Int J Biometeorol (1995) 39:64–68

ORIGINAL ARTICLE

A.P. Singh · D. Majumdar · M.R. Bhatia
K.K. Srivastava · W. Selvamurthy

Environmental impact on crew of armoured vehicles: effects of 24 h combat exercise in a hot desert

Received: 25 November 1994 / Revised: 6 January 1995 / Accepted: 18 July 1995

Abstract A field study was undertaken to investigate the effects of combined noise, vibration and heat stress on the physiological functions of the crew of armoured vehicles during prolonged combat exercise in a desert. The sound pressure level of noise was measured with a sound level meter and accelerations by vibration analyser. The thermal load on the crew was evaluated by calculating the wet bulb globe temperature index. The physiological responses of the subjects (n=9), included significant increases in the heart rate, 24 h water intake and urinary catecholamine concentration. A significant decrease was recorded in body mass, peak expiratory flow rate and 24 h urinary output. The high heat load on the crew resulted in a hypohydration of 3% body mass and appeared to be the dominant factor in producing the physiological strain.

Key words Environmental factors · Heat · Combat exercise · Hypohydration · Physiological strain

Introduction

Armed forces personnel functioning as the crew of armoured vehicles are exposed to a variety of environmental stresses during combat exercises, especially those performed in deserts and in hostile climatic conditions. In addition to the extremes of climate, the crew are exposed to high levels of noise and mechanical vibration whilst at work. Studies on the effects of combined noise, vibration and heat on human health and performance have reported synergistic as well as antagonistic interactions. Heat has been found to potentiate the risk of auditory damage (Rentzsch and Minks 1989). Similarly vibration has been reported to interfere with the normal cooling process in a hot environment (Spaul et al. 1986); together with noise and heat, vibration antagonistically interacts with other physiological and psychological functions (Grether et al. 1971). Heat stress in a desert assumes a dominating role over other environmental factors and has an effect on thermoregulation (Adolph 1949). Heat exposure, when combined with moderate exercise, helps in the acclimatization to heat (Leithead and Lind 1964).

One of the principal problems during military exercises in a desert is that of fluid deficit incurred by the soldiers. Studies on diverse military activities in desert have indicated an increased sweating rate (Adolph 1947), which was found to vary with the intensity of exercise (Shapiro et al. 1982). Investigations on US armed forces after Operation 'desert storm' have emphasized the need for high aerobic fitness, heat acclimatization and an adequate regime of fluid intake as pre-requisites to sustained military performance (Bennett 1991). In addition, the protective clothing of the soldiers has been suggested to interfere with their physiological tolerance to heat (Scott et al. 1994).

In the foregoing investigations, the thermoregulatory responses of men have been examined with exercise under heat-stress conditions, and the exercise intensity has been found to be a contributory factor to body heat storage and rise in core temperature. However, there is not much information about the physiological responses of the crew of armoured vehicles during prolonged combat exercises comprising exposure to vehicle noise, vibration and high heat load along with mild to moderate physical exertion. The purpose of the present study was to investigate the effects of combined noise, vibration and heat stress in the desert on the physiological functions of heat-acclimatized crew of armoured vehicles. The crew were engaged in 24 h combat exercise and were wearing the normal summer uniform of the Indian army.

Methods

Nine healthy male soldiers functioning as the crew of armoured vehicles served as subjects. Their mean age was 30.3 years (range 25–42 years). The mean body mass and height of the subjects

---

A.P. Singh (✉) · D. Majumdar · M.R. Bhatia · K.K. Srivastava
W. Selvamurthy
Defence Institute of Physiology and Allied Sciences,
Lucknow Road, Timarpur, Delhi-110 054, India

were 64.18 kg (range 56.3–72.2 kg) and 1.70 m (range 1.64–1.76 m) respectively. They were housed in tents and were exposed to natural weather conditions. The daily physical activity and nutritional status of all the subjects were similar. The unit was deployed in the desert for 45 days before the onset of combat exercise, and crew members performed their routine physical activity including P.T., parade, vehicle maintenance in the open for 5–6 h daily, etc. during this period. The resting heart rate, oral temperature (recorded between 0900 and 1100 hours every day) and 24 h water intake of subjects recorded on three consecutive days, before the onset of exercise, did not indicate any variations in these three observations. This result was assumed to indicate that the subjects were acclimatized to the hot weather conditions prevalent at that time in the desert.

