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Self-Pacing as a Protective Mechanism against the Effects of Heat Stress

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Objective: Self-pacing or avoidance of physiological strain by adjustment of work rate may be an important protective behaviour for manual workers in severe thermal conditions. Data were gathered at a number of industrial sites in the United Arab Emirates to assess whether self-pacing takes place in these workers.

Methods: Heart rate and aural temperature were monitored in 150 subjects for 12 h daily over 2 consecutive days. Environmental parameters were measured for quantification of heat stress by the thermal work limit.

Results: There was no evidence of an effect of variation in environmental thermal stress on either average working heart rate or aural temperature.

Conclusion: These studies provide evidence that self-pacing is a protective response to working in heat which does not require a highly informed workforce; recognition of this should form part of a holistic approach to management of heat stress in hot climates.

Keywords: heat adaptation behaviour; heat management; heat stress; manual work; self-pacing; thermal strain; Thermal Work Limit

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INTRODUCTION

Workers in severe thermal environments are at risk of a range of heat-related illnesses which may in severe cases be fatal. Protecting them against heat illness without unnecessary loss of productivity is important from both the moral and economic perspective. Traditionally, management of heat stress has largely been based on monitoring the environment, and a number of heat stress indices have been developed for this purpose, often empirical and industry specific, e.g. the wet bulb globe temperature, effective temperature, etc.

Humans evolved in equatorial regions and are physiologically well adapted to hot environments (Sawka *et al.*, 1996). Optimizing these adaptations by ensuring that workers are adequately hydrated and acclimatized to the conditions enables work to continue safely in environments that would be unacceptable according to most of these indices (Miller and Bates, 2007). In severe conditions, reduction of work rate may still enable a useful level of work to be safely sustained. Evidence from previous studies has suggested that informed workers who are encouraged to self-pace can regulate their workload under thermally stressful conditions to avoid physiological strain (Brake and Bates, 2002a; Miller and Bates, 2007). However, to what extent this behaviour is spontaneous and to what extent it must be learned or consciously employed has not been clarified.

In thermally stressful conditions, workers producing metabolic heat faster than physiological mechanisms and environmental conditions permit the heat

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to be lost, will be in a state of positive heat balance or heat storage. This leads inevitably to a rise in core temperature and ultimately severe heat illness (heat stroke) if work rate does not decrease. Highly motivated individuals or those who are unable to control their own work rate are at greatest risk; hence, the majority of heat stroke cases are seen in endurance athletes or in the military (Armstrong *et al.*, 1987; Heled *et al.*, 2004). Prior to the onset of heat illness, physiological strain is evident as a rise in heart rate as thermoregulatory demands for increased cutaneous blood flow are added to those of the working muscles in competition for the cardiac output (Parsons, 1993). Work capacity (Gonzalez-Alonso *et al.*, 1999; Walters *et al.*, 2000; Marino *et al.*, 2004; Lu and Zhu, 2007) and cognitive function (Pilcher *et al.*, 2002; McMorris *et al.*, 2006) suffer and the worker may succumb to heat exhaustion. The effects of heat stress are often inadequately recognized as a cause of accidents and lost time injuries.

The thermal work limit (TWL) (Brake and Bates, 2002b) is a modern, validated (Miller and Bates, 2007), and rational heat index. The premise is that for any combination of environmental and clothing parameters, there is a maximum rate at which heat can be dissipated from the body and hence a limiting metabolic rate. TWL uses five environmental parameters (dry bulb, wet bulb and globe temperatures, wind speed, and atmospheric pressure) and accommodates for clothing factors to predict a safe, maximum, continuously sustainable metabolic rate (Watts per square metre) for the conditions, i.e. the TWL. At high values of TWL, the thermal conditions impose no limits on work. Where the TWL is lower than the heat load generated by moderate workloads ($\sim$140 W. m^{-2}), the environmental conditions are limiting to work. Only those whose thermoregulatory mechanisms are not compromised, e.g. by illness, dehydration, or lack of acclimatization, may continue safely and the ability to self-pace is crucial for them to do so. TWL values below 115 W. m^{-2} indicate that even light work is likely to exceed the sustainable metabolic heat load for the environment and workers should be withdrawn. A thermal environment can therefore be classified on the basis of TWL with unambiguous interventions specified at different values of the index (these are accessible at www.haad-safe.ae). TWL was used to assess the thermal environments in this study.

