



The transactional psychobiological nature of cognitive appraisal during exercise in environmentally stressful conditions

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Abstract

Background and Purpose: Successful adaptation to the stress of physical exertion in adverse environmental conditions (heat, cold, high altitude) is of great concern when optimal performance within safe parameters is the goal. The perception of the psychophysical demands imposed by the stressful situation and the perceived capability to cope with these demands is a process that can dramatically alter the intensity of the ensuing physiological activation. Thus, exercise in environmentally stressful conditions provides an excellent model for examining the relationship between the cognitive appraisal of the physical stress and the ensuing stress response. A brief review of the research on cognitive appraisals during exercise in stressful environments provides evidence of the connection between cognitive appraisals and the stress response during exercise under environmental stress and demonstrates a need for a transactional psychobiological model proposed in this paper. This model attributes a central role to the continuous cognitive appraisal of the situation by the individual.

Methods: Computer searches of psychological, sport science, and medical databases using the terms exercise, heat, cold, high altitude, environmental stress, and ratings of perceived exertion were conducted. Additionally, the reference citations in the obtained articles were searched for relevant studies. An abridged integrated review summarizes the critical findings and limitations. Furthermore, literature supporting the proposed transactional psychobiological model is presented.

Results and Conclusions: Further investigation into the psychophysical and the affective responses to exercise in adverse environmental conditions can be facilitated through the utilization of the proposed transactional psychobiological model. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Cognitive appraisals; Environmental stress; Effort sense

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Meeting the challenge of successfully adapting to the stress of physical exertion in adverse environmental conditions (heat, cold, high altitude) can be facilitated by understanding the mechanisms responsible for the psychobiological responses to multiple stressors during exercise. The purpose of this paper is to demonstrate the transactional psychobiological nature of cognitive appraisal during exercise in environmentally stressful conditions and propose a model for further investigation. The central thesis is that the perception of the psychophysical demands imposed by the stressful situation and the perceived capability to cope with these demands is a process that can dramatically alter the intensity and the emotional concomitants of the ensuing physiological activation. Thus, exercise in environmentally stressful conditions provides an excellent model for examining the relationship between cognitive appraisal of the physical stress and the ensuing stress response.

This paper presents a brief review of the research on the psychophysical and affective responses to exercise in the adverse environmental conditions of heat, cold, and high altitude with a focus on the cognitive appraisal of effort sense. The appraisal of effort has received a great deal of attention in the literature and thus serves as a focal point in examining the effects of environmental stress on cognitive appraisal and the potential reciprocal effects on physiological responses. The review is intended to provide evidence of the connection between cognitive appraisals and the stress response during exercise under environmental stress and demonstrate a need for a model that comprises a psychophysical interaction. The second section of this paper outlines the conceptual framework for investigating the dynamic relationship of psychological and physiological responses during exercise under environmental stress. This transactional psychobiological model attributes a central role to the continuous cognitive appraisal of the situation by the individual. Support for this model is enhanced with a summary of the investigations that have attempted to utilize psychological techniques to alter physiological responses to the stress of exercise.

To locate studies assessing RPE during exercise in environmentally stressful conditions, computer searches of psychological, sport science, and medical databases using the terms exercise, heat, cold, high altitude, environmental stress, and ratings of perceived exertion were conducted. Additionally, the reference citations in the obtained articles were searched for relevant studies. Twenty studies were obtained. All twenty studies were experimental or quasi-experimental. The 20 studies that were obtained provide the content for a summary of findings (Table 1 and Table 2) and highlight the psychophysical nature of perception during exercise under environmental stress.

Psychological responses during exercise in neutral and stressful environments

Individuals interested in achieving optimal performance during physical activity cognitively appraise their effort in determining optimal levels of exertion. Interest in this intuitive appraisal and the inability to explain theoretical problems outside of the physiological spectrum initiated Borg's development of the ratings of perceived exertion scale (RPE; Borg, 1962). Since the introduction of this scale a plethora of research has accumulated. This has led to several research reviews that have been updated periodically (Watt & Grove, 1993). Typically, scientists have investigated the physiological independent variables that underlie the perceptual response. A two-

factor model has been proposed for evaluating central (sensations primarily associated with the cardiorespiratory system) and local (sensations from exercising muscles and joints) input to RPE. Research suggests that local cues dominate at varying intensities, while central cues become more salient at higher work intensities. In addition, if a single factor is intense enough, it may dominate RPE rating. That is, if discomfort from heat or cold is extreme, it may be the primary and overwhelming influence on RPE. This would suggest that in a hypoxic condition, when greater ventilatory effort is perceived, ventilatory sensation may dominate RPE.

Following an examination of the research on RPE, Morgan (1973) stated that physiological variables account for approximately 67% of the variance in RPE, suggesting that the unexplained variance (33%) is dependent upon psychological factors. Furthermore, others have presented a case for the influence of psychological factors such as personality variables, past experience, motivation and emotion in determining RPE (Morgan, 1994; Rejeski, 1985).

Rejeski (1985) further theorized that the relative contribution of psychological and physiological input to RPE varies with exercise intensity. More specifically, at high intensities of exertion, physical sensory cues are so strong they dominate perception. Additionally, Rejeski has proposed that the parallel-processing model of pain (Leventhal & Everhart, 1979) is effective in describing how physiological sensory information is processed. By examining changes in affect and RPE at varying intensities of exercise, several investigators (Acevedo, Rinehardt, & Kraemer, 1994; Hardy & Rejeski, 1989) have demonstrated support for the parallel-processing model and the isomorphic nature of affect and RPE. Research examining duration effects have demonstrated similar responses (Acevedo, Gill, Goldfarb, & Boyer, 1996).

Psychological factors in varying thermal conditions

The focus of this section will be on effort sense and affect in the heat and cold. In addition, this section will focus on the transactional psychobiological responses that may explain the relationship of the physical stress, the cognitive appraisal, and the feedback of sensory cues during exercise in heat and cold.

