Setting heat stress limits for acclimatised soldiers exercising in heat

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SUMMARY: Heat illness is a recognised risk of military training. The Combat Fitness Test (CFT) has been identified as an activity that has been associated with heat casualties. The aim of this study was to establish whether a heat stress limit could be set for acclimatised soldiers performing the CFT by measuring the group mean rises in core temperature whilst performing the CFT at various environmental temperatures. The study showed that CFTs should not be undertaken when the start or expected end Wet Bulb Globe Test (WBGT) is greater than 25°C if the group mean rise in core temperature is not to exceed 0.6°C (95% CI 0.2°C to 1°C).

Introduction

Collapse during exertion in hot weather is a well recognised risk associated with military training. This can cause liver damage, renal failure, muscle damage, clotting dysfunction, brain damage and death. Loss of a significant number of personnel from this condition may have serious consequences for a military commander. The storage of heat in the human body is commonly summarised by the 'heat balance equation' shown at Table 1. If the net effect of the heat balance equation causes heat storage then the core temperature may rise. It is presumed that the *sine qua non* of heat illness is a rise in core temperature. Military training may cause heat casualties by increasing the heat load by exercise or decreasing heat loss by the wearing of protective clothing or exposure to high environmental temperatures.

Table 1
Heat Balance Equation

Heat storage =	heat gained from basal metabolic heat heat from exercise	–	heat lost from evaporation conduction radiation convection
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Studies have shown that the steady state core temperature is proportional to exercise intensity over a wide range of environmental temperatures (1,2,3). At low environmental temperatures core temperature rises in proportion to environmental temperature. A steady state develops between heat production as a consequence of exercise and heat loss as a consequence of thermoregulatory responses as the environmental temperature rises. A 'prescriptive zone' has been defined as the temperature range at which core body temperature is stable in spite of an increase in the environmental temperature. At a certain environmental heat load thermoregulation is overwhelmed and core temperature again rises in proportion to heat load. The point of change from the steady state in the prescriptive zone to

an increase in core temperature has been identified as the critical point of decompensation. The range of the prescriptive zone is dependant on the intensity of heat generated. It is possible to exceed the thermoregulatory control system by increasing the work intensity at a given environmental temperature or by increasing the environmental temperature at a given work intensity. This is summarised in Figure 1. The development of a predictive model for the prevention of heat casualties should therefore focus on identifying the point at which the steady core temperature is overcome, the 'critical temperature'.

Fig 1. Core Temp Against Environmental Temp (at constant work rate)

The effective environmental temperature is dependant on the meteorological conditions. There are various techniques for estimating this, the most widely used being the WBGT index. This can be calculated using the following equation:

$$\text{WBGT} = 0.7 \text{ Natural Wet Bulb} + 0.2 \text{ Globe} + 0.1 \text{ Dry Bulb}$$

The WBGT as an index of heat stress was developed in the 1950s to aid the prevention of heat casualties in US Marine Corps recruits (4). This index was introduced into the British Army in the 1970s (5). The most recent policy document for the prevention of heat casualties

uses these same guidelines (6). The WBGT index has been revised for civilian use and standards have been published by various international organisations (7,8,9,10).

A recent analysis of reported cases of heat injury in both UK and Cyprus found that the Combat Fitness Test (CFT) caused approximately 15% of cases (11). The Combat Fitness Test is a mandatory annual test to be performed by all Army personnel. It is a 8 mile forced march (12.8 km) carrying 36 pounds of personal equipment which has to be completed in 2 hours. This represents a fixed work rate and therefore it might be possible to determine the 'critical temperature' at which this test can be performed safely by careful experimentation.

The aim of this study was to measure the rise in core temperature of soldiers performing a CFT at different environmental temperatures in order to experimentally determine whether a heat stress limit could be defined.

Method

The experiment was conducted at intervals during the summers of 1993, 1994 and 1995 in Cyprus using soldiers from the resident infantry battalion in Episkopi. The experimental design involved cohorts of soldiers performing a CFT at varying environmental temperatures. The core temperature and pulse rate of each soldier was measured before and after conducting the CFT. The mean gain in core temperature for each group was plotted against the environmental temperature. It was calculated that a minimum cohort size of 6 was required to give a 95% chance of detecting a difference of 0.5°C gain in core temperature between two groups.

The CFT was conducted in accordance with the instructions in Army Training Directive Number 7 (12) and run by trained physical training staff. Helmets were to be carried and desert combat dress was worn. There were water stops at the 3, 5, 6 and 7 mile points.

Soldiers were instructed to count their own pulse rates at the start and the end of the CFT with a start and stop time given by the investigator. Core temperature measurements were made at the start and the end of the CFT with an IVAC Corecheck™ aural thermometer. This device has already been described in a previous paper (13). Measurements were taken from both ears and the maximum reading obtained was used.

The environmental temperature was measured using a Metrosonics Hs 360 WBGT meter set up at the start point of the CFT. This machine was calibrated annually in accordance with the manufacturer's instructions. The WBGT was obtained at the start and the end of the CFT.

