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Physiological strain associated with wearing body armour of increasing ballistic protection

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PHYSIOLOGICAL STRAIN ASSOCIATED WITH WEARING BODY ARMOUR OF INCREASING BALLISTIC PROTECTION

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INTRODUCTION

Clothing, body armour and metabolic heat production can independently elevate thermal strain in individuals working in the heat. This change can impair physical and cognitive performance, whilst simultaneously increasing the risk of exertional heat illness. When climate, clothing and metabolic rate are dictated by external factors, and when cooling is not possible, the only way to manipulate thermal loading is to modify the level of ballistic protection.

Body armour is necessarily heavy, and it impedes evaporative cooling. Thus, superior protection induces more heat storage and greater performance decrements, while lower ballistic protection increases heat loss. This trade-off between protection and performance has long been understood, and the purpose of this study was to evaluate the thermal strain imposed by a four-tier system of ballistic protection during an urban patrol simulation conducted in dry heat. Accordingly, the affects of variations in body-armour mass and surface area coverage were explored.

METHODS

Eight healthy males completed five trials, each lasting 120 min, in hot-dry conditions that simulated Middle East summer climate (45°C, 20% relative humidity) with a substantial radiant heat source (infra-red lamps: ~750 W.m^{-2}). Subjects first walked on a treadmill at 4 km.h^{-1} (1% gradient, 90 min). This was designed to simulate the movement speed of an urban military patrol, and a total metabolic rate of ~320 W. Subjects walked for 28 min, and then rested for 2 min, during which time 300 mL of water was consumed (at chamber temperature), with this cycle completed three times. At the end of this 90-min period, both walking speed and gradient were increased, and subjects attempted 30 min of higher-intensity exercise. This phase was used to simulate an attack scenario, and a total metabolic rate of ~700 W. Subjects now walked at 6 km.h^{-1} (4% gradient) for 30 min, or until fatigued or reaching one of the trial termination criteria. A fan was set in front of each subject to produce a constant wind velocity (4 km.h^{-1}) for the entire trial.

Trials differed only with respect to ballistic protection and the torso surface area covered by the different vests that carried the torso armour. In all trials, subjects wore a standard camouflaged combat uniform (insulation 0.29 m^{2}K.W^{-1}) and helmet. Subjects wore each of five different levels of protection (Figure 1). Control (*Tier zero*): vest and webbing without body armour; *Tier one*: lightest armour mass (3.4 kg) with the smallest torso surface area coverage (0.24 m^2); *Tier two*: intermediate armour mass (6.8 kg) and surface area coverage A (0.30 m^2); *Tier three*: intermediate armour mass (7.8 kg) and surface area coverage B (0.44 m^2); *Tier four*: heaviest armour mass (11.0 kg) with greatest surface area coverage (0.52 m^2).

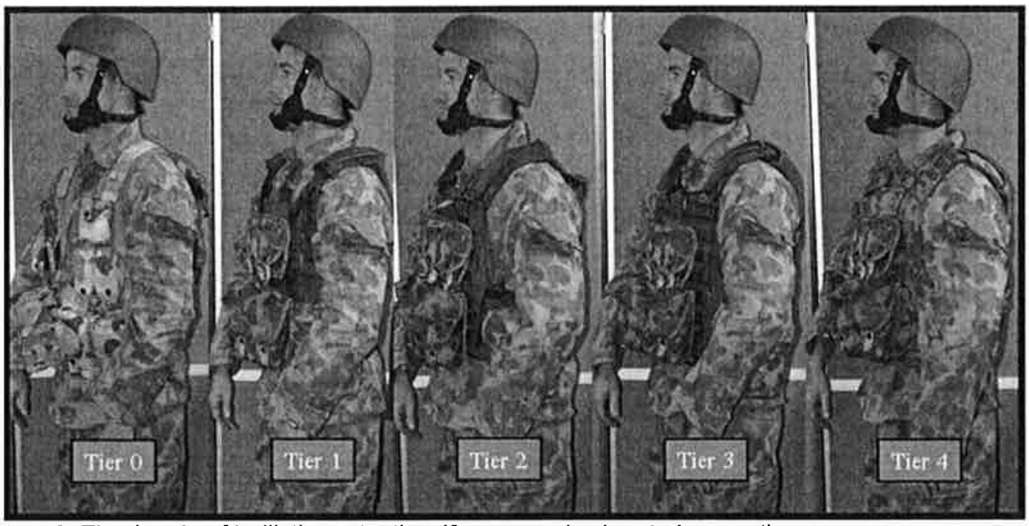

Figure 1. Five levels of ballistic protection (0 = none, 1 = least, 4 = most).

