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ACCURACY EVALUATION OF THE HEAT STRAIN DECISION AID (HSDA) FOR MODELING AND SIMULATION OF ACTIVITIES WEARING CHEMICAL, BIOLOGICAL, AND RADIOLOGICAL PROTECTIVE ENSEMBLES

United States Army
Medical Research & Development Command

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This report provides a brief review of the HSDA and includes a brief summary of validation conditions and results for chemical protective clothing and tables of chemical protective clothing values for use in HSDA. This work specifically supports requirements to evaluate the US Army Research Institute of Environmental Medicine (USARIEM) Heat Strain Decision Aid (HSDA) for use in modeling and simulation (M&S) in support of the Uniform Integrated Protective Ensemble – Aircrew (UIPE-Air) Operational Test and Evaluation (OT&E). These analyses provide evidence that new UIPE-Air ensembles will be adequately represented by HSDA predictions and we recommend accreditation of the model for UIPE-Air.

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EXECUTIVE SUMMARY

This report provides a brief review of the HSDA and includes a brief summary of validation conditions and results for chemical protective clothing and tables of chemical protective clothing values for use in HSDA. This work specifically supports requirements to evaluate the US Army Research Institute of Environmental Medicine (USARIEM) Heat Strain Decision Aid (HSDA) for use in modeling and simulation (M&S) in support of the Uniform Integrated Protective Ensemble – Aircrew (UIPE-Air) Operational Test and Evaluation (OT&E).

The UIPE-Air Capability Development Document (CDD) has identified physiological load intensification as compared to the current Chemical, Biological, and Radiological (CBR) Joint Protective Air Crew Ensemble (JPACE) as a Key System Attribute. The intent for UIPE-Air is to reduce thermal burden and improve heat stress management to better support completion of operational missions in a CBR environment. Due to safety considerations, the resolution of this requirement cannot be tested outright with operational users in order to prevent physically exerting aircrew and/or soldiers to dangerous levels. Additionally, UIPE-Air OT-C1 lacks the time and ability to control the range of environmental conditions described in the CDD. The Heat Strain Decision Aid (HSDA) model provides users with quantitative predictions that allow them to mitigate these limitations. A previous configuration of the model was accredited by Marine Corps Operational Test and Evaluation Agency during UIPE Increment 1. This report presents additional validation data for accreditation of HSDA for use during UIPE-Air integrated testing in support of Commander, Operational Test and Evaluation's Operational Evaluation Report.

This report compares human test data with HSDA core temperature predictions for a wide variety of CBR ensembles. The data outlined demonstrate that HSDA consistently and acceptably predicts core body temperature (T_c) when individuals are wearing a range of chemical protective clothing. The currently assessed version of HSDA has been shown to be acceptable using a direct measurement criteria bias of ± 0.27°C, and prediction errors (mean absolute and root mean square error (MAE, RMSE)) within observed SD criteria. For previously tested ensembles similar to UIPE-Air Baseline (JPACE) HSDA core temperature predictions were within ± 0.20°C of measured values throughout 120 minutes of work rest cycles. For previously tested ensembles similar to UIPE-Air, measured core temperatures were within ± 0.26°C for 120 minutes of continuous exercise wearing the Chemical-Biological Lightweight Improved Thermal Ensemble 1-AerO (CBLITE AerO) and within ± 0.24°C for 60 minutes of continuous exercise in CBLITE AerO plus ballistic protection.

These analyses provide evidence that new UIPE-Air ensembles will be adequately represented by HSDA predictions and we recommend accreditation of the model for UIPE-Air.

INTRODUCTION

Thermal strain during military activities is a serious and constant threat for Warfighters. This threat is especially true for those wearing chemical, biological, radiological, and nuclear (CBRN) personal protective equipment (PPE) ensembles. These ensembles, by design, impede exchange of vapor and dry heat dissipation, from the human to the environment and vice versa. This design enables the protection of individuals from CBRN threats from entering the ensemble; however, this restricted exchange also decreases the ability for heat exchange putting the wearer at increased risk of thermal stress (i.e., if nothing gets in, nothing gets out).

The Uniform Integrated Protective Ensemble – Aircrew (UIPE-Air) program has recognized this increased risk of thermal strain in their Capability Development Document (CDD), with the emphasized need for reducing thermal burden to improve heat stress management to improve operational success. The UIPE-Air program has chosen the HSDA as a potential tool for use in modeling and simulation (M&S) efforts to conduct evaluations and assessments of various PPE system improvement efforts. The current UIPE-Air effort seeks to replace the Joint Protective Air Crew Ensemble (JPACE) with a less thermally burdensome alternative.

In 2012, a verification and validation (V&V) report was approved by a Joint Chemical, Biological, Radiological and Nuclear (CBRN) Defense group for the use of HSDA for "Thermal Burden Assessment of Chemical/Biological (CB) Ensembles". The biophysical properties of the CB ensembles assessed in this report for UIPE-Air specific accreditation are all within the range of biophysical properties of the ensembles examined in the 2012 accreditation. The current work described in this report seeks to expand upon and verify this earlier V&V work and to verify that the current version of HSDA is appropriate for simulations of UIPE-Air specific CB ensembles.

Heat Strain Decision Aid (HSDA)

The U.S. Army's Heat Strain Decision Aid (HSDA) is an empirically based thermoregulatory model that predicts core body temperature (T_c) from inputs related to an individual (or group average), clothing values, environmental conditions, and activity-related factors (1). HSDA was been developed and refined based on three main equations developed by Givoni and Goldman that were created to predict T_c at rest, rise in T_c during exercise, and the decrease in T_c following exercise (2, 3). From these equations, a final equilibrium model was generated that predicts T_c trajectory or rate of rise based on inputs of the biophysical conditions (e.g., human, environment). The model in its current embodiment is designed with several modular components to allow for incremental improvements to component subroutine equations.

The HSDA method relies on the heat balance equation (Eq. 1), where in order to predict heat rise or fall in humans, heat storage (S) is calculated from the sum of heat produced, heat gained, and via heat dissipation to the four pathways of heat exchange:

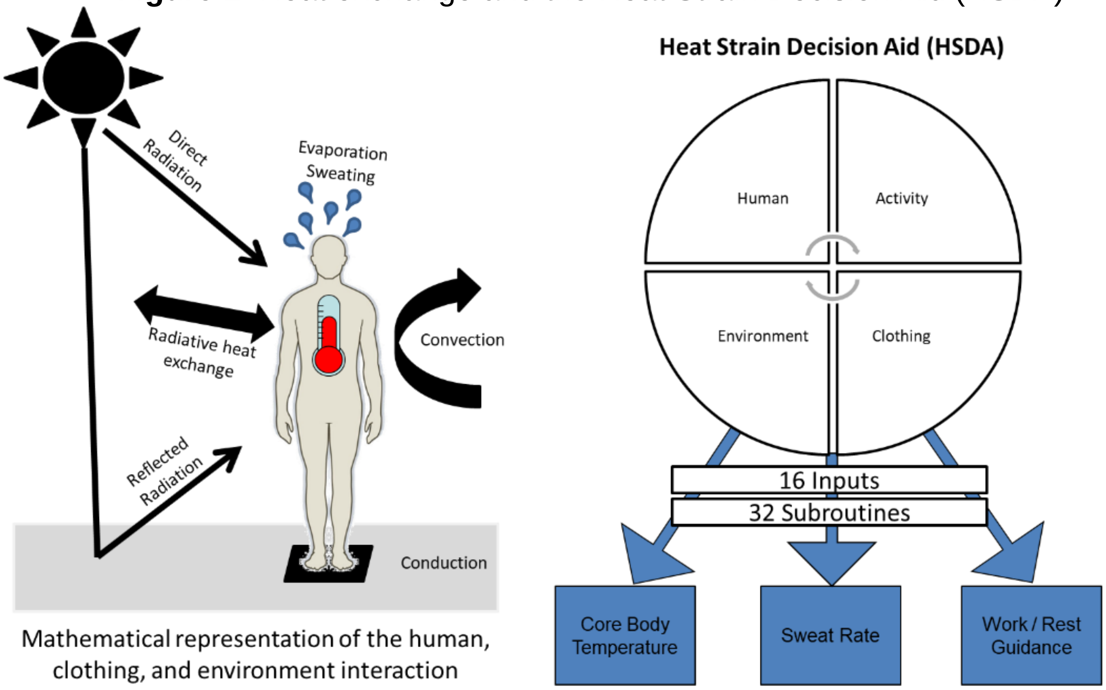
$$S = M \pm W \pm R \pm C \pm K - E \ [\mathrm{W/m^2}] \qquad \text{Eq. 1}$$

where M and W represent metabolism and work rate; R is radiation transferred via electromagnetic waves (e.g., solar or infrared); C is convective heat transfer with fluid contact (e.g., air or water); K is conductive heat transfer from direct contact with solid objects (e.g., touching a cold surface); E is evaporative heat loss to the environment of water from liquid to vapor (e.g., sweat and respiratory evaporative water loss). HSDA requires ~16 inputs that are passed into a series of approximately 32 subroutine equations (1) that are collectively used to make predictions of T_c and sweating rates (S_{wt}), which can then be used to produce maximal safe (uninterrupted one-time) work times, optimal work rest cycles for prolonged work, estimation of water requirements, and establish cooling requirements (Figure 1).

Improvements to underlying equations and methods have been made over the past several years. These improvements include exercise coefficients (4), improved sweat rate predictions (5, 6), calculation methods for clothing wind assessments (7, 8), body surface area calculations (9), accurate predictions of metabolic costs of military activities (10-12), and for added costs of locomotion over various terrains (13, 14).

HSDA has been used to generate guidance for military doctrine (15), public fluid intake (16), and emergency response efforts (17). The model has also been used extensively for evaluation of military clothing, to include general uniforms (18-21), body armor systems (22-24), chemical protective ensembles (25, 26), physical fitness clothing (27), and cold weather clothing (28, 29). Additionally, HSDA modeling has provided simulated guidance related to effectiveness of personal cooling systems (30, 31)

Figure 1. Heat exchange and the Heat Strain Decision Aid (HSDA)



Mathematical representation of the human, clothing, and environment interaction

Biophysical clothing inputs to HSDA

Biophysical inputs to HSDA include the clothing ensemble's total thermal resistance (I_T) in units of clo, and the ratio of vapor permeability (i_m) to thermal resistance, expressed as i_m/clo, or maximal evaporative potential, each measured at 1 m/s. Also needed as inputs are air velocity coefficients for I_T ($I_T V^g$) and for evaporative potential (i_m/clo V^g). These coefficients were historically determined by conducting biophysical assessments for I_T and i_m at multiple wind speeds but it is also possible to empirically estimate these coefficient values (7, 8).

Chemical Protective Clothing Validation

HSDA has been validated for heat stress guidance in Soldiers (32, 33). HSDA's predictive accuracy of T_c has been shown to be acceptable in Studies 1-4 based on group mean (32) and individual (33) inputs for healthy and active Soldiers wearing various chemical protective clothing ensembles during separate laboratory and field exercises in hot and humid conditions. Criterion for acceptable accuracies were based on bias, mean absolute error (MAE), and root mean square error (RMSE). A direct measurement accuracy criterion of mean bias ± 0.27°C was used, as well as MAE and RMSE within observed SD values (4, 34, 35). These studies included a wide range of CB ensembles, work rates, and environments.

Study 5 (36) specifically examines HSDA predictions for a prior version of the JPACE ensemble, worn with USAF CWU-66/P with aviation life support equipment in a configuration which is similar to the UIPE-Air JPACE baseline ensemble. Study 6 (37) specifically examines predictions for ensembles using similar materials as UIPE-Air candidate ensembles for improved thermal burden. The Chemical and Biological Lightweight Improved Thermal Ensemble (CBLITE) configuration consists of ~35% 2PUG stretch material (torso, inner arms, top of knee) and ~65% woven composite. In separate experiments, CBLITE AerO was worn with and without ballistic protection consisting of Improved Outer Tactical Vest (IOTV) and Army Combat Helmet (ACH).

Field and Lab Validation Individual Comparisons [Study 1 and 2]

A validation study by Potter et al. (33) found HSDA acceptably predicted T_c for individuals when wearing chemical protective clothing during laboratory and field exercises in hot and humid conditions. The laboratory study included eight male volunteers (age 24 ± 6 years; height 178 ± 5 cm; body mass 76.6 ± 8.4 kg) wearing three different chemical protective ensembles during intermittent treadmill marching in an environmental chamber (air temperature 29.3 ± 0.1°C; relative humidity 56 ± 1%; wind speed 0.4 ± 0.1 m/s). The field experiment included twenty (nineteen males, one female) activity military volunteers (26 ± 5 years; 175 ± 8 cm; 80.2 ± 12.1 kg) wearing four different chemical protective ensembles during a prolonged road march (26.0 ± 0.5°C; 55 ± 3%; 4.3 ± 0.7 m/s). HSDA predictions of T_c met the acceptable criteria for each chemical protective ensemble in both the laboratory (Bias -0.10; MAE 0.28; RMSE 0.37°C) and field experiments (Bias 0.23; MAE 0.30; RMSE 0.40°C). Additionally, 72%

of all predictions were within one SD of the observed data including 92% of predictions for the laboratory experiment (SD ± 0.64°C) and 67% for the field experiment (SD ± 0.38°C). Individual-based predictions showed modest errors outside the SD range with 98% of predictions falling < 1°C; while, 81% of all errors were within 0.5°C of observed data. Figures 2-3 show the comparison of observed (measured T_c) and HSDA predictions for the laboratory (Figure 2) and field (Figure 3) studies. Clothing properties are shown in Table 1.

