British Journal of Health Psychology (2002), 7, 47–66
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The affective beneficence of vigorous exercise revisited

Eric E. Hall, Panteleimon Ekkekakis* and Steven J. Petruzzello
Department of Kinesiology, University of Illinois at Urbana-Champaign, USA

Objectives. High exercise intensity may be associated with reduced adherence to exercise programmes, possibly because it is perceived as aversive. However, several authors have suggested that an intensity as high as 60% or 70% of maximal aerobic capacity (VO_{2max}) is necessary for exercise to elicit positive affective changes. To elucidate this discrepancy, the affective responses to increasing levels of exercise intensity were examined.

Design. In total, 30 volunteers rated their affect every minute as they ran on a treadmill while the speed and grade were progressively increased.

Method. The methodology was unique in three respects: (1) affect was assessed in terms of the dimensions of the circumplex model instead of distinct affective states, (2) affect was assessed repeatedly before, during, and after exercise, not only before and after, and (3) exercise intensity was standardized across participants in terms of metabolically comparable phases (beginning, ventilatory threshold, VO_{2max}) instead of percentages of maximal capacity.

Results. Pre-to-post-exercise comparisons indicated affective benefits in the form of increased energetic arousal and decreased tense arousal. During exercise, however, affective valence deteriorated beyond the ventilatory threshold and until VO_{2max}, a trend that reversed itself instantaneously during cool-down.

Conclusions. Exercise intensity that requires a transition to anaerobic metabolism can have a transient but substantial negative impact on affect and this may, in turn, reduce adherence to exercise programmes.

Physical activity surveys indicate that the proportion of the population that engages in regular physical activity is alarmingly low. Specifically, in the United States, the 1998–99 progress review of the Healthy People 2000 programme shows that only 23% of adults engage in light-to-moderate physical activity five times per week and only 16% engage in light-to-moderate physical activity seven times per week (United States National Center for Health Statistics, 1999). Both figures have remained virtually unchanged since

*Requests for reprints should be addressed to Panteleimon Ekkekakis, 253 Barbara E. Forker Building, Department of Health and Human Performance, Iowa State University, Ames, IA 50011, USA (e-mail: ekkekaki@iastate.edu).

1985 (22% and 16%, respectively) and both fall short of the targets for the year 2000 (30% for both categories).

In an effort to increase physical activity participation and adherence rates, recently issued physical activity recommendations have called for activities of moderate intensity, such as walking (National Institutes of Health Consensus Development Panel on Physical Activity and Cardiovascular Health, 1996; Pate *et al.*, 1995; United States Department of Health and Human Services, 1996). These recommendations were influenced by two main considerations. First, there is accumulating evidence that *some* activity is better than *no* activity for accruing health benefits. Second, the focus on moderate intensity activities was motivated by the belief that such activities are likely to be more enjoyable or at least more tolerable (Brewer, Manos, McDevitt, Cornelius, & Van Raalte, 2000) and, as a result, they are also 'more likely to be continued than are high-intensity activities' (National Institute of Health Consensus Development Panel on Physical Activity and Cardiovascular Health, 1996, p. 243).

The notion of an inverse relationship between exercise intensity and adherence has been supported by several studies (Epstein, Koeske, & Wing, 1984; Lee *et al.*, 1996; Sallis *et al.*, 1986). However, it is still unknown whether this effect is moderated by the participants' affective responses to physical activities of different intensities. To date, no published studies have examined the association between affective responses to single bouts of activity performed at varying intensities and long-term adherence. The few studies that have examined the effects of different exercise intensities on adherence and have included assessments of psychological variables examined only chronic psychological changes (i.e. changes over the course of the entire training period, not in response to single bouts of activity). These studies either showed significant intensity effects on psychological outcomes but no effect on adherence (Moses, Steptoe, Mathews, & Edwards, 1989) or no intensity effects on either psychological outcomes or adherence (Blumenthal, Emery, & Rejeski, 1988; King, Haskell, Taylor, Kraemer, & DeBusk, 1991; King, Haskell, Young, Oka, & Stefanick, 1995; King, Taylor, & Haskell, 1993). In summary, although direct empirical evidence is still lacking, a causal chain from intense exercise to negative affect and, ultimately, to reduced adherence remains a distinct possibility.

The assumption of high exercise intensity having a negative impact on affect and adherence, however, appears to be in contrast to a long-held belief in exercise psychology, namely that, in order to produce affective benefits, physical activity must be performed at an intensity characterized as 'vigorous' as opposed to 'mild'. This idea has remained popular since Morgan's (1985) influential review published under the title 'Affective beneficence of vigorous physical activity'. In this oft-cited paper, Morgan asserted that 'improved affective states accompany . . . acute . . . physical activity of a vigorous nature' (p. 99). Furthermore, it has been suggested that a vigorous exercise intensity is a *necessary* condition for affective benefits. Specifically, some authors have proposed that, in order to achieve significant reductions in state anxiety, exercise intensity should exceed 60% (Raglin & Morgan, 1985) or 70% (Dishman, 1986) of maximal aerobic capacity (VO_{2max}). Similarly, for mood enhancement (Berger & Motl, 2000), psychotherapeutic effects (Hays, 1999; Ojanen, 1994), or general psychological benefits (Kirkcaldy & Shepherd, 1990), vigorous exercise intensity is believed to be necessary.

Therefore, the exercise science literature appears to contain a puzzling contradiction. On the one hand, there is a belief in the 'affective beneficence' of vigorous physical activity. On the other hand, recent physical activity recommendations reflect

the notion that high exercise intensity may be partly responsible for the high dropout rates, presumably because it is experienced as aversive. These two views are difficult to reconcile. Research in general psychology has shown that people are likely to do what makes them feel good and avoid what makes them feel bad. For example, Emmons and Diener (1986) showed that the positive affect experienced in a situation was a good predictor of the amount of time people chose to spend in that situation. If vigorous physical activity is associated with positive affective changes, then why are most people avoiding vigorous physical activity?