Some evidence that self-pacing occurs has accrued from studies in underground miners (Brake and Bates, 2002a) and outdoor workers (Miller and Bates, 2007) in Australia. The average working heart rates of most workers in the Australian studies were found to be similar over a wide range of thermal conditions. Heart rate is a reflection of physiological strain and is influenced by a variety of factors including health and emotional state; however, in the context of working in heat, the dominant influences are work rate and thermal stress (Parsons, 1993). If work rate remains constant, then an increase in environmental heat stress increases thermal strain resulting in a rise in heart rate related to the increased thermoregulatory demands on the circulation.

The Arabian Gulf region is subject to severe thermal conditions during the summer months. Many of the region's oil-rich states have over the last decade experienced a spectacular building boom. The construction industry in the region has been powered by the importation of large numbers of expatriate workers, predominantly from south Asia, and heat-related illness is a major health and safety issue. The government of the United Arab Emirates (UAE) (which includes the emirates of Abu Dhabi and Dubai) has imposed a mandatory work break for construction workers between 12.30 and 3 pm in the hottest months of July and August. This goes some way towards addressing the problem; however, this system lacks the flexibility to accommodate for hot weather outside of this period and ignores the fact that thermal stress may actually be higher in the mornings and late afternoons due to the high relative humidity, often exceeding 80% (at ambient temperatures of 30°C or more), and the lack of air movement. A more flexible management system has been proposed, using TWL to assess thermal stress and identify unsafe thermal conditions, and focussing on protective measures and behaviours emphasizing the role of hydration and self-pacing. The previous studies referred to above provided evidence that informed workers regulate their workloads to avoid physiological strain. We studied a variety of workplaces in the UAE over a 2 year period to verify whether expatriate labourers without the same training spontaneously self-pace and can therefore safely continue working in hostile conditions permitting a useful level of work.

METHODS

The studies reported in this paper were carried out between 2007 and 2008 at construction sites and industrial facilities in Abu Dhabi and Dubai. These studies were conducted without intervention in order to document the working heart rates of representative groups of expatriate workers in a range of environments in the UAE. Protocols varied slightly depending on the nature of the workplace, the organization of the work shift, and arrangements with the man-

