9^a	34.1^a	32.3^b	27.3^c	
	Std Dev	1.9	1.5	1.3	1.5	1.7	

*** Significant difference between Men and Women (p<.0001), † Values with like letters are not statistically different (p<.05)

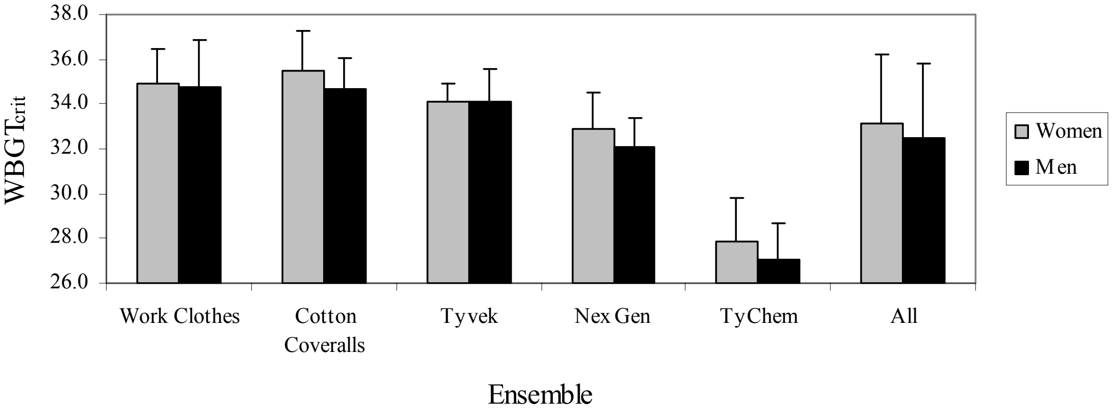

Figure 1. Comparison of $WBGT_{crit}$ for men and women in all ensembles.

Heat Strain

Mean values and standard deviations for T_{re} for men and women in all five ensembles are reported in Table 5. Figure 2 depicts the mean T_{re} values by ensemble. Two-way ANOVA procedures revealed no significant difference between genders (p = 0.055) for T_{re}. There were also no significant differences in T_{re} among ensembles (p = 0.990) and for interactions (p = 0.249).

Table 5

Core Temperature (T_{re} °C) Means and Standard Deviations at the Critical Condition for Men, Women, and Both Wearing All Ensembles

		Work Clothes	Cotton Coveralls	Tyvek	NexGen	Tychem	All
Women	Mean	37.8	37.8	37.7	37.8	37.9	37.8
	Std Dev	0.4	0.3	0.3	0.3	0.3	0.3
Men	Mean	37.8	37.7	37.8	37.7	37.7	37.7
	Std Dev	0.2	0.2	0.3	0.3	0.3	0.3
Both	Mean	37.8	37.7	37.8	37.7	37.8	
	Std Dev	0.3	0.3	0.3	0.3	0.3	

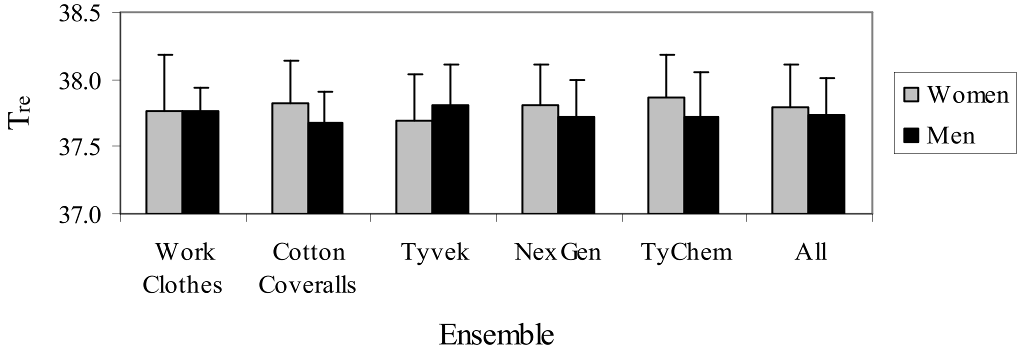

Figure 2. Comparison of T_{re} at $WBGT_{crit}$ for men and women in all ensembles.

Means and standard deviations of HR at the critical condition are reported in Table 6. The mean values for HR are shown in Figure 3. The two-way ANOVA revealed that women (HR = 125 bpm) had a significantly higher HR than men (HR = 112 bpm). There was no significant difference among ensembles (p = 0.926) and there was no interaction in HR between gender and ensemble (p = 0.385).

Table 6

Heart Rate (HR) at the Critical Condition for Men, Women, and Both Wearing All Ensembles

		Work Clothes	Cotton Coveralls	Tyvek	NexGen	Tychem	All
Women	Mean	120	127	123	126	129	125
	Std Dev	15	16	14	16	18	16
Men	Mean	115	111	112	109	111	112***
	Std Dev	17	13	14	13	19	15
Both	Mean	116	116	116	114	117	
	Std Dev	17	16	15	15	20	

*** Significant difference between women and men (p<.0001)

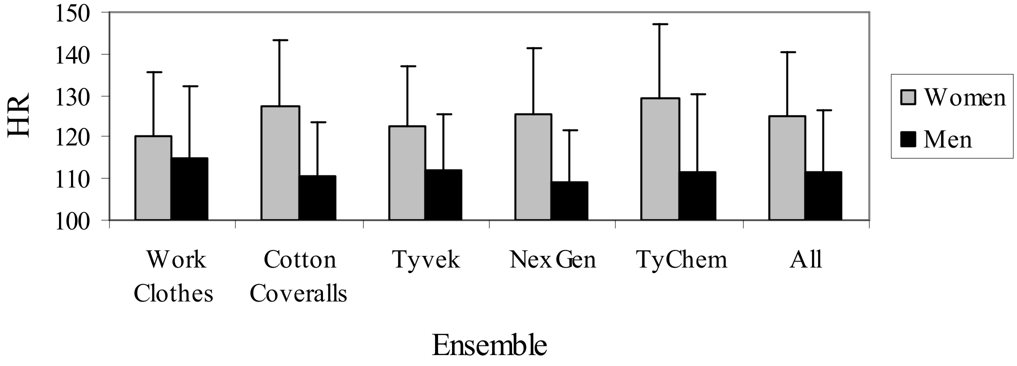

Figure 3. Comparison of HR at WBGT_{crit} for men and women in all ensembles.

For weighted mean skin temperature (T_{sk}) means and standard deviations are reported in Table 7. The mean values for T_{sk} are represented graphically in Figure 4. Women had a significantly higher mean value than men (T_{sk} = 36.4 °C and 36.2 °C, respectively). There were no differences among ensembles ($p = 0.767$) and no interactions ($p = 0.678$).

Table 7

Skin Temperature (T_{sk} °C) at the Critical Condition for Men, Women, and Both Wearing All Ensembles

		Work Clothes	Cotton Coveralls	Tyvek	NexGen	Tychem	All
Women	Mean	36.4	36.6	36.3	36.4	36.5	36.4*
	Std Dev	0.5	0.6	0.8	0.4	0.8	0.6
Men	Mean	36.3	36.3	36.3	36.1	36.1	36.2
	Std Dev	0.5	0.5	0.5	0.5	0.8	0.6
Both	Mean	36.3	36.4	36.3	36.2	36.2	
	Std Dev	0.5	0.5	0.6	0.5	0.8	

* Significant difference between Women and Men (p<.05)

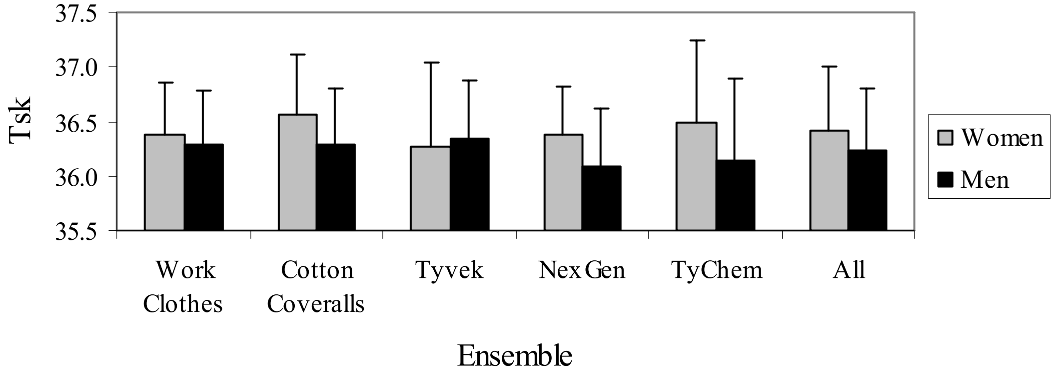

Figure 4. Comparison of T_{sk} at $WBGT_{crit}$ for men and women in all ensembles.

The means and standard deviations for PSI are reported in Table 8. The mean values for PSI are presented graphically in Figure 5. There was a significant difference between genders, where the value for men was 3.80 ± 1.01 compared to 4.53 ± 1.16 for women. As reported for all of the physiological responses, there were no significant differences in PSI among ensembles ($p = 0.961$) and there were no interactions ($p = 0.245$) between gender and ensemble.

Table 8

PSI at the Critical Condition for Men, Women, and Both Wearing All Ensembles

		Work Clothes	Cotton Coveralls	Tyvek	NexGen	Tychem	All
Women	Mean	4.3	4.7	4.3	4.6	4.8	4.5***
	Std Dev	1.3	1.0	1.2	1.1	1.3	1.2
Men	Mean	4.0	3.7	3.9	3.6	3.8	3.8
	Std Dev	1.0	0.9	1.0	0.8	1.4	1.0
Both	Mean	4.1	4.0	4.1	4.0	4.1	
	Std Dev	1.1	1.0	1.0	1.0	1.4	

*** Significant difference between Women and Men ($p<.0001$)

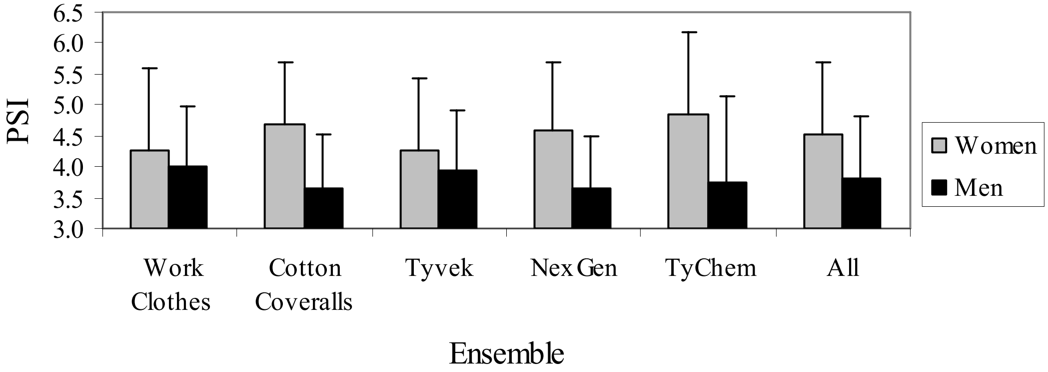

Figure 5. Comparison of PSI at WBGT_{crit} for men and women in all ensembles.

In summary (Table 9), there were no differences among ensembles in T_{re}, HR, T_{sk}, and PSI. There was also no difference in T_{re} between genders. There were differences between genders for HR ($p<0.0001$), average T_{sk} ($p = 0.034$), and PSI ($p<0.0001$).

Table 9

Summary of Differences Between Gender and Among Ensembles for Physiological Responses

	Gender	Ensemble
T_{re}	NS	NS
HR	<0.0001	NS
T_{sk}	0.0338	NS
PSI	<0.0001	NS

Effect of Metabolic Rate

The average MSA during experiments was 165 W/m^2. But, men had an MSA that was 20 W/m^2 higher than women. To evaluate the effects of metabolic level on gender differences in physiological response to heat stress, a subset of the data using three metabolic levels was examined. The relationship of change in MSA to the difference in WBGT_{crit} and all physiological responses (HR, T_{re}, T_{sk}, and PSI) was investigated.

Slope is the ratio of change in one variable (the metrics of WBGT_{crit}, HR, T_{re}, T_{sk}, PSI) for a given change in the another variable (the confounder, MSA). Slopes for the metrics were computed with a least squares fit through three points. The slope values are reported in Table 10 for women, men and both.

Table 10

Relationship of WBGT_{crit} and Physiological Responses to Normalized Metabolic Rate (MSA)

		M1	M2	M3	Slope
MSA (W/m^2)	Women	103	173	245	
	Men	120	186	259	
	Both	112	180	252	
WBGT_{crit} (°C)	Women	35.7	32.8	29.5	-0.044
	Men	35.2	32.4	30.2	-0.036
	Both	35.4	32.6	29.9	-0.039
HR (bpm)	Women	115	126	141	0.18
	Men	108	114	125	0.12
	Both	111	120	133	0.16
T_{re} (°C)	Women	37.6	37.8	37.9	0.0021
	Men	37.5	37.7	38.0	0.0036
	Both	37.5	37.8	37.9	0.0028
T_{sk} (°C)	Women	36.8	36.3	35.3	-0.011
	Men	36.6	36.3	35.7	-0.0065
	Both	36.7	36.3	35.5	-0.0086
PSI (°C)	Women	3.7	4.5	5.5	0.013
	Men	3.2	3.9	4.8	0.012
	Both	3.4	4.2	5.2	0.013

Adjusted values for WBGT_{crit} and physiological responses were calculated by multiplying the slope of the metric variable for both women and men by the difference in MSA between men and women and adding that adjustment to women. Results are reported in Table 11. In addition, the level of statistical significance of the difference is provided.

Table 11

Adjusted Values of $WBGT_{crit}$ *and Physiological Responses Based on the Difference in MSA*

	Men	Women	$\text{Men}_{\text{adjusted}}$	Result	P
MSA (W/m^2)	172	152			
WBGTcrit	32.5	33.1*	33.2	NSD	0.45
T_{re}	37.7	37.8	37.6	W > M	<0.001
HR (bpm)	112	125*	109	W > M	<0.0001
T_{sk}	36.2	36.4*	36.4	NSD	≈1.0
PSI	3.8	4.5*	3.54	W > M	<0.0001

* Significant difference between genders before adjustment

DISCUSSION

Gender differences in $WBGT_{crit}$ and associated physiological variables were explored for five clothing ensembles under moderate environmental conditions and a fixed moderate metabolic rate.

Level of Heat Stress

Because normalized metabolic rate was a controlled variable in the experimental design, it is important to confirm that it was adequately controlled. In fact, there was a significant gender difference in MSA, where the men were 20 W/m^2 or 11% higher than the women. This could lead to a bias toward lower $WBGT_{crit}$ for men. The difference was 0.6 °C-WBGT, and statistically significant. From Table 11, the ratio of change for $WBGT_{crit}$ divided by normalized metabolic rate was -0.039 °C-WBGT W^{-1} m^2. Cortés-Vizcaino and Bernard (55) found a ratio of -0.018 and O'Conner and Bernard (10) found a ratio of -0.007. This would suggest that the observed mean male $WBGT_{crit}$ could be between 0.1 and 0.8 ºC-WBGT lower because of the higher metabolic rate. Kenney and Zeman (56) looked at unacclimated semi-clothed men and women at the upper limit of compensable heat stress, where $WBGT_{crit}$, was 31.3°C for men and 32.3°C for women and the metabolic rate differed by 52 W/m^2 (M = 191, W = 139 W/m^2). The ratio of change for $WBGT_{crit}$ divided by normalized metabolic rate was -0.02 °C-WBGT W^{-1} m^2. The adjusted mean value of $WBGT_{crit}$ for women was 31.3ºC, equating the values for men and women and equating the heat load. The differences in MSA could be a plausible explanation for the gender difference in $WBGT_{crit}$.

While there were differences in normalized metabolic rate and $WBGT_{crit}$, the differences were small and compensatory.