One way to resolve this seeming paradox is to critically reexamine the relationship between exercise intensity and affective responses. A recent review of this literature concluded that the extant studies do not allow any definitive statements to be made regarding the form of the dose-response relationship between exercise and affect (Ekkekakis & Petruzzello, 1999). This can be attributed to several key conceptual and methodological issues, including (a) the measurement of affect, (b) the timing of assessment of affective responses, and (c) the selection of exercise intensity levels. These issues are discussed in more detail next, along with the tentative solutions incorporated in the present study.

The measurement of affect

Among the various problems that reviewers of the literature on the relationship between exercise and affect have identified, the measurement of affect has probably received most critical attention (Byrne & Byrne, 1993; Ekkekakis & Petruzzello, 1999; McAuley & Rudolph, 1995; Mutrie & Biddle, 1995; Steptoe, 1992; Tuson & Sinyor, 1993). In most studies of this type, affect has been operationalized in terms of distinct states, such as anxiety, depression, or various sets of moods. This approach is termed 'categorical' because it reflects the assumption that affective states are unrelated, organized in conceptually distinct categories. In contrast, 'dimensional' approaches are based on the assumption that affective states are systematically interrelated, such that their relationships can be modelled by a parsimonious set of dimensions. Both categorical and dimensional models have relative strengths and weaknesses, therefore the decision to adopt one or the other depends on the nature of the research problem. The main advantage attributed to dimensional models is their parsimony; that is, they can account for a large portion of the variation in affective states in terms of only a few basic dimensions (Larsen & Diener, 1992). Thus, they can provide a broad investigative scope, which is particularly useful when the goal is to describe the nature of the affective changes that occur in a given situation. Discussing the implications of this issue for the study of the affective changes associated with physical activity, Gauvin and Brawley (1993) noted that:

> . . . (a dimensional approach) seems better suited to the study of exercise and affect because the models stemming from it are intended to be broad, encompassing conceptualizations of affective experience. Because the affective experience that accompanies exercise has not been thoroughly described, a model of affect that has a wider breadth is more likely to capture the essence of exercise-induced affect than a model that, at the outset, limits the focus of investigation to specific emotions (p. 152).

Thus, since there is at present no evidence that changes in anxiety or depression (for example) are the most salient affective changes associated with exercise, a narrow focus on these distinct variables is unlikely to capture the impact of exercise on affect in general (Ekkekakis, Hall, & Petruzzello, 1999). To address this problem in the present

study, in accordance with Gauvin and Brawley's (1993) and Ekkekakis and Petruzzello's (1999) suggestions, affect was examined from a dimensional perspective.

Specifically, the two-dimensional circumplex model of affect was used, as described by Russell (1978, 1980, 1989, 1997). According to the circumplex, the affective space is defined by two bipolar and orthogonal dimensions: an affective valence dimension and an activation dimension. Affective states are construed as combinations of varying degrees of these two constituent dimensions, such that they can be conceptualized as located around the perimeter of a circle defined by the dimensions of valence and activation. A division of the circle into quadrants produces the following meaningful variants: (1) unactivated pleasant affect, characteristic of relaxation and calmness, (2) unactivated unpleasant affect, characteristic of boredom, fatigue, or depression, (3) activated unpleasant affect, characteristic of tension and distress, and (4) activated pleasant affect, a state characteristic of excitement and enthusiasm (see Fig. 1).

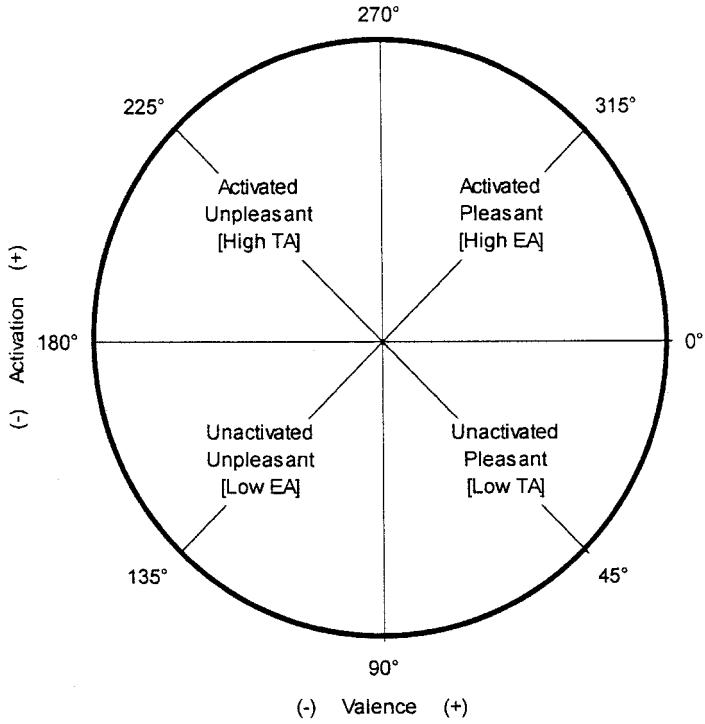

Figure 1. The circumplex model of affect

Timing of assessment of affective responses

Typically, studies examining the effects of acute exercise on affect have included one assessment of affect before and one or more assessments after the bout of exercise. Assessments of affect during the exercise bout have been rare, mainly as a consequence of measuring affect through multi-item questionnaires that are impractical to administer repeatedly during exercise. However, affect changes in a continuous and dynamic fashion. It is, therefore, unlikely that changes from pre- to post-exercise are linear. Assessments of affect made after exercise may only reflect the effects of the few seconds or minutes of recovery from exercise rather than the effects of the entire preceding

exercise bout. Affective changes during exercise may present a different and diverse pattern. Consistent with this possibility, Ekkekakis and Petruzzello (1999) noted that, although the majority (54%) of the studies that involved assessments of affect only before and after exercise showed no evidence of reliable dose-response effects, six of the seven studies that involved repeated assessments of affective valence during exercise showed a reliable dose-response pattern. Specifically, as exercise intensity increased, affective valence was consistently shown to deteriorate (Acevedo, Rinehardt, & Kraemer, 1994; Hardy & Rejeski, 1989; Parfitt & Eston, 1995a; Parfitt, Eston, & Connolly, 1996; Parfitt, Markland, & Holmes, 1994).

