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ORIGINAL ARTICLE

The Relationship Between Exercise Intensity and Affective Responses Demystified: To Crack the 40-Year-Old Nut, Replace the 40-Year-Old Nutcracker!

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Abstract

Background A causal chain linking exercise intensity, affective responses (e.g., pleasure–displeasure), and adherence has long been suspected as a contributor to the public health problem of physical inactivity. However, progress in the investigation of this model has been limited, mainly due to inconsistent findings on the first link between exercise intensity and affective responses.

Purpose The purpose was to reexamine the intensity–affect relationship using a new methodological platform.

Methods Thirty young adults (14 women and 16 men) participated in 15-min treadmill exercise sessions below, at, and above their ventilatory threshold. The innovative elements were the following: (a) Affect was assessed in terms of the dimensions of the circumplex model; (b) assessments were made repeatedly during and after exercise; (c) patterns of interindividual variability were examined; (d) intensity was determined in relation to the ventilatory threshold; and (e) hypotheses derived from the dual-mode model were tested.

Results Intensity did not influence the positive changes from pre- to post-exercise, but it did influence the responses during exercise, with the intensity that exceeded the ventilatory threshold eliciting significant and relatively homogeneous decreases in pleasure.

Conclusions Exceeding the intensity of the ventilatory threshold appears to reduce pleasure, an effect that could negatively impact adherence.

Keywords Affective valence · Activation · Opponent-process

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Introduction

Physical inactivity is one of the most challenging public health problems in industrialized countries. Worldwide, the annual human toll is estimated at approximately 1.9 million deaths and 19 million disability-adjusted life-years lost [1]. In the USA, according to the final review of the Healthy People 2000 program [2], "the proportion of the population reporting physical activity has remained essentially unchanged, and progress is very limited" (p. 29). In 2000, according to data from the Behavioral Risk Factor Surveillance System, 27.4% of adults over the age of 18 years reported no participation in leisure-time physical activity, and 45.4% did not achieve the minimum recommended level of physical activity [3]. The latter number was reduced to 26.2% in 2001, but only after the definition of physical activity in the survey questionnaire was expanded to include such activities as vacuuming, gardening, and yard work.

The problem of physical inactivity is complex and seemingly resistant to research efforts to understand its causes and alter its course. One of the most disconcerting aspects of the problem is the so-called "revolving door" phenomenon [4], the fact that approximately 50% of the individuals who make the important decision to initiate a program of activity drop out within the first few months [5]. Most of the ongoing efforts to dissect this phenomenon utilize theories adopted from social or health psychology (e.g., the health belief model, the theory of planned behavior, social cognitive theory, and the transtheoretical model). In the context of these broad-spectrum theories, however, exercise is viewed as yet another form of social or health behavior, similar to smoking cessation, vegetable consumption, or cautious sexual practices. Consequently, the *unique* challenges associated with exercise are typically not taken into consideration.

A different approach targets the motivational properties of the exercise stimulus itself and, more specifically, the possible motivational implications of the components of the exercise "dose," such as its intensity and frequency. This line of research has shown that the intensity of exercise, more so than its frequency [6], is related to non-adherence and dropout [6–9]. This information has been incorporated in several key documents. For example, according to the National Institutes of Health Development Panel on Physical Activity and Cardiovascular Health [10], "moderate intensity physical activities are more likely to be continued than are high intensity activities" (p. 243).

One likely candidate for mediating the relationship between exercise intensity and adherence is the degree of pleasure that exercisers experience. Researchers have long suspected that, for exercise behavior to be maintained, particularly during the critical early stages, exercise must not just be pleasant but pleasant enough "to compete successfully with other pleasurable options available to the exerciser" ([11], p. 244). A hypothetical causal chain linking exercise intensity to affect and, ultimately, to adherence was proposed almost 30 years ago by Pollock [12]: "People participate in programs they enjoy. The lower-intensity effort makes the programs more enjoyable" (p. 59). This idea has apparently maintained its intuitive appeal, reappearing recently in the text of the Healthy People 2010 program [13]: "each person should recognize that starting out slowly with an activity that is enjoyable…is central to the adoption and maintenance of physical activity behavior" (p. 22–24).

