Eur J Appl Physiol (1993) 67:174–179

European Journal of Applied Physiology and Occupational Physiology

Ratings of perceived exertion and affect in hot and cool environments

Graeme J. Maw, Stephen H. Boutcher, and Nigel A. S. Taylor

Department of Biomedical Sciences, University of Wollongong, Northfields Avenue, Wollongong NSW 2522, Australia

Accepted March 30, 1993

Summary. The effects of hot and cool environments on perceptual and physiological responses during steady-state exercise were examined in men ($n = 14$) performing 30 min of constant exercise (cycle ergometry) at a perceived exertion of "somewhat hard". Subjects exercised at the same absolute exercise intensity in hot (40° C), neutral (24° C), and cool (8° C) conditions. Data were collected for differential ratings of perceived exertion (RPE), affect, thermal sensation, mean skin ($\bar{T}_{sk}$) and rectal temperatures (T_{re}), and cardiac frequency (f_c). The subjects completed the hot exposure with an average $\bar{T}_{sk}$ of 37.5° C (SEM 0.11), while the neutral and cool conditions produced values of 33.8 (SEM 0.09) and 28.2° C (SEM 0.30), respectively. The $\bar{T}_{sk}$ was significantly higher in the hot than the neutral and cool conditions throughout exercise ($P < 0.05$). The f_c was significantly lower in the cool than in the other conditions ($P < 0.05$), and the subjects completed the hot exposure with a mean f_c more than 20 beats·min^{-1} greater than observed in the other conditions. The subjects felt worse (lower affect) in the heat throughout exercise ($P < 0.05$). Overall RPE was significantly lower in the cool than in the heat, while chest RPE scores for the cool and hot conditions were displaced vertically by approximately two points. Subjects perceived work to be harder, felt worse, and experienced greater thermal sensation in the hot condition, compared with the neutral and cool conditions. Changes in cutaneous vasomotor tone and heat-induced influences on the chest may have accounted for the RPE changes observed in the heat.

Key words: Perceived exertion – Affect – Thermal sensation – Cardiac frequency – Thermal stress – Exercise

Correspondence to: N. A. S. Taylor

Introduction

The rating of perceived exertion (RPE) during exercise has been believed to be derived from an integration of both central and local physiological cues (Borg 1961, 1962), but has also been found to be influenced by psychological factors such as self-presentation and hypnotic suggestion (Boutcher et al. 1988; Morgan et al. 1973). Attempts to identify the primary physiological and psychological cues underlying the sense of exercise effort have involved a variety of approaches (see Carton and Rhodes 1985; Pandolf 1983). For example, the effects of exercise modality (Boutcher et al. 1989), physiological stress (Davies and Sargent 1979), physical training (Hill et al. 1987), expected task duration (Rejeski and Ribisl 1980), and environmental conditions (Toner et al. 1986; Young et al. 1982) have all been investigated.

Examination of the influence of environmental conditions on the sense of effort has largely involved the use of heat. It has been shown that exercise in the heat elevates both physiological and perceptual responses above that observed in the thermoneutral state (Kamon et al. 1974; Kuoppasalmi et al. 1986). Kuoppasalmi et al. (1986) have monitored physiological and RPE response in subjects performing 4 h of treadmill exercise under thermoneutral and hot conditions. Their results indicated that the increase in heart rate caused by increased peripheral circulation was associated with an increase in the perception of exertion during exercise.

The influence of cool environments on RPE has received far less attention. In one of the few studies to examine the influence of cold on perceptual and physiological responses during aerobic exercise, Nelson et al. (1991) have indicated that RPE was lowered and self-perceptions enhanced during exercise in cold (−10° and 8° C) compared to thermoneutral environments (26° C). However, exercise was limited to 5 min, and exercise intensity was adjusted throughout to keep heart rate constant. Although exercise intensity was not recorded, it is likely that higher intensities were required in the cold conditions for subjects to achieve comparable heart rates. Despite such differences in exercise intensity, RPE was lower and comfort sensation was more positive as temperature declined. However, it is unclear whether these results would extend to exercise periods longer than 5 min, or to situations where exercise intensity is kept constant. Furthermore, there is a paucity of data collected from subjects studied during both hot and cool conditions.