Figure 2. Modeled to individual observed T_c in CBRN clothing in laboratory hot-humid conditions (29.3 ± 0.1°C; 56 ± 1%RH; wind speed 0.4 ± 0.1 m/s)

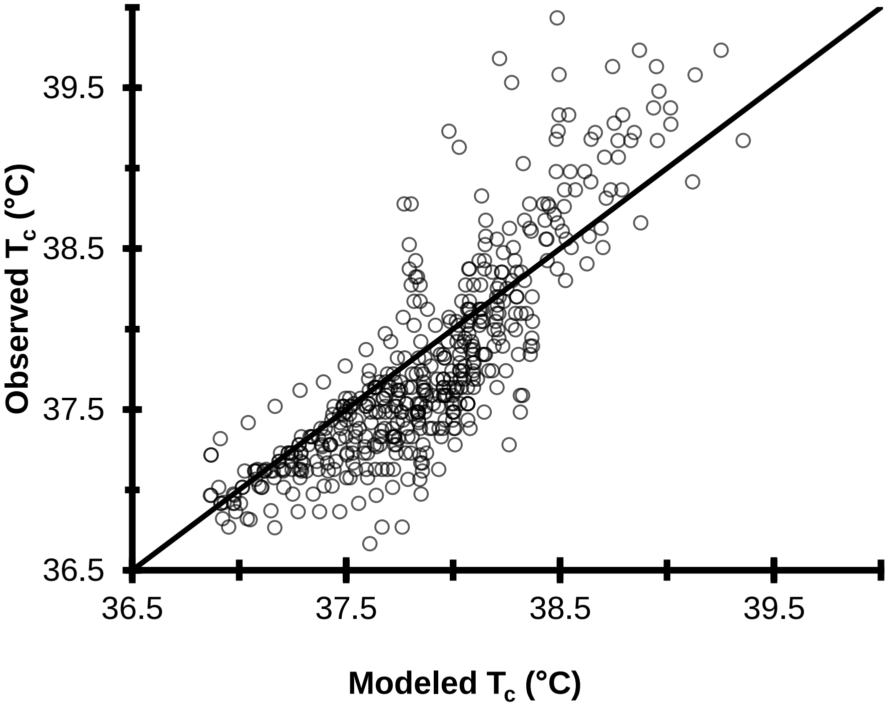


Figure 3. Modeled to individual observed T_c in CBRN clothing in field hot-humid conditions (26.0 ± 0.5°C; 55 ± 3%RH; wind speed 4.3 ± 0.7 m/s)

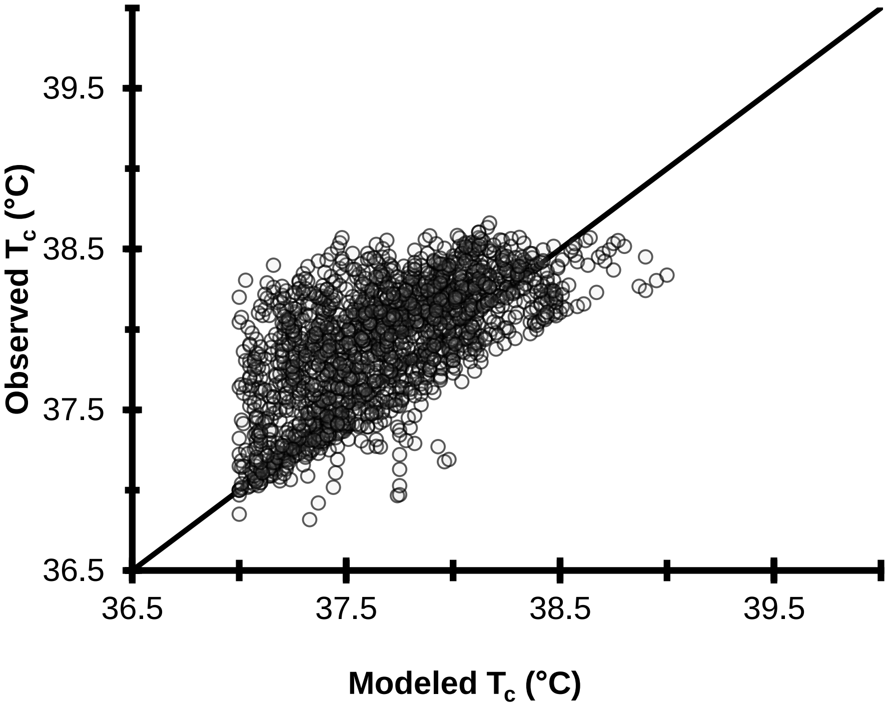


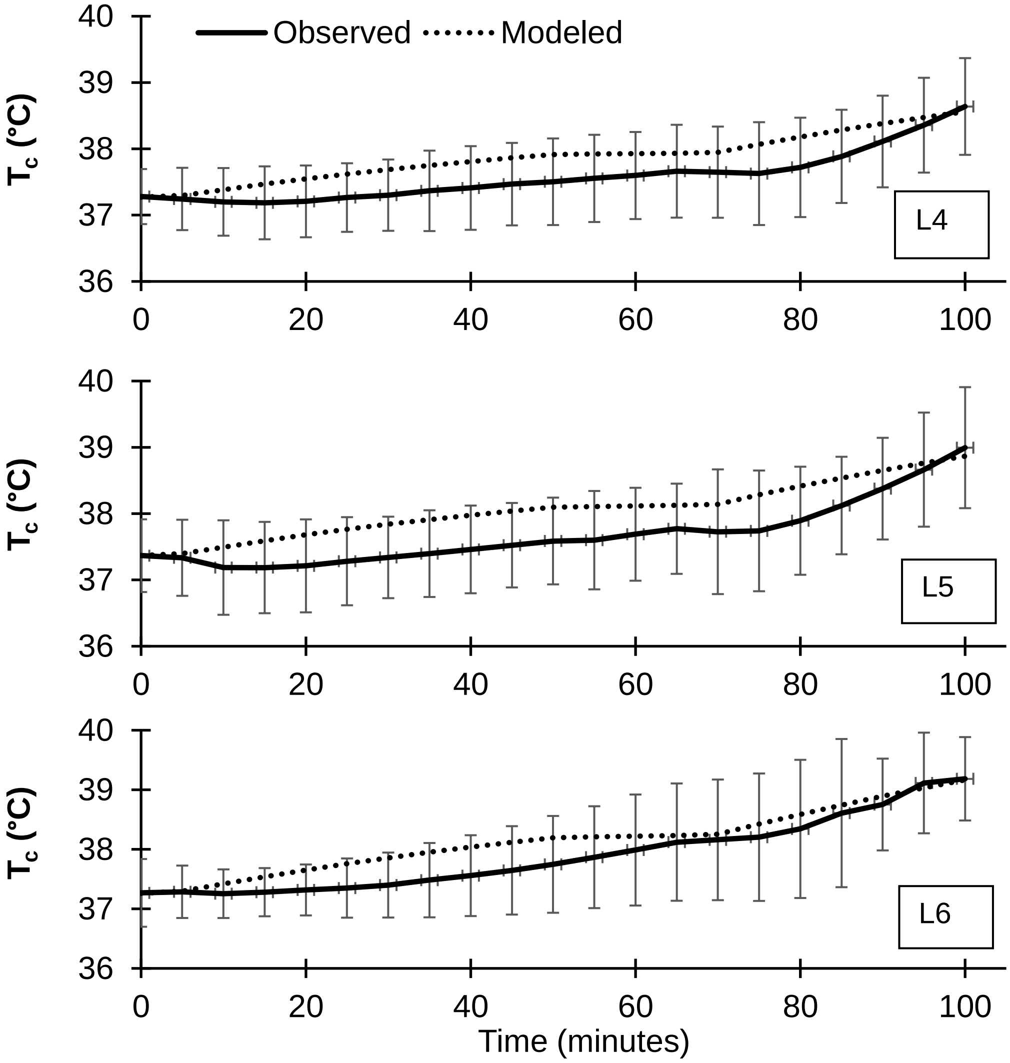
Table 1. Biophysical properties of chemical protective clothing ensembles worn during laboratory (L1-L3) and field (F1-F4) exercises (Study 1 and 2).