To date, no known studies have examined this intensity–affect–adherence causal chain in its entirety. This might seem surprising considering the long history and apparently broad intuitive appeal of this idea. A possible reason is the inability to delineate a reliable dose–response relationship between exercise intensity and affective responses. This problem has been the focus of no fewer than 60 studies over the past four decades, with approximately half of them having been published in the last 10 years (list of references available upon request). Nevertheless, the picture remains unclear. The majority of the studies reviewed by Ekkekakis and Petruzzello [14] did not show evidence that the intensity of exercise influences affective responses.

The continued inability to shed light on the intensity–affect link has apparently also impeded progress in the effort to understand the next link, between affect and exercise behavior or adherence. Despite the long history of the so-called hedonic theory of motivation in psychology and mounting evidence from social psychology [15], behavioral economics [16], and neuroscience [17] that affect plays a central role in behavioral decision-making, this issue has been addressed in only eight known studies in the exercise domain (list of references available upon request). Despite small samples and other methodological limitations, at least some of them have supported the intuitive notion that people tend to do what makes them feel better and avoid what makes them feel worse [18–20]. A recent study also showed that affective associations (i.e., whether exercise has registered in memory as something pleasant or unpleasant) not only directly accounted for significant portions of the variance in physical activity but also mediated the links between cognitive variables (e.g., anticipated benefits, barriers, cognitive attitudes, perceived behavioral control) and physical activity [21].

The present study is predicated upon the following assumptions. First, the intensity–affect–adherence causal chain could be a meaningful model of exercise behavior that warrants systematic investigation. Second, the delineation of the—by all accounts—complex relationship between exercise intensity and affective responses is the essential first step that could lay the foundation for the exploration of the affect–adherence link and the intensity–affect–adherence chain in its entirety. Third, after nearly 40 years of research on the intensity–affect link, an overhaul of the conceptual and methodological platform might be necessary to address the problem. Specifically, this link was reexamined in this study by introducing the following innovations: (a) affect was examined from a dimensional perspective, (b) affect was assessed repeatedly during and after the exercise bout, (c) affective change was examined both at the level of the group and at the level of individuals, (d) exercise intensity was determined in relation to the ventilatory threshold (VT), and (e) hypotheses were derived from a specific conceptual framework, namely the dual-mode theory. The rationale for each of these elements is explained in more detail below.

The Measurement of Affect

In most previous dose–response studies, affect was assessed in terms of distinct states, such as state anxiety, components of mood, or specific states likely to be influenced by exercise, such as revitalization or fatigue [22]. However, it is not presently possible to predict the nature of the affective response that might emerge under various combinations of experimental conditions and participants. Therefore, it is conceivable that a certain exercise bout might have a significant impact on a sector of the affective domain other than those being monitored. In that case, one might be led to the erroneous conclusion that no dose–response effect occurred when in fact such an effect did occur but was not detected.

A possible solution is to measure affect from a dimensional perspective, sacrificing some specificity for a broader scope [14, 23]. The fundamental assumption behind dimensional models is that affective states are systematically interrelated, such that their relationships can be modeled by a few basic dimensions. The dimensional model used in the present study is the circumplex, according to which the affective space can be adequately defined by the orthogonal and bipolar dimensions of affective valence (pleasure–displeasure) and activation [24]. This choice was based on three main considerations [23], namely that the circumplex (a) can offer an encompassing, yet parsimonious, representation of the global affective space, (b) covers pleasant and unpleasant states, as well as low-activation and high-activation states, in a balanced fashion, and (c) is not domain-specific and is, therefore, appropriate for the assessment of affect both during exercise and during the pre- and post-exercise sedentary conditions.