In a review by Kobrick and Johnson (1991) it was concluded that, “With respect to heat, vigilance tasks appear to become impaired above 90 degrees F (32°C) and below 85 degrees F (29°C) with best performance at or about 85 F/63% relative humidity” (p. 218). This review also summarized investigations that included other psychological factors, such as reaction time, sensation, and psychomotor performance. They found that the results in these investigations demonstrated that individual performances vary widely. It should be noted that the effects of temperature on psychological factors often precedes physiological deterioration. These facts may be indicative of the role sensory perception can play in the psychological responses to heat stress.

The effects of cold seem to be associated most with the impairment of manipulative ability (Kobrick & Johnson, 1991). No firm conclusions can be made on the effects of cold on other psychological responses, although with increased discomfort it is expected that there is impaired performance. It may be that in cold, relative to heat, discomfort plays a more significant role in performance decrement.

Effort sense and affect in varying thermal conditions

An examination of the research on effort sense in heat and cold (see Table 1) has demonstrated that when the investigation incorporates a broad range of temperatures, RPE is higher in the heat and lower in the cold relative to neutral temperatures. However, when investigations have utilized a narrow range of temperatures (Bergh, 1986; Bergh & Ekblom, 1979; Israel, Heydon, Edlich, Pozos, & Wittmers, 1989; Kamon, Pandolf, & Cafarelli, 1974; Potteiger & Weber, 1994), results have been equivocal. In addition, the research in this area has tended to utilize small sample sizes, has included exclusively male subjects, and has used predominantly fit individuals. Although empirical evidence is not conclusive, RPE ratings at submaximal exercise intensities tend to be higher in the heat and lower in the cold, relative to neutral conditions.

Maw, Boutcher, and Taylor (1993) and Toner, Drolet, and Pandolf (1986) have suggested that the perceptual cues of HR and ventilation are greater contributors to RPE during thermal stress than the thermal sensations themselves. Maw et al. (1993) also examined affect during exercise. Interestingly, RPE was significantly lower in the cool environment and affect, as measured by the Feeling Scale (FS; Hardy & Rejeski, 1989), was more positive. The authors suggested that lowered RPE and improved affect may have had either beneficial and/or deleterious effects on performance. That is, if an athlete is highly motivated these perceptual responses may facilitate effort and performance. However, for the inexperienced exerciser these responses may lead to overexertion and unexpected fatigue, which could lead to health risks in certain situations.

Psychoneuroendocrinology and thermal stress

A psychoneuroendocrinological hypothetical model has been proposed for thermoregulation. In this model the anterior hypothalamus plays two roles in the control of body temperature. One, through its influence on sympathetic pathways of the autonomic nervous system, and, two, through its ability to control secretion of epinephrine and norepinephrine by the adrenal medulla. These hormones strongly affect metabolism by causing increases in circulating free fatty acids and glucose, both of which are involved in thermoregulation. Francesconi (1988) has published an extensive review on the endocrinological responses to exercise in stressful environments. The influence of psychological stress during exercise on these thermoregulatory responses has not been addressed in the literature. This combination of stressors provides a complex condition that is of concern to those interested in optimal exercise performance while under thermal stress.

The physiological adaptations that occur to chronic heat and cold exposure have been previously reviewed (Cabanac, 1975; Jacobs, Martineau, & Vallerand, 1994). Heat acclimatized individuals produce less of an increase in heart rate, have a lower skin temperature, have a higher sweat rate, and have a reduced subjective feeling of discomfort during physical work than individuals who are unacclimatized. In cold acclimatization, responses have included elevated resting metabolic rate, increased ratio of lean body mass to total body weight, and increased time of onset of shivering. If through acclimatization physiological responses (i.e., catecholamine release) are diminished (Dienstbier, 1989), leading to the decrease in the intensity of the sensory cues listed immediately above, then it should be the case that perceptual responses during exercise would also decrease in intensity. Although the physiological effects of acclimatization are well known, the psychological changes have received little attention. It should be noted that these suggested

Table 1
Studies examining effort sense and thermal sensation during exercise at different temperature conditions

Study	Sample	Exercise	Temperatures	Findings
Bergh, 1986	4 (cycle) +3 (swim) males [VO ₂ max not reported]	Cycling at ~100, 200, 300 W, and swimming at ~0.50, 0.75, 1.00 m/sec	“normal” core temperature (36.5–37.5°C at rest, 37–38°C during exercise) and “subnormal”	For a given submaximal work intensity at reduced body temperature, RPE was lower during cycling, but elevated during swimming at low velocity. RPE was lower at a given oxygen uptake in subnormal body temperature during cycling, but not during swimming. For a given level of heart rate, RPE was elevated by lowered body temperature in swimming, but not in cycling. For a given level of pulmonary ventilation, RPE was lower at subnormal body temperature during cycling, but not during swimming. Given levels of blood lactate were associated with lower RPE at subnormal temperature both in swimming and cycling. During exhaustive exercise, RPE was essentially the same at normal and subnormal body temperature.
Bergh, Danielsson, Wennberg, & Sjodin, 1986	6 males [VO ₂ max not reported]	Incremental cycle ergometry (15 min at 75 W, 5 min at 135, 185, and 215 W)	15, 45°C	RPE was significantly higher during the 45°C condition during exercise, but not at rest. However, at any given level of HR, RPE was higher in the 15°C condition.
Bergh & Ekblom, 1979	8 males [VO ₂ max 4.43 ±0.41 l/min]	Arm and leg cycle ergometry to exhaustion in 3.06 to 6.80 min	38.4±0.1 37.7±0.3 35.8±0.634.9±0.5	There were no differences in RPE between different experimental conditions.
Gamberale & Holmer, 1977	10 males [3 l/min, 2.3–3.8]	Cycle ergometry for 15 min at 50 W, followed by 15 min at 100 W	with gas protective suit (+0.3 to 0.5°C rectal temperature) and without suit (control)	In the unventilated protective suit condition, RPEs were lower than would be predicted from the RPE=HR ^{0.10} formula, with the exception of the 10th minute in the 50 W condition. RPE data from the control condition or statistical comparisons between conditions are not reported.