Environment	Clothing	Thermal insulation (clo) at 1 m/s	Insulation wind effect (clo^g)	Evaporative Potential (i_m/clo) at 1 m/s	Evaporative Potential wind effect (i_m/clo^g)
Laboratory	L1	1.46	-0.23	0.21	0.36
	L2	1.79	-0.18	0.16	0.31
	L3	2.13	-0.15	0.09	0.14
Field	F1	1.83	-0.22	0.15	0.28
	F2	1.98	-0.19	0.16	0.29
	F3	2.00	-0.18	0.15	0.23
	F4	1.93	-0.16	0.15	0.21

Lab Validation Group Comparisons [Study 3]

Eight human research volunteers (age 23.9 ± 5.5 years; 178 ± 5 cm; 76.6 ± 8.4 kg; BMI 24.2 ± 2.7) participated in a controlled laboratory study. Volunteers conducted a 60 minute stage of exercise walking on a treadmill at 0.84 m/s on level gradient (0 %), followed by a 10 minute rest period, and concluded with a second walking exercise period of 30 minutes at 1.68 m/s at a 3% inclined grade. Each volunteer conducted this three stage testing protocol wearing three different chemical protective ensembles (L4, L5, and L6) for a total of 3 tests each and 72 time series periods (24 at level walking, 24 resting, and 24 increased speed at an incline). Volunteers were assessed within a controlled laboratory environment (air temperature: 29.3°C; relative humidity 56%; near still air ~0.4 m/s (indoors)). Core body (rectal) temperatures were collected throughout the duration of each study stage (L4, 37.6 ± 0.38; L5, 37.7 ± 0.49; L6, 37.9 ± 0.60°C). HSDA predictions were made based on the mean values of the group and compared to the mean outputs of the group (32). Similar to work done by Cadarette et al., (4), using a threshold of 2*SD provides an indication that the predictions fall within 95% of an average population's response. While this method is generally less accurate as compared to an individual, the results showed that the RMSE was within this criterion of being within 2*SD of observed values (L4, 0.70; L5, 0.37; L6, 0.25°C) (Figure 4).

Figure 4. Modeled and group observed T_c data for three chemical protective ensembles (L4, L5, and L6), (29.3°C; 56%RH; near still air ~0.4 m/s (indoors)



Note: Error bars represent observed 2*SD

Table 2. Biophysical properties of chemical protective clothing ensembles worn during laboratory exercise (Study 3).

Environment	Clothing	Thermal insulation (clo) at 1 m/s	Insulation wind effect (clo^g)	Evaporative Potential (i_m/clo) at 1 m/s	Evaporative Potential wind effect (i_m/clo^g)
Laboratory	L4	1.59	-0.18	0.18	0.24
	L5	1.83	-0.15	0.14	0.25
	L6	2.20	-0.12	0.07	0.15

Lab Validation Group Comparisons [Study 4]

Data from 19 healthy male human research volunteers (178 ± 6 cm; 81.0 ± 7.1 kg) participated in a controlled laboratory heat stress study. Volunteers conducted 60 minutes of exercise walking on a treadmill at 1.12 m/s on level gradient (0 %). Each volunteer conducted this exercise protocol wearing a control uniform (JSLIST) and then volunteers were randomly assigned into groups to conduct this exercise wearing six different uniforms (Table 3). Volunteers were assessed within a controlled laboratory environment (air temperature: 40.05°C; relative humidity 20%; 1.34 m/s). Core body temperature and mean skin temperature (T_c, T_s) was collected throughout the duration of each exercise. HSDA predictions were made for each individual and compared to the observed outputs (Figure 4). Error over time was plotted for each individual prediction (Figure 5). Analysis showed acceptable bias (-0.08°C), MAE (0.20°C), and RMSE (0.28°C).

Figure 5. Modeled to individual observed T_c in CBRN clothing in hot-dry laboratory conditions (Study 4) (40.05°C; 20%RH; wind speed 1.34 m/s)

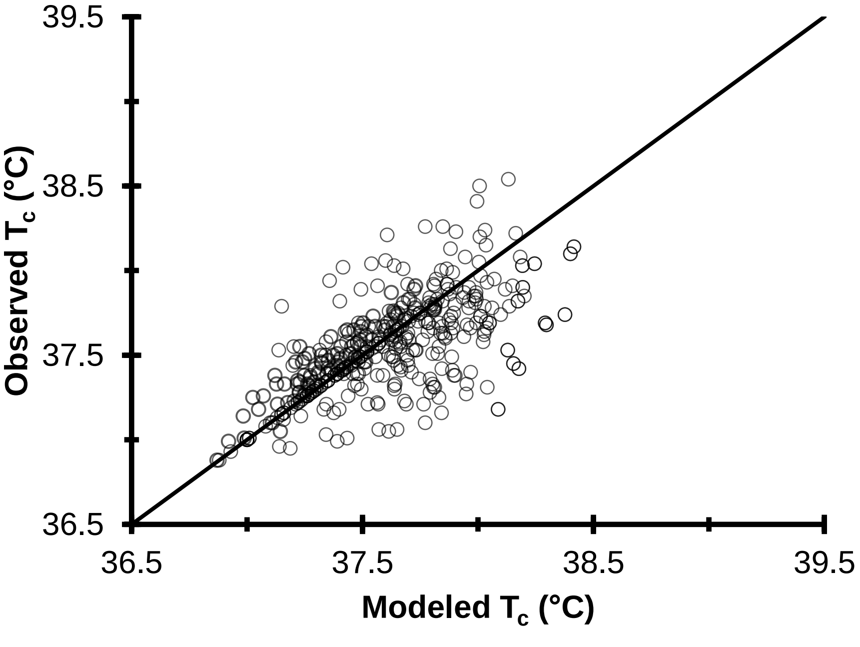


Figure 6. Error by time (observed–predicted) in hot-dry laboratory conditions (Study 4).