Furthermore, the studies that included repeated assessments of affect both during and after exercise have shown that an instantaneous improvement takes place as soon as the exercise bout is terminated (Parfitt *et al.*, 1994; Steptoe & Bolton, 1988; Tate & Petruzzello, 1995). This pattern of responses is consistent with the predictions of the opponent-process theory of affect (Solomon, 1980, 1991; Solomon & Corbit, 1974). When applied to exercise, this theory suggests that the initial affective reaction to vigorous exercise is driven by a so-called '*a*-process', resulting in negative affect. However, the *a*-process arouses an opponent process, the so-called '*b*-process', which is characterized by the opposite affective quality (i.e. positive affect). The interaction of these processes over time controls the intensity and the quality of the resultant affect. The *b*-process is hypothesized to be of longer latency, slower build-up, and slower decay relative to the *a*-process. Thus, its effects persist after the termination of the exercise bout and may be responsible for the feelings of lowered tension and exhilaration that are typically found post-exercise. If the opponent-process theory is correct, then what is typically referred to as the 'exercise-associated feel-better phenomenon' should be more accurately described as the 'exercise recovery-associated feel-better phenomenon', since the effects of exercise and exercise recovery may in fact be different. To investigate this possibility, in the present study, affective responses were assessed repeatedly *during* and *after* exercise.

Selection of exercise intensity levels

One of the main challenges in studies examining the effects of exercise on affect has been the standardization of exercise loads across individuals. Until now, the preferred solution has been to use percentages of maximal capacity (VO_{2max}, maximal heart rate, or heart rate reserve). This is because, although an absolute workload (e.g. 100 W) may induce a different metabolic response in trained versus untrained individuals (i.e. requiring purely aerobic effort in trained but possibly eliciting an anaerobic component in untrained), a percentage of maximal effort (e.g. 70% VO_{2max}) is assumed to represent a metabolically equivalent stimulus across individuals.

However, this assumption appears to be false (Katch, Weltman, Sady, & Freedson, 1978; Meyer, Gabriel, & Kindermann, 1999). For example, Katch *et al.* (1978) reported that, in a sample of 31 participants, when exercise was performed at 80% of maximal heart rate (62.5% VO_{2max}), 17 participants were working at a level above, whereas 14 were working at a level below metabolic acidosis (a sign of anaerobiosis). Given the significant differences in ventilatory, biochemical, and endocrine parameters between aerobic and anaerobic effort, the assumption that the exercise stimulus can be effectively standardized across individuals by selecting percentages of maximal capacity is untenable.

As a potential solution, Ekkekakis and Petruzzello (1999) proposed taking into

account individually determined metabolic landmarks such as the lactate or ventilatory (gas exchange) threshold and the level of critical power or power-time asymptote (Gaesser & Poole, 1996). These metabolic landmarks have a profound adaptational significance, as the metabolic profile changes dramatically when exercise is performed slightly below or slightly above them. Below the lactate threshold, the intensity is characterized as 'moderate'. Within this range, one can exercise for prolonged periods of time, as blood lactate concentration and oxygen uptake remain stable and the capacity for sustained energy repletion is not exceeded. From the lactate threshold to the level of critical power (the highest work rate at which blood lactate can be stabilized), the intensity is characterized as 'heavy'. In this domain, lactate appearance and removal rates are balanced, but at elevated blood lactate concentration levels. Finally, from the level of critical power to VO_{2max}, the intensity is characterized as 'severe'. In this range, neither oxygen consumption nor blood lactate can be stabilized. Both rise inexorably until exhaustion. In the present study, to achieve a more effective standardization of exercise intensity across individuals, exercise intensity was defined relative to individually determined metabolic landmarks, namely the ventilatory threshold (as a less intrusive index of the lactate threshold, which requires repeated blood sampling for its determination) and VO_{2max}.

Affective responses to vigorous exercise reconceptualized

After almost three decades of research on the affective changes associated with acute exercise, the substrates of these changes remain elusive. Several hypotheses have been proposed and tested, but none seems to offer a comprehensive interpretive framework and none has received unequivocal empirical support (for reviews, see Hatfield, 1991; La Forge, 1995; Morgan, 1997a; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991). This may be due to the fact that researchers have been searching for an explanation of changes believed to be exclusively positive. If the possibility of negative affective responses is acknowledged, as the empirical evidence suggests it should (Ekkekakis & Petruzzello, 1999), then the phenomenon is placed under a new light. According to evolutionary conceptualizations, affective responses represent adaptive responses or, in other words, responses that have evolved to promote survival within a specific context (Nesse, 1990, 1998). Thus, the affective responses to vigorous exercise may be seen as adaptive responses that signal survival-critical metabolic changes in the body. As many theorists have noted, affect represents the primary means by which information about critical disruptions of bodily homeostasis enters consciousness (Cabanac, 1995; Damasio, 1995; Panksepp, 1998a, b; Schulze, 1995).

With this as a backdrop, consider the implications of the typology of exercise intensity described above from an adaptational standpoint. Within both the moderate and the heavy domains, the maintenance of a physiological steady state is possible and, therefore, there is no immediate threat to survival. However, the transition to anaerobic metabolism constitutes a significant challenge for the energy system as its performance becomes dependent upon the finite pool of anaerobic energy sources. Above the level of critical power, the energy supply system is overwhelmed and the maintenance of a steady state is no longer possible. For successful adaptation, the importance of the situation must enter consciousness, both when the organism first experiences a challenge (i.e. in the heavy domain) and most certainly when the organism is faced with the impending exhaustion of metabolic resources (i.e. in the severe domain).