The purpose of this study was to examine the effects of hot, thermoneutral, and cool environments on psychophysical and physiological responses during a 30-min, constant intensity, period of exercise. It was hypothesized that subjects would experience less physiological strain and suppressed perceptual responses in the cool conditions, whereas the opposite effects would be elicited in the heat.

Methods

A group of 14 physically active men participated in this study: mean age, 22.6 (SD 4.4) years; mean height, 165.8 (SD 6.2) cm; mean mass, 72.1 (SD 6.9) kg. The subjects were required to perform 30 min of steady-state cycling in each of three environmental conditions (40°, 24°, and 8° C; constant 50% relative humidity; air speed less than 0.5 $m \cdot s^{-1}$) inside a climate chamber with a negligible radiant heat loading. All tests were conducted in accordance with procedures approved by the University of Wollongong Human Experimentation Ethics Committee.

Preliminary tests were undertaken for all subjects, in a thermoneutral environment (24° C), to determine individual exercise intensities for the 30 min of exercise. Each subject was required to cycle at an exercise intensity that evoked an equivalent RPE among the subjects. The preliminary test was completed when each subject consistently indicated a perceived exertion of "somewhat hard", and the corresponding exercise intensity was used for all subsequent experimental conditions. The subjects were instructed to abstain from food and caffeine for 4 h preceeding and to avoid strenuous physical activity within 12 h prior to each test. During all tests subjects wore shorts, T-shirt, and athletic shoes. This ensemble covered approximately 68% of the body surface with an average insulation of 0.02 $m^2 \cdot °K \cdot W^{-1}$. Following subject instrumentation, baseline psychophysical and physiological data were collected, and the subjects consumed 250 ml of water.

The test protocol for each experimental condition consisted of 10 min of seated rest; 5 min of light exercise on a mechanically braked cycle ergometer (Monark 868), gradually increasing to the predetermined intensity; and 30 min of constant intensity cycling [130.7 (SD 28.5) W]. Exercise intensity and pedal frequency were monitored by an experimenter. All subjects experienced the neutral condition first, with the hot and cool exposures being balanced among the subjects; each condition was separated by a minimum of 3 days without heat or cold exposure. Within each trial, the following data were collected:

1. Every 3 min during constant exercise: RPE (Borg 1982), affect (Rejeski 1985), and thermal sensation (Gagge et al. 1967);
2. Every min during exposure: skin and core temperatures, and cardiac frequency (f_c).

Affect was assessed, in response to the question "how are you feeling?", using an 11-point bipolar scale (Rejeski 1985), validated by Hardy and Rejeski (1989). This scale ranges between −5 (very bad) and +5 (very good). Thermal sensation was determined on a 7-point scale ranging from 1 (cold) to 7 (hot) (Gagge et al. 1967), in response to the question "how does the temperature of your body feel?". The RPE was measured using the 15-point Borg Scale (Borg 1962) and was differentiated among body regions by asking the subjects to provide RPE indices for the overall body, legs, and chest. Differential RPE scores were used since Pandolf (1978) has demonstrated that subjects perceive exertion according to the manner in which they experience the exercise stress. Thus, a subject with little cycling experience would be expected to perceive the legs as the site of greatest physiological strain. Instructions for the use of all scales were read to each subject prior to commencing each trial. The RPE data were only collected during exercise.

Skin temperatures were monitored using skin thermistors (Yellow Springs Instruments, mini-thermistor, type EU), secured with a single layer of waterproof tape, and located at eight sites (forehead, back, chest, upper arm, forearm, hand, thigh, and calf). Mean skin temperature ($\bar{T}_{sk}$) was approximated from the equation:

$$\bar{T}_{sk} = 0.07\,T_{forehead} + 0.175\,(T_{chest} + T_{back}) + 0.07\,(T_{upperarm} + T_{forearm}) + 0.05\,T_{hand} + 0.19\,T_{thigh} + 0.20\,T_{calf} \text{ (ISO 1992)}$$

Core temperature was derived from rectal temperature (T_{re}), measured using a thermistor (Yellow Springs Instruments, mini-thermistor, type FF), positioned 12 cm beyond the anal sphincter. Thermistor outputs were recorded using a data logger (Grant Instruments 1200 series, 12-bit squirrel) and subsequently downloaded to computer. The f_c was measured using a Sport Tester (Polar Electro Oy, PE3000), the wrist monitor being kept from the subject's view at all times.