There was no interaction of gender and clothing on $WBGT_{crit}$ and the effects of clothing were described by Bernard, Luecke, Schwartz, Kirkland, and Ashley (57). For this reason the level of heat stress was considered equivalent for women and men.

Heat Strain at $WBGT_{crit}$

The women in this study had a greater heart rate (HR) (125 bpm) than the men (112 bpm), where the subjects were acclimatized and worked at the upper limit of compensable heat stress. These results are in accordance with other investigators (40, 49) who found a difference of 15-20 bpm between men and women exercising at the same absolute workload and environmental conditions. Further, in studies where there were equivalent relative demands in the same environment (41,48), heart rate was still greater in women than in men. When there are equal relative demands and uneven absolute demands in the same environment, MRs on average are different and the heat stress is different. There is a lower requirement for peripheral blood flow for women and therefore a lower heart rate. Here, part of the gender difference may be masked. On the other hand, Frye and Kamon (42) reported equivalent HRs for acclimatized men and women at the critical condition. Their subjects were matched on aerobic capacity which would reduce differences in thermoregulation and equalize heat strain between men and women. In looking at gender differences in HR in response to compensable or uncompensable heat stress, the findings in the current study were in line with others in finding a higher HR response when there is no matching of subjects based on aerobic capacity. Therefore, the fact that women in this study had a higher heart rate was due to a higher relative demand as well as the heat.

The results of this study examining the effects of an intermediate humidity on heat strain while working at the same workload found that T_{re} was about the same for women (37.8 °C) and men (37.7 °C) at the critical condition. Other studies that evaluated T_{re} while participants exercised at the same absolute workload also reported equivalent T_{re} for men and women (49,40,47). The lack of difference between genders was also reported in studies where participants exercised at equivalent relative demands (41,44). Frye and Kamon (42) matched their subjects on aerobic fitness (VO_2 max = 54 and 56 ml kg^{-1} min^{-1} for women and men, respectively) and they were acclimatized. The matching removed an important difference due to gender (i.e., population differences in fitness) and helped to explain the absence of a difference in T_{re} in their study. Kamon, Avellini and Krajewski (49) evaluated men and women exercising at the same absolute workload at critical conditions. The average difference in T_{re} between the men (37.94 ºC) and women (38.02 °C) was not statistically significant but was similar to the current study (0.08 versus 0.1 in the present study).

The current study revealed a gender difference in skin temperature (T_{sk}), with average values of 36.4ºC and 36.2ºC for women and men, respectively. These results are in line with those of other studies (40,45,47) that also reported women to have a higher average T_{sk} for women working at the same workload as men. Yousef et al. (48) also reported a higher T_{sk} for women (+0.1°C); even under equivalent relative demands where the magnitude of the difference may be not be as evident. Several other studies (49,42,42,44,51) reported no difference in T_{sk} between men and women. Frye et al. (42) and Sawka, Toner, Francesconi, and Pandolf (45) found no gender difference between men and women who were matched on fitness. As discussed earlier, the matching removed the difference due to gender and explains the absence of a difference between men and women in T_{sk}.

Physiological Strain Index (PSI) is a composite index using T_{re} and HR to reflect the combined strain of the thermoregulatory and cardiovascular system. Due to the gender differences in heart rate, it was not surprising that women had a higher PSI than men. Moran et al. (45) found no gender difference in PSI. However, in their study there did appear to be a difference in PSI based on fitness with the group of fit men having a lower PSI than the unmatched (less fit) women. The subjects in the current study were not matched on fitness, the women recruited from the university and community were probably less fit than the men further explaining the gender difference in PSI.

Effects of Metabolic Rate

To evaluate the effects of unequal normalized metabolic level on gender differences in physiological response to heat stress, a subset of the data using three metabolic levels was evaluated. The average metabolic rates were 112, 180, and 252 W/m^2. The metabolic rates normalized to body surface area for men were approximately 15 W/m^2 greater than women at each level of metabolic rate. As this might bias men to a lower $WBGT_{crit}$ and higher core temperatures and heart rates, the slope (ratio of change in the physiological metric divided by the change in normalized metabolic rate) was calculated for $WBGT_{crit}$, HR, T_{re}, T_{sk} and PSI. The values of the physiological metrics were adjusted accordingly for the differences in metabolic rate.

The ratio of change for $WBGT_{crit}$ was -0.039°C-WBGT/W m^{-2}. In this study the average metabolic rate difference was 20 W/m^2 greater for men. The mean male critical WBGT was approximately 0.7ºC lower than for the women. Adding 0.7 °C-WBGT to adjust for this bias would make the critical WBGT for men 33.2 °C-WBGT, nearly the same as women (33.1 °C-WBGT). The adjusted value results in no statistical gender difference in $WBGT_{crit}$. Kamon, Avellini and Krajewski (49) evaluated $WBGT_{crit}$ while participants exercised at the same absolute workload. Their results further support our findings of no difference in $WBGT_{crit}$; and this adjustment provided a means to make the heat stress level equivalent.

The ratio of change for HR was 0.16 bpm/W m^{-2}, providing an adjusted mean difference in heart rate for men of 3.2 bpm, still resulting in a significant difference in HR (109 for men versus 125 for women). These results are concordant with those of Kamon, Avellini and Krajewski (49). They found a difference in heart rate of 18 bpm and reported that the difference in HR is proportional to the difference in aerobic capacity in their subjects. This is supported by the work of Frye and Kamon (42) who reported no difference in heart rate in acclimated men and women who were matched on aerobic capacity.

The adjustment for T_{re} resulted in an adjusted mean T_{re} for men of 37.6°C, a slightly, but significantly, lower T_{re} than the women (37.8). Kamon et al. (49) found similar results although the difference between genders was not significant. In their study, the average T_{re} for women was 38.0°C and the average for men was slightly lower at 37.9°C.

The ratio of change for T_{sk} was -0.0086°C-T_{sk}/W m^{-2}. The adjusted mean T_{sk} for the men was approximately 0.2ºC lower than for the women. Adding 0.2 °C to adjust for this bias would make the T_{sk} for men 36.4°C. The adjusted mean resulted in no statistical gender difference in T_{sk}. This is in agreement with Kamon et al. (49) who found no statistically significant difference in average T_{sk} between acclimated men and women exercising at the upper limit of compensable heat stress.

The men had a PSI that was 0.7 lower than the women. The ratio of change for PSI was 0.013 PSI/W m^{-2}. The adjusted mean PSI for the men was approximately 0.26 higher. Subtracting 0.26 to adjust for this bias would make the PSI for men 3.54, still yielding a significant gender difference in PSI.

When the metabolic level is adjusted for subjects to approximate equivalent metabolic and heat loads, the major gender difference was still in HR. When subjects are not matched on aerobic fitness, women appear to experience a greater cardiovascular strain at the upper limit of compensable heat stress.

Conclusion

In conclusion, there is no gender difference in $WBGT_{crit}$ in acclimatized participants wearing a broad range of protective clothing ensembles when normalized metabolic level is similar. At similar heat stress levels, at the upper limit of compensable heat stress at a moderate rate of work, women did experience a greater cardiovascular strain evidenced by a greater HR. Following HR, PSI was also elevated for women. There were no real differences in core and skin temperatures.

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APPENDIX A

PARTICIPANT DATA

Table A1

Participant Characteristics—Main Study

	Subject Code	**Age**	**Height (cm)**	**Weight (kg)**	**BSA (m^2)**
Women (n=9)	S1	26	163	52.0	1.55
	S4	23	152	62.7	1.72
	S5	27	170	91.4	2.36
	S7	39	155	46.0	1.42
	SS1	27	163	52.0	1.55
	SS3	27	170	91.0	2.02
	SS11	18	170	56.8	1.66
	SS12	20	157	56.8	1.57
	S13	44	163	65.0	1.82
Men (n=20)	S0	26	180	92.7	2.14
	S2	24	183	86.0	2.08
	S3	25	183	77.0	1.99
	S6	35	189	101.0	2.28
	S8	20	183	130.0	2.48
	S9	30	191	110.0	2.38
	S10	32	173	71.0	1.84
	S11	43	178	112.0	2.28
	S12	28	185	95.0	2.19
	SS2	28	185	95.0	2.19
	SS4	26	180	95.0	2.15
	SS5	27	175	97.7	2.13
	SS6	20	180	82.7	2.03
	SS7	20	183	71.8	1.93
	SS8	24	163	63.6	1.68
	SS9	43	149	75.0	1.69
	SS10	49	175	86.0	2.02
	SS13	21	185	81.8	2.06
	SS15	22	178	63.6	1.80
	SS16	33	186	86.4	2.11
Mean		**29**	**174**	**80.9**	**1.97**
Std Dev		**8**	**12**	**20.19**	**0.28**

Appendix A (Continued)

Table A2

Participant Characteristics—Subset

	Subject Code	**Age**	**Height (cm)**	**Weight (kg)**	**BSA (m^2)**
Women (n=4)	SS1	27	163	52.0	1.55
	SS3	27	170	91.0	2.02
	SS11	18	170	56.8	1.66
	SS12	20	157	56.8	1.57
Men (n=11)	SS2	28	185	95.0	2.19
	SS4	26	180	95.0	2.15
	SS5	27	175	97.7	2.13
	SS6	20	180	82.7	2.03
	SS7	20	183	71.8	1.93
	SS8	24	163	63.6	1.68
	SS9	43	149	75.0	1.69
	SS10	49	175	86.0	2.02
	SS13	21	185	81.8	2.06
	SS15	22	178	63.6	1.80
	SS16	33	186	86.4	2.11
Mean		**27**	**173**	**77.0**	**1.91**
Std Dev		**9**	**11**	**15.42**	**0.22**

APPENDIX B

EXPERIMENTAL DATA

Experimental Data: Data Dictionary

Title	Description
ID	Participant identification
Gender	Participant gender
Ensemble	Clothing worn: WC: Work Clothes CC: Cotton Coveralls TYV: Particle Barrier NG: Liquid Barrier TYCHEM: Vapor Barrier
ML	Metabolic Demand: M1: 80W/m2 M2: 160 W/m2 M3: 240 W/m2
MR	Calculated metabolic rate based on O_2 consumption (Watts)
MSA	MR divided by body surface area (W/m^2)
HR	Heart rate in beats per minute (bpm)
T_{re}	Body core temperature (rectal) (°C)
T_{sk}	Average skin temperature at four sites (°C)
$WBGT_{crit}$	Calculated wet bulb globe temperature at the critical condition (°C)
PSI	Physiological Strain Index

Appendix B (Continued)

Experimental Data – Main StudyID

	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
S0	M	CC	R5	M2	319	149	96	37.80	35.55	33.8	3.17
S0	M	NG	R5	M2	308	144	93	37.70	34.67	31.4	2.86
S0	M	NG	R5	M2	325	152	95	37.70	35.55	33.2	2.95
S0	M	TYCHEM	R5	M2	448	209	95	37.42	35.53	24.9	2.49
S0	M	TYV	R5	M2	532	249	110	37.95	35.89	31.9	4.08
S0	M	WC	R5	M2	365	171	103	38.00	36.39	35.8	3.83
S1	F	CC	R5	M2	180	116	101	38.00	36.51	35.0	3.74
S1	F	NG	R5	M2	209	135	114	38.00	36.34	33.4	4.36
S1	F	TYCHEM	R5	M2	166	107	158	38.20	36.60	30.3	6.79
S1	F	TYV	R5	M2	186	120	139	37.90	37.20	35.0	5.38
S1	F	WC	R5	M2	198	128	126	38.00	35.66	34.1	4.93
S10	M	CC	R5	M2	326	177	135	38.07	36.61	33.1	5.47
S10	M	NG	R5	M2	320	174	129	37.80	36.70	30.9	4.74
S10	M	TYCHEM	R5	M2	329	179	128	37.82	36.16	26.3	4.72
S10	M	TYCHEM	R5	M2	337	183	146	38.33	36.80	27.4	6.43
S10	M	TYV	R5	M2	281	153	131	37.79	36.93	32.7	4.82
S10	M	WC	R5	M2	320	174	131	37.66	36.82	33.3	4.60
S11	M	CC	R5	M2	445	195	110	37.67	37.58	36.7	3.62
S11	M	NG	R5	M2	394	173	112	37.36	36.19	33.3	3.20
S11	M	TYCHEM	R5	M2	415	182	117	37.89	36.83	26.4	4.32
S11	M	TYV	R5	M2	459	201	110	37.68	35.98	35.1	3.63
S11	M	WC	R5	M2	427	187	115	37.76	37.00	36.5	4.00
S12	M	CC	R5	M2	304	139	103	37.62	36.71	36.7	3.20
S12	M	CC	R5	M2	151	69	122	37.49	35.37	34.7	3.89
S12	M	NG	R5	M2	316	144	105	37.82	36.58	32.3	3.63
S12	M	TYCHEM	R5	M2	325	148	99	37.58	36.05	26.0	2.94
S12	M	TYV	R5	M2	310	142	110	37.54	36.59	34.3	3.40

Appendix B (Continued)

Experimental Data – Main StudyID

	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
S12	M	WC	R5	M2	323	147	119	37.84	36.81	35.3	4.33
S13	F	CC	R5	M2	289	159	128	38.31	37.29	38.2	5.54
S13	F	NG	R5	M2	332	182	123	38.12	36.60	32.1	4.99
S13	F	TYCHEM	R5	M2	310	170	123	38.25	36.51	29.0	5.20
S13	F	TYV	R5	M2	305	168	122	38.16	37.10	34.2	5.00
S13	F	WC	R5	M2	263	145	122	38.41	37.32	36.9	5.42
S2	M	CC	R5	M2	263	126	109	37.70	36.00	35.1	3.62
S2	M	NG	R5	M2	252	121	109	37.20	35.58	30.1	2.79
S2	M	TYCHEM	R5	M2	306	147	100	37.50	35.52	25.0	2.86
S2	M	TYV	R5	M2	306	147	114	37.80	37.21	34.2	4.02
S2	M	WC	R5	M2	281	135	112	37.50	35.69	34.1	3.43
S3	M	CC	R5	M2	283	142	111	37.90	36.29	35.9	4.05
S3	M	NG	R5	M2	206	104	132	38.00	36.25	34.2	5.21
S3	M	NG	R5	M2	244	123	106	38.11	36.34	33.2	4.16
S3	M	TYCHEM	R5	M2	293	147	93	37.50	34.15	25.1	2.52
S3	M	TYV	R5	M2	283	142	105	38.20	35.67	32.8	4.26
S3	M	WC	R5	M2	285	143	113	38.10	35.81	34.4	4.48
S4	F	CC	R5	M2	166	97	124	38.00	36.81	35.1	4.83
S4	F	NG	R5	M2	157	91	127	37.71	36.32	30.8	4.49
S4	F	TYCHEM	R5	M2	192	112	130	37.70	36.19	28.1	4.62
S4	F	TYV	R5	M2	118	69	110	37.47	35.80	32.7	3.28
S4	F	WC	R5	M2	184	107	136	38.00	36.07	34.2	5.40
S5	F	CC	R5	M2	293	124	113	37.33	36.18	33.9	3.19
S5	F	NG	R5	M2	274	116	117	37.51	36.74	32.9	3.68
S5	F	TYCHEM	R5	M2	275	117	107	37.33	36.00	27.0	2.91
S5	F	TYV	R5	M2	280	119	121	37.73	36.83	34.9	4.24

Appendix B (Continued)

