

# Thermal, Cardiovascular, Performance, & Anthropomorphic Evaluation of the American Football Uniform

*Lawrence E. Armstrong Ph.D., Evan C. Johnson M.S., Douglas J. Casa Ph.D.,  
Matthew S. Ganio Ph.D., Brendon McDermott M.S., Linda Yamamoto, M.S.,  
Rebecca M. Lopez M.S., Holly Emmanuel M.S.*

*University of Connecticut, Dept. of Kinesiology, Human Performance Laboratory  
Storrs, CT 06269-1110*

**Contact person:** lawrence.armstrong@uconn.edu

## INTRODUCTION

Military,<sup>1</sup> occupational,<sup>2</sup> and athletic uniforms increase the risk of exertional heat exhaustion and heatstroke.<sup>3</sup> Specifically, the protective equipment and clothing worn during an American Football (AF) contest establishes a microclimate above the skin surface that reduces heat dissipation to the environment via radiation, convection and evaporation.<sup>4</sup> The helmet and pads, for example, cover approximately 50 per cent of the skin surface area whereas other clothing covers an additional 20 per cent. Although 20 exertional heatstroke deaths occurred among high school and collegiate athletes in the United States between 2000 – 2007,<sup>5</sup> few investigations have evaluated the AF uniform systematically in exercising humans. This, coupled with improvements of uniform synthetic materials, leaves us knowing little about the physiological and performance effects of wearing today's uniform.<sup>6,7</sup> Indeed, only two laboratory studies<sup>6,8</sup> provide information about this matter. But, because exercise intensity was not controlled in these studies, the comparison of different uniforms is difficult. Therefore, the purpose of the present investigation was to evaluate the differential effects of two uniform configurations (versus control clothing) on physiological responses and exercise performance in a hot environment.

## METHODS

This study was approved by the university Institutional Review Board for Human Studies. All subjects gave written informed consent at the conclusion of a briefing which described the procedures, risks and benefits of participation. Subjects could withdraw from testing at any time without repercussion or bias. Healthy male test subjects had > 3 y previous high school or college AF experience as a lineman, and were not highly trained, heat acclimatized, or competing in AF at the time of this investigation. Their personal characteristics were: age,  $23.8 \pm 4.3$  y; body mass,  $117.41 \pm 12.59$  kg; height,  $183.9 \pm 6.3$  cm; body fat,  $30.1 \pm 5.5$  %; skin surface area,  $2.4 \pm 0.10$  m<sup>2</sup>; mass-to-surface area ratio,  $48.4 \pm 2.3$  kg·m<sup>-2</sup>.

**Familiarization Session.** Subjects visited the Human Performance Laboratory at least 3 days prior to their first experimental test day. This preliminary visit required about 1 hour, during which height, weight, and age were recorded. Subjects received instructions regarding safe box lifting techniques and practiced these movements. They then completed 5 min of repetitive box lifting (RBL), 5 min of seated recovery, and 10 min of treadmill walking, while wearing all instruments that would be worn during experiments. No blood was collected on this day.

**Experimental Protocol.** The clothing and equipment items worn during the three experimental conditions included one of the following: control clothing (CON; compression shorts, athletic shorts, socks, sneakers), a partial AF uniform (PART; compression shorts, socks, sneakers, gloves, t-shirt, game jersey, game pants, knee pads, and thigh pads), a full AF uniform (FULL; compression shorts, socks, sneakers, gloves, t-shirt, game jersey, game pants, knee pads, thigh pads, helmet, and shoulder pads). Three to seven days elapsed between experiments. Subjects performed only light exercise during the 24 hours prior to experiments. Subjects were paid for the preliminary laboratory visit, each experiment, and received a monetary bonus if they completed all visits successfully.

A 24-hour food and fluid diary was kept prior to the first experimental test session, and this diet (including fluids) was replicated on the day before the subsequent two experiments. On the morning of each experiment, subjects did not eat until they consumed a controlled meal, then relaxed and stretched for 1 hour after eating. To aid in achieving euhydration, participants consumed 592 ml (20 oz) of water prior to going to bed the night before testing, as well as 592 ml of water on the morning of testing. Subjects did not participate if they were dehydrated (urine specific gravity > 1.028) or had a fever (first rectal temperature [ $T_{re}$ ] reading > 37.8°C). Before each test session, body weight was measured on a digital scale ( $\pm$  50 g). Heart rate and  $T_{re}$  were monitored every 5 min during exercise, to ensure test subject safety.