For data analysis averages of adjacent 3-min measurements of RPE, affect, and thermal sensation were taken. For skin and core temperatures, and f_c, averages of adjacent 1-min data points were taken. This resulted in five averages at 6-min intervals during exercise for each variable. A 3 (condition: hot, neutral, cool) ×5 time (4.5, 10.5, 16.5, 22.5, 28.5 min) within-subject design was used to examine each variable during exercise. Affect, body temperatures, and f_c were analysed using difference values (the exercise response minus the pre-exercise response), whereas RPE and thermal sensation were analysed using absolute scores. All analyses involved repeated-measure ANOVA for which the conservative F-test correction for degrees of freedom (Geisser and Greenhouse 1958) was applied. The Bonferroni t-test procedure, which adjusts the significance level to the number of pairwise comparisons, was used to analyse cell means (Myers 1979, p 298).

Results

A summary of the statistical data for each physiological and psychophysical variable is presented in Table 1. The subjects concluded the hot exposure with an average $\bar{T}_{sk}$ of 37.5° C (SEM 0.11) while the neutral and cool conditions produced values of 33.8° (SEM 0.09) and 28.2° C (SEM 0.30), respectively (Fig. 1). When averaged over time, the protocol elicited respective $\bar{T}_{sk}$ of 37.2° (SEM 0.05), 33.3° (SEM 0.14), and 27.9° C (SEM 0.06; Fig.1, inset). Analyses indicated that $\bar{T}_{sk}$ was significantly higher in the hot than in both the neutral and cool conditions throughout exercise ($P < 0.05$).

The T_{re} gradually increased in each condition, concluding with 38.1° (SEM 0.11), 37.7° (SEM 0.06), and 37.9° C (SEM 0.15) for the hot, neutral, and cool exposures, respectively, but showed little difference among conditions. The T_{re} was significantly higher in the cool than in the hot condition at 16.5 and 22.5 min and significantly higher in the hot compared to the neutral condition only at 28.5 min (Fig. 1; $P < 0.05$).

The f_c displayed the classical asymptotic trend in both the neutral and cool conditions, but continued to

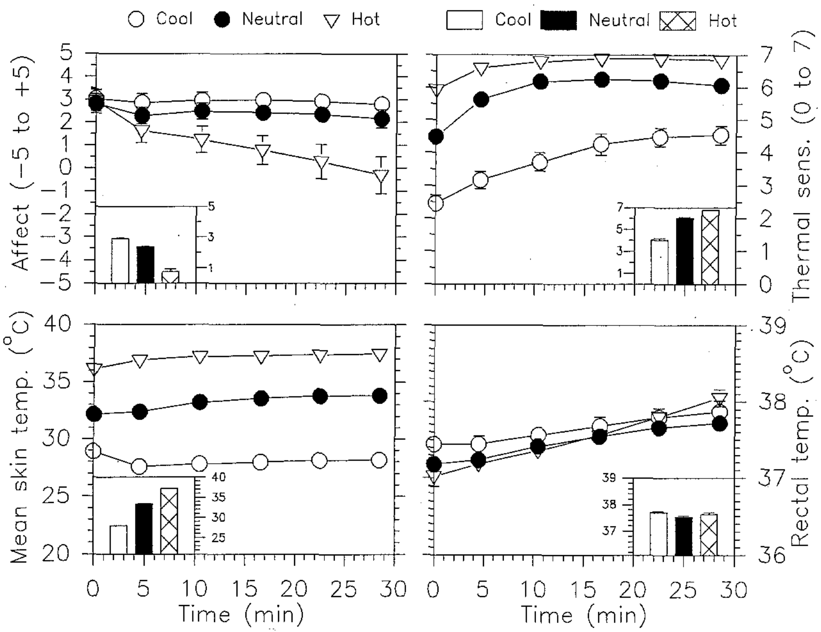

Fig. 1. Affect, thermal sensation, mean skin, and rectal temperatures during 30 min constant intensity exercise in hot (40° C), neutral (24° C), and cool (8° C) conditions (mean with standard error of the means). *Inset Graphs* show data from three conditions averaged over time