Experimental Data – Main StudyID

	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
S5	F	WC	R5	M2	242	103	108	37.50	36.37	34.1	3.24
S6	M	CC	R5	M2	310	136	96	37.72	36.51	37.4	3.03
S6	M	NG	R5	M2	358	157	88	37.60	35.83	31.3	2.45
S6	M	TYCHEM	R5	M2	408	179	85	37.48	35.49	28.4	2.11
S6	M	TYV	R5	M2	357	157	91	37.47	36.22	33.8	2.38
S6	M	WC	R5	M2	299	131	96	37.50	36.09	35.6	2.67
S7	F	CC	R5	M2	284	200	143	38.15	36.57	37.5	5.99
S7	F	NG	R5	M2	275	194	134	37.93	36.84	35.6	5.19
S7	F	TYCHEM	R5	M2	264	186	113	37.64	36.76	28.4	3.71
S7	F	TYV	R5	M2	257	181	118	37.81	36.69	34.9	4.23
S7	F	WC	R5	M2	296	208	136	37.91	36.40	35.1	5.25
S8	F	CC	R5	M2	425	171	146	37.47	36.83	37.7	5.00
S8	F	NG	R5	M2	432	174	129	37.55	35.84	35.8	4.32
S8	M	TYCHEM	R5	M2	430	173	103	37.52	35.16	25.8	3.03
S8	F	TYV	R5	M2	422	170	109	37.11	35.53	34.7	2.64
S8	M	WC	R5	M2	430	173	146	37.56	36.49	41.3	5.15
S9	M	CC	R5	M2	351	147	102	37.39	36.53	35.1	2.77
S9	M	NG	R5	M2	340	143	97	38.17	36.52	33.0	3.83
S9	M	TYCHEM	R5	M2	365	153	89	37.54	36.38	26.2	2.40
S9	M	TYV	R5	M2	376	158	105	37.96	36.98	36.4	3.86
S9	M	WC	R5	M2	356	150	108	37.67	36.50	35.1	3.52
SS1	F	CC	R5	M2	250	161	136	37.81	35.51	35.4	5.09
SS1	F	NG	R5	M2	297	192	111	37.28	35.63	31.7	3.01
SS1	F	TYCHEM	R5	M2	279	180	141	38.17	35.35	23.9	5.93
SS1	F	TYV	R5	M2	257	166	119	37.56	34.69	33.1	3.86
SS1	F	WC	R5	M2	170	110	86	37.01	36.34	38.0	1.37
SS1	F	WC	R5	M2	254	164	120	37.80	36.73	33.2	4.31

Appendix B (Continued)

Experimental Data – Main StudyID

	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS10	M	CC	R5	M2	410	243	116	37.71	36.51	31.9	3.97
SS10	M	NG	R5	M2	372	220	110	37.59	36.91	31.1	3.48
SS10	M	TYV	R5	M2	345	204	101	37.84	35.91	32.4	3.47
SS10	M	WC	R5	M2	385	228	109	37.64	36.01	32.7	3.52
SS11	F	CC	R5	M2	260	157	116	37.57	37.30	35.1	3.74
SS11	F	NG	R5	M2	301	181	119	37.90	37.02	32.7	4.43
SS11	F	TYCHEM	R5	M2	231	139	119	37.72	37.28	28.6	4.13
SS11	F	TYV	R5	M2	260	157	119	37.39	36.07	33.8	3.58
SS11	F	WC	R5	M2	295	178	119	37.38	35.95	33.6	3.56
SS12	F	CC	R5	M2	307	196	149	37.93	36.53	34.3	5.91
SS12	F	NG	R5	M2	290	185	165	38.26	36.12	32.7	7.22
SS12	F	TYCHEM	R5	M2	306	195	154	38.08	37.87	26.0	6.40
SS12	F	TYV	R5	M2	299	190	156	38.21	36.60	34.3	6.71
SS13	M	CC	R5	M2	354	172	132	38.10	37.00	34.8	5.38
SS13	M	NG	R5	M2	356	173	125	37.66	35.85	30.8	4.31
SS13	M	TYCHEM	R5	M2	354	172	136	38.05	36.70	27.6	5.49
SS13	M	TYV	R5	M2	335	163	137	37.86	36.60	35.1	5.22
SS13	M	WC	R5	M2	476	231	156	37.91	37.46	37.6	6.21
SS15	M	CC	R5	M2	318	177	118	37.82	36.21	34.0	4.25
SS15	M	NG	R5	M2	332	184	110	37.56	36.14	32.1	3.43
SS15	M	TYCHEM	R5	M2	301	167	116	37.31	36.34	29.8	3.30
SS15	M	TYV	R5	M2	298	166	116	37.84	36.52	35.7	4.19
SS15	M	WC	R5	M2	285	158	118	37.68	36.55	34.7	4.01
SS16	M	CC	R5	M2	341	162	110	37.53	36.28	34.1	3.38
SS16	M	NG	R5	M2	340	161	101	37.72	36.25	32.8	3.27
SS16	M	TYCHEM	R5	M2	377	179	119	38.28	36.89	28.4	5.06
SS16	M	TYV	R5	M2	354	168	128	38.67	35.65	32.0	6.14

Appendix B (Continued)

Experimental Data – Main StudyID

	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS16	M	WC	R5	M2	346	164	113	37.83	36.33	35.6	4.03
SS2	M	CC	R5	M2	385	176	113	37.46	36.10	34.5	3.41
SS2	M	NG	R5	M2	335	153	120	38.04	36.11	32.2	4.71
SS2	M	TYCHEM	R5	M2	310	142	101	37.36	36.50	29.2	2.67
SS2	M	TYV	R5	M2	399	182	117	37.74	36.79	37.1	4.07
SS2	M	WC	R5	M2	396	181	120	37.80	36.14	34.2	4.31
SS3	F	CC	R5	M2	318	157	116	37.63	36.02	33.2	3.84
SS3	F	NG	R5	M2	341	169	118	37.80	36.34	31.7	4.21
SS3	F	TYCHEM	R5	M2	275	136	117	37.65	35.85	29.6	3.92
SS3	F	TYV	R5	M2	328	162	113	37.61	36.12	33.5	3.66
SS3	F	WC	R5	M2	351	174	128	37.91	36.59	34.9	4.87
SS4	M	CC	R5	M2	411	203	93	37.74	36.02	33.7	2.92
SS4	M	NG	R5	M2	398	197	121	38.16	36.20	34.5	4.96
SS4	M	TYCHEM	R5	M2	464	230	95	37.78	35.17	25.7	3.09
SS4	M	TYV	R5	M2	444	220	95	37.76	35.19	33.3	3.05
SS4	M	WC	R5	M2	441	218	105	37.94	35.69	34.3	3.83
SS5	M	CC	R5	M2	406	201	106	37.45	35.73	34.3	3.06
SS5	M	NG	R5	M2	374	185	107	37.57	35.47	29.9	3.31
SS5	M	TYCHEM	R5	M2	356	176	115	37.47	36.72	29.0	3.52
SS5	M	TYV	R5	M2	377	187	110	37.81	36.42	33.6	3.85
SS5	M	WC	R5	M2	388	192	110	37.80	36.06	32.2	3.83
SS6	M	CC	R5	M2	347	163	85	37.16	36.02	33.7	1.58
SS6	M	NG	R5	M2	361	169	88	37.33	36.21	31.7	2.00
SS6	M	TYCHEM	R5	M2	341	160	90	37.28	36.00	27.2	2.01
SS6	M	TYV	R5	M2	323	152	90	37.20	36.04	34.9	1.88
SS6	M	WC	R5	M2	364	171	73	37.50	35.38	32.5	1.57
SS7	M	CC	R5	M2	339	176	116	37.71	36.41	35.8	3.97

Appendix B (Continued)

Experimental Data – Main StudyID

	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS7	M	NG	R5	M2	339	176	110	37.66	36.66	33.1	3.60
SS7	M	TYCHEM	R5	M2	335	174	122	38.12	36.48	28.6	4.94
SS7	M	TYV	R5	M2	363	188	107	37.62	36.68	34.5	3.39
SS7	M	WC	R5	M2	343	178	103	37.70	36.19	33.9	3.33
SS8	M	CC	R5	M2	306	182	122	37.46	35.74	32.5	3.84
SS8	M	NG	R5	M2	270	161	119	37.39	35.64	29.9	3.58
SS8	M	TYCHEM	R5	M2	334	199	140	37.81	36.82	25.3	5.28
SS8	M	TYV	R5	M2	314	187	134	37.70	36.31	33.0	4.81
SS8	M	WC	R5	M2	276	164	130	38.03	36.32	32.4	5.17
SS9	M	CC	R5	M2	331	196	120	37.92	36.71	35.2	4.51
SS9	M	NG	R5	M2	339	201	114	37.88	36.38	32.5	4.16
SS9	M	TYCHEM	R5	M2	363	215	137	38.26	37.06	29.4	5.89
SS9	M	TYV	R5	M2	372	220	120	37.92	36.83	35.1	4.51
SS9	M	WC	R5	M2	359	212	117	37.86	36.16	34.1	4.27

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS1	F	CC	R5	M1	114	74	86	37.81	37.08	38.1	2.71
SS1	F	CC	R5	M2	250	161	136	37.81	35.51	35.4	5.09
SS1	F	CC	R5	M3	309	199	150	37.71	33.21	30.2	5.59
SS1	F	NG	R5	M1	121	78	89	37.09	35.94	35.9	1.65
SS1	F	NG	R5	M2	297	192	111	37.28	35.63	31.7	3.01
SS1	F	NG	R5	M3	348	225	110	37.74	35.21	29.4	3.73
SS1	F	TY1427	R5	M1	128	83	104	37.21	36.16	35.4	2.56
SS1	F	TY1427	R5	M2	257	166	119	37.56	34.69	33.1	3.86
SS1	F	TY1427	R5	M3	376	243	150	38.11	33.22	26.8	6.25
SS1	F	TYCHEM	R5	M1	116	75	108	37.65	36.98	32.8	3.49
SS1	F	TYCHEM	R5	M2	279	180	141	38.17	35.35	23.9	5.93
SS1	F	TYCHEM	R5	M3	385	248	172	38.34	33.63	24.3	7.69
SS1	F	WC	R5	M2	170	110	86	37.01	36.34	38.0	1.37
SS1	F	WC	R5	M2	254	164	120	37.80	36.73	33.2	4.31
SS1	F	WC	R5	M3	384	248	124	37.51	34.66	30.2	4.02
SS10	M	CC	R5	M1	224	133	99	37.57	36.88	38.7	2.93
SS10	M	CC	R5	M2	410	243	116	37.71	36.51	31.9	3.97
SS10	M	CC	R5	M3	534	316	122	37.91	35.68	29.6	4.59
SS10	M	NG	R5	M1	260	154	93	37.38	36.93	34.3	2.32
SS10	M	NG	R5	M2	372	220	110	37.59	36.91	31.1	3.48
SS10	M	NG	R5	M3	542	321	141	38.15	36.16	31.7	5.89
SS10	M	TY1427	R5	M1	215	127	97	37.44	36.78	35.3	2.61
SS10	M	TY1427	R5	M2	345	204	101	37.84	35.91	32.4	3.47
SS10	M	TY1427	R5	M3	568	336	129	38.16	35.38	31.2	5.34
SS10	M	TYCHEM	R5	M1	235	139	104	37.54	37.25	33.2	3.11
SS10	M	TYCHEM	R5	M3	592	350	140	38.53	36.72	23.5	6.48
SS10	M	WC	R5	M1	231	137	108	37.76	36.93	37.5	3.67

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS10	M	WC	R5	M2	385	228	109	37.64	36.01	32.7	3.52
SS10	M	WC	R5	M3	656	388	141	38.41	36.49	31.0	6.33
SS11	F	CC	R5	M1	165	99	97	37.39	36.91	35.7	2.53
SS11	F	CC	R5	M2	260	157	116	37.57	37.30	35.1	3.74
SS11	F	CC	R5	M3	371	223	136	37.78	35.09	30.3	5.04
SS11	F	NG	R5	M1	194	117	117	37.41	37.49	36.8	3.52
SS11	F	NG	R5	M2	301	181	119	37.90	37.02	32.7	4.43
SS11	F	NG	R5	M3	439	264	129	37.36	35.28	29.2	4.00
SS11	F	TY1427	R5	M1	160	96	107	37.49	36.78	36.1	3.17
SS11	F	TY1427	R5	M2	260	157	119	37.39	36.07	33.8	3.58
SS11	F	TY1427	R5	M3	369	222	125	37.59	35.83	30.6	4.20
SS11	F	TYCHEM	R5	M1	167	101	93	37.20	36.48	29.6	2.02
SS11	F	TYCHEM	R5	M2	231	139	119	37.72	37.28	28.6	4.13
SS11	F	TYCHEM	R5	M3	351	211	115	37.27	36.38	25.6	3.19
SS11	F	WC	R5	M1	181	109	106	37.38	36.58	36.6	2.94
SS11	F	WC	R5	M2	295	178	119	37.38	35.95	33.6	3.56
SS11	F	WC	R5	M3	399	240	136	37.73	35.96	31.5	4.95
SS12	F	CC	R5	M1	170	108	135	37.68	37.38	36.9	4.82
SS12	F	CC	R5	M2	307	196	149	37.93	36.53	34.3	5.91
SS12	F	CC	R5	M3	365	232	171	38.06	35.67	33.0	7.17
SS12	F	NG	R5	M1	105	67	142	37.70	37.57	35.4	5.19
SS12	F	NG	R5	M2	290	185	165	38.26	36.12	32.7	7.22
SS12	F	NG	R5	M3	404	257	145	37.86	34.78	28.6	5.60
SS12	F	TY1427	R5	M1	160	102	146	37.90	36.94	37.4	5.71
SS12	F	TY1427	R5	M2	299	190	156	38.21	36.60	34.3	6.71
SS12	F	TY1427	R5	M3	472	301	164	38.34	36.20	32.1	7.30
SS12	F	TYCHEM	R5	M1	152	97	151	37.98	37.58	34.2	6.09

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS12	F	TYCHEM	R5	M1	174	111	164	38.01	37.50	29.6	6.75
SS12	F	TYCHEM	R5	M2	306	195	154	38.08	37.87	26.0	6.40
SS12	F	TYCHEM	R5	M3	384	245	149	38.06	34.86	23.6	6.12
SS12	F	TYCHEM	R5	M3	369	235	172	38.26	36.44	28.2	7.55
SS12	F	WC	R5	M1	157	100	135	37.70	36.83	36.6	4.86
SS12	F	WC	R5	M3	392	250	182	38.23	36.10	31.1	7.98
SS13	M	CC	R5	M1	209	101	126	37.54	36.15	36.0	4.16
SS13	M	CC	R5	M2	354	172	132	38.10	37.00	34.8	5.38
SS13	M	CC	R5	M3	441	214	144	37.98	34.97	32.4	5.75
SS13	M	NG	R5	M1	244	118	120	37.50	36.70	34.9	3.81
SS13	M	NG	R5	M2	356	173	125	37.66	35.85	30.8	4.31
SS13	M	NG	R5	M3	557	270	164	38.84	36.29	29.9	8.14
SS13	M	TY1427	R5	M1	233	113	129	37.84	37.33	38.5	4.80
SS13	M	TY1427	R5	M2	335	163	137	37.86	36.60	35.1	5.22
SS13	M	TY1427	R5	M3	463	225	132	38.16	35.08	30.3	5.48
SS13	M	TYCHEM	R5	M1	211	102	110	37.31	36.96	31.2	3.02
SS13	M	TYCHEM	R5	M2	354	172	136	38.05	36.70	27.6	5.49
SS13	M	TYCHEM	R5	M3	507	246	138	38.53	34.75	24.1	6.38
SS13	M	WC	R5	M1	210	102	117	36.38	36.66	38.6	1.80
SS13	M	WC	R5	M2	476	231	156	37.91	37.46	37.6	6.21
SS13	M	WC	R5	M3	445	216	147	38.13	35.56	30.0	6.15
SS15	M	CC	R5	M1	221	123	109	37.15	36.30	37.1	2.70
SS15	M	CC	R5	M2	318	177	118	37.82	36.21	34.0	4.25
SS15	M	CC	R5	M3	467	259	135	38.19	35.59	32.9	5.67
SS15	M	NG	R5	M1	223	124	112	37.62	36.68	35.0	3.63
SS15	M	NG	R5	M2	332	184	110	37.56	36.14	32.1	3.43
SS15	M	NG	R5	M3	466	259	128	37.73	35.81	29.4	4.57

