PREDICTIONS OF HUMAN TOLERANCE TO HEAT STRESS DURING SIMULATED FIGHTER AIRCRAFT MISSION SCENARIOS

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INTRODUCTION

New aircrew integrated garments provide enhanced protection against acceleration (G) and altitude stresses. These ensembles have additional clothing layers, often impermeable to moisture vapor and air, and increased body surface coverage. This can lead to increased thermal load, thereby decreasing G-tolerance. Physiologic responses while wearing these garments during realistic simulated fighter aircraft (A/C) mission scenarios were estimated using Wissler’s Texas Model of Thermoregulation (TM) under cool, warm and hot conditions. The aim was to determine if increased G-protection could be provided without inducing the core temperature to rise above 39.5°C or causing excessive dehydration.

METHODS

Rectal (T_r) and skin temperatures (T_s), heart rate (HR, beats/min), sweat rate (SR, kg/h) and accumulated sweat (SWT, kg) of a 2.5% dehyd and by 16% at 3% dehyd. Since TM's fifteen body segments were measured using a thermal manikin. Custom TM garment descriptions were developed based on these values and measurements made in our lab. Body regions covered by pneumatic bladders were modeled as having impermeable outer layers. Statistical tests included paired t-tests and ANOVA. Predicted T_r, T_s, HR, SR and SWT were compared between WC and WE and E Vs A. Significance was set at p ≤ 0.05.
RESULTS

Winter Garments: Estimated thermal loads were greater for WE than WC, as expected. For cool A5, peak $T_e$ was predicted during the pre-flight thermal period (WE: 38.5°C, WC: 38.0°C) and the pilot was estimated d 1% dehydrated prior to launch. WE fluid loss was higher than WC ($p=0.0001$). There were only minor differences under warm conditions. Predicted peak $T_e$ during hot A5 were: WE: $40.7^\circ C$, WC: $39.6^\circ C$. Although estimated dehydrated reached 3% for both ensembles during the "alert 5 status," 6% dehydrated was predicted for WE during ACM. Cool and warm N-ACM predictions were similar to A5. Estimated temperatures during hot N-ACM were less than A5 (e.g. peak $T_e$: WE = 39.3°C; WC = 38.9°C). 3% dehydrated was predicted for both ensembles prior to engagement. Predicted physiologic responses for NOP and N-ACM were essentially the same.

Summer Garments: The overall level of heat stress was predicted to be higher for A than E, although overall CLO values were the same (2.1). Note that mean $T_e$ values were different (0.26 (A) Vs 0.34 (E)). During cool A5, while peak and mean $T_e$ were the same for both garments, mean E fluid losses were lower than A (SWT: 0.5 Vs 0.6 kg, $p=0.045$; SR: 1.0 Vs 1.3 kg/h, $p=0.015$). 1% dehydrated level was predicted during ACMs for A but not until after landing for E. Warm A5 condition estimates were essentially equivalent. Hot A5 predictions were as follows: peak $T_e$: E = 39.8°C (during the initial flight), A = 40.3°C (during ACM); mean $T_e$: E = 38.7°C, A = 39.1°C ($p=0.02$); mean $T_a$: E = 35.9°C, A = 36.9°C ($p=0.002$); mean SR: E = 8.3 kg/h, A = 11.1 kg/h ($p=0.02$). While the pilot was predicted to be 3% dehydrated during ACMs for both garments, 6% dehydrated was predicted to occur during the return flight for A and only after landing for E. Cool and warm N-ACM predictions were similar to A5, though N-ACM peak values were lower. The pilot was estimated to be 1% dehydrated while waiting to launch (E and A) and became 3% dehydrated during debriefing (E) or during the return flight (A). Hot N-ACM predictions were also less than A5 (e.g. estimated peak $T_e$: 38.7°C (E) and 38.9°C (A), during the initial flight). 3% dehydrated was predicted while "on station" for E and A. Predictions for NOP were essentially the same as for N-ACM. No physiologically significant differences in HR were found.

CONCLUSIONS

CNS function was predicted to be critically compromised during the hot A5 while in flight for WE and A. Therefore, based on TM estimates alone, wearing WE or A under these conditions could not be recommended. G-tolerance was also predicted to be reduced prior to engagement for all modeled garments during A5. Hot A5 and N-ACM results indicated that the relatively poorer level of CNS function during A5 was probably due to the period spent on the flight line waiting without external cooling. (Prior to launch, predicted $T_e$ for E = 39.8°C (A5) Vs 38.6°C (N-ACM) and for A = 40.3°C (A5) Vs 38.8°C (N-ACM)). The use of portable cooling units on the flight line would probably ameliorate function degradation. Note that TM does not allow fluid intake during the simulations, even though aviators can bring fluids into the cockpit. This would no doubt have reduced the overall predicted fluid loss. Therefore, it is best to interpret these results as "worst case scenarios." During cool and warm conditions, there were few operationally significant differences predicted between WC and WE. While estimated G-tolerance was reduced, predicted $T_e \leq 39.5^\circ C$. Note that WC and WE were modeled in a hot environment to simulate the case in which an A/C would be launched from a cool area, e.g. Northern Europe, and land in a hot area, e.g. the Middle East. Without fluid supplements available, TM predictions indicated that flying such a route while wearing WE would be hazardous.

<table>
<thead>
<tr>
<th>Ensemble</th>
<th>Description</th>
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<tbody>
<tr>
<td>Winter Control (WC)</td>
<td>US Navy anti-exposure liner (AEL), coverall (AEC), flyers coverall (FC)</td>
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<tr>
<td>Winter EAGLE (WE)</td>
<td>US Navy Enhanced Anti-G Lower Ensemble (EAGLE), US Navy COMBAT EDGE (CE) jerkin, AEL, AEC, FC</td>
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<tr>
<td>Summer EAGLE (E)</td>
<td>EAGLE, CE jerkin, FC</td>
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<tr>
<td>ATAGS (A)</td>
<td>US Air Force Advanced Technology Anti-G Suit (ATAGS), CE jerkin, FC</td>
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REFERENCES