The Commanding Officer of the Resident Infantry Battalion in Episkopi Garrison, Cyprus was asked for permission to conduct this series of experiments using his soldiers. The officer commanding each rifle company was asked to provide a minimum of 10 soldiers for each

CFT. The WBGT measurements over the previous week were examined to predict a suitable time to perform the CFT in order that the existing instructions for the prevention of heat casualties were not broken (7). This set the maximum WBGT for the start of a CFT at 29°C. Soldiers who had been resident in Cyprus for less than 6 weeks were excluded.

When each cohort paraded a detailed explanation of the experimental method was given. As the CFT was being conducted in accordance with existing instructions the only consent required was in relation to the experimental observations. No subject refused to enter the study. Soldiers who were feeling unwell were asked to withdraw.

In view of the potential risks involved in this study each cohort performing a CFT was accompanied by a doctor with a medical assistant and a safety vehicle. Any soldier who showed signs of heat illness was directed to withdraw from the study (often against the individual's will).

The experimental design required the comparison of the means of 11 separate groups. Statistical analysis by means of a series of multiple two sample T-tests would be inappropriate because there would be 55 separate pairs for testing which would give a probability of 90% for at least one pair being significant at the 5% level when in fact the converse was true. The correct method of analysis is an 'analysis of variance' (ANOVA) which was performed using Microsoft Excell software (14).

This project was sponsored by the Army Medical Services Research Executive who also provided ethical approval.

Results

There were 11 separate CFT studies using 130 different subjects. The summary statistics are shown in Table 2. All subjects completed the CFT except one subject in CFT number 10, and 4 subjects in CFT number 11. CFT number 11 included one subject who collapsed with heat illness but recovered quickly with prompt medical attention.

Aural temperatures were measured once from each ear. The maximum value obtained was used in the analysis because the 'true' core temperature was likely to be closer to the maximum measured rather than the mean from the two ears. All CFTs were conducted during the morning, thus the end WBGT was often substantially higher than the start WBGT. It was not possible to monitor the variation in WBGT during the course of the trials because the investigator was occupied supervising the CFT. It was decided to use the end WBGT for analysis as this represented the maximum heat stress exposure for the trial groups. Thus advice based on this figure will err on the side of safety. The single factor ANOVA tables for the comparison of the difference between group mean gains in core temperature and pulse are at Table 3.

Table 2
Summary of Experimental Results

Ser	Number in sample	Date	End WBGT	Mean max start temp	SD	Mean max end temp	SD	Mean temp gain	SD	Mean start pulse	SD	Mean end pulse	SD	Mean pulse rise	SD
1	16	11/05/94	16.6	35.7	0.61	36.1	0.5	0.4	0.52	71.4	11.3	127.4	12.6	56	13.5
2	17	29/04/94	18.1	36.1	0.44	36.9	0.5	-0.06	0.8	78.6	9.6	99.1	12.5	20.5	10.4
3	12	12/06/93	19.9	35.4	0.5	36.4	0.8	0.9	0.9	71.4	12.9	111.2	22.4	39.8	20.5
4	10	08/07/94	20.1	36.2	0.4	36.9	0.5	0.7	0.8	72.4	2.1	104.4	17.8	32	18.4
5	7	20/05/93	21.3	35.6	0.6	36.8	0.4	1.3	0.7	78.7	10.6	100	10.3	21.3	12.1
6	7	25/05/93	22.1	36.1	0.3	36.3	0.3	0.2	0.33	81.6	10.7	143	12.8	61.4	20.9
7	8	02/06/93	22.2	35.7	0.4	36.4	0.4	0.7	0.3	70.7	9.6	127.7	11.5	57.4	12.7
8	6	05/05/94	22.3	35.4	0.9	36.0	0.8	0.65	0.9	66.3	10.8	109.2	19.1	42.8	24.1
9	14	18/05/94	25	35.9	0.3	36.5	0.6	0.6	0.6	74.2	11.4	127.2	11.4	53	24.3
10	19	26/05/94	27.1	36.5	0.5	37.7	0.8	1.2	0.82	66.9	9.9	122.6	27.1	55.7	27.7
11	14	05/07/95	29	36.3	0.3	38.1	0.6	1.8	0.68	68.9	7.6	138	30.9	69.4	32.2

Table 3
Anova for Comparison of Group Mean Gains in Temperature

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	36.63675	10	3.663675	7.122933	1.02E-08	1.91114
Within Groups	61.20756	119	0.514349			
Total	97.84431	129				

Anova for Comparison of Group Mean Gains in Pulse Rate

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	32130.34	10	3213.034	6.995252	1.46E-08	1.91114
Within Groups	54658.65	119	459.3164			
Total	86788.99	129				

The probability of a significant difference between the different group means for gain in core temperature is 1.02×10^{-8} and for the different group means for gain in pulse rate is 1.46×10^{-8} . Therefore the groups can be subjected to a follow-up analysis by plotting the group means against WBGT. Figure 2 shows the plot for the group mean gain in core temperature against WBGT. The group mean gain in pulse rate is plotted against WBGT in Figure 3. The 95% confidence limits for each group are shown by error bars. These confidence limits have been calculated using the pooled standard deviation and the group size to determine the standard error of the mean for each group.