The subjects were exposed to complex environmental conditions in armoured vehicles as a result of participation in a 24 h combat exercise in the desert. They were dressed in the summer uniform of the Indian army and used head gears for communication and noise protection. The crew were engaged in activities such as driving the vehicles, engaging the targets and communicating with others. They were provided with adequate quantities of drinking water and could halt for food and natural calls while on the move.

Noise and vibration

The sound pressure levels (dB) were measured with a set comprising a type 2230 sound level meter and type 4133 condenser microphone (Bruel and Kjaer, Denmark). The frequency analysis was carried out using a type 1625 octave filter set (Bruel and Kjaer) with the sound level meter. The vibratory accelerations (a_z) from the seats of the crew were recorded in m/s^2 with the help of a type 2511 vibration meter in conjunction with a type 4370 accelerometer (Bruel and Kjaer). A tunable band pass filter type 1621 (Bruel and Kjaer) was used with the vibration meter for frequency analysis in the range of 1 to 200 Hz.

Thermal stress

The basic heat parameters such as dry bulb temperature (T_{db}), wet bulb temperature (T_{wb}) and black globe temperature (T_g) inside the crew compartment and in the outdoor environment were monitored every hour from 1100 to 1600 hours. The wet bulb globe temperature (WBGT) heat index was worked out by taking the weighted average of the three temperatures using the following formula developed by Yaglou and Minard (1957):

$$\mathrm{WBGT}=0.7\ T_{wb}+0.2\ T_g+0.1\ T_{db}$$

The T_{db} and T_{wb} were measured with an Assmann psychrometer and T_g was recorded using a mercury thermometer in the centre of a black globe of 6 inches in diameter. There was no provision of air conditioning in the crew compartment or any kind of micro-climate cooling device for the crew. They used only blowers for ventilation and also kept the hatches open whilst on the move.

Physiological variables

The pre-exposure physiological variables, viz. heart rate, blood pressure, oral temperature, peak expiratory flow rate (PEFR), body mass, 24 h water intake and urine output, and urinary catecholamine concentrations were recorded in resting conditions 24 h before the onset of the combat exercise. Post-exposure physiological responses were recorded within 30 min after the termination of the exercise.

The heart rate and blood pressure were measured with a stethoscope and mercury sphygmomanometer. Oral temperature was recorded using a clinical thermometer and a Wright's peak flow meter was used for recording PEFR. An electronic balance sensitive to 20 g was used for the body mass measurements. Water intake and urine output were assessed over 24 h. The subjects were provided with stainless steel tumblers of known volume and were instructed to keep a record of the total number of tumblers consumed in 24 h; this measurement indicated 24 h water intake. The 24 h urine output was recorded by measuring the volume of urine collected in jericans provided to each of the soldiers. They were instructed to pass and collect the urine in jericans. Urine samples were brought to the laboratory and were analysed for catecholamines by the method of Sobel and Henry (1957). The statistical analysis was done by the paired 't'-test method.

Results

The 'A'-weighted sound pressure levels (SPLs) recorded from the crew compartment of the two armoured vehicles AV_1 and AV_2 are presented in Table 1. The noise level in static conditions with the engine running at 800 rpm varied from 98.0 to 101.0 dB. The driving of the vehicles in the desert at an average speed of 10 km/h increased the noise level from 101 to 116 dB in AV_1 and from 98 dBA to 110.5 dBA in AV_2. There was a further increase in the noise level by 2.5 dBA with increase in the speed of the vehicle from 10 to 25 km/h (data not shown). As seen from Table 1, the recorded values of noise levels are much higher than the acceptable upper safe level of 90 dB for a work schedule of 8 h day (International Standards Organization, ISO/R 1999 1975).