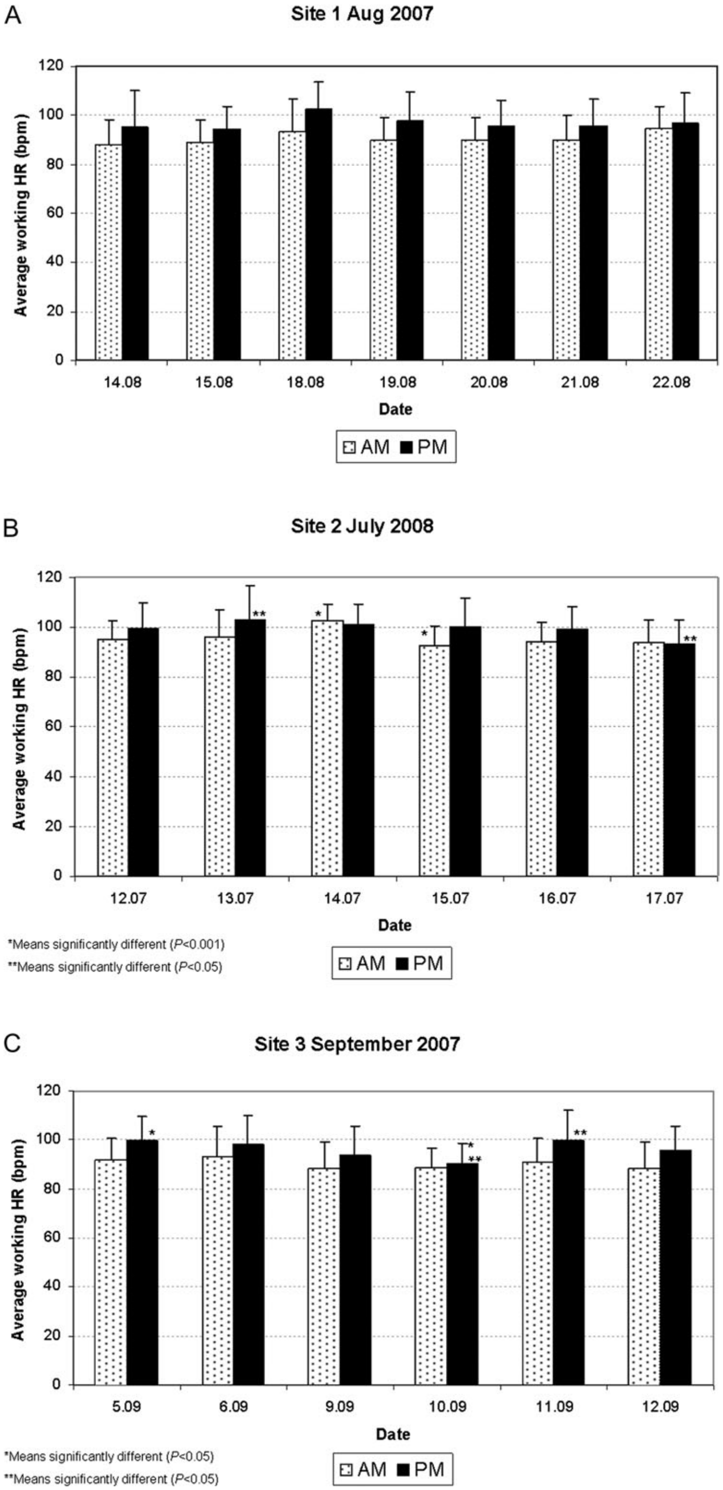

Fig. 1. (a, b, and c) Mean average working heart rates for morning and afternoon work periods from the three field sites in the UAE. Each column is the mean of the results for all subjects ($n = 15$) on a particular day obtained by averaging the continuous heart rate record for each subject over the work period. The *Y*-error bars show standard deviations of the individual records.

Table 1. Average working heart rates (HR_{ave}) and aural temperatures of workers at four sites in the UAE. Data from previously published studies are included for comparison.

Parameter		UAE studies					Australian studies (Miller and Bates, 2007)		
		Site 1 ($n = 120$)	Site 2 ($n = 90$)	Site 3 ($n = 90$)	UAE winter ($n = 72$)	Bates and Schneider (2008)	Site 1	Site 2	Site 3
Resting HR_{ave} (bpm)		64 ± 8.5	63 ± 8	58 ± 7	67 ± 8				
Working HR_{ave} (bpm)	AM	90 ± 10	95 ± 9	91 ± 10	95 ± 10	90			
	PM	97 ± 12	99 ± 11	97 ± 12	100 ± 10	92			
All day HR_{ave} (bpm)		89 ± 10	92 ± 8	93 ± 9	97 ± 9	89 ± 7	88 ± 7	104 ± 12	90 ± 10
Aural temperature (°C)	AM	36.9 ± 0.3	37.0 ± 0.3	36.7 ± 0.3	36.5 ± 0.5	36.4 ± 0.3	36.5 ± 0.2	36.6 ± 0.3	36.7 ± 0.4
	MD	37.3 ± 0.3	37.1 ± 0.4	36.8 ± 0.3	36.8 ± 0.4		36.7 ± 0.2	37.2 ± 0.3	37.0 ± 0.4
	PM	37.2 ± 0.3	37.2 ± 0.4	36.8 ± 0.4	36.8 ± 0.4	36.6 ± 0.4	36.8 ± 0.2	37.2 ± 0.3	37.0 ± 0.3

All data are mean ± standard deviation of all valid data collected at that site.

agement. The two studies on construction sites (sites 1 and 2) were conducted in the July–August period when regulations stipulate an extended break for all construction workers from 12.30 to 3 pm. This break was taken in rest facilities provided on site; the workers then returned to work for a further 3 h until 6 pm.