The exercise protocol consisted of 10 min of repetitive box lifting (RBL), 10 min of seated recovery, followed by up to 60 min of treadmill walking. RBL consisted of lifting a 20.4 kg (45 lb) metal box with handles; the rate of box lifting (10 lifts·min<sup>-1</sup>) was identical in all experiments. Finally, subjects walked briskly on a treadmill (5.6 km·h<sup>-1</sup>, 5% grade) until either 60 min or one of the following termination criteria was reached: signs and symptoms of heat illness appeared; or subjects elected to stop volitionally when exhausted; or  $T_{re}$  rose to 40°C or higher. Subjects consumed no fluid during laboratory experiments.

A 7-ml blood sample was drawn prior to exercise from an antecubital vein by a trained phlebotomist, using sterile technique. Another 7-ml blood sample was drawn when exercise stopped. Blood was analyzed for hematocrit in triplicate, hemoglobin in duplicate, blood glucose and lactate in duplicate, and plasma osmolality in duplicate.

The following measurements were taken before, during and at the end of exercise: blood pressure (BP) using an aneroid sphygmomanometer and stethoscope;  $T_{re}$  via rectal thermister; forearm and posterior neck skin temperature with an infrared temperature scanner placed against the skin; and heart rate via telemetry. Relative humidity inside the uniform was measured with a hand-held meter, by placing the wand sensor under the jersey and t-shirt of the exercising individual, in the lumbar region, without making contact with the skin.

**Statistical Analyses.** Treatment effects were evaluated using a randomized, cross-over design. Data were analyzed using a two-way repeated measures (uniform x time) analysis of variance (ANOVA) and are reported as mean  $\pm$  standard deviation (SD). A Bonferroni correction with *post-hoc* t-tests were used to determine pair-wise differences among uniform type and time. In the event of significant F values ( $p < .05$ ), *post hoc* analysis was done via the Neuman-Keuls test. The magnitude of the effect size was calculated. Also, to evaluate relationships between key outcome variables and subject characteristics, linear regression analysis was performed.

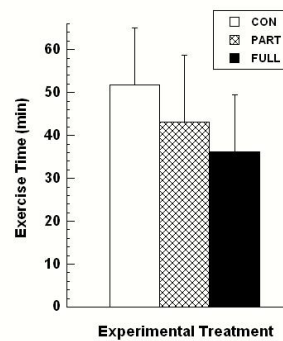
## RESULTS

The present investigation was the first to evaluate different AF uniform configurations in a hot environment within a controlled, randomized, counter-balanced experimental design ( $n = 10$ ). The environmental conditions during all laboratory experiments were similar ( $33.0^{\circ}\text{C}$ , 48-49 %rh). The entering body weight and urine specific gravity of test subjects were statistically similar across days, indicating that they began all experiments in a similar state of hydration.

The relative humidity (%rh) near the skin surface varied among the three clothing conditions. The mean value for CON was  $47 \pm 4$  %rh throughout the entire experiment; the values for PART ranged from  $75 \pm 9$  to  $89 \pm 4$  %rh; and FULL ranged from  $69 \pm 11$  to  $90 \pm 5$  %rh. CON was significantly different ( $p < .000001$ ) from PART and FULL at all time points; %rh for PART and FULL were statistically similar.

Although all subjects completed at least 15 min of treadmill exercise, a different number of subjects completed exercise in each experimental condition (i.e., 60 min treadmill walking, after 10 min RBL and 10 min seated recovery). Seven subjects completed the entire 80-min protocol during CON, three during PART, but only one completed FULL. During 19 out of 30 experiments, test subjects halted their own exercise due to volitional exhaustion.

Figure 1 (below) presents time to exhaustion for CON, PART and FULL.



A main effect of uniform type on skin temperature was detected at the end of treadmill exercise. On the back of the neck, FULL ( $35.6 \pm 1.0^{\circ}\text{C}$ ) was greater ( $p < .001$ ) than CON ( $34.5 \pm 1.1^{\circ}\text{C}$ ), and PART ( $35.3 \pm 1.0^{\circ}\text{C}$ ) was greater ( $p < .05$ ) than CON. On the forearm, the skin temperature for FULL ( $35.2 \pm 0.6^{\circ}\text{C}$ ) was greater ( $p < .05$ ) than CON ( $34.5 \pm 1.0^{\circ}\text{C}$ ).