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Table 1 (continued)

Study	Sample	Exercise	Temperatures	Findings
Israel et al., 1989	5 males [4.02±0.75 l/min upright in air]	30-min semireclining ergometer at 60% VO ₂ max immersed in water, and 60 VO ₂ max in air	21.1, 25.3, 29.4°C in water, 21°C in air	RPE was not significantly different between conditions. Subjects felt warmer with increased water temperature. They felt warmest in the 21°C air condition.
Kamon et al., 1974	10 males [58.80±6.90 ml/kg/min]	Cycle ergometry at five conditions: (i) 40% VO ₂ max at 24°C, (ii) 40% VO ₂ max +20 bpm at 24°C, (iii) 40% VO ₂ max +30 bpm at 24°C, (iv) 40% VO ₂ max at 44°C, and (v) 40% VO ₂ max at 54°C	24, 44, 54°C	RPE was higher in the 40% VO ₂ max +30 bpm at 24°C condition, compared to all other conditions. Among the other four conditions, there were no significant differences in RPE. The 54°C condition was associated with higher thermal sensation compared to the other conditions. Also, the 54°C condition and the 40% VO ₂ max +30 bpm at 24°C were perceived as more uncomfortable, compared to the other conditions.
Kuoppasalmi, Ilmarinen, Smolander, Harkonen, & Korhonen, 1986	8 males [50 to 59 ml/kg/min]	Up to 4-hr treadmill at 30% VO ₂ max	20°C/50% humidity, 40°C/20% humidity, 30°C/80% humidity	Until the 140th minute, when some subjects stopped due to exhaustion, the 40°C/20% and the 30°C/80% conditions were associated with the higher RPEs, compared to the neutral condition (20°C/50%). At the end of the 4-hr trials, the increase in the mean RPE during the 20°C/50% and the 40°C/20% conditions was of the same magnitude, whereas during the 30°C/80% condition the increase in RPE was greater. RPE was correlated with mean HR, mean body temperatures, and serum prolactin. RPE was not affected by the ambient temperature variations. Marked changes were induced in thermal sensation and perceived skin wettedness by each heating or cooling period. Thermal sensations were slightly higher during the 30-min heating periods, compared to the 10-min heating periods. Variations in perceived skin wettedness were larger during the 30-min heating periods, compared to both the 10-min and the 20-min heating periods.
Mairiaux et al., 1984	5 males [3.50±0.23 l/min]	Cycle ergometry at constant workload (50 W, 60 rpm) for 120 min (22 to 28% VO ₂ max)	23, 50.6 °C in heat pulses of 10, 20, 30-min duration	

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Table 1 (continued)

Study	Sample	Exercise	Temperatures	Findings
Maw et al., 1993	14 males [“physically active”]	30-min cycle ergometry constant at intensity previously identified as corresponding to RPE of “somewhat hard”	40, 24, 8°C	RPE was significantly lower in the cool than in the heat, throughout exercise. RPE was higher, affect was lower, and thermal sensation was higher in the heat, compared to cold and the thermoneutral condition.
Nelson, McIntyre, Labrie, & Csiky, 1991 (study 1)	3×12 males [VO ₂ max not reported]	Approximately 45 min of SwedeBall (modified table tennis)	22, 0, -7°C	RPE was significantly lower in the 0°C, compared to the 22°C condition. There was also a tendency for RPE to be higher in 22°C, compared to the -7°C condition. Body distress was most noticeable after play at 22°C and least noticeable at 0°C.
Nelson, McIntyre, Labrie, & Csiky, 1991 (study 2)	8 males [nonobese, nonathletes]	5-min bicycling at 120, 140, 160 bpm	26, 8, -10°C	RPE decreased significantly as temperature declined. As heart rate increased, discomfort increased only in the 8°C and 26°C conditions. However, in the -10°C condition, discomfort was highest in the low-HR condition. Subjects tended to perceive their rate of pedalling to be closer to their maximum capacity when exercising at 160 bpm at 26°C, whereas the most optimistic self-perceptions were associated with the lowest temperature and the 120 bpm condition. Estimates of projected endurance increased as the temperature declined at all three workloads.
Pandolf, Cafarelli, Noble, & Metz, 1972	10 males [57.75±4.4 ml/kg/min]	30-min cycle ergometry at five conditions: (i) 40% VO ₂ max at 24°C, (ii) 40% VO ₂ max +30 bpm at 24°C, (iii) 40% VO ₂ max at 44°C, (iv) 40% VO ₂ max +20 bpm at 24°C, and (v) 40% VO ₂ max at 54°C.	24, 44, 54°C	There were no significant differences in RPE at equal work loads across different temperature conditions. However, higher temperatures led to higher thermal sensation and were rated as “uncomfortable”.

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Table 1 (continued)

