A Report on the Physical Stress and Physiological Strain Experienced by CALM Bushfire Fighters During Performance of a Manual Fireline Clearing Task.

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SUMMARY

The aim of this study is to quantify the extent of physical stress placed on workers participating in a manual fireline clearing task. An initial laboratory aerobic fitness testing session established a regression equation for heart rate and VO_2 data collected from each individual. Field tests involved the measurement of heart rate during the manual construction of a firebreak of approximately one metre width initially in a non fire situation (NFR), then with fire (FR).

Significant physiological responses were recorded during the field tests with mean heart rates of 146 and 157 bpm, VO_2 of 2.28 and 2.62 l min^{-1}., and percent peak VO_2 of 70 and 79% being recorded during the NFR and FR tests respectively. A high energy cost of 550 - 750 kcal. hr^{-1} was estimated for this work. Considerable mean increases in body temperature (NFR = 0.7C, FR = 2.4°C) were recorded along with high rates of fluid loss. (NFR = 600 ml. hr^{-1}, FR + 1200 $ml.hr^{-1}$).

Given these findings it is recommended that:

1. Workers have an adequate level of aerobic fitness and an absence of any medical history likely to compromise the safe performance of duties.

2. A system be established to ensure adequate fluid replacement during work periods.

3. Work to rest cycles be established as per guidelines to allow adequate recovery from periods of heavy work.

At the request of CALM a study was conducted in an attempt to further quantify the extent of physical stress placed on workers participating in bushfire suppression activities. Although generally considered "hard" work a more objective assessment was deemed necessary to accurately define the physical strain inherent in this work.

The aim of this project was to record changes in the physical state of regular bushfire fighters in response to the manual fireline clearing task. This task was chosen as the most physically demanding in bushfire suppression and could therefore provide the peak physical responses to be expected in the particular work environment.

METHODS

Subjects

The ten subjects were all male volunteers from the Mundaring district of CALM. They were all potentially available for rakehoe duties in their jobs although some had limited prior experience of the task. The group varied in age (18 - 42 years), height (172 - 186 cm.) body mass (53 - 85 kg.), skinfolds (sum of eight sites) (49 - 129 mm.) and aerobic fitness (peak VO_2) (34 - 52 ml. kg^{-1} min mass per minute). The variation here suggests that the group was a reasonable cross section of those likely to have to perform this type of work.

Procedures

The study was conducted during November to December 1992 in two phases involving an initial laboratory session and two field testing sessions.

1. Laboratory

Subjects attended the Exercise Physiology laboratory at the Department of Human Movement, UWA. Upon arrival subjects underwent anthropometric assessment involving height, body mass, and skinfolds (sum of 8 sites).

Each subject then completed a graded incremental walking test on a motorised treadmill. The uphill walking test was chosen as it was thought to be most representative of manual bushfire fighting tasks. The test continued until subjects indicated they could no longer go on. In most cases this was at a level to satisfy criteria for the attainment of maximum oxygen consumption (VO_2 max.) However, in three instances subjects discontinued the test without quite reaching VO_2 max. Due to this fact all maximum values have been reported as peak VO_2 rather than VO_2 max.

Heart rate and oxygen consumption were continually monitored throughout the test. The heart rate and VO_2 data were plotted and a regression equation for the line of best fit determined. This was to allow the heart rates from the field test sessions to be used to estimate VO_2 during the work periods, and thereby quantify the intensity of work (ie. % of individuals maximum capacity).

Field 1 - Non-fire Rake

The initial field test involved manually constructing a firebreak of approximately one metre width using a rakehoe (McLeod tool), around an "imaginary" fire. The subjects operated in two groups of five and six each, clearing a firebreak for approximately 30 minutes. The groups were instructed to operate at a "natural" pace for this task. The groups used a step-up method whereby each individual cleared a length of fireline to mineral earth (approx. 5 - 8 m) before stepping-up the line. The stresses of work and the resultant physiological strains were measured at various intervals.