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS15	M	TY1427	R5	M1	222	123	99	37.39	36.71	34.1	2.63
SS15	M	TY1427	R5	M2	298	166	116	37.84	36.52	35.7	4.19
SS15	M	TY1427	R5	M3	484	269	135	37.83	35.83	38.9	5.07
SS15	M	TYCHEM	R5	M1	188	104	103	37.31	37.02	31.5	2.68
SS15	M	TYCHEM	R5	M2	301	167	116	37.31	36.34	29.8	3.30
SS15	M	TYCHEM	R5	M3	453	252	133	37.65	36.48	25.8	4.68
SS15	M	WC	R5	M1	211	117	113	37.44	36.64	37.7	3.38
SS15	M	WC	R5	M2	285	158	118	37.68	36.55	34.7	4.01
SS15	M	WC	R5	M3	476	264	116	37.78	35.62	30.3	4.09
SS16	M	CC	R5	M1	240	114	108	37.56	36.22	36.5	3.34
SS16	M	CC	R5	M2	341	162	110	37.53	36.28	34.1	3.38
SS16	M	CC	R5	M3	511	242	127	38.09	35.77	32.5	5.13
SS16	M	NG	R5	M1	204	97	121	37.79	36.45	34.9	4.34
SS16	M	NG	R5	M2	340	161	101	37.72	36.25	32.8	3.27
SS16	M	NG	R5	M3	468	222	135	37.90	36.15	30.1	5.19
SS16	M	TY1427	R5	M1	192	91	122	37.71	36.56	37.1	4.25
SS16	M	TY1427	R5	M2	354	168	128	38.67	35.65	32.0	6.14
SS16	M	TY1427	R5	M3	450	213	124	37.75	36.04	33.1	4.42
SS16	M	TYCHEM	R5	M1	266	126	119	37.98	36.97	33.2	4.56
SS16	M	TYCHEM	R5	M1	204	97	116	37.43	37.11	39.0	3.50
SS16	M	TYCHEM	R5	M2	377	179	119	38.28	36.89	28.4	5.06
SS16	M	TYCHEM	R5	M3	467	221	139	37.85	36.42	28.9	5.30
SS16	M	TYCHEM	R5	M3	485	230	136	37.83	36.43	28.0	5.12
SS16	M	WC	R5	M1	223	106	109	37.34	36.35	37.9	3.02
SS16	M	WC	R5	M2	346	164	113	37.83	36.33	35.6	4.03
SS16	M	WC	R5	M3	469	222	126	38.02	35.97	34.5	4.96
SS2	M	CC	R5	M2	385	176	113	37.46	36.10	34.5	3.41

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS2	M	NG	R5	M1	235	107	127	37.53	36.81	36.1	4.19
SS2	M	NG	R5	M2	335	153	120	38.04	36.11	32.2	4.71
SS2	M	NG	R5	M3	474	216	127	38.29	35.57	35.1	5.46
SS2	M	TY1427	R5	M1	191	87	111	37.63	36.83	35.9	3.60
SS2	M	TY1427	R5	M2	399	182	117	37.74	36.79	37.1	4.07
SS2	M	TY1427	R5	M3	459	210	122	38.24	35.67	32.7	5.14
SS2	M	TYCHEM	R5	M2	310	142	101	37.36	36.50	29.2	2.67
SS2	M	TYCHEM	R5	M3	478	218	126	38.05	36.08	25.4	5.01
SS2	M	WC	R5	M1	222	101	123	37.36	36.66	38.3	3.72
SS2	F	WC	R5	M1	249	123	106	37.57	36.89	38.8	3.26
SS2	M	WC	R5	M2	396	181	120	37.80	36.14	34.2	4.31
SS2	M	WC	R5	M3	506	231	131	38.33	36.30	35.1	5.72
SS3	F	CC	R5	M1	240	119	116	37.51	36.50	36.5	3.64
SS3	F	CC	R5	M2	318	157	116	37.63	36.02	33.2	3.84
SS3	F	CC	R5	M3	503	249	142	38.07	36.01	30.1	5.81
SS3	F	NG	R5	M1	234	116	112	37.56	36.25	34.1	3.53
SS3	F	NG	R5	M2	341	169	118	37.80	36.34	31.7	4.21
SS3	F	NG	R5	M3	453	224	131	37.85	35.15	28.0	4.92
SS3	F	TY1427	R5	M1	221	109	114	37.49	37.01	37.5	3.51
SS3	F	TY1427	R5	M2	328	162	113	37.61	36.12	33.5	3.66
SS3	F	TY1427	R5	M3	540	267	138	38.08	35.93	30.9	5.63
SS3	F	TYCHEM	R5	M1	232	115	136	38.05	37.18	30.9	5.49
SS3	F	TYCHEM	R5	M2	275	136	117	37.65	35.85	29.6	3.92
SS3	F	TYCHEM	R5	M3	442	219	138	38.42	36.08	25.6	6.20
SS3	F	WC	R5	M2	351	174	128	37.91	36.59	34.9	4.87
SS3	F	WC	R5	M3	505	250	140	38.10	35.82	30.2	5.76
SS4	M	CC	R5	M1	263	130	96	37.40	36.67	38.4	2.50

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS4	M	CC	R5	M2	411	203	93	37.74	36.02	33.7	2.92
SS4	M	CC	R5	M3	282	140	100	37.84	33.95	28.2	3.42
SS4	M	NG	R5	M1	243	120	95	37.76	36.30	34.4	3.05
SS4	M	NG	R5	M2	398	197	121	38.16	36.20	34.5	4.96
SS4	M	NG	R5	M3	591	293	122	38.14	35.36	30.5	4.97
SS4	M	TY1427	R5	M1	215	106	87	37.23	36.37	37.5	1.79
SS4	M	TY1427	R5	M2	444	220	95	37.76	35.19	33.3	3.05
SS4	M	TY1427	R5	M3	587	291	108	38.05	34.66	29.8	4.15
SS4	M	TYCHEM	R5	M1	257	127	90	37.72	36.66	30.4	2.75
SS4	M	TYCHEM	R5	M2	464	230	95	37.78	35.17	25.7	3.09
SS4	M	TYCHEM	R5	M3	561	278	111	37.77	35.38	23.3	3.83
SS4	M	WC	R5	M1	290	144	95	37.62	36.13	36.5	2.82
SS4	M	WC	R5	M2	441	218	105	37.94	35.69	34.3	3.83
SS4	M	WC	R5	M3	465	230	95	37.91	34.86	32.0	3.30
SS5	M	CC	R5	M1	289	143	102	37.19	36.30	35.2	2.44
SS5	M	CC	R5	M2	406	201	106	37.45	35.73	34.3	3.06
SS5	M	CC	R5	M3	476	236	110	37.88	35.45	32.1	3.97
SS5	M	NG	R5	M1	249	123	111	37.44	36.48	34.9	3.28
SS5	M	NG	R5	M2	374	185	107	37.57	35.47	29.9	3.31
SS5	M	NG	R5	M3	489	242	108	37.46	35.16	27.5	3.17
SS5	M	TY1427	R5	M1	252	125	121	37.69	36.61	36.2	4.17
SS5	M	TY1427	R5	M2	377	187	110	37.81	36.42	33.6	3.85
SS5	M	TY1427	R5	M3	453	224	105	37.33	34.65	30.0	2.81
SS5	M	TYCHEM	R5	M1	272	135	113	37.17	36.46	28.6	2.93
SS5	M	TYCHEM	R5	M2	356	176	115	37.47	36.72	29.0	3.52
SS5	M	TYCHEM	R5	M3	525	260	130	37.50	35.74	23.5	4.29
SS5	M	WC	R5	M1	286	142	103	37.71	35.74	34.8	3.35

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS5	M	WC	R5	M2	388	192	110	37.80	36.06	32.2	3.83
SS5	M	WC	R5	M3	477	236	112	37.51	34.52	30.9	3.45
SS6	M	CC	R5	M1	229	108	74	37.19	35.55	35.5	1.10
SS6	M	CC	R5	M2	347	163	85	37.16	36.02	33.7	1.58
SS6	M	CC	R5	M3	503	236	102	37.77	36.36	34.5	3.40
SS6	M	NG	R5	M1	251	118	78	37.37	36.76	35.1	1.59
SS6	M	NG	R5	M2	361	169	88	37.33	36.21	31.7	2.00
SS6	M	NG	R5	M3	578	271	103	37.79	35.68	30.2	3.48
SS6	M	TY1427	R5	M1	227	107	73	37.04	36.26	35.4	0.80
SS6	M	TY1427	R5	M2	323	152	90	37.20	36.04	34.9	1.88
SS6	M	TY1427	R5	M3	415	195	93	37.85	35.65	38.1	3.11
SS6	M	TYCHEM	R5	M1	247	116	75	37.69	36.94	32.0	1.98
SS6	M	TYCHEM	R5	M2	341	160	90	37.28	36.00	27.2	2.01
SS6	M	TYCHEM	R5	M3	513	241	103	37.34	35.52	23.4	2.73
SS6	M	WC	R5	M1	241	113	82	37.59	36.24	36.5	2.15
SS6	M	WC	R5	M2	364	171	73	37.50	35.38	32.5	1.57
SS6	M	WC	R5	M3	511	240	91	37.53	35.78	32.8	2.48
SS7	M	CC	R5	M1	268	139	96	37.13	35.72	34.6	2.05
SS7	M	CC	R5	M2	339	176	116	37.71	36.41	35.8	3.97
SS7	M	CC	R5	M3	636	330	105	37.52	35.66	31.4	3.13
SS7	M	NG	R5	M1	202	105	107	37.84	36.73	34.9	3.76
SS7	M	NG	R5	M2	339	176	110	37.66	36.66	33.1	3.60
SS7	M	NG	R5	M3	592	307	109	37.62	35.06	28.7	3.49
SS7	M	TY1427	R5	M1	220	114	112	37.43	36.04	36.1	3.31
SS7	M	TY1427	R5	M2	363	188	107	37.62	36.68	34.5	3.39
SS7	M	TYCHEM	R5	M1	221	115	106	37.43	36.29	31.8	3.03
SS7	M	TYCHEM	R5	M2	335	174	122	38.12	36.48	28.6	4.94

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS7	M	TYCHEM	R5	M3	497	258	113	37.96	35.13	21.6	4.24
SS7	M	WC	R5	M1	230	119	100	37.22	35.58	35.7	2.39
SS7	M	WC	R5	M2	343	178	103	37.70	36.19	33.9	3.33
SS7	M	WC	R5	M3	507	263	109	37.97	35.68	32.0	4.07
SS8	M	CC	R5	M1	171	102	115	37.10	36.07	34.4	2.90
SS8	M	CC	R5	M2	306	182	122	37.46	35.74	32.5	3.84
SS8	M	CC	R5	M3	447	266	146	37.92	35.89	30.6	5.75
SS8	M	NG	R5	M1	172	102	109	37.42	36.61	33.0	3.15
SS8	M	NG	R5	M2	270	161	119	37.39	35.64	29.9	3.58
SS8	M	NG	R5	M3	408	243	161	38.20	36.40	27.9	6.93
SS8	M	TY1427	R5	M1	171	102	101	36.74	35.75	31.6	1.64
SS8	M	TY1427	R5	M2	314	187	134	37.70	36.31	33.0	4.81
SS8	M	TY1427	R5	M3	404	240	145	37.69	35.80	31.1	5.32
SS8	M	TYCHEM	R5	M2	334	199	140	37.81	36.82	25.3	5.28
SS8	M	TYCHEM	R5	M3	360	214	135	38.00	35.74	24.4	5.36
SS8	M	WC	R5	M1	176	105	118	37.40	36.89	35.3	3.55
SS8	M	WC	R5	M2	276	164	130	38.03	36.32	32.4	5.17
SS8	M	WC	R5	M3	416	248	159	38.12	36.48	31.2	6.70
SS9	M	CC	R5	M2	331	196	120	37.92	36.71	35.2	4.51
SS9	M	CC	R5	M3	487	288	123	37.91	36.18	33.3	4.64
SS9	M	NG	R5	M1	252	149	132	38.11	37.26	34.9	5.40
SS9	M	NG	R5	M2	339	201	114	37.88	36.38	32.5	4.16
SS9	M	NG	R5	M3	527	312	130	38.04	35.69	29.6	5.19
SS9	M	TY1427	R5	M1	243	144	142	37.96	37.07	37.7	5.62
SS9	M	TY1427	R5	M2	372	220	120	37.92	36.83	35.1	4.51
SS9	M	TY1427	R5	M3	520	308	139	38.24	36.73	34.1	5.95
SS9	M	TYCHEM	R5	M1	278	164	133	38.13	37.02	29.9	5.48

Appendix B (Continued)

Experimental Data – Subset

ID	GENDER	Ensemble	RHL	ML	MR	MSA	HR	T_{re}	T_{sk}	$WBGT_{crit}$	PSI
SS9	M	TYCHEM	R5	M2	363	215	137	38.26	37.06	29.4	5.89
SS9	M	TYCHEM	R5	M3	634	375	139	38.33	36.26	25.3	6.10
SS9	M	WC	R5	M1	343	203	119	37.91	36.40	36.4	4.45
SS9	M	WC	R5	M2	359	212	117	37.86	36.16	34.1	4.27
SS9	M	WC	R5	M3	520	308	133	38.15	35.95	30.1	5.51

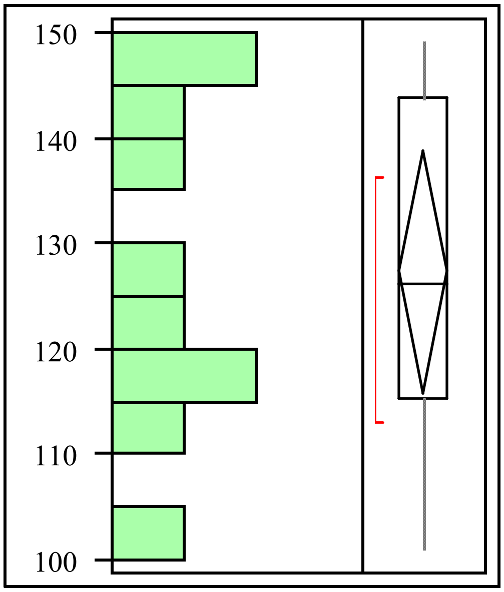
APPENDIX C

DATA ANALYSIS

GENDER=F, Ensemble=CC

Distributions

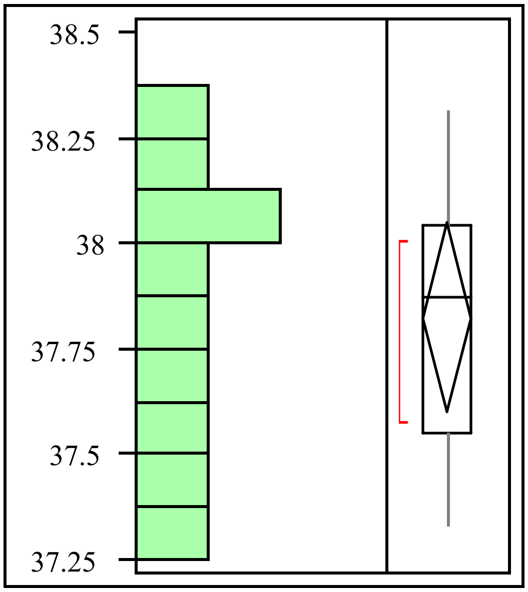
HR



Moments

Mean	127.2
Std Dev	16.005555
Std Err Mean	5.0614008
upper 95% Mean	138.64968
lower 95% Mean	115.75032
N	10