Table 1. Levels of significance in analyses of variance for repeated measures of psychophysical and physiological variables during 30 min of exercise in hot, neutral, and cool conditions

Variable		*F*	*P*
Affect	condition	1.75	0.193
	condition × time	17.09	0.000
Thermal sensation	condition	92.27	0.000
	condition × time	9.10	0.000
RPE: Overall	condition	5.57	0.010
	condition × time	3.37	0.002
Chest	condition	4.08	0.029
	condition × time	4.63	0.000
Legs	condition	2.91	0.073
	condition × time	3.15	0.003
Mean skin temperature	condition	129.41	0.000
	condition × time	20.63	0.000
Rectal temperature	condition	4.39	0.023
	condition × time	14.07	0.000
Cardiac frequency	condition	21.77	0.000
	condition × time	5.35	0.000

$df_{condition} = 2$; $df_{interaction} = 8$
RPE, ratings of perceived exertion

increase in the heat, concluding with respective frequencies of 139.5 (SEM 3.49), 135.1 (SEM 3.44), and 163.5 beats·min^{-1} (SEM 5.11; Fig. 2). The f_c was significantly lower in the cool than in the neutral and hot conditions throughout exercise and was significantly higher in the hot compared to the other two conditions throughout exercise (Fig. 2; $P<0.05$).

Affect in both the neutral and cool conditions remained stable, averaging 2.3 (SEM 0.04) and 2.9 (SEM 0.02) with time (see inset), while during the heat it displayed a negative linear relationship with time, with subjects finishing the exposure with a mean affect of 0.7 (SEM 0.19). The subjects reported feeling significantly worse (lower affect) in the heat than in both the neutral and cool conditions throughout the exercise period (Fig. 1; $P<0.05$).

Thermal sensation scores generally followed the changes seen in $\bar{T}_{sk}$, with subjects rating sensation significantly lower in the cool compared to the neutral or hot conditions throughout exercise, and significantly higher in the hot compared to the other two conditions throughout exercise (Fig. 1; $P<0.05$).

Overall RPE was significantly lower in the cool compared to the hot condition throughout exercise (Fig. 2; inset), averaging 11.7 (SEM 0.15) and 12.9 (SEM 0.20) with experimental time. The RPE data for each condition were regressed against f_c (Fig. 3). Such analyses revealed two temperature effects relative to that observed for the thermoneutral condition. Firstly, the cool condition acted to modify both the *y*-intercept and the slope of the RPE-f_c relationship. This change occurred through an apparent rotation around the point corresponding to a RPE of about 12 and f_c of approximately 138 beats·min^{-1}. Secondly, the hot condition shifted the RPE-f_c relationship to the right, while maintaining a similar slope. Thus, for a given RPE, the subjects in the heat experienced f_c of some 10–14 beats·min^{-1} greater than in the thermoneutral condition.

Chest RPE scores for the cool and hot conditions ran parallel with each other, but were displaced vertically about two points, resulting in significant differences at 4.5, 10.5, and 16.5 min (Fig. 2; $P<0.05$). The RPE scores for the legs generally overlapped each other. However, differences between each of the three conditions were significant at 4.5 min (Fig. 2; $P<0.05$). The RPE responses for the legs were significantly higher than for the chest in all three conditions (Fig. 2; $P<0.05$).