Participants recruited from the expatriate workforce were monitored at three time points: at the beginning of the shift (between 6 and 6.30 am), at the end of the morning work period (between 11.30 am and 12 noon), and at the end of the shift (5.30 to 6 pm). All had been working in the UAE for at least a month and were therefore assumed to be fully acclimatized and were in good health. The majority of subjects participated over a period of 2 consecutive working days. Other than presenting at these times, the subjects were not asked to modify their work behaviour in any way.

The subjects were predominantly young and lean males of south Asian origin (India, Pakistan, and Bangladesh); all were volunteers who gave their written and informed consent to participate in the study. The study was supported and authorized by management at each site and ethical approval was obtained from the Al-Ain Medical District Human Research Ethics Committee.

Data collection

Indicators of physiological strain. Assessment of heat strain from heart rate and core body (rectal) temperature has a sound physiological basis and has been quantified in the physiological strain index (Moran *et al.*, 1998). Brake (Brake and Bates, 2002a) noted a close correlation between heart rate and core body temperature supporting the use of ambulatory heart rate monitoring as an indication of thermal strain.

Heart rate was recorded continuously over the whole shift using Polar™ technology. Participants were fitted with a heart rate monitor on presentation at the start of the shift; this was worn all day including rest periods. At the end of the shift, the information was retrieved for analysis by downloading the files to Polar software.

Aural (tympanic) temperature was measured at each contact time using an over-the-counter instrument (Braun) as an indication of changes in core temperature.

Environmental thermal stress. Heat stress was quantified by the TWL, the limiting metabolic heat load that can be sustained without heat storage under the conditions. TWL values above 140 W. m^{-2} pose no limits on work for acclimatized, healthy, well-hydrated workers. Where $115 < \mathrm{TWL} < 140$ W. m^{-2} conditions are progressively more limiting to the level of sustainable work and where $\mathrm{TWL} \leq 115$ W. m^{-2}, all normal work should cease as no level of work is safely sustainable.

The thermal environment was monitored regularly at representative locations throughout the day using a Calor Instruments heat stress meter (HSM), calibrated by the manufacturer.

The following information was used to calculate the TWL in Watts per square metre using either the software built into the HSM or a 'TWL calculator' program (accessible at www.haad-safe.ae or www.pointhealth.com.au).

Ambient or dry bulb temperature,
Wet bulb temperature and relative humidity,
Globe temperature or radiant heat, and
Wind speed.

Field sites Site 1: August 2007 (120 subject-days).

Unskilled and semi-skilled labourers, the majority doing manual work with some machinery operators. Most were working in full sun throughout the