This conceptualization leads to the formulation of the following hypotheses. When

exercise intensity is in the moderate range, the maintenance of homeostasis is not threatened and, consequently, affective responses, if any, are largely independent of physiological changes. In the heavy domain, affective responses serve the function of 'alerting' consciousness to the strain placed upon the metabolic system. In this domain, affective responses depend partly on physiological changes and partly on various individual-difference and cognitive factors related to coping. Thus, affective responses are likely to vary from individual to individual and may be positive or negative. Finally, in the severe domain, affective responses represent an evolutionarily primitive 'alarming' function, which, much like pain, is aimed to stop and withdraw from the activity that is causing the severe homeostatic perturbation. In this domain, affective responses are, therefore, likely to be driven mainly by physiological changes and be mostly negative.

The present study

The primary purpose of the present study was to examine the pattern of affective responses to increasing levels of exercise intensity through the prism of the conceptual and methodological elements described in the previous sections. Thus, (a) affect was examined from a dimensional, rather than a categorical, perspective, (b) affective responses were assessed repeatedly, throughout the exercise bout and for several minutes into recovery, and (c) exercise intensity was defined relative to the ventilatory threshold and VO_{2max}. A graded treadmill protocol was used as the methodological platform because it allowed the examination of affective responses through the entire range of exercise intensities. Because of the relatively short total duration of the sessions, accumulated fatigue over increasing levels of intensity was not expected to influence the responses.

Method

Participants

A total of 30 healthy university students (13 women, 17 men; mean age $\pm$ SD = 23.9 $\pm$ 3.6 years; mean weight $\pm$ SD = 71.7 $\pm$ 11.2 kg; mean VO_{2max} $\pm$ SD = 49.6 $\pm$ 6.1 ml kg^{-1} ´min^{-1}) volunteered to participate in the study. They were paid $10 each in compensation for their time. Prior to their involvement in the study, all participants had read and signed an informed consent form approved by the University's Institutional Review Board.

Measures

Affect was measured from the perspective of the circumplex model, using both multi-item and single-item instruments, the latter being more appropriate for repeated assessments during exercise. The Feeling Scale (FS; Hardy & Rejeski, 1989) was used as a single-item measure of affective valence and the Felt Arousal Scale (FAS) of the Telic State Measure (Svebak & Murgatroyd, 1985) was used as a single-item measure of perceived activation. The Activation Deactivation Adjective Check List (AD ACL; Thayer, 1989) was used as a multi-item measure of the four quadrants of circumplex affective space (see Fig. 1). All self-report measures were administered with the standard instructions provided by their developers.

The FS (Hardy & Rejeski, 1989) is an 11-point, single-item, bipolar measure of pleasure-displeasure, which is commonly used for the assessment of affective responses during exercise (Ekkekakis & Petruzzello, 1999). The scale ranges from −5 to +5. Anchors are provided at zero ('Neutral') and at all odd integers, ranging from 'Very Good' (+5) to 'Very Bad' (−5). In previous

work in our laboratory, the FS has exhibited correlations ranging from .51 to .88 with the valence scale of the Self Assessment Manikin (SAM; Lang, 1980) and from .41 to .59 with the valence scale of the Affect Grid (AG; Russell, Weiss, & Mendelsohn, 1989).

The FAS (Svebak & Murgatroyd, 1985) is a 6-point, single-item measure of perceived activation. The scale ranges from 1 to 6, with anchors at 1 ('Low Arousal') and 6 ('High Arousal'). In previous work in our laboratory, the FAS has exhibited correlations ranging from .45 to .70 with the arousal scale of the SAM and from .47 to .65 with the arousal scale of the AG. The FAS has been used extensively in the context of reversal theory research, including exercise-related studies (Kerr & Vlaswinkel, 1993; Kerr & Van den Wollenberg, 1997).

The AD ACL is a multi-item measure of the bipolar dimensions of Energetic Arousal (EA) and Tense Arousal (TA), as described by Thayer (1989). Each dimension is represented by ten 4-point Likert-type items. The EA dimension ranges from Energy to Tiredness, whereas the TA dimension ranges from Tension to Calmness. Thayer (1978, 1986, 1989) has provided extensive validity and reliability information on the AD ACL. In the present study, the AD ACL was used within a circumplex framework. As shown in Fig. 1, the Energy pole (high EA) is theorized to map the high-activation pleasure quadrant of the circumplex, Tension (high TA) maps the high-activation displeasure quadrant, Tiredness (low EA) maps the low-activation displeasure quadrant, and Calmness (low TA) maps the low-activation pleasure quadrant (also see Thayer, 1989, pp. 133–134, p. 164; Yik, Russell & Feldman-Barrett, 1999, for an empirical demonstration).

Finally, the Rating of Perceived Exertion (RPE; Borg, 1998) was used as a measure of perceived effort during exercise. The RPE is a 15-point scale ranging from 6 to 20, with anchors ranging from 'Very, very light' to 'Very, very hard'.

Procedures

On arrival at the laboratory, each participant was greeted, given an overview of the procedures to be followed, and asked to read and sign an informed consent form. The purpose of the study was described as an investigation of 'some physiological and psychological responses to vigorous exercise'. This was followed by the fitting of a heart-rate monitor (model Vantage XL; Polar Electro Oy, Finland). Once the integrity of the signal from the monitor was established, the participants were asked to complete a pre-exercise battery of questionnaires that included the FS, FAS, and AD ACL. Next, the participants were shown to a treadmill, were presented with a description of the exercise protocol, and were fitted with a face mask equipped with a low-resistance one-way valve (Hans Rudolph, Kansas City, MO) for the collection of expired gases, ensuring that respiration was unobstructed and comfortable.