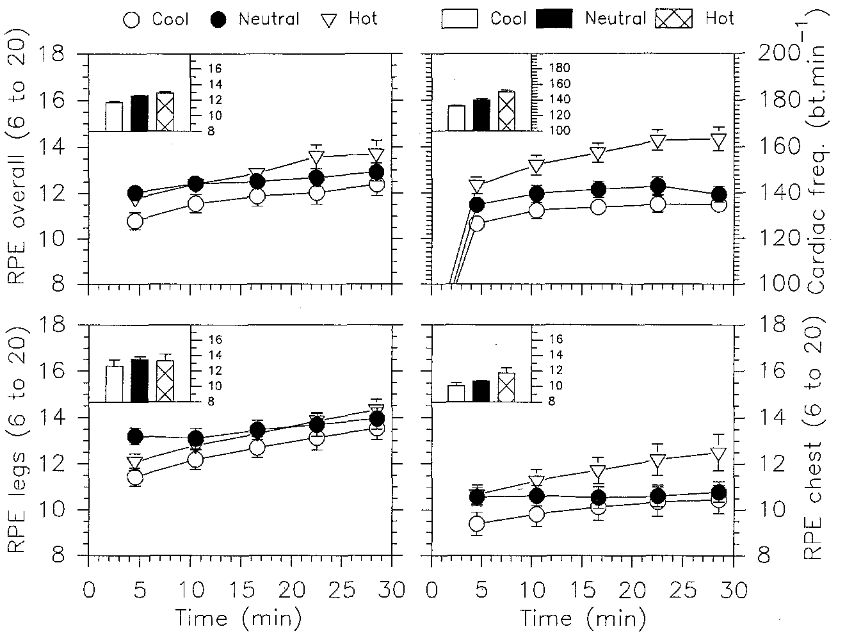

Fig. 2. Overall, chest, and leg ratings of perceived exertion, and cardiac frequency during 30-min constant intensity exercise in hot (40° C), neutral (24° C), and cool (8° C) conditions (mean with standard error of the means). *Inset graphs* show data from three conditions averaged over time

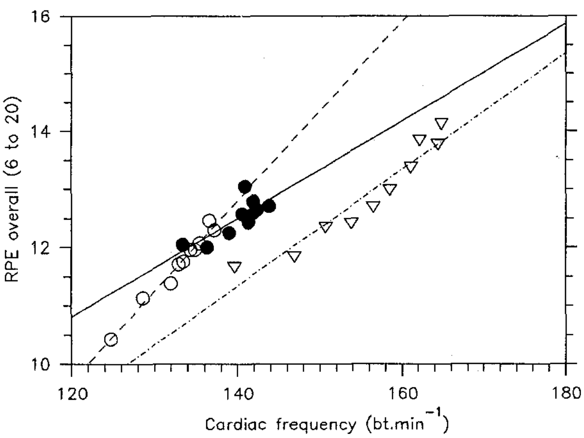

Fig. 3. Relationship between ratings of perceived exertion (*RPE*) and cardiac frequency during 30-min constant intensity exercise in hot (40° C), neutral (24° C), and cool (8° C) conditions. ○ Cool: Y = −8.93 + 0.16X; ● neutral: Y = 0.70 + 0.08X; ▽ hot: Y = −2.71 + 0.10X

Discussion

The results of this study demonstrated that the subjects perceived work to be harder, felt worse, reported greater thermal sensation, and experienced higher $\bar{T}_{sk}$ and f_c in the hot condition, compared to the neutral environment. These responses were reversed in the cool, indicating that during equal intensity exercise, cooler environmental conditions elicited greater psychophysical comfort and less physiological strain.

The $\bar{T}_{sk}$, T_{re}, and f_c responses to hot, neutral, and cool environments followed expected trends. For instance, in accord with previous work (Hardy 1961), $\bar{T}_{sk}$ was influenced more by the environment than by the thermal state of the body core (Fig. 1). The T_{re} increased significantly during exercise in all three conditions (Fig. 1). Over short-duration exercise periods, such changes in T_{re} are believed to occur independently of ambient conditions, and have been shown to be dependent on the relative intensity of the physical activity (Nielsen 1938; Saltin and Hermansen 1966). The current data followed this trend. The greater T_{re} at the onset of exercise in the cool may have been attributable to cold-induced cutaneous vasoconstriction at the start of the exposure, compromising heat dissipation during the early part of exercise.