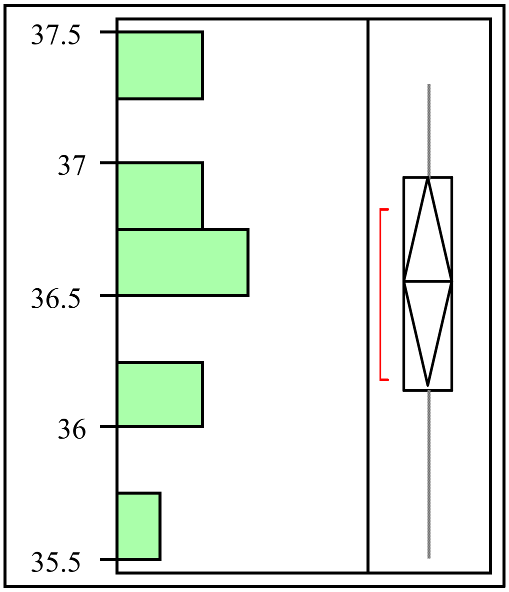
Tre



Moments

Mean	37.82
Std Dev	0.313971
Std Err Mean	0.0992863
upper 95% Mean	38.044601
lower 95% Mean	37.595399
N	10

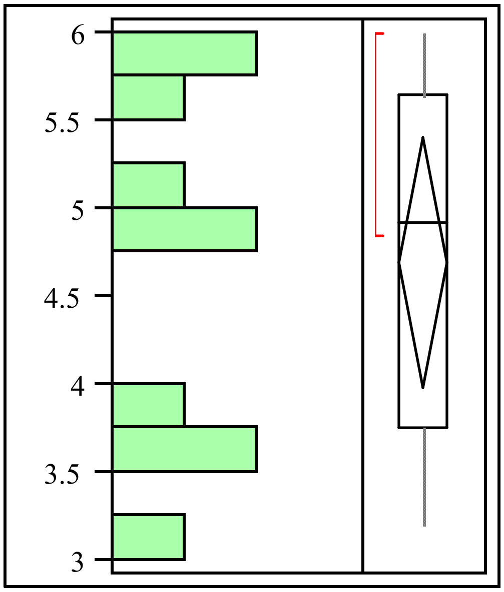
Tsk



Moments

Mean	36.553
Std Dev	0.5518718
Std Err Mean	0.1745172
upper 95% Mean	36.947785
lower 95% Mean	36.158215
N	10

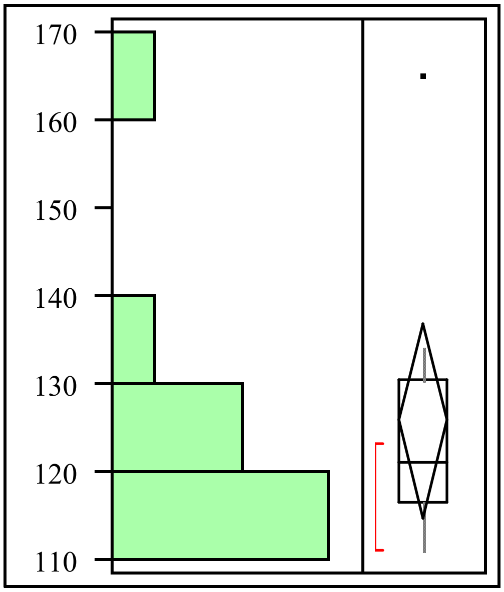
PSI



Moments

Mean	4.6857143
Std Dev	0.9972904
Std Err Mean	0.3153709
upper 95% Mean	5.3991328
lower 95% Mean	3.9722957
N	10

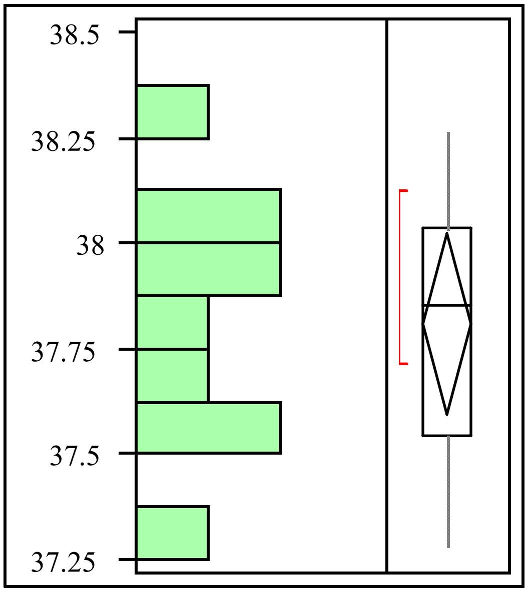
GENDER=F, Ensemble=NG
Distributions
HR



Moments

Mean	125.7
Std Dev	15.513793
Std Err Mean	4.9058921
upper 95% Mean	136.7979
lower 95% Mean	114.6021
N	10

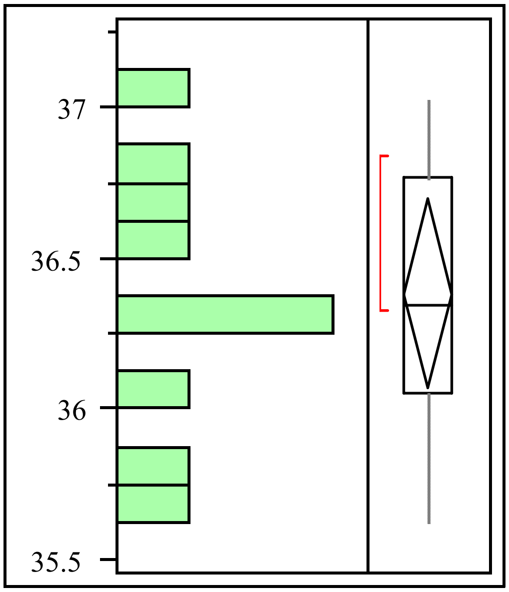
Tre



Moments

Mean	37.806
Std Dev	0.2991915
Std Err Mean	0.0946127
upper 95% Mean	38.020029
lower 95% Mean	37.591971
N	10

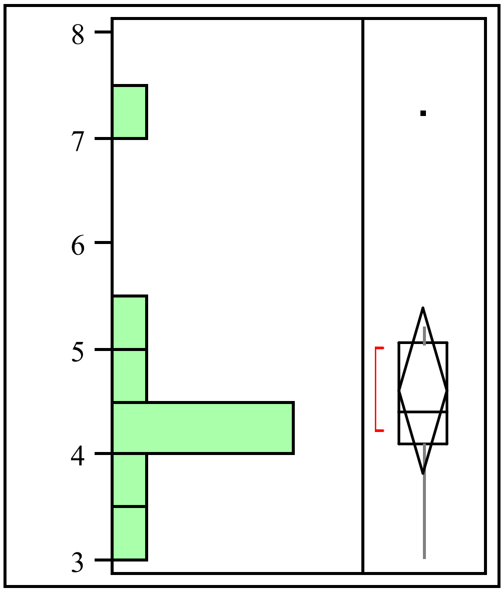
Tsk



Moments

Mean	36.3776
Std Dev	0.4368196
Std Err Mean	0.1381345
upper 95% Mean	36.690082
lower 95% Mean	36.065118
N	10

PSI



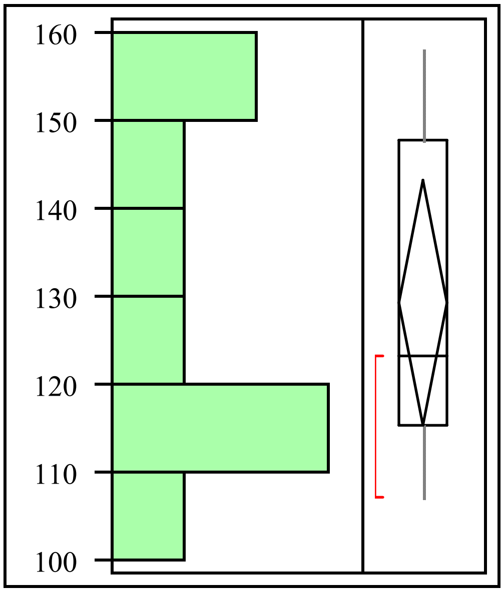
Moments

Mean	4.5909524
Std Dev	1.1075418
Std Err Mean	0.3502355
upper 95% Mean	5.38324
lower 95% Mean	3.7986647
N	10

GENDER=F, Ensemble=TYCHEM

Distributions

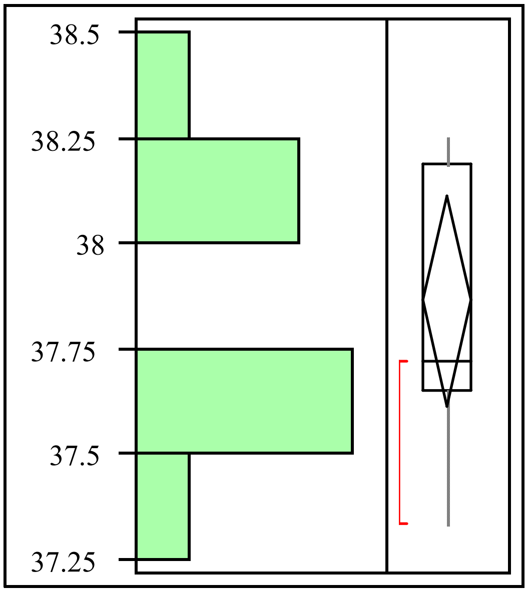
HR



Moments

Mean	129.11111
Std Dev	18.134528
Std Err Mean	6.0448427
upper 95% Mean	143.05054
lower 95% Mean	115.17168
N	9

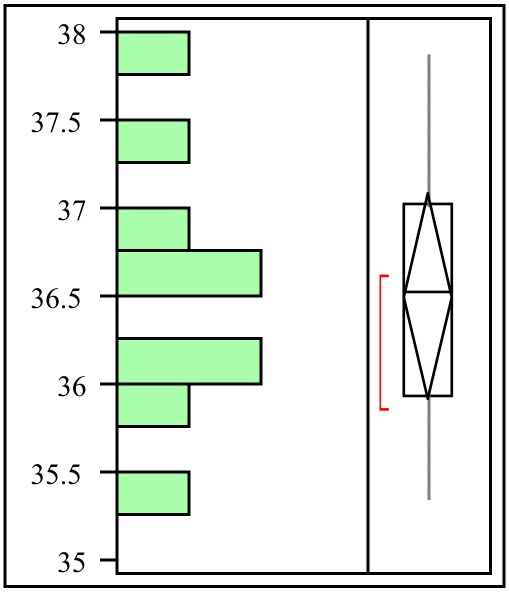
Tre



Moments

Mean	37.86
Std Dev	0.3222577
Std Err Mean	0.1074192
upper 95% Mean	38.107709
lower 95% Mean	37.612291
N	9

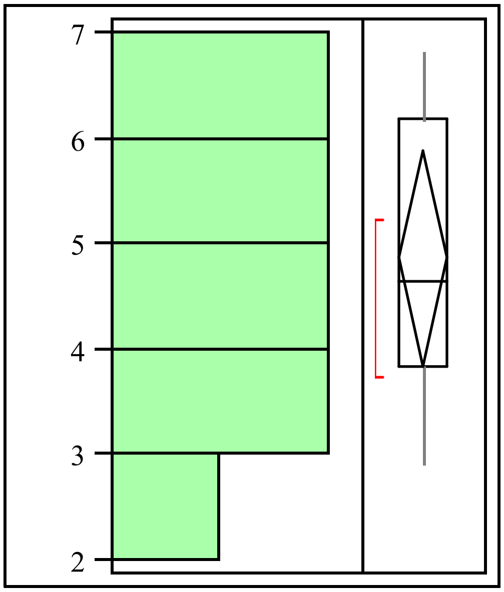
Tsk



Moments

Mean	36.489667
Std Dev	0.7606517
Std Err Mean	0.2535506
upper 95% Mean	37.074355
lower 95% Mean	35.904978
N	9

PSI



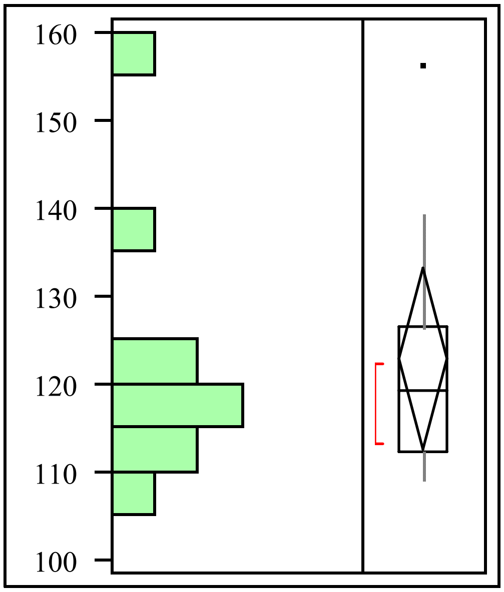
Moments

Mean	4.8433862
Std Dev	1.319896
Std Err Mean	0.4399653
upper 95% Mean	5.8579481
lower 95% Mean	3.8288243
N	9

GENDER=F, Ensemble=TYV

Distributions

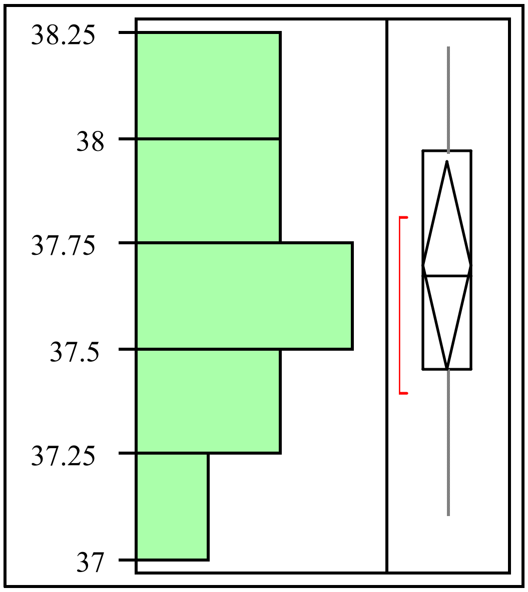
HR



Moments

Mean	122.6
Std Dev	14.41604
Std Err Mean	4.5587523
upper 95% Mean	132.91261
lower 95% Mean	112.28739
N	10

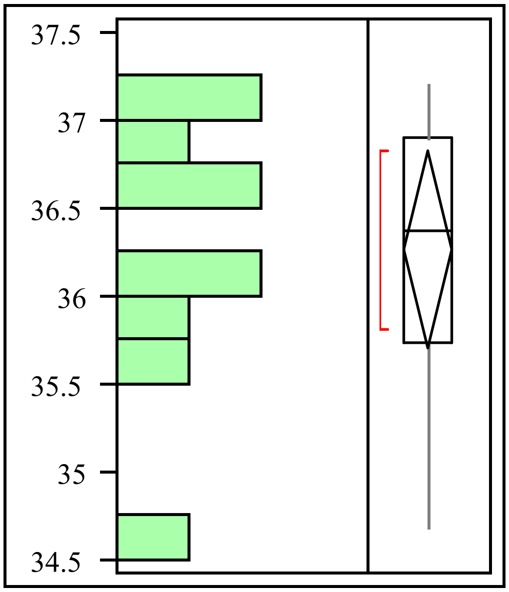
Tre



Moments

Mean	37.695
Std Dev	0.341443
Std Err Mean	0.1079738
upper 95% Mean	37.939254
lower 95% Mean	37.450746
N	10

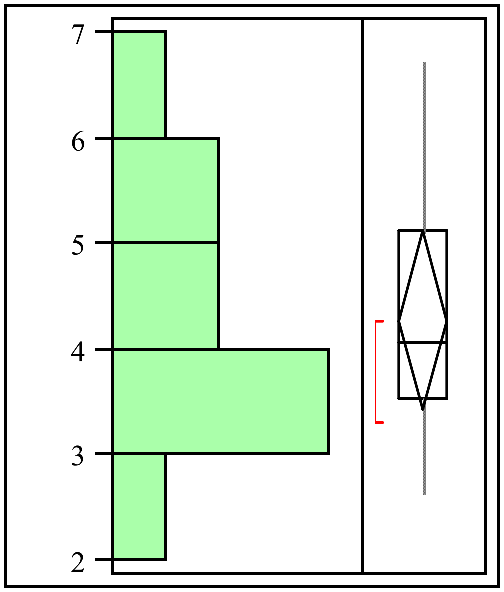
Tsk



Moments

Mean	36.2621
Std Dev	0.7794683
Std Err Mean	0.2464895
upper 95% Mean	36.819698
lower 95% Mean	35.704502
N	10