Study	Sample	Exercise	Temperatures	Findings
Pivarnik, Grafner, & Elkins, 1988	8 males [4.07±0.52 l/min]	60-min cycle ergometry with arm or leg (75 W, 75 rpm)	22.8°C, 75% humidity, 33.5°C, 57% humidity	RPE increased over time in all experiments, but average values were higher when exercise was performed with the arms as opposed to the legs. This paralleled the pattern found for HR. There was no effect of temperature on RPE. No differences in RPE across different temperature conditions were found.
Potteiger & Weber, 1994	9 males [53.3±8.9 ml/kg/min]	Cycle ergometry to exhaustion at intensity corresponding to the onset of blood lactate accumulation	30, 22, 14°C	
Skinner, Hutsler, Bergsteinova, & Buskirk, 1973	8 lean 8 obese males [VO ₂ max not reported]	Incremental treadmill to exhaustion, while lean subjects were carrying or not carrying excess weight	23–25°C, 20–30% humidity, 31–33°C, 8–12% humidity	VO ₂ was unchanged in the heat and essentially identical for lean, obese and weighted lean subjects. For a given VO ₂ , lean subjects gave significantly higher RPEs in the 32°C environment than at 24°C. They gave approximately the same RPE whether or not they were carrying excess weight. The obese subjects gave identical RPEs in the 24°C and the 32°C environments. Their ratings were similar to those given by lean subjects carrying excess weight in the warm environment. Significantly higher RPEs were given by obese subjects at 24°C, compared to lean subjects whether or not they were weighted. RPE did not differ between water temperature conditions. At the 60% intensity condition, when VO ₂ max was matched across temperature conditions, RPE was lower in the 20°C condition, compared to the 26°C condition. RPE was correlated with heart rate, ventilation, and oxygen uptake.
Toner, Drolet, & Pandolf, 1986	8 males [49.9±6.1 ml/kg/min]	45 min arm, leg, and arm and leg exercise in water at approximately 40% and 60% VO ₂ max	20, 26°C	

psychological responses due to acclimatization could also be due to increased expectations of success and improved motivation.

Psychological factors in hypoxic conditions

The effects of altitude on psychological factors are associated with the impact of hypoxia on the central nervous system. The pattern of symptoms that occurs with acute exposure to high altitudes (above 3,000 m) is characterized as acute mountain sickness (AMS). Symptoms include headache, dizziness, dyspnea, nausea, vomiting, loss of appetite, dim vision, loss of coordination, apathy, irritability, fatigue, unwillingness to continue to work, disobedience, confusion, and initial euphoria followed by depression with a general decline in cognitive function (Banderet & Burse, 1991). Symptomology varies from person to person with the number, severity, rapidity of onset, and duration of symptoms being relative to the level of altitude and the rate of ascent. Additionally, the most severe reactions occur during the first two days of exposure and gradually diminish over the following 2–4 days while one remains at altitude.

Effort sense and affect in hypoxic conditions

A summary of the research on effort sense during exercise under hypoxic conditions is presented in Table 2. Horstman, Weiskopf, and Robinson (1979) have suggested that local factors exert greater influence on the perception of effort at exercise intensities that do not exert great stress on the ventilatory and circulatory systems. Conversely, at high intensities central factors exert greater influence on RPE when the perceptual cues of tachypnea and tachycardia are of sufficient magnitude to be perceived as stressful.

The examination of RPE as a local muscular rating, a central rating (effort sense of a cardiorespiratory nature), and as an overall rating is referred to as differentiated RPE. It has been demonstrated that the relative impact of perceptual cues during exercise is altered in hypoxic conditions (Young, Cymerman, & Pandolf, 1982). More specifically, acute exposure to high altitude tends to elevate local RPE and have no effect on central and overall RPE. In addition, following chronic exposure local RPE responses were significantly reduced. Maresh, Deschenes, Seip, Armstrong, Robertson, and Noble (1993) further examined differentiated RPE in people living in either low or moderate altitude. These researchers demonstrated that moderate altitude residents reported significantly lower central RPE at 75% and 85% intensities and lower overall RPE at the 75% intensity than the lower altitude residents. These results provide evidence suggesting that alterations in RPE at relatively high intensities of exercise in hypoxic conditions are impacted by cardiorespiratory perceptual cues. This seems reasonable considering the impact of high altitude cardiorespiratory stress.

The research on mood decrements at altitude has been reviewed (Bahrke & Shukitt-Hale, 1993) and includes decreases in friendliness, clear thinking, alertness, and vigor, and increases in sleepiness, dizziness, and fatigue. The relationship of these mood changes and AMS has been documented, and it seems clear that a more negative mood is associated with more severe AMS. Furthermore, Missoum, Rosnet, and Richalet (1992) have suggested that because of the apparent ability of anxiety to predict AMS, anxiety reducing methods such as relaxation training and self-hypnosis may help to prepare susceptible climbers and diminish AMS.

Table 2
Summary of studies examining perceived exertion responses to exercise at high altitude

Study	Sample	Exercise	Altitudes	Findings
Horstman et al., 1979	20 males [48.8±1.2 ml/kg/min] [sea level residents]	Cycle ergometry for 6 min at 60, 80, 95% VO ₂ max and exercise to exhaustion at 85% VO ₂ max	sea-level, 4300 m (acute)	VO ₂ and absolute workload at each altitude-specific relative exercise intensity, and VO ₂ max were reduced at altitude. RPE was significantly less at sea level for the lower intensities of submaximal exercise and early during prolonged exercise.
Maresh et al., 1993	6 males [50.7±9.8 ml/kg/min] [low-altitude] 8 males [46.7±8.5 ml/kg/min] [moderate-altitude]	Cycle ergometry at 33, 55, 75, 85, and 100% VO ₂ max	residence altitudes (366 and 2200 m), and 4270 m (447 mm Hg) (2-d of acclimatization)	There were no differences in RPE between low- and moderate- altitudes natives at their respective residence altitude. At hypobaric hypoxia, overall RPE was less in the moderate- compared to the low-altitude natives at the 75% relative intensity.
Robinson & Haymes, 1990	7 males [52±6 ml/kg/min]	30-min of cycle ergometry at 50% of HRmax reserve	(i) normoxia, 25°C, (ii) normoxia, 8°C, (iii) hypoxia (12% O ₂), 25°C, (iv) hypoxia, 8°C	Hypoxia increased heart rate, systolic blood pressure, pulmonary ventilation, respiratory exchange ratio, lactate, and RPE, while depressing rectal temperature and oxygen uptake. No difference in RPE was found between temperature conditions.
Young et al., 1982	8 males [39.9±0.11 ml/kg/min] [low-altitude residents]	30-min of cycle ergometry at 85% VO ₂ max	sea level, 4300 m (acute and after 18 d of acclimatization)	Absolute exercise intensity was reduced at 4300 m. Overall RPE at high altitude did not differ from the corresponding values at sea level.