Heart rates were measured at 15 second intervals during work through the use of portable monitors the subjects wore under their clothing. Internal body temperature was measured prior to work and at 10 minute intervals during the work period. Measurements were taken in the ear using a portable tympanic probe. Body Mass loss was assessed by weighing the subjects prior to and as soon as possible post work. This allowed for an assessment of the rate of fluid loss from the body. Subjects were weighed in exactly the same clothing before and after and no food or drink was ingested during the time between measurements. All subjects wore work boots and clothing to cover the arms and legs. These items were usually cotton pants and long sleeved shirt or cotton overalls.

Environmental conditions were assessed using standard techniques both before, and during the work periods. Measurements included dry bulb, wet bulb, and globe temperatures along with wind speed.

Field Test 2 Fire Rake

The same measurement protocols were used for this field test in which a firebreak was cleared around an actual fire. The fire rake (FR) was conducted in the same unburnt pocket of land as the non-fire rake (NFR) and at the same time of day (10am to 12 noon). A fire line was lit and allowed to burn for approximately 10 minutes before the firebreak construction commenced. The subjects were again instructed to work at a "normal" pace for approximately 30 minutes. The subjects worked at varying distances of 2 to 8 m from the edge of the fire depending upon fire intensity and wind direction. At times smoke was a problem necessitating some brief stoppages to recover from its effects on some subjects. Both of the field tests were conducted in an area with moderate vegetation and fuel density. During the FR, fire intensity was moderate to high, with a flame height of 2 - 3 m and a rate of spread of 60 - 70 $m.hr^{-1}$.

RESULTS

Laboratory

The ten subjects had a men peak VO_2 of 45.1 $ml.kg^{-1}$ min^{-1} (range 34.1 - 51.5). This would place the group in the average category when compared with norms for the general population. This is true even if the sample is separated for age as shown below in Table 1.

Table 1 **Mean Peak Oxygen Consumption Values for subjects according to age categories.**

Age	Mean Peak VO_2 $ml.kg^{-1}$ min^{-1}	Minimum	Maximum	Australian Normative Value
18 - 30	48.2	41.1	51.2	46 - 51
31 - 43	38.8	34.0	45.6	37 - 41

The most important element of the laboratory tests was the establishment of a relationship between heart rate and oxygen consumption for each subject. The regression equations so determined allowed an accurate assessment of oxygen consumption from heart rates recorded during the field tests.

Field Heart Rate and Oxygen Consumption

Figures 1 and 2 display the heart rates, and percentage of peak VO_2 for each five minute period of the NFR and FR. During the NFR the subjects had a mean heart rate of 146 bpm, VO_2 of 2.28 $l.min^{-1}$, and worked at 70 percent of their peak VO_2 value. All of these results increased with the addition of fire to 157 bpm, 2.62 $l.min^{-1}$, and 79 percent respectively. The estimated energy cost of this activity ranged from 550 - 750 $kcal.hr.^{-1}$ with the fire situation resulting in the higher value. This high energy cost places this type of work in the "heavy" category according to guidelines used by the Department of Occupational Health and Safety in Western Australia. (DOHSWA).

Body Temperature

Figure 3 shows mean increase in body temperature recorded during the NFR was 0.7°C (Range 0.3 - 1.2°C), while during the FR mean body temperature increased an average of 2.4°C (range 1.6 - 2.9°C).