Figure 1 gives the frequency spectrum of the armoured vehicle noise from AV_1. The acoustic energy is concentrated predominantly in the lower frequencies of less than 500 Hz with a spectral peak at 63 Hz. There is a progressive lowering of amplitude towards higher frequencies and a steep fall between 4 and 8 kHz. Figure 2 depicts the mean rms acceleration (a_z) from the driver's seat of armoured vehicle AV_1. As can be seen from the figure, the acceleration amplitudes in the frequency range of 1–80 Hz, which are considered important from the point of view of human working comfort under exposure to whole body vibration, were of fairly low magnitude. The rms accelerations in this frequency range varied from 0.03 to 0.67 m/s^2. However, between 80 and 120 Hz there was a sharp rise in acceleration from 0.67 to 4.0 m/s^2.

The hourly variations in T_{db} in the micro-environment of the crew compartment of AV_1 are presented in Fig. 3. The T_{db} in the crew compartment varied from 46.5 to 52.8° C between 1100 and 1600 hours. In the outdoor

Table 1 The 'A'-weighted sound pressure levels (SPL) in static and dynamic runs. Reference sound pressure, 20 μPa

Armoured vehicle	SPL in static run	SPL in dynamic run	Average speed of vehicle during run (km/h)
AV_1	100.0	116.0	10
	101.0	115.0	10
AV_2	100.0	110.5	10
	98.0	113.0	25

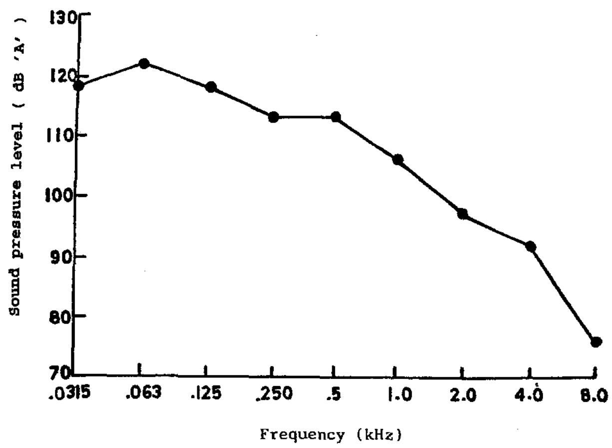

Fig. 1 Frequency spectrum of noise produced by armoured vehicle (AV_1) while on the move at an average speed of 10 km/h. Reference sound pressure, 20 μPa

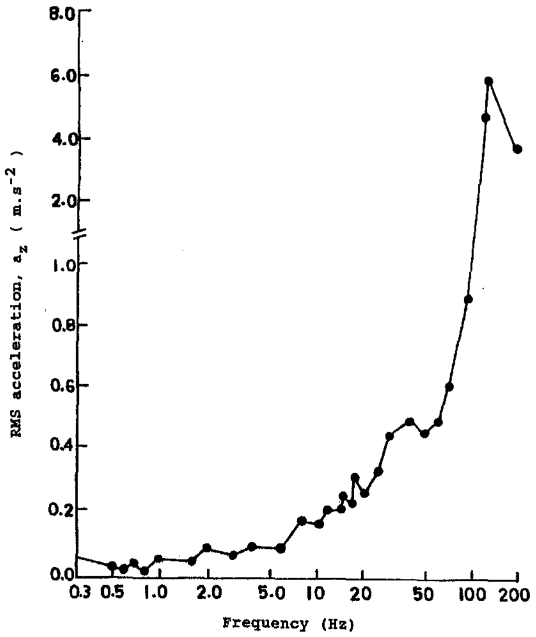

Fig. 2 Vibratory acceleration (a_z) recorded from the driver's seat in armoured vehicle (AV_1) while on the move

environment, T_{db} (values not given in the figure) increased from 40.4 to 43.5° C during this period. The relative humidity (RH) in the outdoor environment and the crew compartment varied from 22 to 28% and from 18 to 22% respectively. The WBGT index in the crew compartment increased from 31.75 to 34.04° C between 1100 and 1600 hours (Fig. 4). The WBGT values are higher than the recommended safe limit of 30.0° C for heat-acclimatized humans engaged in light physical activities in a hot environment (Malhotra 1959).