Psychoneuroendocrinology in hypoxic conditions

While exercising at altitude at a given absolute workload norepinephrine (NE) and epinephrine (E) are higher in hypoxia than in normoxia for trained subjects; however, at similar relative workloads there are no differences in E and NE (Francesconi, 1988). Other researchers (Richalet, Mehdioui, Rathat, Vignon, Keromes, Herry et al., 1988) have documented that for the same NE increase under hypoxic and normoxic conditions the VO_2 and HR increase was lower in the hypoxic condition. Thus hypoxia can induce a decrease in cardiac chronotropic response to adrenergic activation during submaximal exercise. This decrease in central cues provides an explanation for the reported lower RPE ratings. Investigations into E, NE, and cortisol changes with RPE, mood and AMS have not been published.

Future questions

A complete understanding of the relationship of RPE to physiological sensory cues and how these may change across temperature and intensity of exercise is lacking. In addition, the influence of affect on effort sense during exercise under environmental stress is unexamined. Information leading to a better understanding of these responses will allow for a more direct approach in the application of psychological interventions for coping with these conditions.

Individuals who have experienced the fear and anxiety associated with hypoxia and/or hypothermic-like symptoms realize the role affect plays in diligence to the task, confidence, and perceptual appraisals. The questions that have not been asked include: “What is the relationship among RPE, affect and psychoneuroendocrinological responses in the heat, in the cold and under hypoxic conditions at altitude?” and “What role does the cognitive appraisal of threat and control play in the psychoneuroendocrinological responses during exercise in the heat, in the cold and under hypoxic conditions?” Determination of the specific responses and their relationship to perceptual appraisals may provide information to exercisers that will allow exercisers to appraise the information differently, enhance performance, and alter affect.

Conceptual framework for addressing future questions

A conceptual representation of an individual’s cognitive appraisals (RPE, affect, thermal tolerance) during exercise and the related neuroendocrine responses that alter peripheral physiological responses are presented in Fig. 1. This transactional psychobiological model of stress during exercise acknowledges the necessity to examine both the physical and the psychological aspects of exercise in adverse environmental conditions and is congruent with contemporary views of stress (Johnson, Kamilaris, Chrousos, & Gold, 1992). In addition, this model addresses the influence of other psychological catalysts (personality, attitude, motivation, past experience) in the process of cognitive appraisal. It is proposed that this conceptual framework be utilized for examining the role of cognitive appraisal in understanding the body’s response to physical exertion in environmentally stressful conditions.

A more complete description of the physiology of the stress response has been presented by Johnson et al. (1992) and Sothmann, Buckworth, Claytor, Cox, White-Welkley, & Dishman

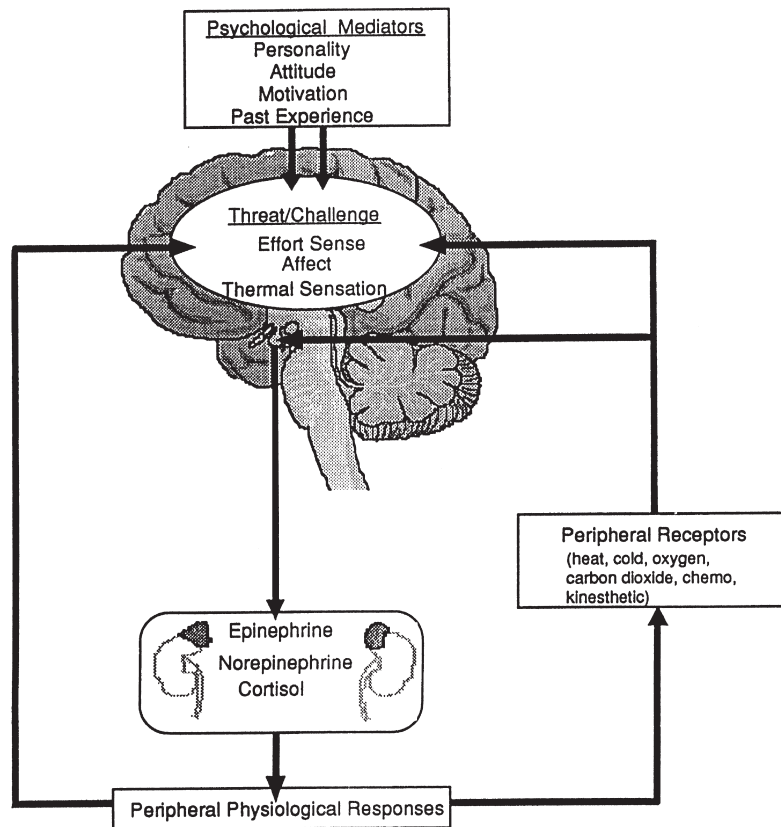


Fig. 1. Transactional psychobiological model of cognitive appraisal during exercise. Included are the cognitive appraisals which have received the most attention in theory and investigation.

(1996). The external initiation of a physiological stress response begins with sensory receptor stimulation from the peripheral nervous system. Information is sent through the sensory neural pathways to the limbic system and cortical levels of the brain. The cortical levels of the brain, where analytical interpretation of the stimulus occurs, can initiate an internal stress response. Integration of the appraisal from the cortical levels with limbic system stimulation leads to an activation of two main physiological axes. These two axes are the neural and neuroendocrine systems.

The area of investigation into “stress” has long suffered from a dichotomy between the study of physiological and psychological aspects of the stress process. Physiologists and psychologists have tended to disregard the relevant findings of the other’s discipline. Physiologists were first influenced by Selye’s initial theorizing that focused on the “chemical nature” of the messenger that is responsible for the activation of the hypothalamic–pituitary–adrenocortical axis. Although Selye initially made no reference to the psychological aspects of stress, he introduced psychological concepts in his more popular writings during the 1970s. This introduction was made within the context of his notion of “nonspecificity”. Nonspecificity proposes that psychological stimuli can produce a stress response, but that response is identical to one caused by physical stressors.