PSI



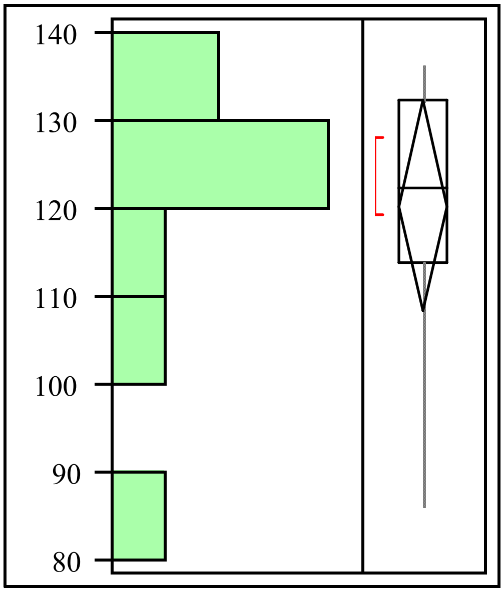
Moments

Mean	4.2583333
Std Dev	1.1726744
Std Err Mean	0.3708322
upper 95% Mean	5.0972141
lower 95% Mean	3.4194526
N	10

GENDER=F, Ensemble=WC

Distributions

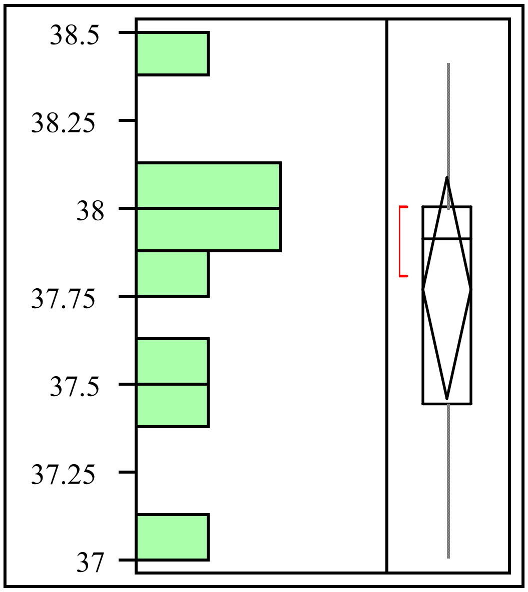
HR



Moments

Mean	120.11111
Std Dev	15.479377
Std Err Mean	5.1597923
upper 95% Mean	132.00961
lower 95% Mean	108.21261
N	9

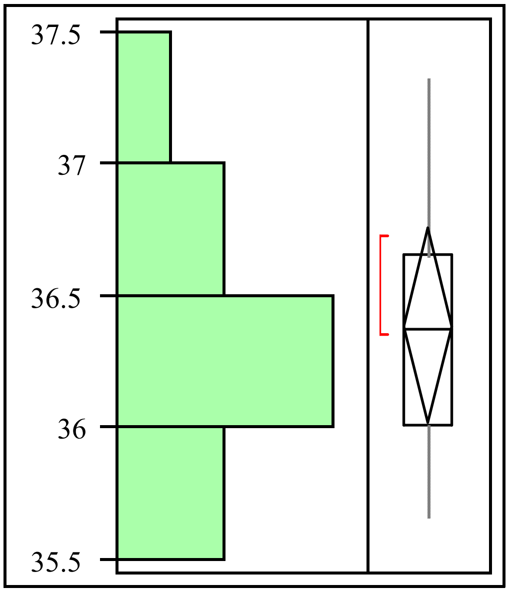
Tre



Moments

Mean	37.768889
Std Dev	0.4120208
Std Err Mean	0.1373403
upper 95% Mean	38.085596
lower 95% Mean	37.452182
N	9

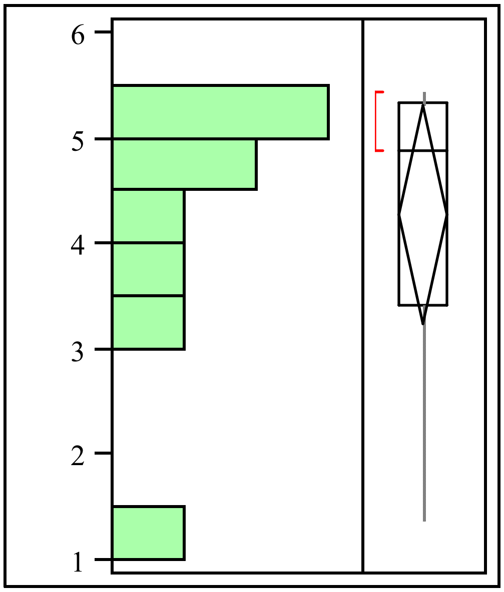
Tsk



Moments

Mean	36.380778
Std Dev	0.4811327
Std Err Mean	0.1603776
upper 95% Mean	36.750609
lower 95% Mean	36.010946
N	9

PSI



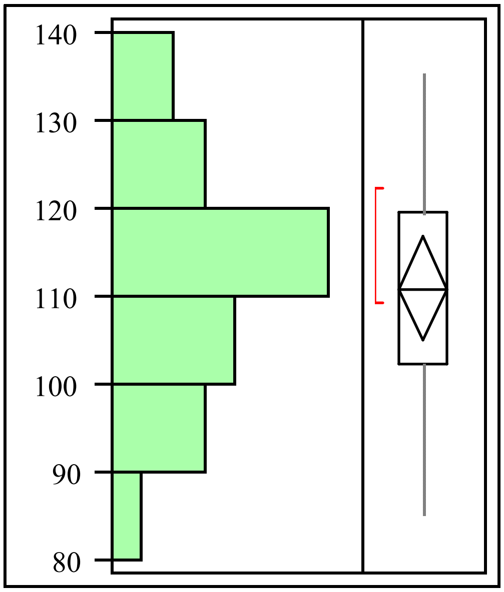
Moments

Mean	4.262963
Std Dev	1.338693
Std Err Mean	0.446231
upper 95% Mean	5.2919735
lower 95% Mean	3.2339524
N	9

GENDER=M, Ensemble=CC

Distributions

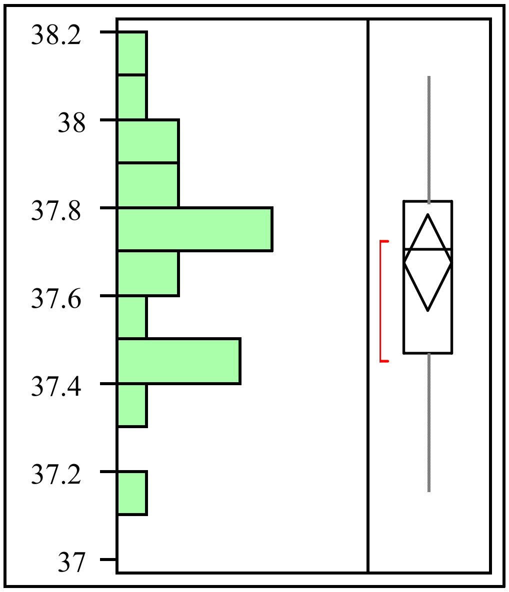
HR



Moments

Mean	110.75
Std Dev	12.706712
Std Err Mean	2.8413071
upper 95% Mean	116.69692
lower 95% Mean	104.80308
N	20

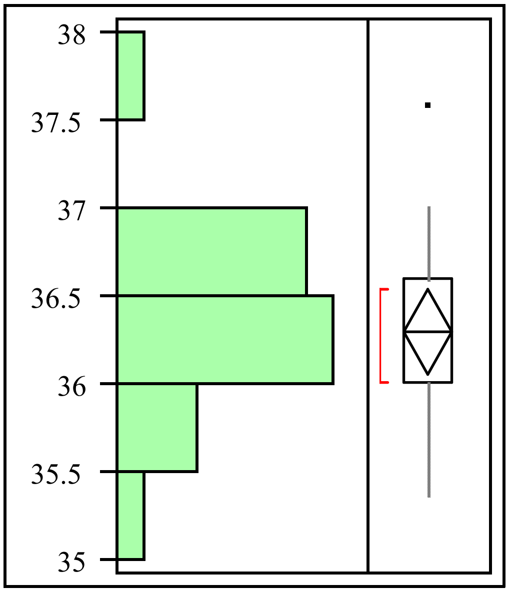
Tre



Moments

Mean	37.671
Std Dev	0.2340468
Std Err Mean	0.0523345
upper 95% Mean	37.780537
lower 95% Mean	37.561463
N	20

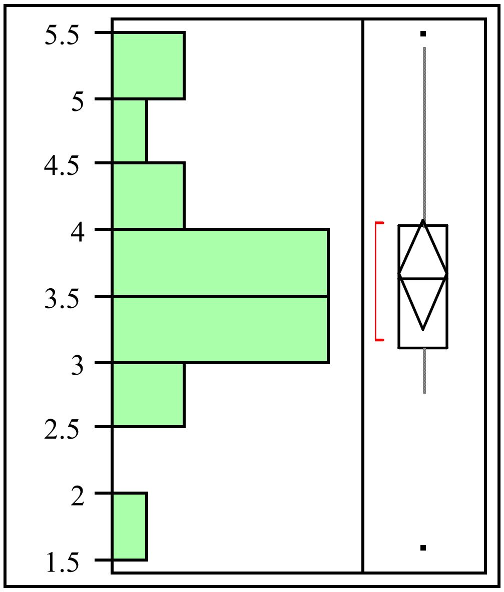
Tsk



Moments

Mean	36.2933
Std Dev	0.5158137
Std Err Mean	0.1153395
upper 95% Mean	36.534708
lower 95% Mean	36.051892
N	20

PSI



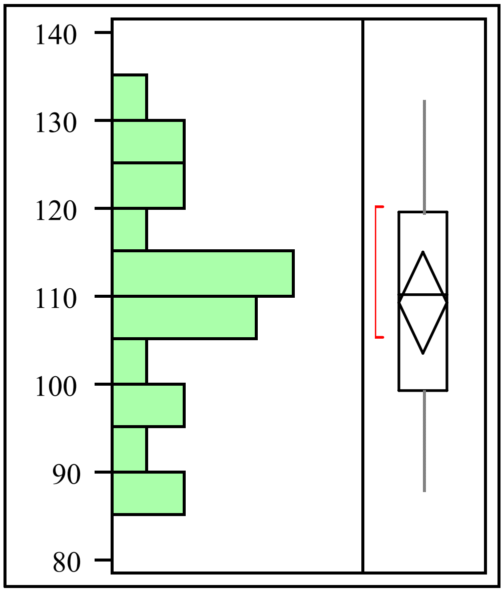
Moments

Mean	3.6540476
Std Dev	0.8817449
Std Err Mean	0.1971642
upper 95% Mean	4.0667169
lower 95% Mean	3.2413783
N	20

GENDER=M, Ensemble=NG

Distributions

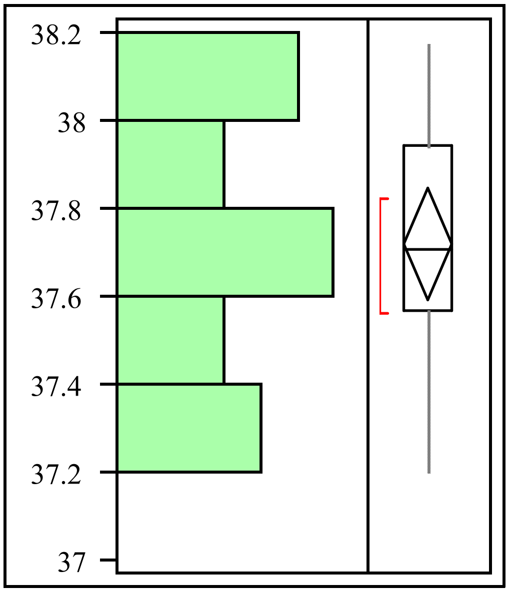
HR



Moments

Mean	109.09524
Std Dev	12.565448
Std Err Mean	2.7420055
upper 95% Mean	114.81496
lower 95% Mean	103.37551
N	21

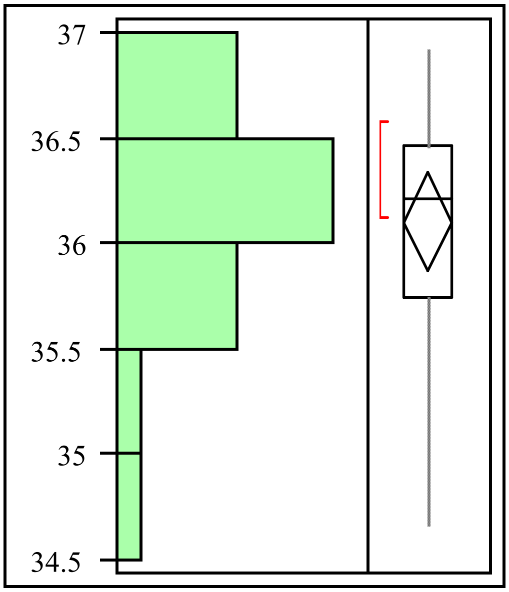
Tre



Moments

Mean	37.715238
Std Dev	0.2755834
Std Err Mean	0.0601372
upper 95% Mean	37.840682
lower 95% Mean	37.589794
N	21

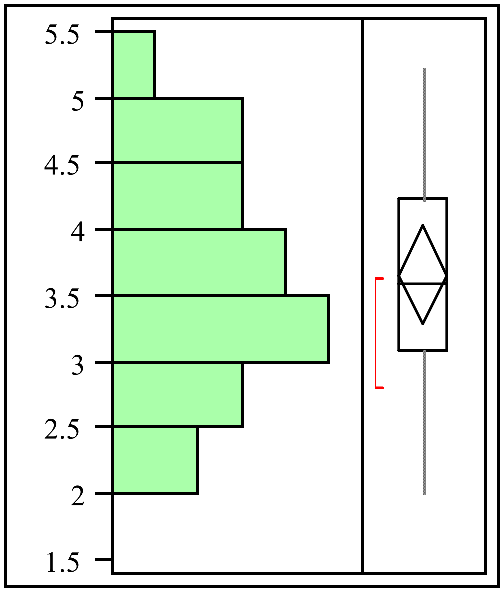
Tsk



Moments

Mean	36.095524
Std Dev	0.5160604
Std Err Mean	0.1126136
upper 95% Mean	36.330432
lower 95% Mean	35.860616
N	21

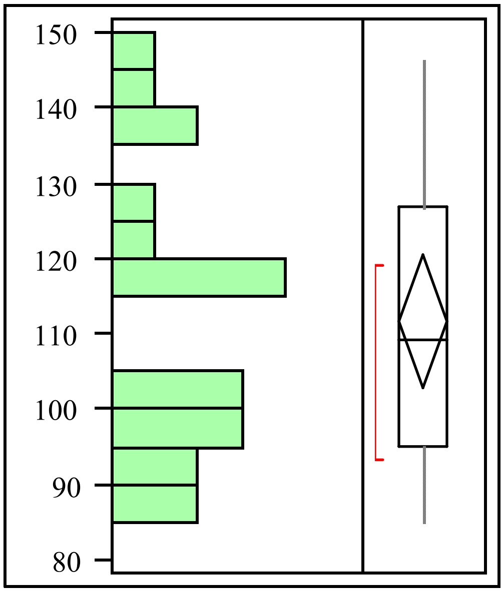
PSI



Moments

Mean	3.6489796
Std Dev	0.8370975
Std Err Mean	0.1826696
upper 95% Mean	4.0300218
lower 95% Mean	3.2679374
N	21