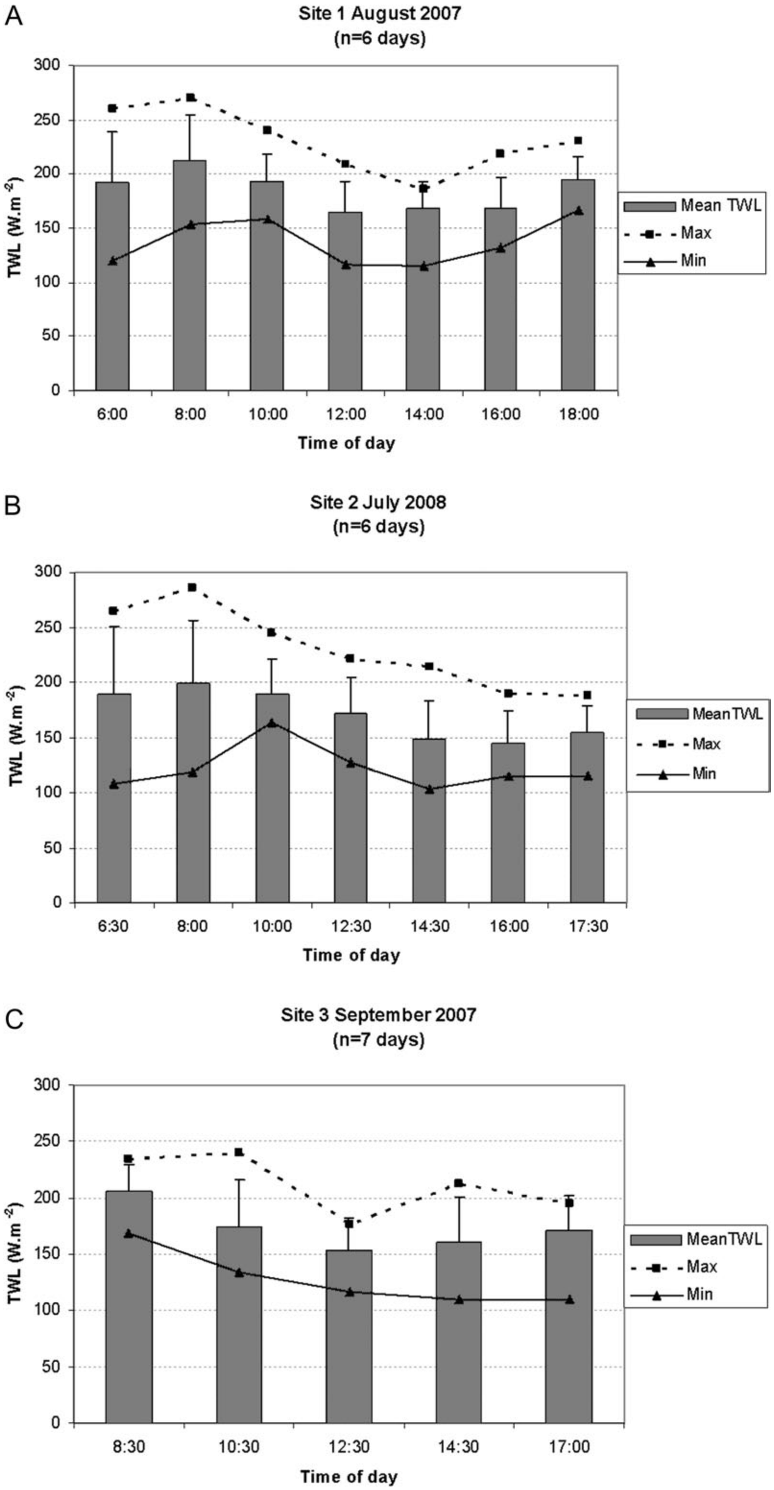

Fig. 2. (a, b, and c) Variations in environmental heat stress over the course of the day at each field site. The columns are the means of the daily TWL values recorded at each time point over the duration of the study. *Y*-error bars show the standard deviations of the daily records. The range of values recorded at each time point is shown by the maximum and minimum.

shift—Mean age 31.9 ± 7.3 (range 20–52) years. Mean body mass index (BMI) 23.3 ± 3.4 (17.4–31.0).

Site 2: July 2008 (90 subject-days).

Skilled and semi-skilled construction workers, work environments ranged from below ground level to several floors above and varied in terms of exposure to sun and air movement—Mean age 31.8 ± 9.2 (range 20–60) years. Mean BMI 21.8 ± 3.0 (16.3–30.8).

Site 3: September 2007 (90 subject-days).

Mainly skilled tradesmen, many exposed to increased thermal stress through use of personal protective equipment and heat-generating processes such as welding—Mean age 36.9 ± 6.1 (range 26–49) years. Mean BMI 23.8 ± 3.7 (17.3–32.9).

Treatment of heart rate data. Heart rates were averaged over the morning and afternoon work periods excluding the lunch/rest break and also over the entire shift. The independent *T*-test carried out using SPSS Statistics 17.0 was used to analyse differences between means of these averaged heart rates.

RESULTS

Means of the working heart rates averaged for each subject over the morning and afternoon work periods for each day of each study are shown in Fig. 1a–c. These data are summarized in Table 1. The winter data were collected from manual workers at a heavy industrial plant in the UAE during the month of December. These workers were demographically comparable with the subjects in this study; however, in contrast with sites 1–3, in most parts of the plant the environmental conditions were mild and pleasant. Previously published data from the UAE (Bates and Schneider, 2008) and from North-West Australia (Miller and Bates, 2007) are also included in this table for comparison.