In the heat, f_c was significantly accelerated at all times compared with the neutral condition, and f_c was significantly depressed throughout exercise in the cool. These differences in f_c reflected the respective demands for peripheral blood flow in the various conditions. In the heat, the rapid onset of a thermal sensation of heat (Stevens et al. 1970) has been found to be quickly followed by cutaneous vasodilatation, elevating the demand on cardiac output, which must serve both metabolic and thermoregulatory demands. As exercise was probably close to, or above the level where stroke volume was maximal, elevations in cardiac output were primarily achieved through increments in f_c, and f_c differences between the conditions may be readily explained on the basis of differential thermal loads upon the cardiovascular system.

In the neutral and cool conditions, the f_c responses showed an asymptotic tendency. However, in the heat there was a continual elevation in f_c throughout the exercise period, with the subjects finishing this condition with a mean f_c of 163.5 beats·min^{-1}, more than 20 beats·min^{-1} greater than either of the other two conditions (Fig. 2). This cardiovascular drift was attributed to the combination of elevated $\bar{T}_{sk}$ and T_{re}.

Thermal sensations were significantly different between each of the experimental conditions with time, indicating that subjects effectively differentiated between the 8°, 24°, and 40° C environments, and that their thermal perception was unaffected by the imposition of an exercise load (Fig. 1). This is not surprising, as the test conditions were designed to exceed both the range of thermoneutrality and the range of normal daily environmental exposures. It has been shown that neural inputs from different regions of the body surface play a variable role in thermoregulation in hot and cold environments (Crawshaw et al. 1975; Nadel et al. 1973), and that thermal sensation is derived primarily from cutaneous thermoreceptors and the rate of change of $\bar{T}_{sk}$ (Hardy 1961). The present observations generally supported this, while demonstrating a minimal influence of T_{re} on thermal sensation. The failure of thermal sensation to increase during exercise in the heat may have indicated a limitation in the scale used rather than a lack of changing sensation, as the environment was already considered "hot" (the uppermost rating) at the onset of exercise.

Affect deteriorated significantly during exercise in the hot environment (Fig. 1), being significantly lower than in either the neutral or cool conditions. It has previously been suggested that people feel most comfortable exercising in cool or temperate conditions (Nelson et al. 1991) and reports of severe physiological strain in the heat are abundant (see Sutton and Bar-Or 1980). The interaction of physiological cues upon affect during thermal stress is poorly understood. However, it is feasible that affect is directly influenced by thermal comfort. For instance, thermal discomfort (the unpleasantness of the sensation) has been associated with the rate of sweating (Gagge et al. 1938) and cutaneous vasodilatation (Hardy 1970). Vasdilatation can intensify the sensation of warmth at the skin surface, precipitate skin irritation, intensify the sensations of cardiac activity, and may lead to hypotension and dyspnoea. In addition to these peripheral factors, there may also have been a central influence on the affect state. It is possible that an increase in hypothalamic temperature may have caused a negative affect change, since it has been documented that subjects placed in high ambient temperatures show increased aggression and negative affect compared to thermoneutral environments (Baron 1977). While deep tissue temperatures were not measured in the present study, we have previously shown that rectal, oesophageal, and aural temperatures change in parallel and by equal magnitude during similar exercise in hot conditions (Maw and Taylor 1992).

Overall, RPE was significantly lower at all points of measurement during exercise in the cool compared with the hot condition, while RPE in the cool was lower than RPE in the neutral condition only during the first 20 min of exercise (Fig. 2). These results occurred despite a standardised exercise intensity during all trials. Prior research has indicated that at moderate exercise intensities RPE and f_c co-vary (Borg 1961). The RPE is typically linked to f_c by a factor of 10. As f_c was significantly elevated in the hot condition, it would be expected that RPE would also be higher. This response was found in the present study, although the factor 10 relationship was changed in the hot condition. For example, for the last 20 min of exercise in the cool condition average RPE was 12.1, whereas f_c was 135 beats$\cdot$min^{-1}. In contrast, in the hot condition average RPE was 13.5, whereas f_c was 161 beats$\cdot$min^{-1}. This effect, where the f_c at the same RPE was elevated in the hot compared to the cool condition, is indicated in Fig. 3. Thus, it would appear that the ability to rate perceived exertion during exercise in hot environments may be confounded when the cardiac stimulus includes a significant thermal drive in addition to that provided by exercise.