The physiological responses of the subjects recorded before and after the combat exercise are shown in Table 2. The data of Table 2 show an increase in the mean heart rate from 63 to 81 beats/min; the increase in the heart rate was statistically significant ($P<0.001$). The

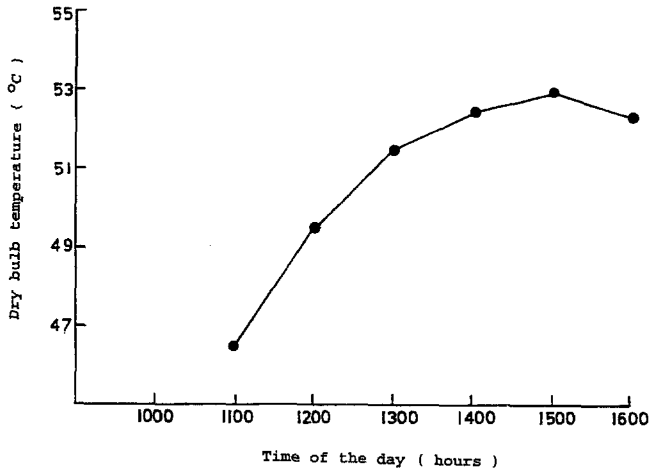

Fig. 3 Hourly variation in the dry bulb temperature (T_{db}) of the crew compartment of armoured vehicle AV_1 recorded from 1100 to 1600 hours

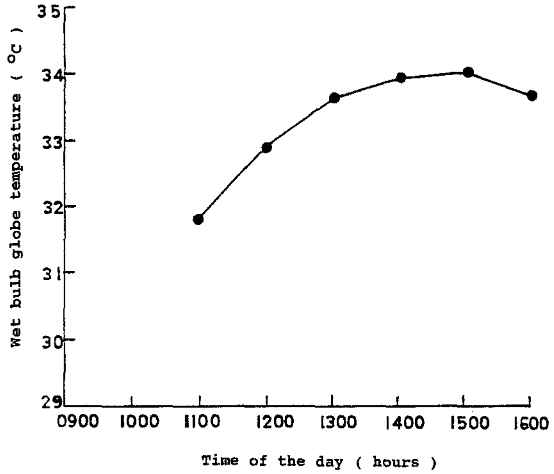

Fig. 4 Variation in the wet bulb globe temperature (WBGT) heat index in the crew compartment from 1100 to 1600 hours

systolic as well as the diastolic blood pressure changes were non-significant. Similarly the oral temperature showed a non-significant increase of 0.12° C. A significant reduction was observed in PEFR, which decreased from an initial value of 511 l/min to a final value of 480 l/min ($P<0.05$). The mean body mass of the subjects decreased significantly ($P<0.001$) from 64.18 to 62.14 kg representing a presumed hypohydration level of 3% body mass. The 24 h water intake during the course of the exercise increased by a factor of 2.5 from a pre-exercise volume of 7.5 l to 18.4 l/person per day. On the other hand, urinary output decreased from 1.6 to 0.5 l/person per day. These changes in water intake and urine output were statistically significant ($P<0.001$). The mean urinary catecholamine concentration increased significantly ($P<0.05$) from a pre-exercise level of 197.86 μg/litre to 380.71 μg/litre after the combat exercise.

Table 2 Physiological responses of the crew (n=9) before and after 24 h exposure to simulated combat exercise

Parameter		Before exercise		After exercise		Significance of difference
		Mean	SEM	Mean	SEM	
Heart rate (beats/min)		63.00	1.50	80.78	2.38	$P<0.001$
Blood Pressure (mm Hg)	Systolic	112.00	3.64	114.22	2.37	NS
	Diastolic	69.78	3.03	73.11	2.69	NS
Oral temperature (°C)		36.82	0.07	36.94	0.07	NS
Peak expiratory flow rate (l/min)		511.11	21.32	480.56	22.55	$P<0.05$
Urinary catecholamine (μg/l)		197.86	62.86	380.71	77.64	$P<0.05$
Body weight (kg)		64.18	2.50	62.14	2.44	$P<0.001$
24 h water intake (l)		7.46	0.30	18.40	0.75	$P<0.001$
24 h urinary output (l)		1.60	0.11	0.50	0.05	$P<0.001$