Additionally, his latest writings include abundant references to the role of psycho-emotional factors in the genesis of the stress response:

“Emotions — love, hate, joy, anger, challenge, and fear — as well as thoughts, also call forth the changes characteristic of the stress syndrome. In fact, psychological arousal is one of the most frequent activators.” (Selye, 1983, p. 10)

Furthermore, psychological factors were considered important potential mediators in the process of adaptation. In describing the concepts of his General Adaptation Syndrome (GAS), Selye used the following pertinent example:

“. . . running produces a stress situation mainly in our muscles and cardiovascular system. To cope with this, we first have to limber up and get these systems ready for the task at hand; then for a while we will be at the height of efficiency in running; eventually, however, exhaustion will set in. This sequence could be compared with an alarm reaction, a stage of resistance, and a stage of exhaustion, all limited to the muscular and cardiovascular systems; yet such an exhaustion is reversible — after a good rest we will be back to normal. It nevertheless remains true that the adaptive response can break down or go wrong because of innate defects, under-stress, over-stress, or psychological mismanagement.” (Selye, 1982, p. 14)

The notion of “nonspecificity”, wherein both psychological and physiological “stressors” produce the same effects, namely the activation of the pituitary–adrenocortical system and, secondarily, the sympathetic adrenomedullary system, has been a target of criticism and investigation (Mason, 1971). Mason observed that psychological stimuli were very potent in causing secretion of cortisol and other adrenocortical hormones and that “sterilizing” a physical stimulus from its emotional concomitant was virtually impossible. He demonstrated that if monkeys were subjected to fasting but were given placebo food, or if heat was increased in a slow gradual manner instead of abruptly, 17-OHCS (metabolic end products of cortisol metabolism) responses were generally not significant, although other hormonal responses were noted. These observations led Mason to postulate that (a) “the ‘primary mediator’ underlying the pituitary–adrenal cortical response to the diverse ‘stressors’ or earlier ‘stress’ research may simply be the psychological apparatus involved in emotional or arousal reactions to threatening or unpleasant factors . . .” (Mason, 1971, p. 329), and (b) that “different, relatively specific emotional states may be correlated with different, specific patterns of multiple hormonal responses” (Mason, 1975, p. 170). These postulates have formed the basis for contemporary investigations into the psychoneuroendocrinology of stress.

The importance of the psychological nature of Mason’s first postulate is supported by several developments in psychology relative to cognitive appraisal. Lazarus (1966) introduced the concept of “appraisal” as the central mediator of the stress response and associated emotions. He proposed that the individual is involved in a continuous, ever-changing transaction with the environment, in which the individual is evaluating potential threat with the ultimate goal of safeguarding himself or herself. Additionally, this appraisal process is highly individualized and situation dependent, thus the same stimulus may be considered as either threatening or as challenging by different individuals or by the same individual under different conditions. Finally, Lazarus states that “the

cognitive activity in appraisal does not imply anything about deliberate reflection, rationality, or awareness” (Lazarus, 1982, p. 1022).

Leventhal and Everhart (1979) have proposed a parallel processing model for describing the manner in which individuals cognitively appraise physiological input. This model suggests that physiological cues and emotion are processed prior to the arrival of sensory information to the cortex. Thus, perceptions are constructed preconsciously, and affect can play a role in the perception of the physiological cues. In addition, the ability to attend to multiple cues is limited and various stimuli can distract an individual from distressful cues. Thus, distraction or perceptual overload can alter the relationship of cognition and emotion to physiological cues. Several investigators (Acevedo et al., 1994, 1996; Hardy & Rejeski, 1989; Kenney, Rejeski, & Messier, 1987) have demonstrated support for this model in the area of perception of exertion during exercise.

Research into Mason’s second postulate has focused on the differing patterns of hormonal responses on the two major neuroendocrine axes. The sympathetic–adrenomedullary and the pituitary–adrenocortical have reflected the basic dimensions of the stress experience. Several investigators have proposed similar models containing two factors: one reflecting the degree of activation and energy mobilization of the physiological response and the other reflecting the experiential quality of the experience (Cox, 1978; Selye, 1983). Based on this conceptual framework and on empirical evidence (Henry & Stephens, 1977; Mason, 1975), Frankenhaeuser (1991) proposed a psychobiological model of stress. She has suggested that the balance of catecholamine (norepinephrine; epinephrine) and cortisol secretion can distinguish among four variants of the stress experience.

Frankenhaeuser’s (1991) two dimensions of experiential stress are “effort” and “distress”. In the case that passivity or lack of activity and effort is coupled with a lack of distress, stress hormone output remains low, the body remains at a basal state, and one feels pleasantly relaxed. When passivity is paired with distress, an outflow of cortisol is noted, while the catecholamines may or may not show a small increase. However, when effort is coupled with lack of distress, and the person is in a productive or joyful state, catecholamines are elevated, whereas cortisol levels remain unchanged or may even be suppressed. Finally, when effort is paired with distress, as in low control, physically demanding situations, both cortisol and catecholamine secretion is increased. Thus, generally, cortisol is regarded as an index of distress, helplessness, and perceived uncontrollability, whereas catecholamine secretion is considered an index of activation and mobilization of resources and a facilitator in the process of adaptation (Dienstbier, 1989). However, when an exaggerated appraisal of the situational demands elicits catecholamine secretion far exceeding the minimal levels necessary for adaptation, it may be the case that resources are expended in an uneconomical fashion.

Furthermore, it has been documented that even the anticipation of strenuous exercise leads to physiological activation (Mason, Hartley, Kotchen, Mougey, Ricketts, & Jones, 1973). Once exercise begins, psychological stress can then increase physiological activation beyond metabolically necessary levels (Roth, Bachtler, & Fillingim, 1990). This additive effect on heart rate suggests that physiological coping resources are being utilized inefficiently. The notion that psychological factors can negatively affect performance is further supported by evidence that fear and anxiety induced by dangerous environments increases arousal and may lead to debilitated performance (Idzikowski & Baddeley, 1983), and that biomechanical patterns are expected to be more economical in cases where arousal is appropriate and emotions are positive (Crews, 1992).