Webbing pouches were filled with foam to ensure that they behaved as they would in the field, but without mass affecting the subject or the properties of each pouch. This also simulated equipment bulk which influences arm movements and clothing (bellows) ventilation. To further increase the reality of the simulation with respect to clothing ventilation, subjects carried a simulated weapon to limit arm motion. To remove order effects, the trial sequence was balanced across subjects, with each completing the experiment in a different order, with at least 1 week separating successive trials on the same subject.

All testing was conducted at the same time of day, using fully-hydrated subjects. Prior to commencing each experiment, all subjects had a pre-exposure urine specific gravity <1.029 (euhydrated). Measures included body core and skin temperatures, heart rate, whole-body sweat and evaporation rates, and psychophysical responses.

RESULTS

These armoured ensembles had a significant impact upon work tolerance times, which decreased as ballistic protection increased, with this difference being statistically significant between Tiers 1 and 4 ($P<0.05$).

Core temperatures did not plateau during any trial, and, beyond 40 min, data started to deviate among the trials as time progressed (Figure 2). Statistically significant deviations were evident for comparisons between Tier 0 and Tier 4 ($P<0.05$), Tiers 1 and 2 versus Tier 3 ($P<0.05$), and Tiers 1 and 2 compared with Tier 4 ($P<0.05$). There were no significant thermal differences among Tiers 0-2, or between Tiers 3 and 4 ($P>0.05$). Thus, it appeared that Tiers 0-2 imposed an equivalent, but lower thermal stress on subjects, while Tiers 3 and 4 were also equivalent, but exerted a greater thermal load.

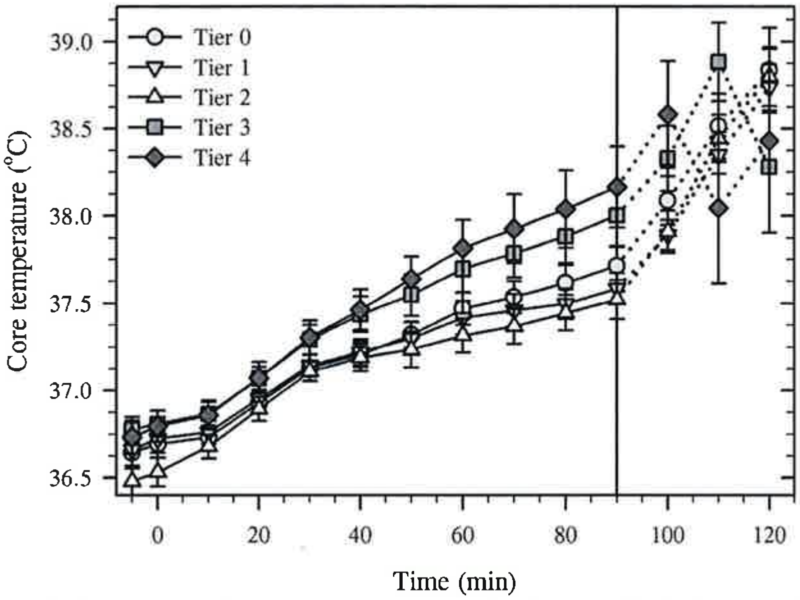

Figure 2. Core temperature responses across five levels of ballistic protection (0 = none, 1 = least, 4 = most) during a simulated urban military patrol.

Distinct separations of the thermal influences of the body armour on mean skin temperature were also apparent ($P<0.05$). It was again clear that Tiers 0-2 formed one group, while Tiers 3 and 4 fell into another. In this latter group, the armour was preventing heat loss. However, within each group, there were no significant differences among the armour tiers ($P>0.05$).

Finally, the heart rate responses were clearly separated among trials beyond the first 40 min. Tier 4 always elicited greater strain, with comparisons between Tiers 1 and 4, and between Tiers 2 and 4 being statistically significant for the time by armour interactions ($P<0.05$). No significant differences were evident among Tiers 0-2, or between Tiers 3 and 4 ($P>0.05$).

CONCLUSION

These observations support the classification of these protection tiers into two equally stressful groups: Tiers 0, 1 and 2; and Tiers 3 and 4. Since there was no evidence of statistically significant differences among the tiers within either of these two groups, then decisions concerning the use of each tier within an equally stressful group can be made solely upon the basis of ballistic protection required for each operational scenario. However, moving from one group to the other will affect both ballistic protection and physiological strain.

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