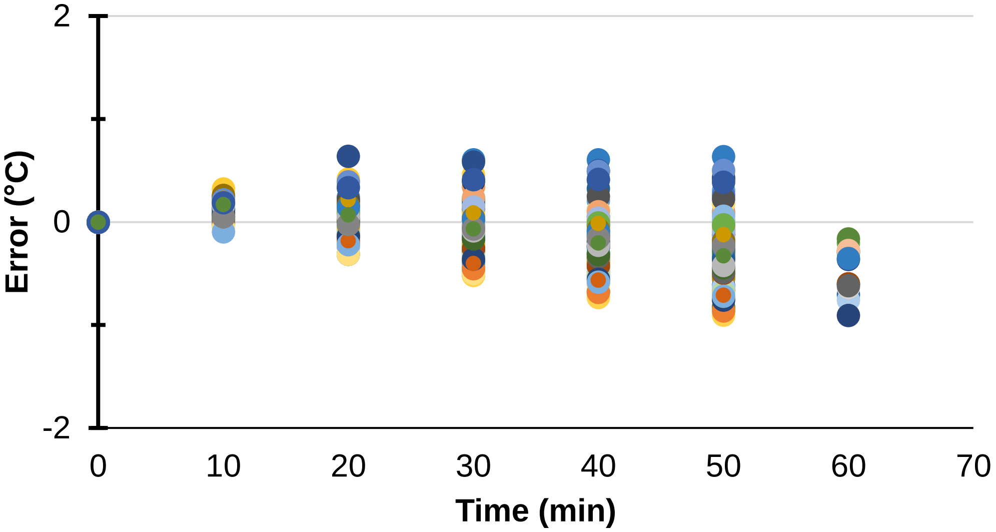


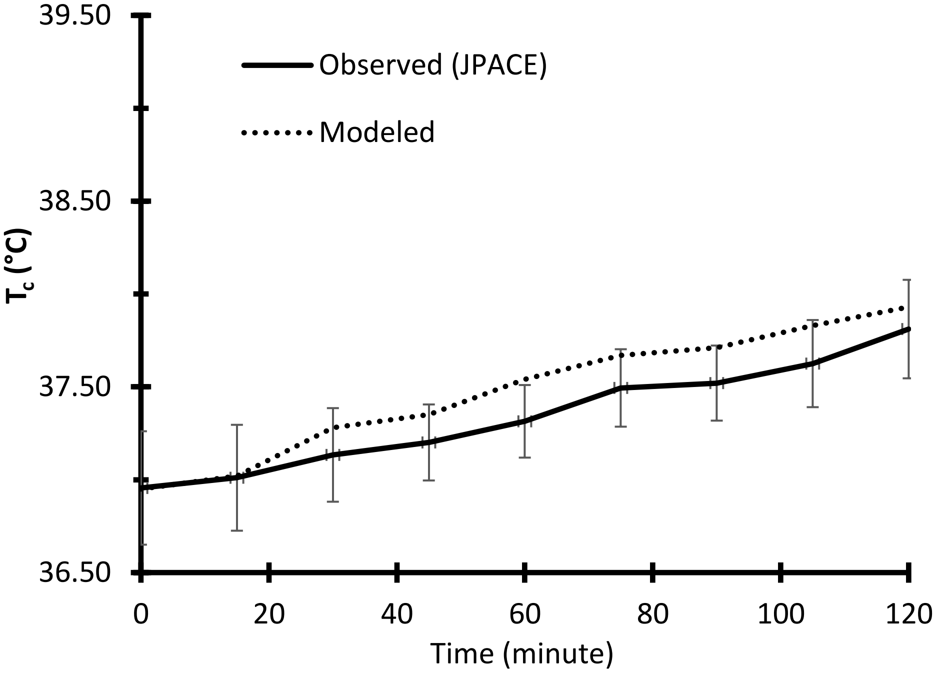
Table 3. Biophysical properties of chemical protective clothing ensembles worn during laboratory exercise (Study 4).

Environment	Short Description	Clothing	Thermal insulation (clo) at 1 m/s	Insulation wind effect (clo^g)	Evaporative Potential (i_m/clo) at 1 m/s	Evaporative Potential wind effect (i_m/clo^g)
Laboratory	JSLIST+FRACU	L7	2.15	-0.13	0.16	0.25
	JSLIST+PTs	L8	1.78	-0.16	0.19	0.22
	CBCC Type A	L9	1.73	-0.16	0.19	0.24
	CBCC Type B V1	L10	1.66	-0.16	0.18	0.22
	CB FRACU	L11	1.77	-0.16	0.19	0.22
	CBUG+eFRACU	L12	1.80	-0.15	0.17	0.21
	CBEC	L13	1.96	-0.15	0.17	0.23

Lab Validation Group Comparisons for JPACE [Study 5]

Eight healthy, heat acclimated human research volunteers (7 male, 1 female, 21±3 years, 172 ± 4 cm; 77.0 ± 9.2 kg, 19.5 ± 6.3 % body fat) participated in a laboratory heat stress study. Volunteers were assessed within a controlled laboratory environment (air temperature: 30°C; relative humidity 30%; 0.9 m/s wind speed). Volunteers walked (362 ± 56 W) for 30 minutes three times with 15 minute rest periods between each exercise bout for a mean weighted work rate of 303 ± 46 W. Core body temperature and mean skin temperature (*T_c, T_s*) were collected throughout these work rest cycles. HSDA T_c predictions were compared to the observed T_c (Figure 7). Clothing properties are shown in Table 4. Properties for UIPE-Air ensembles are included for comparison. This data shows predictions to be acceptable to within the observed SD criteria.

Figure 7. Modeled and group observed T_c data for 2006 JPACE laboratory study (Study 5) (30°C; 30%RH; wind speed 0.9 m/s)



Note: Error bars represent observed 1*SD

Table 4. Biophysical properties of chemical protective clothing ensembles worn during laboratory exercise (Study 5) and UIPE-Air JPACE ensemble.

Clothing	Thermal insulation (clo) at 1 m/s	Insulation wind effect (clo^g)	Evaporative Potential (i_m/clo) at 1 m/s	Evaporative Potential wind effect (i_m/clo^g)
Lab Study JPACE	1.80	-0.20	0.17	0.33
UIPE-Air JPACE	1.54	-0.16	0.15	0.20

Lab Validation Group and Individual Comparisons for CB-LITE [Study 6]

Seven healthy, heat acclimated human research volunteers (enlisted men, 170.4 cm, 74.7kg) participated in a laboratory heat stress study wearing CB garments partially composed of 2-PUG, with and without ballistic protection. Volunteers walked 1.2 m/s on

0% grade treadmill (335 W) for 120 minutes wearing CBLITE AerO ensemble within a controlled laboratory environment (air temperature: 40°C; relative humidity 20%; 3.0 m/s wind speed). On another test day, the same volunteers walked 1.2 m/s on 0% grade treadmill (370 W) for 70-105 minutes wearing CBLITE AerO ensemble, IOTV), and ACH within a controlled laboratory environment (air temperature: 40°C; relative humidity 20%; 3.0 m/s wind speed). Core body temperature and mean skin temperature (T_c, T_s) were collected continuously. HSDA T_c predictions were compared to the observed T_c (Figure 8). Additionally, while individual characteristics were unavailable for the analyses (height, weight, hydration statuses, metabolic rates, etc.), individual comparisons were made based on the group mean values as inputs (described above) and with observed initial T_c and were modeled for each individuals' observed measure of T_c (Figure 9). Clothing properties are shown in Table 5. Properties for UIPE-Air ensembles are included for comparison. This data shows predictions to be acceptable to within the observed SD criteria for the group analyses and to be within the criteria for the limited data for individuals for both the no-armor (Bias -0.04, MAE 0.20, and RMSE 0.30) and armor conditions (Bias 0.07, MAE 0.11, and RMSE 0.17).