Furthermore, hormonal responses exhibit a specific pattern in response to specific cognitive appraisals to adverse or threatening stimuli. This hormonal patterning may also influence peripheral physiological adaptations and cues, which during exercise are related to perceptions of effort. Thus, the hormonal responses, physiological cues and the appraisal process, work in a continual feedback manner that is described by the transactional psychobiological model.

The past literature on physiological stress and cognitive appraisal has provided the basis for proposing a transactional psychobiological model of stress as the conceptual framework for this paper (Cox, 1978). Each theoretical approach has added new dimensions to our understanding of cognition, emotion, and physiological responses. The psychobiological nature of stress is beyond doubt. Furthermore, the physiological demands imposed by the combination of exercise and adverse environmental conditions has received little attention and proposes a great number of specific conditions to examine. In addition, these physiological demands are not the sole determinants of the ensuing stress response. The stress response includes cognitive, emotional, behavioral, and physiological changes, which are perceived through various feedback loops, and thus influence the continuous process of appraisal. According to this model, an unrealistic appraisal can potentially reduce adaptability by either leading to an uneconomical investment of metabolic resources or by intensifying the perception of pain, exertion, and emotional discomfort.

Psychological impact on physiological responses to environmental stress and exercise

The appraisal of stress can determine the emotional response and the effort put forth to either cope with or adapt to stress. As presented earlier in this paper, Frankenhaeuser (1991) has proposed a psychobiological model of stress that specifies when effort is high, distress is low, and the person is in a productive or joyful state, the endocrine system may be in its most effective mode to cope with stress. Thus, the appraisal of the stressor can be the central mediator of the stress response (Lazarus, 1966). Several areas of investigation have demonstrated support for the notion that appraisal mediates effort and emotional response to stress. An area of investigation that examines similar psychological challenges to exercise in stressful environments is the area of pain perception and control (Chapman & Turner, 1986).

Most of the studies in the area of pain perception have used experimentally induced cold (cold pressor) as the physical stressor. Using this methodology it has been demonstrated that perceived threat can mediate tolerance for pain. More specifically, subjects who were informed of the normal physiological reactions to hand immersion in cold water were less tolerant and reported more pain than subjects who were told the investigation was a “study of the perception of novel stimuli”. Furthermore, if the subject’s thoughts either exaggerate the aversive aspects of the stimuli, focus on the inability to cope with the stimuli, or exaggerate a negative outcome, then tolerance time is diminished.

A perceived “sense of control” has been demonstrated to positively affect a person’s response to a stressor (Arntz & Schmidt, 1989). A “sense of control” may be effective because it (a) allows the individual to predict the stressful process, (b) provides for a more positive self image, and (c) provides information about future outcomes. However, although the “sense of control” does positively affect pain perception, the cognitive mechanism(s) is/are difficult to determine and at this time unknown. Although, it has been demonstrated that those who benefit most from control

are those that are most confident they can complete the task (Litt, 1988; Mairiaux, Libert, Candas, & Vogt, 1984).

Furthermore, subjects in uncontrollable conditions report higher ratings of helplessness, tension, stress, unhappiness, anxiety, and depression and have elevated adrenocorticotropin hormone (ACTH; stimulates the secretion of cortisol), higher levels of epinephrine, and higher levels of skin conductance (which suggests greater sympathetic nervous system activity). Voigt, Ziegler, Grunert-Fuchs, Bickel, and Fehm-Wolfsdorf (1990) have supported this in the exercise condition by demonstrating that perceived controllability of the exercise seems to be a significant mediator of the psychoneuroendocrine response during exercise. This evidence, in combination with the findings showing that self-efficacy is also a mediator of the endocrine responses (Frankenhaeuser, 1991), provides support for the mediating role of cognition in the stress response.

In an attempt to enhance the tolerance of and the response to pain, medical researchers have investigated psychological techniques that can be utilized to control acute pain (Chapman & Turner, 1986). Investigations in lab settings have typically addressed cognitive strategies including attentional cues, hypnosis, progressive relaxation, and expectancy management. In summation these investigations suggest that when subjects either establish predictability, perceive control or are distracted from the discomfort to an appropriate extent, pain tolerance is enhanced and pain perception is diminished. In addition, Berntzen (1987) has demonstrated that training in multiple coping strategies is more effective than training in a single coping strategy. The Committee on Techniques for the Enhancement of Human Performance from the National Research Council of the National Academy of Sciences has published three reports that provide step by step presentations of the implementation of these techniques and others for those interested in human performance (Druckman & Bjork 1991, 1994; Druckman & Swets, 1988).

To address the ability of an individual to cope with environmental stress during exercise without emphasizing the inherent danger of hypoxia, heat stroke, and hypothermia would be irresponsible. Thus, prior to any attempt at altering cognitive responses under these conditions the exerciser must be made well aware of the danger signs and symptoms of hypoxia, heat stroke, and hypothermia. These include for hypoxia — headache, dizziness, dyspnea, nausea, vomiting, loss of appetite, dim vision, loss of coordination, apathy, irritability, fatigue, and confusion; for heat stroke — lessening or lack of sweating, fast pulse, hot and dry skin, headache, confusion, blackouts, and convulsions; and for hypothermia — lethargy, shallow breathing, and slow breathing.