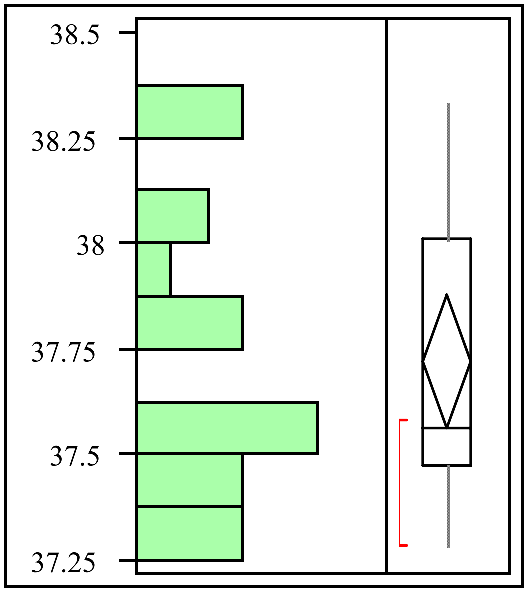
GENDER=M, Ensemble=TYCHEM
Distributions
HR



Moments

Mean	111.3
Std Dev	18.893329
Std Err Mean	4.2246769
upper 95% Mean	120.14235
lower 95% Mean	102.45765
N	20

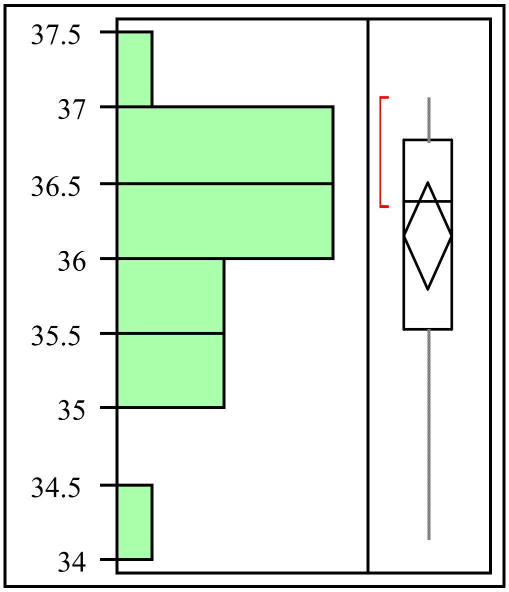
Tre



Moments

Mean	37.715
Std Dev	0.3392329
Std Err Mean	0.0758548
upper 95% Mean	37.873766
lower 95% Mean	37.556234
N	20

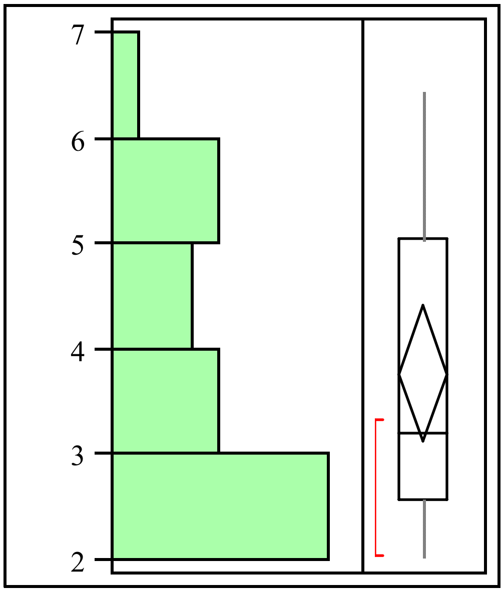
Tsk



Moments

Mean	36.1371
Std Dev	0.7555119
Std Err Mean	0.1689376
upper 95% Mean	36.49069
lower 95% Mean	35.78351
N	20

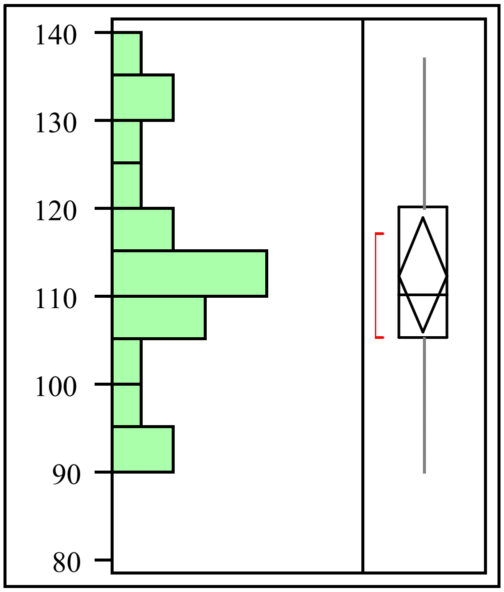
PSI



Moments

Mean	3.7535714
Std Dev	1.3756515
Std Err Mean	0.307605
upper 95% Mean	4.3973961
lower 95% Mean	3.1097467
N	20

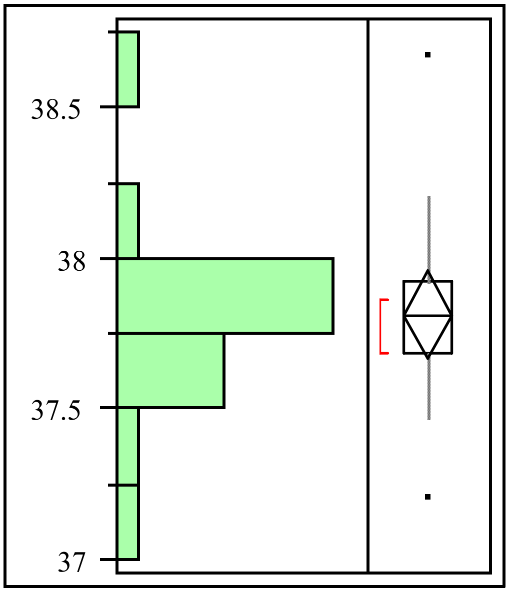
GENDER=M, Ensemble=TYV
Distributions
HR



Moments

Mean	112.15789
Std Dev	13.557545
Std Err Mean	3.1103141
upper 95% Mean	118.69242
lower 95% Mean	105.62337
N	19

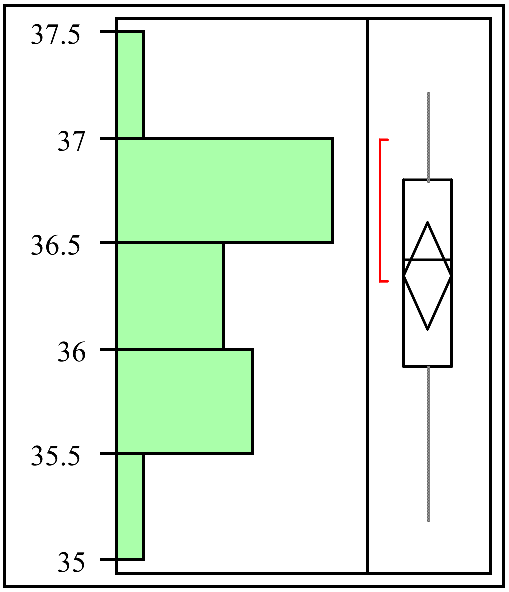
Tre



Moments

Mean	37.807895
Std Dev	0.2966213
Std Err Mean	0.0680496
upper 95% Mean	37.950862
lower 95% Mean	37.664928
N	19

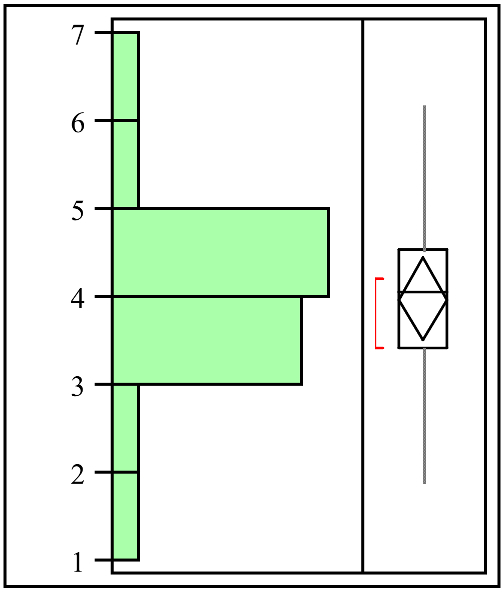
Tsk



Moments

Mean	36.337316
Std Dev	0.5329635
Std Err Mean	0.1222702
upper 95% Mean	36.594196
lower 95% Mean	36.080436
N	19

PSI



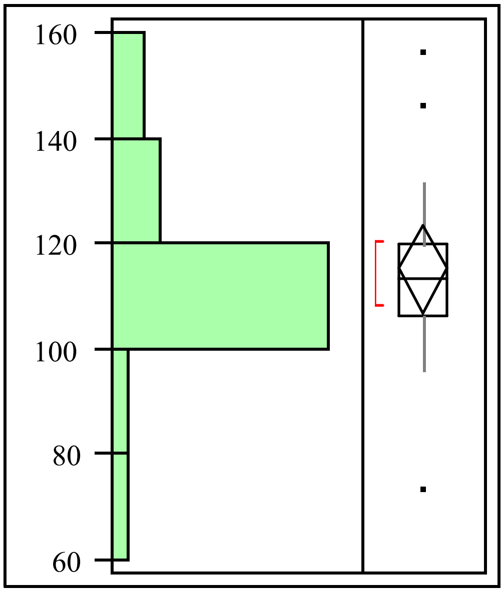
Moments

Mean	3.9492481
Std Dev	0.969536
Std Err Mean	0.2224268
upper 95% Mean	4.4165495
lower 95% Mean	3.4819467
N	19

GENDER=M, Ensemble=WC

Distributions

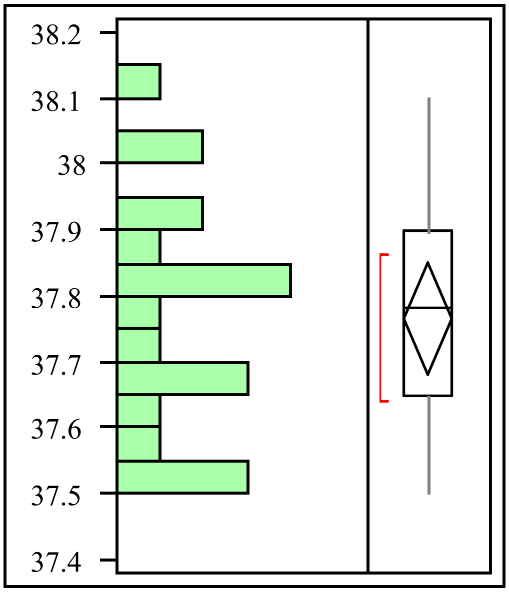
HR



Moments

Mean	114.85
Std Dev	17.496691
Std Err Mean	3.9123791
upper 95% Mean	123.0387
lower 95% Mean	106.6613
N	20

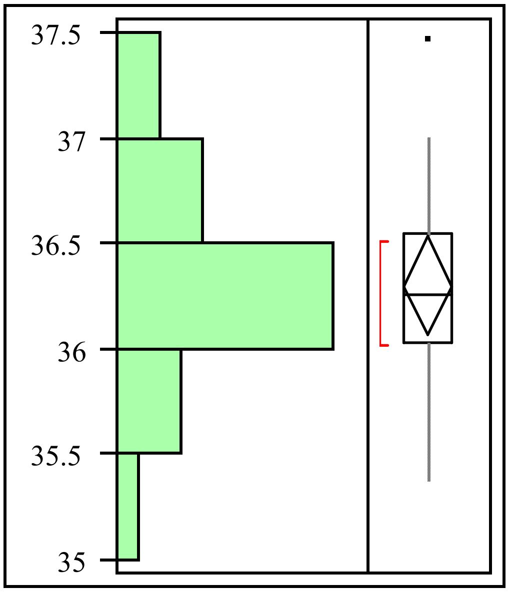
Tre



Moments

Mean	37.764
Std Dev	0.1792499
Std Err Mean	0.0400815
upper 95% Mean	37.847892
lower 95% Mean	37.680108
N	20

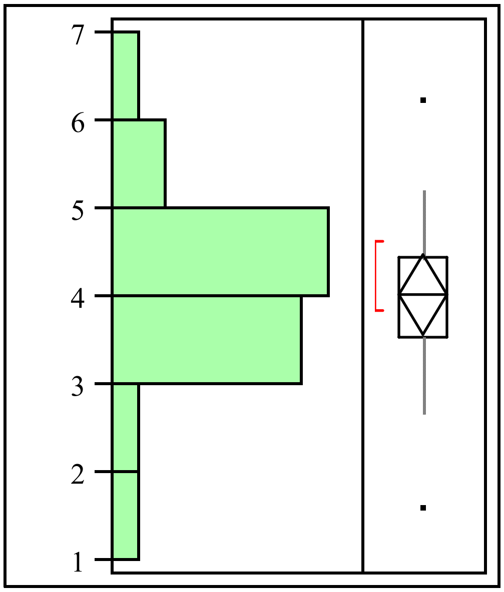
Tsk



Moments

Mean	36.2933
Std Dev	0.4920157
Std Err Mean	0.1100181
upper 95% Mean	36.52357
lower 95% Mean	36.06303
N	20

PSI



Moments

Mean	4.0042857
Std Dev	0.9572263
Std Err Mean	0.2140423
upper 95% Mean	4.4522814
lower 95% Mean	3.55629
N	20

Least Squares Fit
Response MR
Whole Model
Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
GENDER	1	1	171798.09	141.6154	<.0001
Ensemble	4	4	5218.17	1.0754	0.3721
ID[GENDER]	28	28	400153.85	11.7804	<.0001

GENDER
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	277.21045	5.1143628	269.646
M	351.54755	3.5785060	347.430

Ensemble
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
CC	307.89104	6.4959604	315.733
NG	306.58908	6.4180577	315.710
TYCHEM	320.47817	6.6641313	327.207
TYV	319.98621	6.5763847	328.966
WC	316.95048	6.6773862	324.069

ID[GENDER]
Response MSA
Whole Model
Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
GENDER	1	1	11065.93	36.0548	<.0001
Ensemble	4	4	999.30	0.8140	0.5188
ID[GENDER]	28	28	106323.97	12.3722	<.0001

GENDER
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	153.90953	2.5724696	152.395
M	172.77598	1.7999501	171.521

Ensemble
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
CC	160.45285	3.2673983	162.288
NG	159.99514	3.2282141	162.356
TYCHEM	166.31736	3.3519865	167.447
TYV	165.46301	3.3078509	168.440

Level	**Least Sq Mean**	**Std Error**	**Mean**
WC	164.48540	3.3586536	166.367

ID[GENDER]

Response WBGT
Whole Model
Summary of Fit

RSquare	0.851683
RSquare Adj	0.808749
Root Mean Square Error	1.417156
Mean of Response	32.71224
Observations (or Sum Wgts)	148

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	33	1314.6997	39.8394	19.8371
Error	114	228.9497	2.0083	**Prob > F**
C. Total	147	1543.6494		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	109	212.77956	1.95211	0.6036
Pure Error	5	16.17011	3.23402	**Prob > F**
Total Error	114	228.94968		0.8488
				Max RSq
				0.9895

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
GENDER	1	1	9.1983	4.5801	0.0345
Ensemble	4	4	1165.7700	145.1168	<.0001
ID[GENDER]	28	28	125.5953	2.2335	0.0016

GENDER
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
F	33.143711	0.20809193	33.1341
M	32.599773	0.14560137	32.5098

Ensemble
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CC	35.110741	0.26430603	34.9427
NG	32.542649	0.26113634	32.3418
TYCHEM	27.456306	0.27114852	27.3203
TYV	34.267264	0.26757831	34.0945
WC	34.981749	0.27168784	34.8105

ID[GENDER]

Least Squares Fit

Response Tre

Whole Model

Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
GENDER	1	1	0.1091280	2.1312	0.1472
Ensemble	4	4	0.0148255	0.0724	0.9903
ID[GENDER]	28	28	6.2388656	4.3515	<.0001
GENDER*Ensemble	4	4	0.2808914	1.3714	0.2485

GENDER

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	37.783761	0.03333006	37.7890
M	37.724429	0.02325649	37.7337