Figure 8. Modeled and group observed T_c data for 2018 CBLITE laboratory study (Study 6) (40°C; 20%RH; wind speed 3.0 m/s)

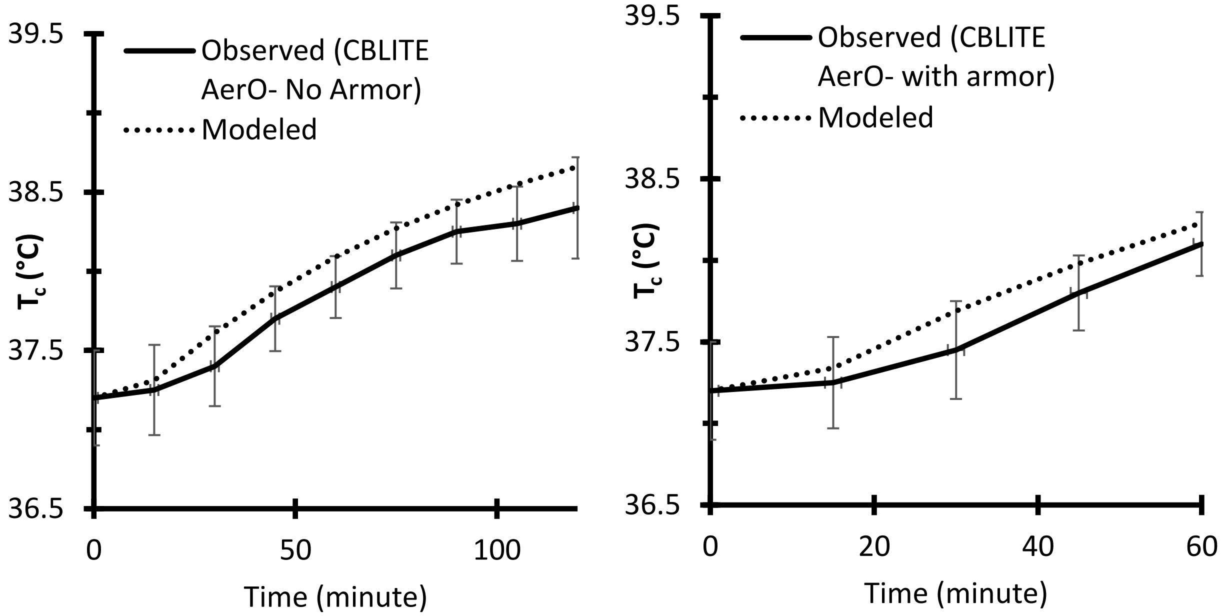
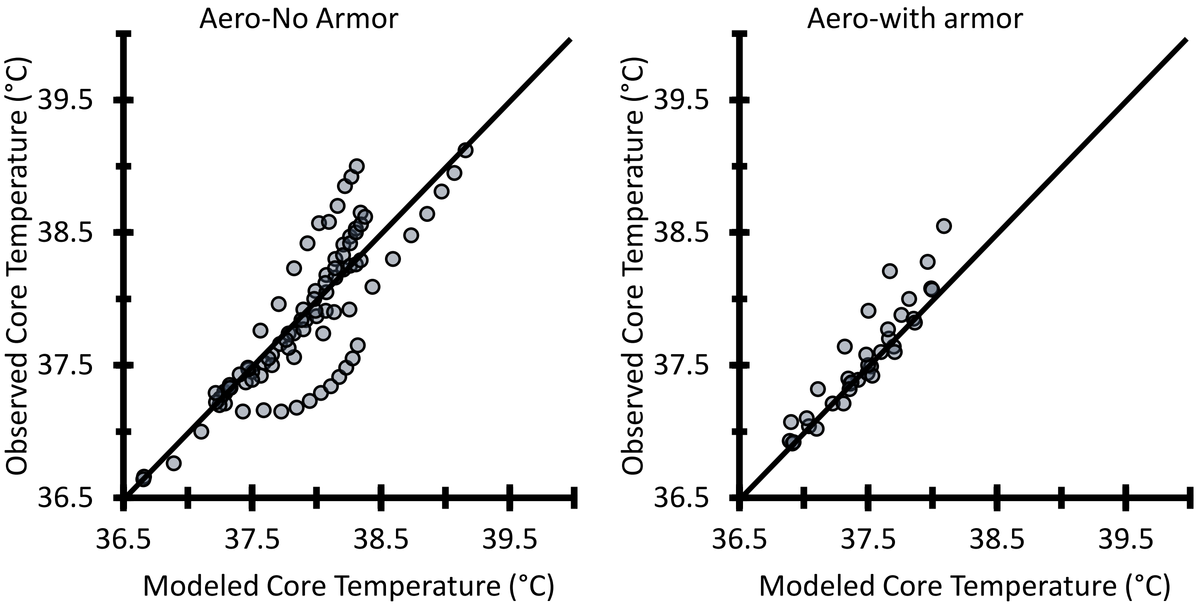


Figure 9. Modeled to observed individual T_c data for 2018 CBLITE laboratory study (Study 6) (40°C; 20%RH; wind speed 3.0 m/s)



Note: Data is based on limited information regarding individuals

Table 5. Biophysical properties of chemical protective clothing ensembles worn during laboratory exercise (Study 6) and UIPE-Air ensembles.

Clothing	Thermal insulation (clo) at 1 m/s	Insulation wind effect (clo^g)	Evaporative Potential (i_m/clo) at 1 m/s	Evaporative Potential wind effect (i_m/clo^g)
CBLITE AerO	1.24	-0.16	0.27	0.17
CB Lite AerO, IOTV, ACH	1.49	-0.17	0.23	0.23
2PUG with 27P	1.50	-0.17	0.17	0.21
2PUG with A2CU	1.55	-0.17	0.16	0.21
2PUG with 27P, **no t-shirt**	1.48	-0.17	0.16	0.21

DISCUSSION

The range of PPE clothing assessed within this report include biophysical properties similar to those expected for a variety of CB ensembles. The range of thermal insulation (clo) were from 1.24 – 2.20; while evaporative potential (i_m/clo) values ranged from 0.07 to 0.27. All of the UIPE-Air specific ensembles and the previously tested ensembles studied for comparison had biophysical properties falling within the ranges examined in this report. HSDA consistently and acceptably predicts T_c when individuals are wearing chemical protective clothing. The HSDA has been shown to be acceptable using a direct measurement criteria of a bias of ± 0.27°C, and modeled errors (MAE, RMSE) within observed SD criteria. For both the JPACE and CBLITE ensembles, HSDA predictions were within the acceptable criteria. Based on this range of assessed ensembles, it can be reasonably assumed that HSDA will acceptably predict T_c for other PPE ensembles within this range of values.

As an empirically designed method, there are several limitations to HSDA. However, the modular design has allowed for continued updating and improvements to specific equations (e.g., body surface area, metabolic rate). While more inclusive data is currently being sought within a military context; a significant limitation that exists with the validation datasets is an underrepresented sample of females. Additional limitations include the need for continued validation and potential improvements related to the ability to account for higher resolution in individual differences. Recent work has found differences in heat stress responses based on age (38-41), sex (42, 43), body morphology (44, 45), and fitness-related factors (46-48). Modeling methods of making these adjustments within HSDA are fairly straightforward (e.g., adding weighted factors for sex, fitness, age) or creating additional components for differences in body composition that can be expansive (e.g., include body tissue distribution, fat-free mass, muscle) or simple factors for body surface area that have recently been developed that currently account for sex (9).