Mean whole body sweat rate (pre-exercise versus post-exercise) was lowest during CON ( $1.24 \pm 0.16 \text{ L}\cdot\text{h}^{-1}$ ); this value was different ( $p < .001$  to  $.0001$ ) from PART ( $1.86 \pm 0.25 \text{ L}\cdot\text{h}^{-1}$ ) and FULL ( $2.05 \pm 0.34 \text{ L}\cdot\text{h}^{-1}$ ), but PART and FULL were statistically similar. The total sweat losses during experiments, expressed as a percentage of body weight, were minor (CON, -1.0%; PART, -2.0%; FULL, -2.0%).

The final heart rate was measured at the point of exhaustion, at a different exercise duration for each uniform condition, and at near-maximal heart rates; final heart rate for CON ( $164 \pm 14 \text{ beats}\cdot\text{min}^{-1}$ ) was less ( $p < .025$ ) than during PART ( $178 \pm 8 \text{ beats}\cdot\text{min}^{-1}$ ;  $d = 0.92$ ) and FULL ( $180 \pm 13 \text{ beats}\cdot\text{min}^{-1}$ ;  $d = 1.41$ ); PART and FULL were not different at any time point.

Systolic and diastolic blood pressures ( $n = 9$ ) for three phases of the experimental protocol indicated a main effect of time ( $p = .0002$  to  $.0007$ ), in comparisons of Pre-RBL versus IP RBL (effect size  $d = 0.37$  to  $0.98$ ) as well as Pre-RBL versus IP Treadmill Walking ( $d = 1.33$  to  $1.41$ ). A main effect of time ( $p = .0001$  to  $.0002$ ) was detected for systolic blood pressure, when

IP-RBL was compared to IP Treadmill Walking ( $d = 1.38$ ). Although the blood pressure comparisons among clothing types were statistically similar at all time points, a between-uniform trend (main effect,  $p=.09$ ) was detected for systolic pressure.

Hematologic variables were analyzed in samples collected before RBL and immediately after the end of treadmill walking. No between-uniform differences were found for plasma lactate, glucose, osmolality, or percent change of plasma volume.

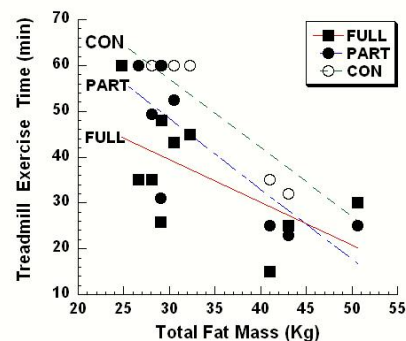
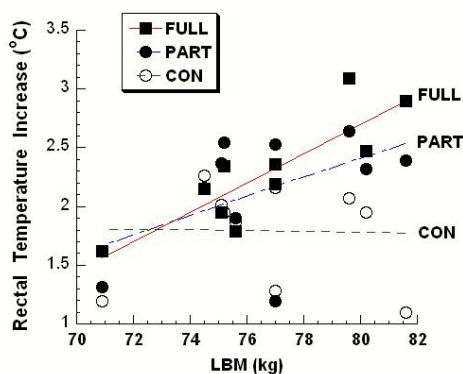
Subjects began RBL with similar  $T_{re}$ : CON,  $37.2 \pm 0.1^\circ\text{C}$ ; PART,  $37.2 \pm 0.1^\circ\text{C}$ ; FULL,  $37.2 \pm 0.1^\circ\text{C}$ . At the end of treadmill exercise, subjects experienced similar elevated final  $T_{re}$  when wearing a uniform (PART,  $39.2 \pm 0.6^\circ\text{C}$ ; FULL,  $39.2 \pm 0.5^\circ\text{C}$ ). Final  $T_{re}$  was lower ( $p<.05$ ) for CON ( $38.8 \pm 0.5^\circ\text{C}$ ) than for PART ( $d = 0.86$ ) and FULL ( $d = 1.04$ ). Thus, elevated  $T_{re}$  coincided with earlier exhaustion in FULL and PART (versus CON). However, because the starting  $T_{re}$  was similar in all conditions, linear regression analysis showed that the initial  $T_{re}$  (pre-RBL) was not correlated with total exercise time for the CON, PART and FULL conditions ( $R^2 = 0.01$  to  $0.02$ ,  $p=.68$  to  $0.78$ ).

Table 1 (below) presents data regarding the change of  $T_{re}$  and the rate of  $T_{re}$  increase; the duration of total heat exposure was different for each uniform type (see Fig. 1).