Power Details

Test

GENDER

Power

Alpha	**Sigma**	**Delta**	**Number**	**Power**
0.0500	0.226284	0.027154	148	0.3044

Ensemble

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
CC	37.742306	0.04406991	37.7207
NG	37.749053	0.04376613	37.7445
TYCHEM	37.759812	0.04608021	37.7600
TYV	37.746346	0.04439274	37.7690
WC	37.772957	0.04667123	37.7655

Power Details

Test

Ensemble

Power

Alpha	**Sigma**	**Delta**	**Number**	**Power**
0.0500	0.226284	0.010009	148	0.0641

ID[GENDER]

GENDER*Ensemble

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**
F,CC	37.820000	0.07155743
F,NG	37.806000	0.07155743

```
Level             Least Sq Mean            Std Error
F,TYCHEM              37.815889           0.07667499
F,TYV                 37.695000           0.07155743
F,WC                  37.781915           0.07843840
M,CC                  37.664613           0.05146030
M,NG                  37.692106           0.05041260
M,TYCHEM              37.703736           0.05113206
M,TYV                 37.797691           0.05255849
M,WC                  37.764000           0.05059875
Response HR
Whole Model
Effect Tests
Source               Nparm     DF   Sum of Squares     F Ratio     Prob > F
GENDER                   1      1         6059.321     57.8534       <.0001
Ensemble                 4      4           92.493      0.2208       0.9263
ID[GENDER]              28     28        21501.783      7.3320       <.0001
GENDER*Ensemble          4      4          439.719      1.0496       0.3851

GENDER
Least Squares Means Table
Level        Least Sq Mean          Std Error        Mean
F                125.88340          1.5074011     124.958
M                111.90266          1.0518089     111.600

Ensemble
Least Squares Means Table
Level            Least Sq Mean          Std Error        Mean
CC                   119.33038          1.9931266     116.233
NG                   118.03283          1.9793876     114.452
TYCHEM               119.73528          2.0840450     116.828
TYV                  117.69612          2.0077268     115.759
WC                   119.67055          2.1107751     116.483
Power Details
Test
Ensemble
Power Details
Test
Ensemble

Power
     Alpha         Sigma        Delta     Number      Power
    0.0500      10.23405     0.790538        148     0.0962

ID[GENDER]
```

GENDER*Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	127.20000	3.2362901
F,NG	125.70000	3.2362901
F,TYCHEM	129.42593	3.4677391
F,TYV	122.60000	3.2362901
F,WC	124.49110	3.5474921
M,CC	111.46075	2.3273679
M,NG	110.36567	2.2799839
M,TYCHEM	110.04462	2.3125225
M,TYV	112.79225	2.3770348
M,WC	114.85000	2.2884027

Response Tsk

Whole Model

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
GENDER	1	1	1.203569	4.6204	0.0338
Ensemble	4	4	0.475687	0.4565	0.7674
ID[GENDER]	28	28	18.692422	2.5628	0.0003
GENDER*Ensemble	4	4	0.604577	0.5802	0.6776

GENDER

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
F	36.422108	0.07517557	36.4117
M	36.225068	0.05245474	36.2289

Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CC	36.410652	0.09939918	36.3799
NG	36.252987	0.09871399	36.1865
TYCHEM	36.285505	0.10393336	36.2465
TYV	36.289676	0.10012730	36.3114
WC	36.379119	0.10526642	36.3204

Power Details

Test

Ensemble

Power

Alpha	Sigma	Delta	Number	Power
0.0500	0.510382	0.056693	148	0.1542

ID[GENDER]

GENDER*Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	36.553000	0.16139695
F,NG	36.377600	0.16139695
F,TYCHEM	36.452900	0.17293954
F,TYV	36.262100	0.16139695
F,WC	36.464938	0.17691690
M,CC	36.268303	0.11606811
M,NG	36.128375	0.11370503
M,TYCHEM	36.118109	0.11532776
M,TYV	36.317252	0.11854505
M,WC	36.293300	0.11412488

Response PSI

Whole Model

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
GENDER	1	1	18.124775	31.4221	<.0001
Ensemble	4	4	0.356015	0.1543	0.9607
ID[GENDER]	28	28	96.263605	5.9603	<.0001
GENDER*Ensemble	4	4	3.187918	1.3817	0.2450

GENDER

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
F	4.5626204	0.11186649	4.52723
M	3.7979845	0.07805631	3.79902

Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CC	4.1814810	0.14791290	3.99794
NG	4.1309371	0.14689330	3.95284
TYCHEM	4.2299382	0.15466009	4.09179
TYV	4.1103914	0.14899640	4.05583
WC	4.2487644	0.15664377	4.08456

Power Details

Test

Ensemble

Power

Alpha	Sigma	Delta	Number	Power
0.0500	0.759484	0.049046	148	0.0813

ID[GENDER]

GENDER*Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	4.6857143	0.24016992
F,NG	4.5909524	0.24016992
F,TYCHEM	4.7848589	0.25734609
F,TYV	4.2583333	0.24016992
F,WC	4.4932431	0.26326468
M,CC	3.6772478	0.17271745
M,NG	3.6709219	0.16920101
M,TYCHEM	3.6750176	0.17161575
M,TYV	3.9624494	0.17640330
M,WC	4.0042857	0.16982578

Least Squares Fit
Response MSA
Whole Model
Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
ML	2	2	567744.40	558.0851	<.0001
GENDER	1	1	3379.99	6.6450	0.0107
Ensemble	4	4	819.21	0.4026	0.8066
GENDER*Ensemble	4	4	1869.79	0.9190	0.4539
ID[GENDER]	14	14	89177.15	12.5228	<.0001
GENDER*ML	2	2	207.55	0.2040	0.8156

ML
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
M1	111.67242	3.4655702	114.732
M2	179.55324	3.8225026	180.043
M3	252.08461	3.7746999	253.812

GENDER
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	173.94310	5.2588656	170.489
M	188.26374	1.7907827	188.875

Ensemble
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
CC	177.98690	4.5545482	181.990
NG	183.68601	4.5059642	185.070
TY1427	181.49371	4.5203980	179.170
TYCHEM	179.25844	4.3804743	184.508
WC	183.09206	4.1402492	188.117

GENDER*Ensemble
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**
F,CC	169.58810	8.1117875
F,NG	177.87204	8.1117875
F,TY1427	179.84698	8.1117875
F,TYCHEM	168.10401	7.7851015
F,WC	174.30439	7.2906034
M,CC	186.38570	4.1442179
M,NG	189.49998	3.9260357
M,TY1427	183.14043	3.9918538
M,TYCHEM	190.41287	4.0182602

Level	**Least Sq Mean**	**Std Error**
M,WC	191.87972	3.9260357

ID[GENDER]

GENDER*ML

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**
F,M1	102.97529	6.1761336
F,M2	173.46620	7.0007304
F,M3	245.38782	6.8937147
M,M1	120.36956	3.1458038
M,M2	185.64027	3.0717878
M,M3	258.78140	3.0773582

Response WBGT

Whole Model

Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
ML	2	2	897.8666	165.7265	<.0001
GENDER	1	1	0.0836	0.0309	0.8607
Ensemble	4	4	1005.3415	92.7820	<.0001
GENDER*Ensemble	4	4	4.9040	0.4526	0.7704
ID[GENDER]	14	14	141.0609	3.7195	<.0001
GENDER*ML	2	2	14.0807	2.5990	0.0769

ML

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
M1	35.446547	0.25290563	35.2049
M2	32.604100	0.27895335	32.4998
M3	29.856876	0.27546487	29.7806

GENDER

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	32.671455	0.38377428	32.1835
M	32.600227	0.13068529	32.5630

Ensemble

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
CC	34.243250	0.33237557	33.9767
NG	32.354446	0.32883007	32.2159
TY1427	34.033911	0.32988341	34.1510
TYCHEM	28.180942	0.31967224	28.0487
WC	34.366657	0.30214143	34.1741

GENDER*Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	34.348219	0.59197090
F,NG	32.482802	0.59197090
F,TY1427	33.734885	0.59197090
F,TYCHEM	28.272904	0.56813046
F,WC	34.518465	0.53204365
M,CC	34.138281	0.30243105
M,NG	32.226091	0.28650884
M,TY1427	34.332937	0.29131203
M,TYCHEM	28.088979	0.29323908
M,WC	34.214848	0.28650884

ID[GENDER]

GENDER*ML

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,M1	35.733449	0.45071341
F,M2	32.783474	0.51088969
F,M3	29.497441	0.50308005
M,M1	35.159645	0.22957016
M,M2	32.424726	0.22416871
M,M3	30.216311	0.22457522

Response Tre

Whole Model

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
ML	2	2	4.7803507	35.7713	<.0001
GENDER	1	1	0.0137261	0.2054	0.6509
Ensemble	4	4	0.3870919	1.4483	0.2196
GENDER*Ensemble	4	4	0.4086949	1.5291	0.1953
ID[GENDER]	14	14	6.1620914	6.5873	<.0001
GENDER*ML	2	2	0.1055284	0.7897	0.4555

ML

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	37.530170	0.03972014	37.5126
M2	37.754806	0.04381107	37.7386
M3	37.937972	0.04326319	37.9485

GENDER

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean

Level	Least Sq Mean	Std Error	Mean
F	37.755412	0.06027374	37.7528
M	37.726553	0.02052480	37.7299

Ensemble
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CC	37.698084	0.05220131	37.6631
NG	37.719124	0.05164447	37.7398
TY1427	37.749219	0.05180990	37.7350
TYCHEM	37.826601	0.05020619	37.8180
WC	37.711886	0.04745288	37.7182

GENDER*Ensemble
Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	37.761127	0.09297211
F,NG	37.666127	0.09297211
F,TY1427	37.763627	0.09297211
F,TYCHEM	37.898165	0.08922784
F,WC	37.688015	0.08356022
M,CC	37.635041	0.04749837
M,NG	37.772121	0.04499770
M,TY1427	37.734811	0.04575207
M,TYCHEM	37.755036	0.04605472
M,WC	37.735758	0.04499770

ID[GENDER]

GENDER*ML
Least Squares Means Table

Level	Least Sq Mean	Std Error
F,M1	37.576222	0.07078688
F,M2	37.766541	0.08023788
F,M3	37.923474	0.07901134
M,M1	37.484119	0.03605519
M,M2	37.743071	0.03520686
M,M3	37.952470	0.03527071

Response HR
Whole Model
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
ML	2	2	13816.236	66.0475	<.0001
GENDER	1	1	2174.609	20.7911	<.0001
Ensemble	4	4	737.267	1.7622	0.1381

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
GENDER*Ensemble	4	4	525.989	1.2572	0.2883
ID[GENDER]	14	14	41460.047	28.3138	<.0001
GENDER*ML	2	2	530.193	2.5346	0.0819

ML

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	111.20834	1.5715024	110.333
M2	119.84081	1.7333574	116.986
M3	132.90026	1.7116807	130.613

GENDER

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
F	127.05982	2.3846926	129.574
M	115.57312	0.8120509	115.581

Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CC	120.09367	2.0653118	117.143
NG	119.57750	2.0432808	118.800
TY1427	121.47674	2.0498260	119.000
TYCHEM	125.10962	1.9863760	124.174
WC	120.32481	1.8774432	117.795

GENDER*Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	127.41257	3.6783826
F,NG	122.24590	3.6783826
F,TY1427	127.82924	3.6783826
F,TYCHEM	132.34358	3.5302431
F,WC	125.46781	3.3060073
M,CC	112.77476	1.8792429
M,NG	116.90909	1.7803057
M,TY1427	115.12425	1.8101516
M,TYCHEM	117.87567	1.8221259
M,WC	115.18182	1.7803057

ID[GENDER]

GENDER*ML

Least Squares Means Table

Level	Least Sq Mean	Std Error

Level	**Least Sq Mean**	**Std Error**
F,M1	114.60840	2.8006382
F,M2	126.01944	3.1745610
F,M3	140.55163	3.1260336
M,M1	107.80829	1.4265006
M,M2	113.66217	1.3929372
M,M3	125.24889	1.3954632

Response Tsk
Whole Model
Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
ML	2	2	45.137179	95.8702	<.0001
GENDER	1	1	0.030712	0.1305	0.7183
Ensemble	4	4	2.712920	2.8811	0.0239
GENDER*Ensemble	4	4	0.873114	0.9272	0.4492
ID[GENDER]	14	14	24.048220	7.2968	<.0001
GENDER*ML	2	2	3.797653	8.0661	0.0004

ML
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
M1	36.693911	0.07455449	36.6491
M2	36.301233	0.08223314	36.2744
M3	35.474111	0.08120477	35.5953

GENDER
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	36.134835	0.11313348	36.1541
M	36.178003	0.03852494	36.1705

Ensemble
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
CC	36.053472	0.09798157	36.0309
NG	36.121201	0.09693639	36.1682
TY1427	36.030325	0.09724690	36.0971
TYCHEM	36.363865	0.09423674	36.3792
WC	36.213230	0.08906879	36.1387

GENDER*Ensemble
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**
F,CC	36.072099	0.17450813
F,NG	36.036432	0.17450813
F,TY1427	35.934182	0.17450813

Level	**Least Sq Mean**	**Std Error**
F,TYCHEM	36.316273	0.16748016
F,WC	36.315188	0.15684207
M,CC	36.034846	0.08915417
M,NG	36.205970	0.08446044
M,TY1427	36.126468	0.08587638
M,TYCHEM	36.411457	0.08644446
M,WC	36.111273	0.08446044

ID[GENDER]

GENDER*ML
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**
F,M1	36.825585	0.13286659
F,M2	36.325376	0.15060606
F,M3	35.253544	0.14830384
M,M1	36.562238	0.06767538
M,M2	36.277091	0.06608308
M,M3	35.694679	0.06620292

Response PSI
Whole Model
Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
ML	2	2	84.77518	65.4493	<.0001
GENDER	1	1	5.83642	9.0118	0.0030
Ensemble	4	4	5.35596	2.0675	0.0866
GENDER*Ensemble	4	4	4.52511	1.7468	0.1413
ID[GENDER]	14	14	166.94944	18.4129	<.0001
GENDER*ML	2	2	0.31393	0.2424	0.7850

ML
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
M1	3.4411575	0.12366034	3.37027
M2	4.2266200	0.13639660	4.06377
M3	5.1537750	0.13469087	5.06248

GENDER
Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**	**Mean**
F	4.5713928	0.18764967	4.68673
M	3.9763089	0.06389967	3.98234

Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CC	4.1441244	0.16251784	3.94529
NG	4.1546116	0.16078424	4.15201
TY1427	4.2952099	0.16129928	4.15357
TYCHEM	4.5971735	0.15630644	4.53835
WC	4.1781349	0.14773460	4.06818

GENDER*Ensemble

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,CC	4.5977152	0.28944917
F,NG	4.1933502	0.28944917
F,TY1427	4.6217232	0.28944917
F,TYCHEM	5.0609217	0.27779219
F,WC	4.3832539	0.26014724
M,CC	3.6905335	0.14787621
M,NG	4.1158730	0.14009092
M,TY1427	3.9686967	0.14243948
M,TYCHEM	4.1334253	0.14338172
M,WC	3.9730159	0.14009092

ID[GENDER]

GENDER*ML

Least Squares Means Table

Level	Least Sq Mean	Std Error
F,M1	3.6798176	0.22038013
F,M2	4.5403984	0.24980383
F,M3	5.4939624	0.24598524
M,M1	3.2024973	0.11225027
M,M2	3.9128417	0.10960919
M,M3	4.8135876	0.10980795

ABOUT THE AUTHOR

Christina L. Luecke received a Master of Science in Public Health in Industrial Hygiene in 2000 from the University of South Florida (USF). She then managed a NIOSH Heat Stress Lab at USF for the next three years while she began work on her doctorate in Industrial Hygiene. She also worked as an OSHA Compliance Consultant, providing training and compliance services to medical and dental professionals. She now works in Tampa, Florida doing comprehensive industrial hygiene consulting for OHC Environmental Engineering.