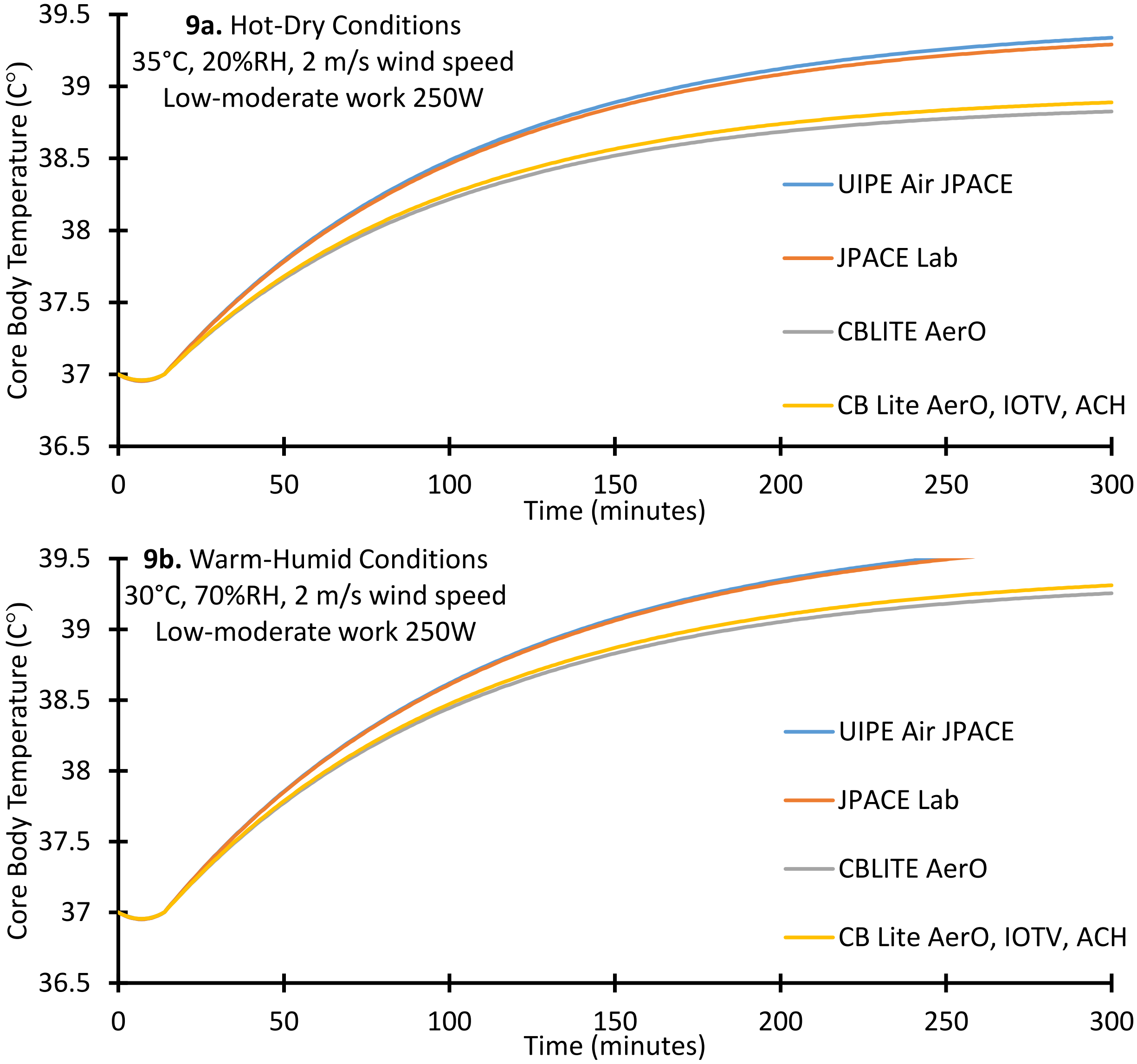
Thermoregulatory models like these provide quantitative means of making predictions and simulations that can be used in planning to help provide guidance and potentially mitigate thermal injuries. These models are also used extensively to assess clothing and individual equipment based on predictions of thermal strain (19, 22, 23, 28). Wide-scale use of these models also allows for continued collection of data to conduct validation and modeling improvements. This information can be used for public safety (17), for competitive sporting events (49), or for use in providing guidance to mitigating heat or cold related risks globally on land (50, 51) and in immersed environments (52-56). Additionally, methods like these have larger future implications specific to climate change and increased risks of thermal injuries (57-61).

Data from multiple environmental conditions would allow for more robust assessment of the human and environment heat transfer calculation methods (62, 63). Assessment of these models with more diverse human characteristics are needed to evaluate the models' accuracy specific to some areas where there are known differences in thermal responses, e.g., females, age groups, and fitness levels (38, 39, 41-43, 46). Assessing the accuracy of these models during more dynamic activity conditions will also allow for an assessment of the issues related to shifts in metabolic demands and enable comparisons of more realistic conditions (10, 64-66). Future work should be conducted to specifically and systematically address these limitations.

Modeled Comparison of Clothing

For comparison purposes, Figure 10 shows modeled comparisons of four configurations plotted at low-moderate work (250W) in two environmental conditions; hot-dry (35°C, 20%RH) (9a) and warm-humid (30°C, 70%RH) (9b), each with 2 m/s wind speed.

Figure 10. Modeled Comparison of responses to ensembles in hot-dry (a) and warm-humid (b) conditions



CONCLUSIONS

Core temperature predictions from the current version of HSDA adequately represent core temperatures of test participants walking while wearing CB protective ensembles. Data from multiple studies with a range of clothing and ancillary gear were examined. UIPE-Air ensemble clothing properties fall within the range of clothing properties of ensembles studied in this report. The HSDA uses inputs related to the clothing biophysical properties, therefore this analysis provides evidence that new clothing not covered in this report is still adequately represented by the model predictions.

Studies included in this report were conducted in a wide range of laboratory and outdoor environments. Air temperature ranged from 26°C - 40°C, relative humidity ranged from 20% - 56%, wind speeds ranged from 0.4 m/s – 4.3 m/s, and solar load ranged from none (indoors) to full sun. Work rates to be simulated for UIPE-Air thermal burden analyses were within the range and similar to work rates examined in this report.

This work specifically supports requirements to evaluate the US Army Research Institute of Environmental Medicine (USARIEM) Heat Strain Decision Aid (HSDA) for use in modeling and simulation (M&S) in support of the Uniform Integrated Protective Ensemble – Aircrew (UIPE-Air) program and Operational Test and Evaluation (OT&E). These analyses provide evidence that new UIPE-Air ensembles will be adequately represented by HSDA predictions and we recommend accreditation of the model for UIPE-Air.