FIGURE 1. HEART RATE DURING FIELD TESTING

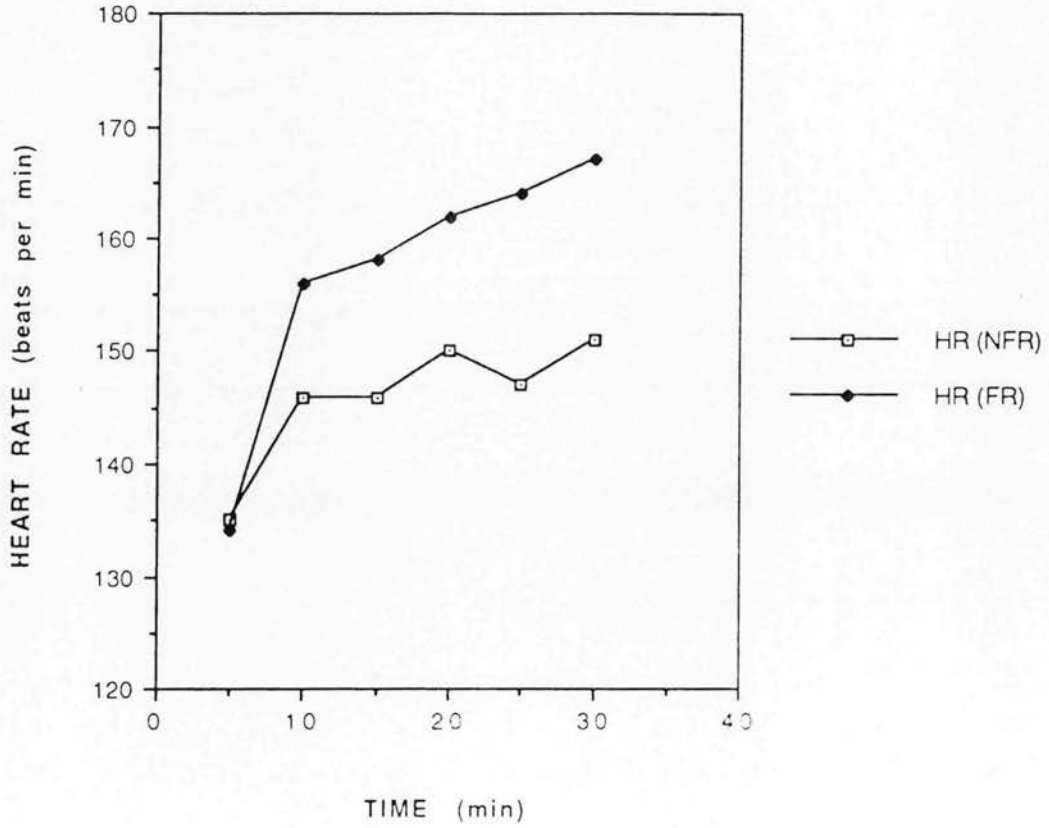


FIGURE 2. PERCENT ENDURANCE CAPACITY UTILISED DURING FIELD TESTS

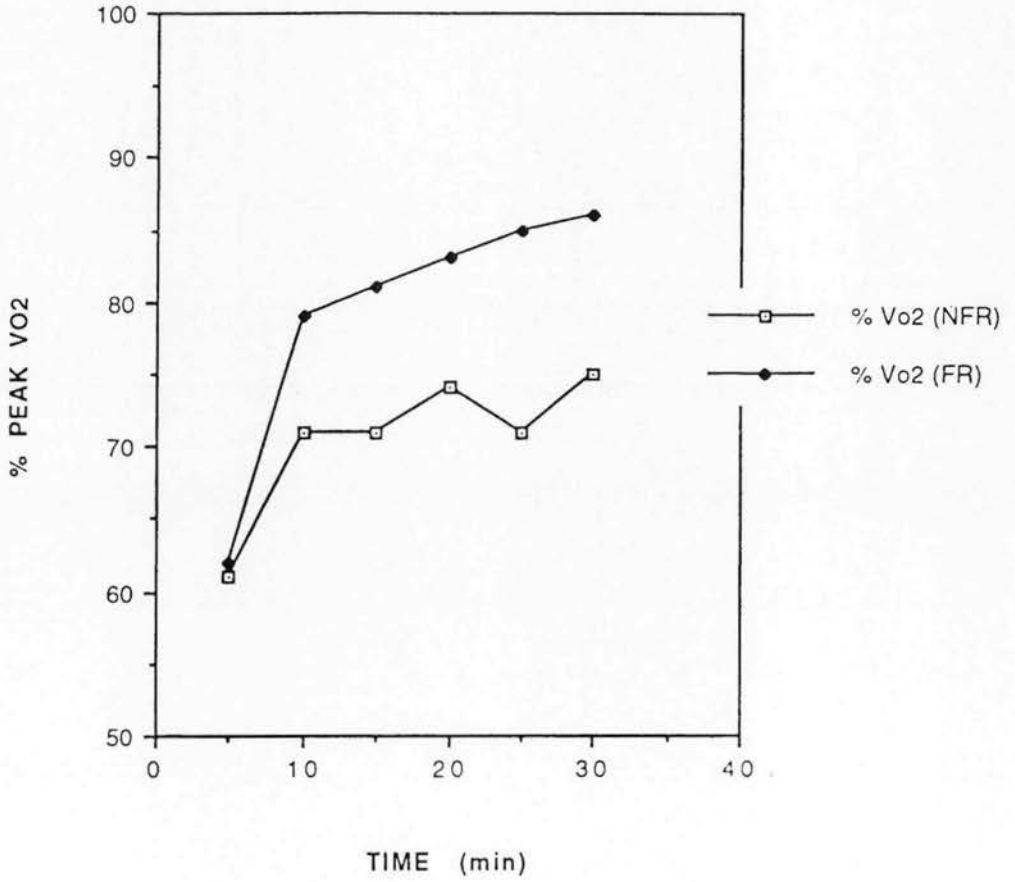
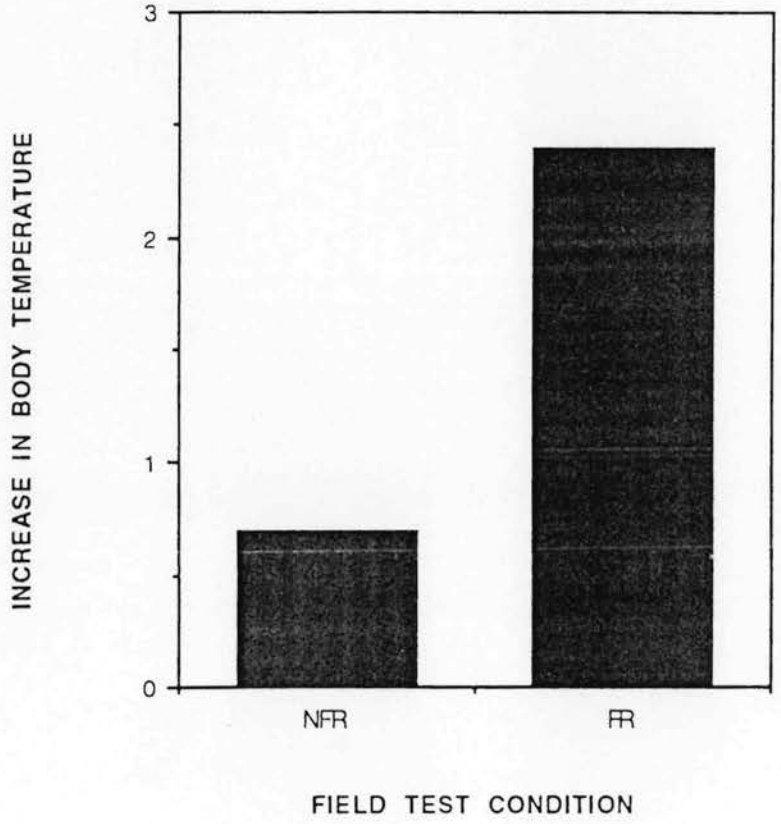


FIGURE 3. CHANGE IN BODY TEMPERATURE DURING FIELD TESTING



Environment

The environmental conditions prevailing during the field testing are displayed in Table 3.

Table 3 Environmental Conditions recorded during field testing

		Dry Bulb °C	Wet Bulb °C	WB GT °C	Relative Humidity °C	Wind Speed km.hr^{-1}
Day 1	Non-Fire Rake	21-23.5	15.5	19-20	50-55	5-8
Day 2	Fire Rake	23-27	15.5-16.0	20-22	40-45	8-12

The average air temperature on the fireline was increased by 1 - 5°C. due to the fire, with temporary elevations considerably higher than that experienced. The Wet-bulb Globe Temperature (WBGT) index close to the fire ranged from 20 - 28°C. This index which takes into account radiant heat from the fire is possibly underestimated here as the globe was not held close to the fire for longer than three minutes at one time.

Productivity

An average fireline of 320 m and 350 m was cleared during the 30 minute work period for the NFR and FR respectively.