Over all working heart rates in the afternoon were significantly higher than in the morning (2-tailed $P < 0.001$); this difference was least evident at site 2. Working heart rates were higher overall at site 2 than at the other two sites ($P < 0.001$) largely because of the consistently higher morning heart rates at this site. Daily means of the average working heart rates (Fig. 1a–c) over the morning work period ranged from 88 to 102 beats per minute (bpm). Afternoon heart rates were higher on most days with means ranging from 93 to 102 bpm. The *Y*-error bars are standard deviations for the daily records and show similar variability morning and afternoon on all days and all sites. Comparing means of average working heart rates between days at each site over either the morning or the afternoon work periods identified some differences that were significant at sites 2 and 3, but not at site 1 (Fig. 1a–c). In three out of the four cases, these differences were between different groups of subjects who may have been engaged in different tasks. Average working heart rates in Table 1 are means of all individual data collected at each site. The 'all day' average heart rates include the midday break, which at sites 1 and 2 was the 3 h break required in July and August, but at site 3 was only a 1 h lunch break.

Aural temperatures measured at the beginning and end of the morning work period and at the end of the afternoon work period are also shown in Table 1. There were no significant differences between sites or between times of day. Variation within individuals (0.5 ± 0.25°C) was consistent with normal diurnal temperature variation (∼0.5–1.0°C); no temperatures indicative of hyperthermia were recorded.

Environmental data collected at each site were used to assess environmental heat stress by computing the TWL. Environment sampling times varied slightly depending on arrangements at each site, but on most days, data were collected at regular intervals throughout the day. Figure 2a–c show the means of the daily TWL values recorded at each time point over the duration of the study ($n = 6$ days for sites 1 and 2 and 7 days for site 3). *Y*-error bars show the standard deviations of the daily records. The range of values recorded at each time point is shown by the maximum and minimum TWL values for that time point.

Mean TWL values at different times of day varied considerably but all fell between 140 and 200 W. m^{-2}. Values in this range indicate that acclimatized, well-hydrated individuals would be able to perform a moderate level of work without heat storage. There was, however, a high level of day to day variability at each time point, as shown both by the standard deviations and the range of values recorded, indicating that for all sites conditions at any time of the day could be limiting to work (TWL < 140 W. m^{-2}), in some cases severely limiting to the point where a 'stop work' action is recommended (TWL < 115 W. m^{-2}). Overall, there was no pattern of correlation either between lower TWL values and higher working heart rates or vice versa.

DISCUSSION

It is essential that heat generation does not exceed the capacity of the individual to dissipate the heat to the environment. In severe thermal environments, heat gain from the environment contributes to heat load and the only available avenue for heat loss is the evaporation of sweat. Where atmospheric humidity is high, the efficiency of evaporative heat loss is reduced adding to the environmental heat stress. As physical work is the main source of heat production in the body, this means that the work rate must be adjusted to restrict heat generation to a level at which heat storage does not occur. This can be achieved either by reducing work intensity, i.e. self-pacing, or if this is not possible by worker rotation or work–rest cycling.

Evidence from previous studies has suggested that adjustment of work rate to a safe level for the conditions (self-pacing) occurs in well-informed workers who are able to do so (Brake and Bates, 2002a). Legislation in Australia requires that all workers receive a comprehensive site induction before commencing work and education is ongoing through regular toolbox talks and seasonal refresher programmes prior to the hot months. It is to be expected that they will consciously adjust their work rate to suit the conditions. Observations from field studies in Australia (Brake and Bates, 2002a; Miller and Bates, 2007) suggest that few workers will voluntarily work at a pace that requires sustaining an average heart rate >110 bpm for any length of time, a level consistent with the WHO recommendation (WHO, 1969). Laboratory studies in a heated chamber showed that when subjects were exercised at a level that elevated their heart rates above this threshold, the majority were unable to stabilize heart rate and core temperature (Miller and Bates, 2007), in other words they were in a situation of uncompensable heat stress. For a 30-year-old, this represents usage of ~35% of cardiac reserve, a level which, if sustained, is considered liable to lead to fatigue (Eastman Kodak Company, 1986). The majority of workers in this study (>92% in the mornings and >88% in the afternoons) appear to self-regulate at a lower heart rate than this, and this appears to be remarkably consistent, both across the three worker groups in the UAE whose data are reported in this paper (Table 1) and the Australian groups previously reported (Miller and Bates, 2007), whose mean average working heart rates ranged from ~89 bpm for most groups to 104 bpm for one highly motivated team of contract workers. Standard deviations were similar to those reported in the UAE studies. Even more striking is the similarity in working heart rates between the workers in this study and the data collected from a comparable group in the UAE winter (Table 1). TWL values for the winter work environments exceeded 300 W. m^{-2} in most parts of the plant, indicating that there was no thermal limitation to work.