The graded exercise protocol was as follows. First the oxygen and carbon dioxide analysers (models S-3A/I and CD-3A, respectively; Ametek Applied Electrochemistry, Pittsburgh, PA) were calibrated using a gas with a known mixture of oxygen and carbon dioxide and room air. Then the participants' expired gases were analysed for 2 min while they were seated on a stool, to ensure the proper functioning of the various components of the metabolic analysis system. This was followed by a 3-min walk at 4.8 km hr^{-1} (0% grade), which served as a warm-up. Once the warm-up was completed, the speed of the treadmill was increased to 8 km hr^{-1} (0% grade). Beyond this point, the workload was increased every 2 min by alternating between increases in speed by 1.6 km hr^{-1} and increases in grade by 2%. This procedure was continued until each participant reached the point of volitional exhaustion. This was verified by at least two of the standard criteria for reaching VO_{2max}, namely (a) reaching a peak or plateau in oxygen consumption (changes of less than 2 ml kg^{-1} min^{-1}) followed immediately by a decrease in consumption with increasing workloads; (b) attaining a respiratory exchange ratio equal to or higher than 1.1; and (c) reaching or exceeding age-predicted maximal heart rate (i.e. 220 – age). The participants then cooled down by walking on the treadmill for 2 min at 4.8 km hr^{-1} and 0% grade. Finally, the participants sat in a chair doing nothing for a recovery period of 20 min.

From the beginning of the incremental phase (8 km hr^{-1}; 0% grade) until the end of the cool-down, the participants gave self-ratings on the RPE, FS, and FAS every minute by pointing out their

selections on a poster-size version of the scales which was placed directly in front of them. After each response, a research assistant repeated the participant's selection out loud to ensure that the information would be recorded correctly. Immediately after the cool-down, as well as 10 and 20 min later, the participants completed the FS, FAS, and AD ACL again.

Data reduction and analysis

Given that the duration of the graded treadmill protocol varied between individuals, exercise intensity was standardized using the following times, which were considered to reflect metabolically comparable conditions across all participants: (a) the beginning of exercise, (b) the ventilatory threshold (VT), and (c) the end of exercise. Two methods were followed to determine the VT, one graphical and one quantitative. The graphical method, described by Davis, Frank, Whipp, and Wasserman (1979), entails plotting the ventilatory equivalents for oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2) across work rates and visually identifying the point at which there is a systematic increase in V_E/VO_2 without a corresponding increase in V_E/VCO_2. The quantitative method involves an iterative regression procedure, described by Jones and Molitoris (1984), that can identify the 'break point' between two regression lines running through the data points defined by oxygen consumed and carbon dioxide produced. These techniques have been shown to lead to a determination of the VT with satisfactory accuracy (Ahmaidi *et al.*, 1993; Caiozzo *et al.*, 1982).

Following the identification of the VT, the FS and FAS ratings made at the following ten time points during exercise were retained: the first 2 min, the minute before the VT, the minute of the VT, 2 minutes following the VT, the last 2 min, and the 2 min of the cool-down period. In order to reduce the number of data points in the repeated-measures analyses, the patterns in the data were examined and the following five time points were entered in statistical analyses: minute 2, the minute of the VT, the second minute after the VT, the last minute, and the second cool-down minute (i.e. every alternate one of the above 10 time points).

For all multivariate analyses, the self-report scales were organized in two pairs, with each pair considered to provide an independent representation of the circumplex affective space. One pair consisted of EA and TA and the second pair consisted of the FS and FAS. As noted earlier, the affective dimensions represented by EA and TA were theorized to be 45° rotational variants of the dimensions represented by FS and FAS (see Fig. 1).

A central purpose of the present investigation was to contrast the patterns of affective change that emerge from protocols limited to pre- and post-exercise assessments as opposed to repeated assessments during exercise. To address this issue, two sets of analyses were performed. The first set involved an examination of change across four time points: pre-exercise, post-0′, post-10′, and post-20′. These analyses involved both EA/TA and FS/FAS. The second set examined changes in affect *during* exercise using the FS/FAS.

Analyses of change across time began with repeated-measures multivariate analyses of variance (MANOVAs) on each of the two sets of self-report scales. Statistically significant findings were followed up by univariate analyses and an examination of simple effects within each scale, using Fisher-Hayter tests (q_{FH}) for pairwise comparisons. Moreover, effect sizes were computed [$d = (M_i - M_j)/SD_{pooled}$] to assess the magnitude of the differences.

Results

The average duration of exercise until the point of volitional exhaustion was 11.3 minutes (SD = 2.29 minutes; range 8–17 minutes). The average terminal RPE was 17.77 (SD = 1.89; between 'Very hard' and 'Very, very hard').

To ensure that the AD ACL scales performed satisfactorily, their internal consistency was examined. Indeed, the α coefficients ranged from .84 to .91 for EA and from .70 to .78 for TA.

The first set of analyses examined changes in affect from pre-exercise to post-0′, post-10′, and post-20′. A positive effect was found, evidenced by both EA/TA and FS/FAS. A repeated-measures MANOVA (pre, post-0′, post-10′, post-20′) on EA and TA showed a significant main effect of Time, Wilks' $\lambda = .167$, $F(6,23) = 19.169$, $p < .001$, attributable to both EA ($F(3,84) = 15.134$, $p < .001$) and TA ($F(3,84) = 21.808$, $p < .001$). The results of the multiple comparisons for EA and TA are shown in Table 1. Immediately after the exercise bout, there was an increase in EA compared to baseline, followed by decreases in TA at post-10′ and post-20′ (see Fig. 2).

Table 1. Descriptive statistics (means, SD) and results of statistical comparisons (Fisher-Hayter tests, effect sizes) of EA and TA scores at pre- and post-exercise time points

		$M \pm SD$	Post-0′	Post-10′	Post-20′
EA	Pre	26.41 ± 5.61	1.13**	0.44	0.08
	Post-0′	32.41 ± 4.95		−0.73	−1.10**
	Post-10′	28.76 ± 5.03			−0.38
	Post-20′	26.83 ± 5.20			
TA	Pre	21.41 ± 3.81	0.38	−0.81*	−1.02*
	Post-0′	22.86 ± 3.77		−1.19**	−1.44**
	Post-10′	18.31 ± 3.87			−0.14
	Post-20′	17.79 ± 3.27			

*: $p < .05$; **: $p < .01$ (based on Fisher-Hayter tests).