Body Mass

Subjects lost an average 310g and 600g during the two field tests. It can be assumed that this loss was all fluid as the subjects were weighed in exactly the same clothing before and after work. This is equivalent to a rate of fluid loss of 600 ml.hr^{-1} and 1200 ml.hr^{-1} respectively for the two conditions. These values are underestimations of fluid loss from the body as a great deal of sweat was absorbed in the clothing and not evaporated. Thus, although lost from the body it was not recorded as a loss on the scales.

DISCUSSION

The results from this study support the notion that manual fireline construction is a very physically taxing task. The subject group as a whole were of average aerobic fitness when compared to general population norms. However, the heart rate and estimated VO_2 responses in Figures 1 and 2 show that the work required a considerable physical effort. The rakehoe task itself required a high degree of work with an average heart rate of 146 bpm and 70-75% of the subjects maximal aerobic power. The added stress of the fire caused a significant increase in heart rate to an average 157 bpm while the percentage of peak VO_2 required rose to nearly 80%. Interestingly, the least fit individuals, as determined by the treadmill test, showed the largest responses to the work stimulus. They also reported feeling more signs of distress than those individuals with greater aerobic fitness. At the heavy work-load recorded during the field tests (550-750 $kcal.hr^{-1}$) DOHSWA guidelines recommended a 50% work, 50% rest protocol for conditions where the WBGT index is 27.9°C or higher. During this study WBGT index scores of 28°C were recorded indicating that this may need to be an important consideration when conducting manual fireline construction.

The significant rates of fluid loss recorded in this study show that this should be an area of considerable concern to bush fire fighters. The risk of heat illnesses and dehydration would quickly increase at the fluid loss rate of 1.2 $l.hr^{-1}$ recorded during the second field test which itself is an underestimate. The fact that the ambient temperature on these days was not high and that the work period was short makes this finding even more significant.

It would seem imperative for firefighters working in these conditions to have a regular, well organised system of fluid replacement in place to avoid the effects of dehydration. The high sweat rates recorded came as a result of a significant increase in heat load brought about by the increased metabolic rate from performing work and the radiant heat from the fire. The internal body temperature as measured increased during both field tests with the fire condition causing the most significant rise. As already noted, there was a significant increase in sweat rates as a response to this rise in body temperature. Two factors which play a substantial role in facilitating heat loss are the amount of body fat and type of clothing worn. The group mean for body fat from skinfold measurements was in the average range for the normal population. However, those subjects with high levels of body fat are compromising their body's capacity to dissipate heat. Fat acts as an insulator and therefore restricts the flow of heat away from the body's core. This may partially explain the significant increase in body temperature recorded during the fire rake. Therefore it would seem prudent for bushfire fighters to be aware of body fat levels and maintain them at average to low levels.

RECOMMENDATIONS

Significant physiological changes were recorded in the group in relatively mild ambient temperatures, average humidity and a work period of one half hour. Clearly during a WA summer bushfire fighters will have to operate in environmental conditions considerably greater than those experienced in this study, and for longer periods. This situation could only increase the magnitude of physiological responses reported here.

Manual fireline construction has been shown to require a considerable percentage of each individuals maximal capacity to perform work. The subjects experienced significant increases in heart rate, body temperature and sweat rates, suggesting that more lengthy periods of work at this level could begin to compromise performance and possible safety.
Given that this is a serious consideration the following recommendations are made with a view to alleviating potential dangers.

1. It would be advisable to ensure workers performing duties such as the rakehoe task, have an adequate level of aerobic fitness and an absence of any medical history or condition that may compromise their health during performance eg. heart disease, hypertension, heat illness. It is considered that anyone with a fitness level beneath the low end of the normative range for their age should increase their aerobic fitness before performing this task. It may be necessary to instigate a system of physical conditioning for workers to develop fitness and provide regular monitoring to see that adequate levels are being maintained.

2. A system of fluid replacement during work performance should be instigated to prevent the effects of dehydration occurring. The ingestion of 150-200ml. of cool water (10°C-15°C) every 15 - 20 minutes while performing physical tasks in the heat is recommended.

3. With the heavy workload imposed by the manual fireline clearing task a system of work to rest periods is necessary as recommended in DOHSWA guidelines. At least 15 minutes break every hour is recommended with 30 minutes break every hour necessary in more taxing conditions. It is possible that a system of two teams may be useful operating on a work-rest roster of 15 minutes at a time.