Discussion

The subjects of the present study were exposed to intense noise, mild to moderate vibration, and high heat load during the course of combat exercises in the desert. The 'A'-weighted sound pressure levels, which were higher than the acceptable limit of 90 dB (ISO/R-1999 1975), are capable of causing auditory as well as non-auditory system responses in humans (Manninen and Aro 1979); the non-auditory effects may, however, be of little consequence in the physically fit and relatively young subjects of this study (Singh et al. 1982). The auditory effect of the noise may also have been considerably reduced due to the use of head gear while the crew was on exercise.

The rms acceleratins (a_z) of the order of 0.03 to 0.67 m/s^2, in the frequency range of 1–80 Hz, are within the safe limits (ISO 2631 1978) with respect to human exposure to whole body vertical vibration in vehicles. The higher vibratory accelerations at frequencies of more than 80 Hz are of less consequence because of greater attenuation by the human body. The effect of whole body vibration as an environmental stress in the present study therefore does not appear to have constituted any health or efficiency risk to the crew. Thus, the heat load in the crew compartment of the armoured vehicles appears to be the dominating factor in the present study.

The subjects were heat acclimatized, as manifested by the consistency in their mean resting heart rate, oral temperature and 24 h water intake values recorded consecutively for 3 days prior to their participation in the combat exercise. This consistency of physiological parameter values may be because the subjects had been in the desert for 45 days and carried out their routine activities including P.T., parade, etc. in the open during this period. In addition, moderate physical exertion in a hot environment helps human beings to become acclimatized to heat (Leithead and Lind 1964). Acclimatization has been reported to improve the sweating rate compared to non-acclimatized humans at similar levels of rectal temperature (Fox et al. 1963; Nadel et al. 1974; Wyndham 1967). As a defence mechanism, an increase in the cutaneous blood flow (Edholm et al. 1956) together with the triggering of sweating and evaporative cooling remains the only avenue left for the regulation of core temperature in the absence of any microclimatic cooling device. Hence the subjects lost a considerable amount of sweat leading to a body mass loss of more than 2 kg per person. The hypohydration indicated was of the order of 3% despite increased water intake; the ad libitum water intake could not completely replace the body water losses. This finding was similar to that observed by others (Adolph 1947; Bar-Or et al.1980).

The hypohydration level of 3% body mass resulted in a 29% increase in the heart rate and a non-significant rise in the oral temperature (mean 0.12° C; Table 2). The hypohydration-associated increase in heat storage (increase in core temperture) has been reported to be the result of either an increase in the production of metabolic heat or a decrease in evaporative heat dissipation (Sawka and Neufer 1993).

In the present study, the environmental conditions in the crew compartment (T_{db} 46.5 to 52.8° C with 20% RH and adequate ventilation) allowed efficient evaporative cooling and therefore prevented body heat storage in the subjects. Moreover, the crew members were not involved in any physical exertion capable of producing metabolic heat. The subjects were also heat acclimatized, which would provide further resistance to a change of the core temperature (Wenger 1988). In addition during periods of heat exposure, the regulation of body temperature gets priority over the regulation of body water as reported by Rodahl and Guthe (1988). In a hot environment, a moderate (2 to 4%) water deficit has been demonstrated to reduce the physical work capacity (Craig and cummings 1966) and to affect mental functioning (Sharma et al. 1986) of humans. Our subjects might have suffered a decrease in mental and physical performance as a result of hypohydration.

In conclusion, this study has demonstrated that prolonged exposure to a hot environment with mild to moderate exertion resulted in hypohydration, and ad libitum water intake was not able to completely replenish the water loss. Exposure for a duration beyond 24 h may result in higher levels of hypohydration and a concomitant increase in the core temperature, which may lead to deteriorations in the mental and physical performance of the solidiers.