In mild environmental conditions, work rate is the primary driver of heart rate as dissipation of the heat generated presents no problems. As environmental conditions become less favourable to heat loss, and at high temperatures (dry bulb or radiant) add an additional heat load that must be rejected, thermoregulation becomes an increasingly important consumer of the cardiac output. At comparable work rates, the heart rate increases with thermal stress, the fact that in all the reported studies under varying environmental conditions the heart rates are so uniform is interpreted as evidence that workers from different backgrounds respond similarly to heat stress by adjusting their workload in order to avoid physiological strain. We believe that this suggests a physiological adaptation, which may be augmented by behavioural responses conditioned by cultural awareness or training.

The comparatively high mean average working heart rate at site 2 in the morning of the 14 July corresponded to the most severe conditions recorded at this site; a high early morning humidity (72% at 7.00 am) and high ambient temperature (40°C at 10.30 am) yielding TWL values in many parts of the worksite that identified the conditions as limiting to work; however, even under these conditions, the mean average working heart rate (102 bpm) did not exceed WHO guidelines. Other than this, there was no clear pattern relating working heart rates to environmental conditions, those differences in heart rates that were demonstrated are more likely to reflect other factors in the workplace such as the nature of the work performed at a particular site or on a particular day by a particular group of subjects.

The higher heart rate over the afternoon work period is a pattern that has been consistently observed in all our studies, which we believe to be due to a diurnal rhythm. What is noticeable is that the between-site variation in working heart rate is smaller in the afternoon than in the morning. At all sites, the TWL tended to be lower in the afternoon than in the morning. This higher level of heat stress combined with any accumulated fatigue would be expected to increase physiological strain and heart rate variability; however, there is no evidence for this, supporting the concept of spontaneous regulation of physiological strain. The small increases in tympanic temperature over the day are also of the order of the known diurnal variation and not indicative of any increase in core temperature related to work or heat strain.

Traditionally, in management of work in hot environments, the emphasis has been on monitoring the environment. Whilst this cannot be ignored, workers who are able to adapt both physiologically and behaviourally to the thermal stress may remain productive in conditions where work is prohibited or severely restricted by conventional heat stress standards. Maintenance of productivity in hot environments without compromising worker safety is possible through adoption of a flexible management approach, combining the use of TWL with emphasis on the importance of hydration, acclimatization, and self-pacing (Brake and Bates, 2002a). This reduces reliance on fixed protocols dictated by either the calendar or by an empirical index, which is often a single environmental parameter such as ambient or dry bulb temperature. In this approach, it is essential that management and supervisors recognize the role of self-pacing as a protective behaviour in thermally stressful conditions and allow for it. This may require permitting more frequent rest breaks, assignment of additional workers to a task when conditions are severe, reduction of quotas, or other strategies. Workers in hot environments need to be taught to recognize and respond to signs of heat strain in themselves and others. Where self-pacing is not feasible or is unacceptable, then arrangements must be made to limit work time in severe conditions by rotating workers or by work–rest cycling.

Conclusions

The workers studied in Australia were well educated in comparison with the expatriate workers in the UAE and well informed on the risks of working in the heat. These studies provide encouraging evidence that comparatively uneducated workers also regulate their workload in thermally stressful conditions enabling them to continue working in harsh conditions without evidence of physiological strain.

In light of this, recognition needs to be given to the importance of self-pacing as a protective behaviour. Well-hydrated, acclimatized workers who are permitted to self-pace may safely continue working under conditions that would be prohibited by most conventional heat stress indices.

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