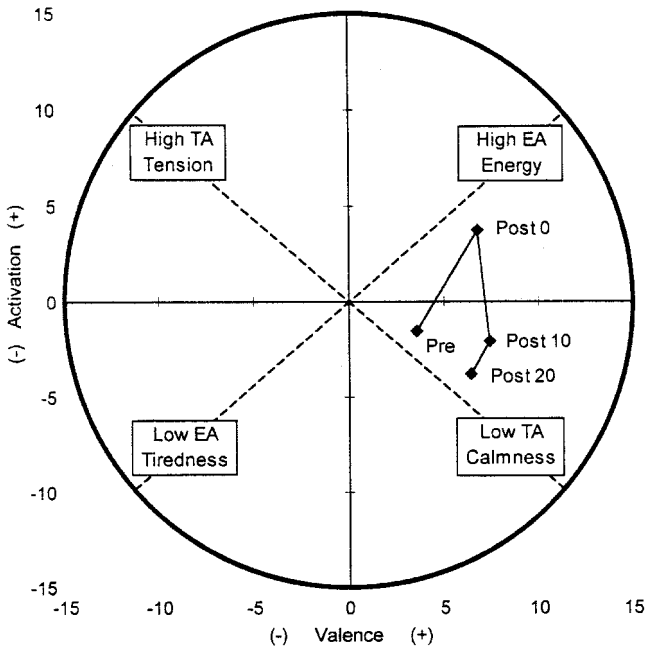

Figure 2. Responses to the EA and TA scales of the AD ACL plotted in circumplex space. The scales were rotated 45° for plotting using trigonometric procedures

Similarly, a repeated-measures MANOVA on FS and FAS showed a significant main effect of Time, Wilks' $\lambda = .203$, $F(6,23) = 15.030$, $p < .001$, attributable to both the FS ($F(3,84) = 16.174$, $p < .001$) and the FAS ($F(3,84) = 10.409$, $p < .001$). The results of the multiple comparisons for FS and FAS are shown in Table 2. Compared to baseline, there was a significant improvement in affective valence (i.e. FS) across all post-exercise time points. Perceived activation (i.e. FAS) showed a significant decrease at post-10′ and post-20′ compared to baseline and post-0′.

Table 2. Descriptive statistics (means, SD) and results of statistical comparisons (Fisher-Hayter tests, effect sizes) of FS and FAS scores at pre- and post-exercise time points

		$M \pm SD$	Post-0′	Post-10′	Post-20′
FS	Pre	2.07 ± 1.58	0.63**	0.81**	0.96**
	Post-0′	3.00 ± 1.34		0.20	0.32
	Post-10′	3.31 ± 1.49			0.07
	Post-20′	3.41 ± 1.18			
FAS	Pre	3.00 ± 1.13	0.10	−0.46**	−0.83**
	Post-0′	3.10 ± 1.11		−0.55**	−0.94**
	Post-10′	2.48 ± 1.15			−0.33
	Post-20′	2.14 ± 0.92			

*: $p < .05$; **: $p < .01$ (based on Fisher-Hayter tests).

The second set of analyses examined the affective responses during exercise. A repeated-measures MANOVA on FS and FAS showed a significant main effect of Time, Wilks' $\lambda = .120$, $F(8,21) = 19.327$, $p < .001$, attributable to both the FS ($F(4,112) = 57.052$, $p < .001$) and the FAS ($F(4,112) = 30.203$, $p < .001$). The results of the multiple comparisons are shown in Table 3. Affective valence, as indexed by FS, showed a marked decline from the second minute after the VT and until exhaustion. Immediately after exercise was terminated and the cool-down began, however, there was an instantaneous improvement (see Fig. 3). Perceived activation, as indexed by the FAS, increased throughout the exercise bout and decreased during the cool-down (see Fig. 3).

Discussion

The purpose of the present study was to examine the immediate affective responses to increasing levels of exercise intensity. Three conceptual and methodological innovations were incorporated into this experiment.

First, affect was examined from a dimensional perspective as opposed to the commonly employed categorical approaches that focus on a few, distinct affective variables. The broad and balanced scope afforded by the circumplex model was expected to enable the identification of any salient affective changes, regardless of direction. Consistent with this expectation, mapping the affective responses on the two-dimensional circumplex space revealed a diversity of patterns and dynamic changes in response to the stages of the exercise protocol. Specifically, it was found that, in the early incremental stages, affective change was characterized primarily by an increase in activation, with little change in affective valence. After the transition to anaerobic

Table 3. Descriptive statistics (means, SD) and results of statistical comparisons (Fisher-Hayter tests, effect sizes) of FS and FAS scores during exercise and cool-down

		$M \pm SD$	VT	VT + 2	End	Cool 2
FS	Min 1	2.24 ± 1.43				
	Min 2	2.34 ± 1.40	−0.27	−0.67**	−2.08**	0.38*
	VT-1	2.14 ± 1.55				
	VT	1.93 ± 1.62		−0.42**	−1.77**	0.61**
	VT + 1	1.79 ± 1.90				
	VT + 2	1.14 ± 2.12			−1.22**	0.95**
	End-1	0.07 ± 1.94				
	End	−1.48 ± 2.18				2.32**
	Cool 1	2.76 ± 1.53				
	Cool 2	2.90 ± 1.54				
FAS	Min 1	2.83 ± 1.04				
	Min 2	2.97 ± 0.94	1.03**	1.53**	1.81**	0.13
	VT-1	3.69 ± 0.60				
	VT	3.79 ± 0.62		0.72**	1.15**	−0.83**
	VT + 1	4.00 ± 0.65				
	VT + 2	4.31 ± 0.81			0.53**	−1.32**
	End-1	4.65 ± 0.97				
	End	4.83 ± 1.10				−1.63**
	Cool 1	3.59 ± 1.09				
	Cool 2	3.10 ± 1.01				

*: $p < .05$; **: $p < .01$ (based on Fisher-Hayter tests).

metabolism, however, the continued increase in perceived activation was coupled with a substantial shift toward affective negativity, leading to an activated unpleasant state presumably indicative of effort-related tension. Once the strenuous exercise was terminated and the cool-down began, there was an instantaneous drop in activation in conjunction with a marked improvement in valence, leading, in the course of 1 min, to a deactivated pleasant state presumably associated with calmness and relaxation. Furthermore, when the pre-exercise state was compared to the post-exercise state using AD ACL, a transient increase in energetic arousal was found, followed by a drop in tension and an increase in calmness. Tapping into this phenomenological diversity would have arguably been impossible had affect been measured through 'categorical' instruments (i.e. by assessing only a few, distinct affective variables).