From Figure 2 it can be seen that the gain in core temperature is probably between 0.5°C and 1°C when the WBGT is less than 25°C . When the environmental

temperature is around 25°C the ability to maintain a stable core temperature is overwhelmed and there is a mean gain in core temperature within the group of subjects. The confidence limits for the groups at WBGTs between 19.9°C and 22.3°C overlap so although there seems to be substantial variation between groups this can accounted within the limits of sampling.

Figure 3 shows substantial overlap of group confidence limits at all WBGTs. There is no clear trend. Thus there is no demonstrable association between the group mean gain in pulse rate and WBGT.

Discussion

Overall this study has shown that the group mean gain in core temperature whilst performing the CFT is independent of environmental temperature until a threshold at approximately 25°C WBGT when the core temperature rises. This study is valid for acclimatised caucasian males only. There was no demonstrable association between rise in pulse rate and environmental temperature.

These results are in keeping with experimental evidence from climatic chamber studies (1). It has been shown that there is a 'prescriptive zone' of environmental temperature where the gain in core temperature is dependant on exercise intensity and not environmental temperature. However there seems to be a critical environmental temperature (or threshold) where the thermoregulatory systems are overwhelmed and the gain in core temperature is proportional to environmental temperature.

This study identifies this threshold for fit acclimatised male soldiers performing the CFT as approximately 25°C WBGT if the group mean rise in core temperature is not to exceed 0.6°C (95% CI 0.2°C to 1°C). The study utilised a standard work test that is understood by most soldiers (particularly the effort involved). It utilised the usual heterogeneous military population and no specific

Fig 2. Group Mean Gain in Core Temperature Against WBGT

Fig 3. Group Mean Gain in Pulse Rate Against WBGT

restrictions were imposed. Thus the conclusions are likely to be valid and applicable to the military population.

What is the most appropriate statistical summary of the population? Is the mean value the most appropriate, or should the 95th centile (or some other value) be chosen if the intention is to provide guidance to ensure safe training for all soldiers? If such a limit was chosen then the safe gain in core temperature would need to be identified. The WBGT threshold would be identified by choosing the highest group whose 95% confidence limit did not exceed the predetermined threshold. This method is flawed because there are many individual factors (such as concurrent illness, hydration, individual susceptibility) that contribute to individual risk of heat illness. The intention of guidance based on environmental temperature is to avoid exposure of soldiers to conditions where it is known that the thermoregulatory system will be overwhelmed. Thus advice determined by evidence based on the mean effects on a group is most appropriate.

The exact environmental threshold temperature could be refined by conducting trials in a climatic chamber so that the heat load of subjects is more closely monitored. It is unlikely that such trials would produce an improvement to the quality of evidence as in practice the WBGT will vary during the course of a CFT and thus advice for exposure should reflect this. If soldiers have to be exposed to conditions outside the threshold of environmental temperature then it may be appropriate to conduct hot chamber experiments to determine the work/rest cycles necessary to ensure safety.

This study should be repeated using the same methodology for unacclimatised troops and females.

Conclusion

This study has shown that CFTs should not be undertaken when the start or expected end WBGT is greater than 25°C if the group mean rise in core temperature is not to exceed 0.6°C (95% CI 0.2°C to 1°C). Advice based on the results of this study is summarised in Table 4. The effectiveness of this advice depends on education of commanders and the availability of equipment for measuring the WBGT.

Table 4
Advice to Commanders for the Prevention of Heat Illness in Acclimatised Soldiers

- 1. Physical work whilst exposed to a hot environment has the risk of causing heat casualties.
- 2. All soldiers exposed to the risk of becoming a heat casualty should be fit and fully hydrated.
- 3. If the work rate required to pass a CFT is taken as a standard, soldiers should not perform continuous work when the expected end WBGT is greater than 25°C.
- 4. If physical work is necessary and the WBGT is likely to exceed 25°C then medical advice should be sought to determine the appropriate work/rest cycle to reduce the risk of heat casualties.

Acknowledgements

I would like to thank all soldiers who took part in this series of experiments and the staff at the Garrison Medical Centre Episkopi. I would like to acknowledge the contribution the following people made to this study:

Major A File from the Army School of Physical Training for detailed advice regarding the Combat Fitness Test.

Col DW Smith FRCGP, late RAMC, Lt Col SA St Miller MSc, MFPHM, RAMC, Col TP Finnegan MSc, FFOM, late RAMC, Dr R Whitey, Dr C Millard and M Walters of the Centre for Human Sciences.

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J R Army Med Corps first published as 10.1136/jramc-143-01-09 on 1 February 1997. Downloaded from <http://militaryhealth.bmj.com/> on April 26, 2023 by guest. Protected by copyright.