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APPENDIX A. PHOTOS OF PROTECTIVE ENSEMBLE CONFIGURATIONS

Joint Protective Aircrew Ensemble (JPACE) Configuration

UIPE FoS Air 2PUG under the CWU-27/P Configuration

UIPE FoS Air 2PUG under the Army Aircrew Combat Uniform (A2CU) Configuration

CWU-66/P Chemical Protective Coveralls Configuration

CBLITE AERO

APPENDIX B. SUMMARY DATA USED FOR VALIDATION

Figures 3-4 Observed Data

Trial/Subject Time (min)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
L1- Sub1	37.28	37.23	37.13	37.13	37.28	37.38	37.38	37.48	37.48	37.54	37.54	37.59	37.59	37.64	37.69	37.69	37.64	37.84	38.05	38.30	38.56	38.81
L1- Sub2	37.52	37.52	37.47	37.47	37.52	37.57	37.62	37.72	37.82	37.87	37.92	37.97	38.02	38.12	38.12	38.12	38.17	38.27	38.47	38.68	38.98	39.33
L1- Sub3	37.02	36.97	36.92	36.92	37.02	37.12	37.17	37.27	37.32	37.37	37.42	37.52	37.57	37.62	37.52	37.52	37.67	37.92	38.12	38.37	38.63	38.78
L1- Sub4	37.43	37.38	37.33	37.28	37.23	37.23	37.28	37.28	37.33	37.38	37.38	37.38	37.43	37.48	37.48	37.38	37.54	37.64	37.84	38.10	38.30	38.51
L1- Sub5	37.02	36.92	36.86	36.81	36.76	36.86	36.86	36.86	36.92	36.97	37.02	37.07	37.12	37.17	37.17	37.07	37.22	37.47	37.77	38.02	38.37	38.63
L1- Sub6	37.23	37.23	37.18	37.13	37.13	37.13	37.18	37.23	37.23	37.33	37.33	37.38	37.43	37.48	37.48	37.48	37.54	37.64	37.84	38.05	38.35	38.66
L1- Sub7	37.47	37.47	37.52	37.57	37.52	37.57	37.62	37.72	37.77	37.82	37.92	37.97	38.02	38.12	38.07	38.12	38.27	38.42	38.68	38.98	39.28	39.63
L2- Sub1	37.64	37.54	37.48	37.48	37.54	37.59	37.59	37.64	37.69	37.74	37.74	37.84	37.84	37.89	37.94	37.89	38.05	38.20	38.40	38.66	38.92	39.17
L2- Sub2	37.28	37.23	37.18	37.18	37.23	37.33	37.33	37.38	37.48	37.48	37.54	37.59	37.69	37.74	37.79	37.74	37.84	38.05	38.35	38.76	39.22	39.73
L2- Sub3	37.52	37.52	37.52	37.57	37.62	37.72	37.82	37.92	38.02	38.07	38.17	38.27	38.37	38.42	38.53	38.58	38.68	38.83	39.03	39.33	39.63	
L2- Sub4	37.12	37.07	37.12	37.02	37.02	37.12	37.17	37.22	37.27	37.37	37.42	37.47	37.52	37.62	37.62	37.62	37.67	37.82	38.02	38.17	38.42	38.58
L2- Sub5	37.64	37.74	37.69	37.64	37.64	37.64	37.64	37.69	37.69	37.74	37.79	37.84	37.89	38.00	38.05	38.10	38.20	38.35	38.61	38.86	39.17	39.48
L2- Sub6	37.13	37.13	37.02	37.07	37.07	37.02	37.07	37.07	37.13	37.23	37.28	37.38	37.48	37.64	37.59	37.54	37.74	38.05	38.35	38.71	39.07	39.38
L2- Sub7	36.97	36.92	36.82	36.77	36.82	36.87	36.97	36.97	37.02	37.07	37.13	37.13	37.23	37.28	37.33	37.33	37.38	37.59	37.74	37.94	38.25	38.56
L2 - Sub8	37.64	37.54	36.67	36.77	36.77	36.97	37.13	37.28	37.38	37.48	37.64	37.28	37.48	37.59			37.59	38.10	38.51	38.86	39.27	
L3- Sub1	37.23	37.18	37.13	37.23	37.28	37.33	37.33	37.43	37.48	37.59	37.69	37.84	37.94	38.10	38.00	38.15	38.25	38.56	38.86	39.17	39.58	
L3- Sub2	37.54	37.48	37.43	37.43	37.48	37.48	37.54	37.59	37.64	37.69	37.74	37.89	38.00	38.10	38.20	38.20	38.35	38.51	38.76	39.07	39.38	39.73
L3- Sub3	36.92	37.22	37.22	37.32	37.42	37.52	37.62	37.67	37.77	37.87	37.97	38.07	38.17	38.27	38.32	38.32	38.42	38.78	39.13	39.53		
L3- Sub4	36.92	36.97	36.97	37.02	37.12	37.12	37.22	37.32	37.42	37.57	37.67	37.82	38.02	38.17	38.27	38.37	38.53	38.78	39.23	39.68		
L3- Sub5	37.33	37.33	37.23	37.28	37.28	37.28	37.28	37.33	37.33	37.38	37.43	37.54	37.64	37.74	37.79	37.84	37.89	38.05	38.30	38.61	38.86	39.17
L3- Sub6	37.12	37.12	37.12	37.12	37.12	37.12	37.17	37.27	37.32	37.42	37.52	37.62	37.72	37.87	37.92	37.87	38.07	38.37	38.78	39.18		
L3- Sub7	37.38	37.33	37.33	37.18	37.13	37.13	37.13	37.13	37.23	37.23	37.33	37.38	37.43	37.54	37.54	37.54	37.64	37.89	38.20	38.56	38.92	39.22
L3- Sub8	37.72	37.67	37.62	37.67	37.72	37.82	37.92	38.12	38.27	38.42	38.63	38.78	38.98	39.18	39.23	39.33	39.58	39.93				

Figures 7-8 Observed Data

Elapsed time (minutes)	Observed (JPACE)	SD
0	36.96	0.31
15	37.01	0.29
30	37.13	0.25
45	37.20	0.20
60	37.31	0.20
75	37.49	0.21
90	37.52	0.20
105	37.63	0.23
120	37.81	0.27

CBLITE - Aero	0	10	20	30	40	50	60	70	80	90	100	110	120
Subj-1	37.29	37.3	37.42	37.56	37.74	37.92	38.09	38.3	38.48	38.64	38.81	38.95	39.12
Subj-2	37.33	37.35	37.45	37.58	37.74	37.92	38.06	38.18	38.3	38.41	38.47	38.53	38.65
Subj-3	36.66	36.64	36.76	37	37.21	37.37	37.52	37.66	37.74	37.84	37.87	37.91	37.9
Subj-4	37.25	37.2	37.15	37.16	37.15	37.18	37.23	37.29	37.34	37.41	37.48	37.55	37.65
Subj-5	37.33	37.33	37.39	37.5	37.63	37.77	37.91	38.05	38.16	38.22	38.25	38.26	38.29
Subj-6	37.47	37.48	37.55	37.69	37.84	38	38.12	38.23	38.33	38.42	38.5	38.56	38.62
Subj-8	37.22	37.29	37.43	37.76	37.96	38.23	38.42	38.57	38.58	38.7	38.85	38.92	39
Mean	37.22	37.23	37.31	37.46	37.61	37.77	37.91	38.04	38.13	38.23	38.32	38.38	38.46
SD	0.24	0.25	0.25	0.26	0.29	0.34	0.37	0.40	0.41	0.43	0.46	0.48	0.51

CBLITE Aero+Armor	0	10	20	30	40	50
Subj-1	37.04	37.1	37.21	37.39	37.6	37.88
Subj-2	37.36	37.4	37.49	37.64	37.85	38.08
Subj-3	36.91	36.93	37.02	37.21	37.44	37.7
Subj-4	N/A	N/A	N/A	N/A	N/A	N/A
Subj-5	37.37	37.32	37.42	37.6	37.82	38.07
Subj-6	37.5	37.58	37.77	38	38.28	38.55
Subj-8	36.92	37.07	37.32	37.64	37.91	38.21
Mean	37.2	37.2	37.4	37.6	37.8	38.1
SD	0.23	0.22	0.23	0.24	0.26	0.27