Second, affective responses were assessed repeatedly during and after the exercise bout, as opposed to assessment protocols that only examine changes from pre- to post-exercise. In previous research examining the effects of graded exercise protocols on a variety of affective variables from pre- to post-exercise, the results have been perplexing in their inconsistency, running the gamut of possible outcomes (Goldfarb, Hatfield, Sforzo, & Flynn, 1987; Hatfield, Goldfarb, Sforzo, & Flynn, 1987; Koltyn, Lynch, & Hill, 1998; Morgan, Horstman, Cymerman, & Stokes, 1980; O'Connor, Petruzzello, Kubitz, & Robinson, 1995; Pronk, Crouse, & Rohack, 1995; Steptoe, Kearsley, & Walters, 1993). In the present study, by using single-item scales and, thus, minimizing the burden placed on the participants, it was possible to track the dynamics of affect throughout the

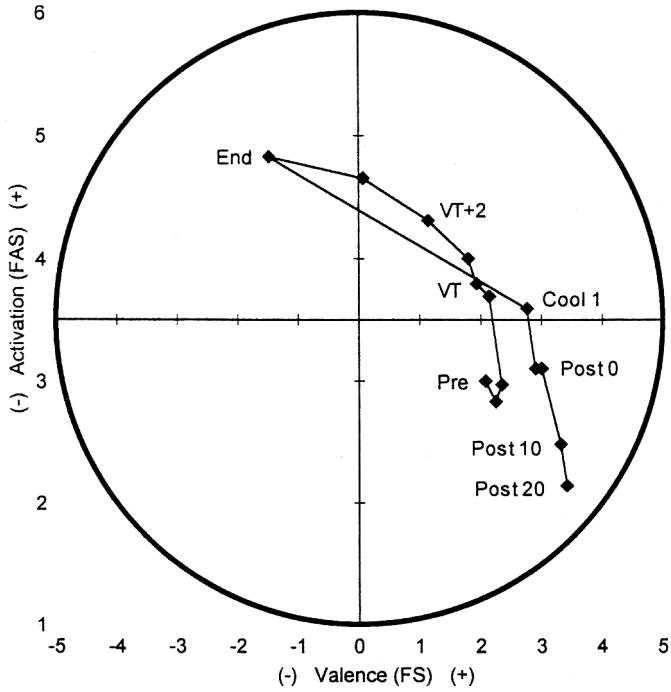

Figure 3. Responses to FS and FAS across the stages of exercise, cool-down, and recovery plotted in circumplex space

exercise bout and recovery with sufficient temporal resolution to ensure that no meaningful changes could escape detection. A comparison of the patterns that emerged from pre-to-post versus repeated assessments (see Figs 2 and 3) shows that taking into consideration only the pre- and post-exercise time points would have led to a misrepresentation of the impact of exercise on affect. It is also apparent that affect continued to change during the cool-down and recovery. Therefore, the timing of affect assessments can substantially influence the results from studies of the exercise–affect relationship and this factor should, therefore, be considered in future research.

Third, the intensity of exercise was standardized in terms of phases considered to be metabolically equivalent across individuals, such as the beginning of exercise, the VT, and VO_{2max}. This was based on the premise that affective responses to acute exercise, particularly under conditions of vigorous effort, are tied to adaptationally important metabolic events. The results of the present study revealed a clear dose-response pattern, thus providing indications of a causal link between exercise-induced homeostatic perturbations and affective responses. The decline in affective valence 2 minutes after the occurrence of the VT suggests that the transition to anaerobic metabolism represents an inherently negatively-charged stimulus. It is possible that this response reflects an evolutionarily primitive mechanism that has remained functional in contemporary humans due to its adaptational value. Much like pain, this negative affective reaction has a strong impact on consciousness and reinstates survival as the top priority; if the heavy demand on metabolic resources continues, exhaustion, and possibly death, are inevitable.

Although words like 'pain' and 'struggle' are often used by sedentary people to

describe the experience of vigorous exercise and the popular media abound with messages about products that promise weight loss and health benefits without having to 'suffer through exercise', the possibility of acute exercise having a negative affective impact has yet to be widely acknowledged in the exercise science literature. When negative effects are identified, they are typically dismissed as being transient and, instead, emphasis is placed on the fact that they are succeeded by longer-lasting and more robust positive changes. For example, Morgan and Ellickson (1989) discounted the findings of increased state anxiety scores during and immediately after vigorous exercise, characterizing the response as reflecting '*eustress* rather than *stress*' (p. 172). This is because the increase is followed by 'a sudden decrease in state anxiety during the post-exercise recovery period' (p. 172). Likewise, Parfitt and Eston (1995b), based on findings of decreasing FS scores with increasing exercise intensities among low-active individuals (Parfitt & Eston, 1995a; Parfitt *et al.*, 1994, 1996), recommended that these individuals simply 'be encouraged to focus upon how they feel after exercise has ended in order to facilitate them interpreting their physiological cues more positively' (p. 876). However, it should be emphasized that there is presently no evidence to support the notion that the positive post-exercise effect can outweigh any negative during-exercise effects in shaping motivational tendencies. To ensure that the exercise stimulus will not be paired to negative affect in memory, perhaps a more reasonable choice would be to avoid any negative effects altogether.