References

Adolph EF (1947) Physiology of man in the desert. Interscience Publishers, New York

Adolph EF (1949) Desert. In: Newburgh LH (ed) Physiology of heat regulation and the science of clothing. W.B. Saunders, Philadelphia, pp 330–338

Bar-Or O, Dotan R, Invar O, Rothstein A, Zonder H (1980) Voluntary hypohydration in 10 to 12 year old boys. J Appl Physiol 48:104–108

Bennett BL (1991) Body water homeostasis and human performance in high heat environments: fluid hydration recommendations for operation desert storm. Final report, United States

Craig FN, Cummings EG (1966) Dehydration and muscular work. J Appl Physiol 21:670–674

Edholm O, Fox RH, Macpherson RK (1956) The effect of body heating on the circulation in skin and muscle. J Physiol 134:612–619

Fox RH, Goldsmith R, Kidd DJ, Lewis HE (1963) Blood flow and other thermoregulatory changes with acclimatization to heat. J Physiol 166:548–562

Grether WF, Harris CS, Mohr GC, Nixon CW, Ohlbaum M, Sommer HC, Thaler VH, Veghte JH (1971) Effects of combined heat, noise and vibration stress on human performance and physiological functions Aerospace Med 42:1092–1097

International Standards Organization, ISO/R-1999 (1975) Assessment of occupational noise exposure for hearing conservation purposes

International Standards Organization, ISO 2631 (1978) Guide for the evaluation of human exposure to whole body vibration, Geneva

Leithead CS, Lind AR (1964) Heat stress and heat disorders. Cassell, London

Malhotra MS (1959) Habitability survey on ships. Armed Forces Med J 15:212–219

Manninen O, Aro S (1979) Noise induced hearing loss and blood pressure. Int Arch Occup Environ Health 42:251–256

Nadel ER, Pandolf KB, Roberts MF, Stolwijk JAJ (1974) Mechanism of thermal acclimatization to exercise and heat. J Appl Physiol 37:515–520

Rentzsch M, Minks B (1989) Investigation of the risk of hearing defects for the occupational groups of welders and plant assembly works. In: Manninen O (ed) Recent advances in users researches on the combined effects of environmental factors. Proceedings of the Third International Conference on combined effects of environmental factors PK-paino Oy Printing House Tampere, Finland, pp 463–476

Rodahl K, Guthe T (1988) Physiological limitations of human performance in hot environments, with particular reference to work in heat-exposed industry. In: Mekjavic IB (ed) Environmental ergonomics: Taylor and Francis, New York

Sawka MN, Neufer PD (1993) Fluid replacement and heat stress. In: Marriott BM (ed) National Academy Press, Washington DC, pp 85–97

Scott JM, Sawka MN, Cadarette BS, Quigley MD, McKay JM (1994) Physiological tolerance to uncompensable heart stress: effects of exercise intensity, protective clothing and climate. J Appl Physiol 77:216–222

Shapiro Y, Pandolf KB, Goldman RF (1982) Predicting sweat loss response to exercise, environment and clothing. Eur J Appl Physiol Occup Physiol 48:83–96

Sharma VM, Sridharan K, Pichan G, Panwar MR (1986) Influence of heat stress induced dehydration on mental functions. Ergonomics 29:791–799

Singh AP, Rai RM, Bhatia MR, Nayar HS (1982) Effects of acute exposure to noise on physiological functions in man. Int Arch Occup Environ Health 50:169–174

Sobel C, Henry RJ (1957) Determination of catecholamine (adrenaline and nor adrenaline) in urine and tissue. Am J Clin Pathol 27, p 240

Spaul WA, Spear MR, Greenleaf JE (1986) Thermoregulatory responses to heat and vibration in man. Aviat Space Environ Med 57:1082–1087

Wenger CB (1988) Human heat acclimatization. In: Human performance physiology and environmental medicine at terrestrial extremes. Benchmark, Indianapolis, IN

Wyndham CH (1967) Effect of acclimatization on the sweat rate, rectal temperature relationship. J Appl Physiol 22:27–30

Yaglou CP, Minard D (1957) Control of heat casualties at a military training centre. AMA Arch Ind Health 16:302–316