Trial	Mean rectal temperature increase ( $^\circ\text{C}$ )	Mean rectal temperature rise ( $^\circ\text{C}\cdot\text{min}^{-1}$ ) during the entire experiment (rest + exercise)	Mean rectal temperature rise ( $^\circ\text{C}\cdot\text{min}^{-1}$ ) during treadmill exercise
CON	$1.81 \pm 0.40$	$0.026 \pm 0.008$	$0.037 \pm 0.015$
PART	$2.36 \pm 0.24$	$0.034 \pm 0.006 \ddagger$	$0.052 \pm 0.012$
FULL	$2.37 \pm 0.45$	$0.042 \pm 0.010 \dagger$	$0.071 \pm 0.032 \dagger$

$\dagger$ , significantly greater than CON and PART ( $P<.05$  to  $.0005$ ;  $d=0.79$  to  $1.10$ );

$\ddagger$ , significantly greater than CON ( $P<.0005$  to  $.05$ ;  $d=1.13$  to  $1.77$ ).



Figures 2 and 3 (above) illustrate the results of two linear regression analyses ( $n = 10$ ). These relationships involve (a)  $T_{re}$  increase ( $^\circ\text{C}$ ; entire exercise-heat protocol) versus lean body mass (LBM) while wearing FULL (solid squares), PART (solid circles), and CON (open circles); and (b) total fat mass (kg), measured via DEXA scan, versus treadmill exercise time. The former variables (Fig. 2) were strongly positively correlated during FULL ( $R^2 = 0.71$ ,  $p<.005$ ), indicating that the  $T_{re}$  ( $^\circ\text{C}$ ) increased in proportion to lean body mass (kg), but not during PART ( $R^2 = 0.25$ ,  $p=.15$ ) or CON ( $R^2 = 0.01$ ,  $p=.95$ ). The latter variables (Fig. 3) were strongly and negatively correlated ( $n = 10$ ) during CON ( $R^2 = -0.90$ ,  $p<.00005$ ) and PART ( $R^2 = -0.69$ ,  $p<.005$ ) but not during FULL ( $R^2 = -0.36$ ,  $p>.05$ ).

## CONCLUSIONS

1. Only one subject completed the entire prescribed 60-min of brisk treadmill walking during FULL; in comparison, three subjects completed PART and seven completed CON.
2. a) Exhaustion occurred during FULL and PART at the same mean final  $T_{re}$  ( $39.2^{\circ}\text{C}$ ), although subjects exercised for different durations (FULL,  $36.2 \pm 13.2$ ; PART,  $43.0 \pm 15.6$ ; CON,  $51.7 \pm 13.4$  min). These data support the existence of a critical internal temperature as a possible mechanism for exhaustion.  
b) The mean final heart rates also were similar during FULL ( $180 \pm 13$  beats $\cdot$ min $^{-1}$ ) and PART ( $178 \pm 8$  beats $\cdot$ min $^{-1}$ ), but both were significantly greater than ( $p < .05$ ) than CON ( $164 \pm 14$  beats $\cdot$ min $^{-1}$ ;  $d = 0.92, 1.41$ , respectively).  
c) Both systolic and diastolic hypotension developed throughout exercise (all clothing conditions, main effect of time).  
d) Thus, critical internal temperature, near-maximal heart rate, and hypotension existed concurrently with exhaustion during uncompensable (FULL) or nearly-uncompensable (PART) heat stress.
3. Mean sweat rate and heart rate during CON were significantly different from both PART and FULL ( $p < .05$  to  $.0005$ ; effect size  $d = 0.42$  to  $1.41$ , respectively); no treatment differences were detected for blood lactate, glucose, osmolality, and plasma volume change.
4. FULL (versus PART) resulted in a faster rate of  $T_{re}$  increase ( $p < .0005$ ,  $d = 0.79$ ), decreased treadmill exercise time ( $p < .005$ ,  $d = 0.48$ ), and fewer completed exercise bouts.
5. A significant correlation coefficient existed between (a)  $T_{re}$  increase and lean body mass during FULL ( $R^2 = 0.71$ ,  $p < .005$ ), and between (b) treadmill exercise time versus total fat mass (kg) during both CON ( $R^2 = -0.90$ ,  $p = .00005$ ) and PART ( $R^2 = -0.69$ ,  $p = .005$ ).
6. These findings support sports medicine guidelines<sup>4,9</sup> that limit use of a helmet and shoulder pads during the initial days of heat exposure, to reduce the risk of exertional heat illness.

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