As noted earlier, the transition to anaerobic metabolism presents the exerciser with a challenge, as a multitude of salient interoceptive cues charged with negative affect enter consciousness. This, however, does not necessarily mean that all individuals are likely to respond with negative affect. This is because individual differences in preference for (Berger, 1994; Morgan, 1997b) or tolerance of (Mogil, 1999) intense stimulation or relevant cognitive variables such as self-efficacy (McAuley, Talbot, & Martinez, 1999) may play a role in modulating affective experiences. In the present study, it was only 2 min after the occurrence of the VT that average self-ratings of affective valence exhibited a significant decline compared to the beginning of exercise. This generalized decline may reflect what Edwards (1983) called the 'straw that breaks the camel's back' (p. 21). According to Edwards, there is a point during exercise where vertically organized (i.e. across levels of organizations, from the muscle cell to the brain) protective mechanisms cause a failure in neuronal or muscular excitation in order to avoid the depletion of energy stores. Edwards speculated that this work rate may trigger a 'conscious or unconscious need to cease the bombardment of afferent signals' (p. 21). It is possible that beyond this point the intensity of interoceptive cues becomes such that it overpowers the effects of individual-difference and cognitive variables, leading to uniformly negative affective responses.

Consistent with previous research (see Ekkekakis & Petruzzello, 1999, for a review), the results of the present study showed a pronounced and instantaneous rebound from affective negativity to affective positivity as soon as the vigorous exercise stimulus was terminated. As discussed in the introduction, this pattern is consistent with the predictions of the opponent-process theory of affect (Solomon 1980, 1991; Solomon & Corbit, 1974). Although the substrates of this phenomenon remain elusive, it is theoretically and practically interesting and warrants further research attention. For example, it is unclear at this point whether, as Solomon (1991) suggested, the post-exercise improvement will only occur if the during-exercise affective deterioration exceeds a certain threshold. It is also unknown whether there is a relationship between the *a*- and *b*-processes, such that a more

pronounced negative affective response during exercise will be followed by a stronger or longer-lasting improvement post-exercise.

An overarching question is whether *vigorous* exercise can indeed produce positive affective changes, as is commonly believed. The data from the present study showed that, on average and within the range of intensities examined, this was not the case. Only a few individuals showed improvements in affective valence during exercise. Moreover, these changes were transient and inconsistent, and were limited to intensities below and up to a minute beyond the VT. The improvements in affective valence that were found, although large and shared by all participants, only occurred once the vigorous exercise stimulus was terminated. Therefore, it is more accurate to state that this positive response accompanied the cessation of exercise and the beginning of recovery rather than the vigorous exercise itself. It is interesting to contrast these findings to those of a recent study examining affective responses to 10–15 min bouts of walking at intensities much lower than those used in the present study (i.e. 14%–22% of maximal age-predicted heart rate reserve, approximately equivalent to 14%–22% VO_{2max}). In this study, Ekkekakis, Hall, VanLanduyt, and Petruzzello (2000) found significant, albeit short-lived, improvements in affective valence both during and after the activity. This suggests that 'affective beneficence' may be achieved with physical activities performed at lower intensities and for shorter durations than originally thought.

Despite the effort that was made in the present study to improve the standardization of exercise intensity across individuals by taking into account the balance between aerobic and anaerobic metabolism, it would be imprudent to attempt any generalization of the findings to other populations without further study. The fact that only young, healthy, and mostly physically active individuals participated in the present study raises the possibility that part of the findings were influenced by these characteristics. It is reasonable to assume, however, that if older, less fit, or medically vulnerable populations exhibit a different pattern of responses, the differences would probably be on the side of accentuated negativity rather than positivity. It is important that, even in the present sample, exercise intensity that required substantial anaerobic effort (i.e. exceeded the VT) led to a significant decline in affective valence during exercise.

This finding has significant practical implications. Exercise practitioners should consider these findings in conjunction with the following two points. First, in sedentary adults and elderly individuals, the lactate and ventilatory thresholds can occur at 50% VO_{2max} or less. Given that these populations are typically characterized by a low absolute level of fitness, this means that exceeding these thresholds could be brought about by activities generally considered as mild. Second, exercise performed at intensities above the lactate and ventilatory thresholds has not been shown to confer any additional fitness benefits compared with exercise performed at or slightly below these thresholds in previously untrained individuals (Belman & Gaesser, 1991; Weltman *et al.*, 1992). Therefore, considering the potential for a negative impact on affect and long-term adherence that exercise intensity above these thresholds entails, it may be beneficial to emphasize careful self-regulation, particularly to novice exercisers. Interestingly, research has shown that the lactate and ventilatory thresholds correspond to stable ratings of perceived exertion that are unaffected by gender, training, or exercise modality (DeMello, Cureton, Boineau, & Singh, 1987; Hetzler *et al.*, 1991; Hill, Cureton, Grisham, & Collins, 1987; Purvis & Cureton, 1981). Similarly, Acevedo *et al.* (1998) reported that a running velocity only 10% higher than the onset of blood lactate accumulation (i.e. $4\,mmol\,l^{-1}$) led to a significant decline in affective valence. This

finding, which is consistent with the findings of the present study, suggests that, in addition to perceptual cues associated with perceived exertion, affective cues, such as a decline in affective valence, could be used to aid exercisers in recognizing the transition to anaerobic metabolism.

In conclusion, the finding that 'vigorous' exercise has a transient but significant negative impact on affect might shed some light on the prevalence of inactivity and the high dropout rates from exercise programmes. Although negative affective responses are but one possible explanation, they might prove to be an important one. Thus, exercise practitioners should be sensitized to the importance of prudent and conservative selection of workloads and teaching novice exercisers to self-monitor and self-regulate the intensity of their efforts.

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Received 9 March 2000; revised version received 22 September 2000