The specific content of the most effective cognitive techniques for coping with environmental stressors is unknown, and inappropriate cognition may lead to unexpected results. This has been represented in a study by Mittleman, Doubt, and Gravitz (1992), in which subjects were trained in self-induced hypnosis following the assessment of change in body heat storage during a head-out immersion in 25°C water. The self-induced post-hypnotic suggestion was utilized to improve thermogenic responses. However, the second immersion demonstrated no difference in rates of heat production, heat loss, mean skin temperature, and rectal temperature from the first immersion. The authors explained these results by stating that 3 of the 12 subjects used images of warm environments during their hypnotic immersion and lost heat faster than the previous trial. Thus, the hypnotic suggestion of a warm day may either relax the individual and suppress or delay shivering, or the image of a warm day may evoke vasodilation. In both cases the rate of heat loss would be enhanced which is an undesired response. This example illustrates the significance of utilizing an appropriate cognitive technique to achieve a desired physiological response when under environmental stress.

The utilization of psychological techniques to alter physiological responses during exercise

Morgan and Pollock (1977) first classified marathoners' cognitive activities as either associative (attending closely to physiological sensory cues) or dissociative (attending to thoughts unrelated to the activity). Furthermore, they postulated that elite marathoners employ predominantly associative strategies, while less than elite marathoners employ dissociative strategies during running. More recently, Masters and Ogles (1998) have provided an extensive review of the research in this area and stated that associative strategies are related to faster running performances, although it may be that dissociative strategies may be more effective for prolonged effort. Further clarification by Stevinson and Biddle (1999) suggest that a task-irrelevant focus may be detrimental in prolonged events.

Although the research in this area has not elucidated all the specifics on which cognitive strategies to use in every particular condition for all types of exercisers, it seems clear that "mental strategy training" for athletes should include an associative approach. Such an approach would improve an athlete's ability to increase training effort without risk of injury and thus improve fitness level and performance time. In addition, the importance of the ability to manage exercise distress has been demonstrated by Kenney et al. (1987). These authors examined the effects of a broad spectrum cognitive/behavioral stress management program on the psychological responses of novice runners. Results revealed that during the latter stages of a submaximal run, subjects given the stress management program reported significantly lower RPE ratings and exhibited a more positive affect than the control group.

Benson, Dryer, and Hartley (1978) trained subjects in a relaxation response and noted decreases in oxygen consumption during very light exercise. Ziegler, Klinzing, and Williamson (1982) also reported diminished oxygen consumption values in two groups trained in stress management compared to a control group. The subjects in Ziegler's study also exercised at a relatively low intensity (50% VO_2). Morgan (1994) summarized the utility of hypnosis to alter effort sense and cardiorespiratory responses during exercise. Two studies have demonstrated that hypnotic suggestions of heavy and light work can increase and decrease, respectively, subjects' perceptions of effort, although the intensity of work is maintained at a relatively low intensity. Moreover, these increases and decreases in perception occur in conjunction with the expected changes in HR, ventilatory minute volume, and excess carbon dioxide production. Hatfield, Spalding, Mahon, Slater, Brody, and Vaccaro (1992) chose to examine the effects of ventilatory and EMG feedback on effort sense, cardiorespiratory responses, and muscular activity at a relatively high intensity (71% VO_2). This presumably associative strategy resulted in reduced RPE, no change in EMG of the trapezius and forearm, and reduced ventilation. Acevedo, Dzewaltowski, Kubitz, and Kraemer (1999) have further suggested that psychological effects may be less pronounced at higher intensities of exercise. Nonetheless these studies present firm evidence of the significant beneficial effects of cognitive techniques on the reduction of effort sense and ventilation during exercise. It should be noted that intensity of exercise, individual fitness level, and experience may determine the relative effects of these techniques. Additionally, these studies do not assess the relationship of these physiological responses to performance outcomes, nor do these studies examine the possible feedback mechanism of cognitive appraisal and stress hormone response during exercise.

Reflections and future directions

Hormonal responses and cognitive appraisals during exercise under environmental stress have received little attention in the literature. This is also true for the examination of hormonal responses and cognitive appraisals during exercise in neutral environments. Research into this area would provide a better understanding of the mechanisms responsible for performance under stressful environmental conditions. Furthermore, this area lends itself to the examination of mechanisms responsible for affective responses during and after exercise, an issue of great relevance to the exerciser interested in maintaining motivation and improving mental and physical health.

The challenge of understanding the mechanisms responsible for the psychophysiological responses to multiple stressors is of concern to those interested in physical activity in adverse environmental conditions. The nature of the adaptation response to multiple concurrent stressors has been investigated with the assumption that there is a synergistic, additive effect of multiple stressors on the stress response. Selye first suggested that additional stressors dramatically reduce resistance to stress. This is supported by other researchers who have suggested that there is an increase in physiological responses with additional stressors. Powers, Howley, and Cox (1982) showed that norepinephrine responses to the combination of exercise and heat stress were higher than what would be expected by simply adding the responses of heat and exercise together. Interestingly, Myrtek and Spital (1986) have demonstrated that psychological and physiological stressors in combination may have differential effects on the psychological and physiological responses, suggesting that, although a combination of stressors may elicit below maximal physiological responses, psychological responses may be exaggerated and this may be the limiting factor for adaptation.

For the exerciser attempting to cope with a stressful environment, safety is of primary concern. Additionally, although little has been documented on techniques utilized in these conditions, research from other related areas suggests that the exerciser should become aware of expected events including physiological responses, perceptual sensory responses, cognitive appraisals, and affective responses. If possible the exerciser should be assisted in achieving a “sense of control” and develop cognitive strategies that will enhance self-efficacy when developed to proficiency. It should be noted that the most appropriate cognitive cues and strategies have not been identified empirically.

Finally, researchers interested in this area of investigation have many issues to address. These include the examination of sex differences, age differences, differences in individuals with varying body fat characteristics, and the effects of medications and caffeine. If cognitive appraisal plays a mediating role in the physiological responses to environmental stress, then researchers interested in enhancing exercise performance under these conditions must vigorously pursue an understanding of the mechanisms responsible. The potentially most enlightening area of investigation is in the responses to combinations of stressors, including multiple stressors. This understanding would provide for the information base necessary for specific and effective psychological interventions directed toward physiologically efficient performance.

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