Few investigators have explored the possible influence of body temperature on RPE (Kamon et al. 1974; Kuoppasalmi et al. 1986). However, the results of this study would suggest that $\bar{T}_{sk}$ rather than T_{re} is a contributor to effort perception. Thus, it would appear that RPE was most sensitive to peripheral input, as $\bar{T}_{sk}$ and f_c were driven by both thermal and metabolic loads, whereas T_{re} behaved independently of environmental conditions.

Differentiated RPE displayed dissimilar patterns in the three conditions (Fig. 2). The most striking responses were the diminished overall, chest, and leg RPE in the cool condition, and the elevation of chest RPE in the hot condition. Subjects perceived work to be significantly harder when asked to rate thoracic exertion during exercise in the hot environment. It appears that when subjects exercised in the hot condition the combined influence of heat and exercise on the chest may have had a strong influence on RPE. It has been reported that individual cues for RPE (e.g. chest, legs) become more important if environmental conditions make them the dominant cues (Pandolf 1983).

It is possible that heat-induced cutaneous vasodilatation produced thoracic sensations which the subject associated with greater exertion. For example, elevated thoracic sensations, throbbing, and dyspnoea are known to accompany exercise in the heat (Hardy 1970). Although, from the present data, we are unable to speculate further concerning such feedback, these changes may account for greater chest than leg RPE under the same exercise stimulus in hot environments.

The modification of effort perception in diverse thermal conditions dictates caution in the application of RPE (Fig. 3). It may not be possible to determine accurately exercise intensity from perceptual reactions without also accounting for the prevailing temperature. Affect feelings may be equally misleading depending on the environment. The enhancement of affect in the cool shows that work is viewed more favourably at low temperatures. The combination of reduced RPE, improved affect, and lower f_c in the cool may entice extra effort during exercise in cool conditions. While this may lead to enhanced performance in the well-conditioned and highly motivated individual, it may be disadvantageous to workers involved in stressful occupations. Workers in the cool may feel better, perceive less thermal strain, and have a lower f_c, yet they may be working equally as hard as those in a natural environment, who are experiencing a sense of effort consistent with work-related stress. The result of lower subjective sensation may be an increased work effort in the former group. Such a change in exercise intensity should be treated with caution, since, depending upon the nature of the industry, this change may reduce the margin of worker safety, predispose the worker to greater risks of acute stress-related injury, and elevate the cumulative fatigue over the work shift.

In summary, the results of this study have extended knowledge gained from previous research which has established variations in perceptual responses to short-duration (5 min) exercise in cool and thermoneutral environments. Our data indicated that perception responses to longer periods of exercise (30 min) are also influenced by hot and cool conditions. Compared to the neutral condition, exercise in the cool was perceived to be less demanding and more comfortable, while exercise in the heat had the opposite effect. Changes in cutaneous vasomotor tone and heat-induced influences on the chest would appear to influence RPE in hot as opposed to cool exercise conditions. The variability of perceptual responses to exercise under thermal stress would indicate the use of caution when monitoring exercise intensity in diverse thermal environments.

References

Baron RA (1977) Human aggression. Plenum Press, New York

Borg GAV (1961) Perceived exertion in relation to physical work load and pulse rate. K Fysiogr Saellsk Lund Foerh 31:105–115

Borg GAV (1962) Physical performance and perceived exertion. Gleerup, Lund

Borg GAV (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14:377–381

Boutcher SH, Fleischer-Curtian LA, Gines SD (1988) The effects of self presentation on perceived exertion. J Sport Exerc Psychol 10:270–280

Boutcher SH, Seip RL, Hetzler RK, Pierce EF, Snead D, Weltman A (1989) The effects of specificity of training on rating of perceived exertion at the lactate threshold. Eur J Appl Physiol 59:365–369

Carton RL, Rhodes EC (1985) The effects of endurance training upon ratings of perceived exertion. Aust J Sci Med Sport 17(4):19–24

Crawshaw LI, Nadel ER, Stolwijk JAJ, Stamford BA (1975) Effect of local cooling on sweating rate and cold sensation. Pflügers Arch 354:19–27

Davies CTM, Sargent AJ (1979) The effects of atropine and practolol on the perception of exertion during treadmill exercise. Ergonomics 22:1141–1146

Gagge AP, Winslow CEA, Herrington LP (1938) Influence of clothing on the physiological reactions of the human body to varying environmental temperatures. Am J Physiol 124:30–50

Gagge AP, Stolwijk JAJ, Hardy JD (1967) Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environ Res 1:1–20

Geisser S, Greenhouse SW (1958) An extension of Box's results on the use of the F distribution in multivariate analysis. Ann Math Stat 29:885–891

Hardy JD (1961) Physiology of temperature regulation. Physiol Rev 41:521–606

Hardy JD (1970) Thermal comfort: skin temperature and physiological thermoregulation. In: Hardy JD, Gagge AP, Stolwijk JAJ (eds) Physiological and behavioral temperature regulation. Thomas, Springfield, Ill.

Hardy CJ, Rejeski WJ (1989) Not what, but how one feels: the measurement of affect during exercise. J Sport Exerc Psychol 11:304–317

Hill DW, Cureton KJ, Grisham C, Collins MA (1987) Effect of training on the rating of perceived exertion at the ventilatory threshold. Eur J Appl Physiol 56:206–211

ISO (1992) Evaluation of thermal strain by physiological measurements. International Standards Organisation, Geneva ISO 9886: 1992 [E]

Kamon E, Pandolf K, Cafarelli E (1974) The relationship between perceptual information and physiological responses to exercise in the heat. J Hum Ergol 3:45–54

Kuoppasalmi K, Ilmarinen R, Smolander J, Harkonen M, Korhonen O (1986) Relationship between physiological responses and perceived exertion of muscular exercise under various environmental conditions. Psychiatr Fenn [Suppl]:69–77

Maw G, Taylor NAS (1992) Dissociation of rectal and aural temperatures during lower-body exercise. Physiologist 35:175

Morgan WP, Raven PB, Drinkwater BL, Horvath SM (1973) Perceptual and metabolic responsivity to standard bicycle ergometry following various hypnotic suggestions. Int J Clin Exp Hypn 21:86–101

Myers JL (1979) Fundamentals of experimental design (3rd ed) Allyn and Bacon, Boston

Nadel ER, Mitchell JW, Stolwijk JAJ (1973) Differential thermal sensitivity in the human skin. Pflügers Arch 340:71–76

Nelson TM, McIntyre JWR, LaBrie IG, Csiky A (1991) Self-perception of the ability to work in the cold. Behav Med 17:15–23

Nielsen M (1938) Die Regulation der Körpertemperatur bei Muskelarbeit. Skand Arch Physiol 79:193–230

Pandolf KB (1978) Influence of local and central factors in dominating rated perceived exertion during physical work. Percept Mot Skills 46:683–698

Pandolf KB (1983) Advances in the study and application of perceived exertion. Exerc Sport Sci Rev 11:118–158

Rejeski WJ (1985) Perceived exertion: an active or passive process? J Sport Psychol 7:371–378

Rejeski WJ, Ribisl P (1980) Expected task duration and perceived effort: an attributional analysis. J Sport Psychol 2:227–236

Saltin B, Hermansen L (1966) Esophageal, rectal, and muscle temperature during exercise. J Appl Physiol 21:1757–1762

Stevens JC, Adair ER, Marks LE (1970) Pain, discomfort, and warmth as functions of thermal intensity. In: Hardy JD, Gagge AP, Stolwijk JAJ (eds) Physiological and behavioral temperature regulation. Thomas, Springfield, Ill.

Sutton JR, Bar-Or O (1980) Thermal illness in fun running. Am Heart J 100:778–781

Toner MM, Drolet LL, Pandolf KB (1986) Perceptual and physiological responses during exercise in cool and cold water. Percept Mot Skills 62:211–220

Young AJ, Sawka MN, Epstein Y, DeCristofano B, Pandolf K (1982) Cooling different body surfaces during upper and lower body exercise. J Appl Physiol 63:1218–1223