The Timing of Affect Assessment

In most previous studies on the influence of exercise bouts on affect, affect was only assessed before and at various time points after exercise. This practice might have been based on the assumption that affect changes in a linear fashion from pre- to post-exercise or it might have been dictated by the lack of brief self-report measures that could be administered conveniently at multiple time points during exercise. As noted earlier, most of the studies examining the effects of different exercise intensities on affective changes from pre- to various time points post-exercise have failed to show evidence of reliable dose–response differences [14]. However, given the timing of assessments, it is possible that dose–response effects might have occurred *during* exercise but had dissipated by the time the post-exercise assessments took place. In fact, the only evidence for a consistent dose–response effect has come from studies in which affective valence was assessed repeatedly during exercise by single-item rating scales. These studies have consistently shown a decrease in pleasure with increasing exercise intensity. The same studies have also shown that, upon the cessation of exercise, there is an immediate rebound that often results in a post-exercise affective state that is rated as even more pleasant than the pre-exercise one [25–30]. Therefore, in the present study, affect was assessed repeatedly during and after exercise, to obtain a more complete depiction of the affective response.

Individual and Aggregate-Level Changes

An informal, yet oft-cited, estimate is that as many as 85% of exercise participants feel better when they exercise [31]. In general, individual differences in the affective response to exercise have been assumed to be solely a matter of degree (i.e., with some individuals feeling a little better and others feeling a lot better). Midrange-intensity exercise (i.e., not “too low,” not “too high”), in particular, is believed to provide an optimal stimulus for positive affective changes for all or most individuals. As a corollary, it has been said [32] that, although physiological and psychological individual differences probably influence affective responses to exercise, it might still be “possible to defend a single exercise prescription for all individuals” (p. 11), estimated at around 70% of maximal aerobic capacity.

These views were formulated primarily on the basis of studies that examined affective changes from before to after exercise, a methodological approach that, as noted earlier, might have concealed the changes during exercise. In a study in which individual changes were examined *during* a 30-min bout of stationary cycling at 60% of estimated maximal aerobic capacity, 44.4% of the participants reported a progressive improvement in affective valence, whereas 41.3% reported a progressive decline [33]. Yet, as a result of these divergent trends, analysis of change at the level of the entire group showed no significant changes in affective valence during exercise. Both subgroups reported improvements after the bout, after a rebound among those who had reported declines during the bout. Therefore, had the analysis been limited to the group aggregate, the decline in affective change during exercise in almost half of the participants would not have been detected. Thus, in the present study, in addition to examining changes in affect at the level of the group aggregate, we also examined individual changes.

Standardization of Exercise Intensity

Standardizing the intensity of exercise across participants with different levels of fitness has always been one of the toughest methodological challenges in dose–response research. “Relative” methods (i.e., intensities eliciting a certain percentage of measured or estimated maximal heart rate or aerobic capacity) have generally been preferred to “absolute” methods (e.g., a fixed work rate or an intensity eliciting a certain heart rate), precisely because they are believed to take into account individual differences in fitness. However, even relative approaches suffer from at least two shortcomings: (a) the percentages of maximal capacity are selected essentially arbitrarily (e.g., there is usually no specific rationale for selecting 30%, 50%, and 70% over 40%, 60%, and 80%) and (b) this approach does not take into account the balance of the metabolic processes involved (i.e., aerobic and anaerobic metabolism).

The latter problem has been identified since the 1950s [34]. The transition to an exercise intensity that requires substantial supplementation by anaerobic metabolic pathways is commonly (although not without controversy) demarcated by the ventilatory or the lactate threshold (i.e., a nonlinear increase in expired carbon dioxide relative to the consumed oxygen or a rise in blood lactate concentration as a result of the rate of production exceeding the rate of clearance). Exercise physiology studies have shown that, when exercising, for example, at 70% of aerobic capacity, some individuals might be below and some above their ventilatory or lactate threshold [35]. Today, some experts assert that "assigning work intensity either as multiples of resting metabolic rate or as percentages of [maximal aerobic capacity] seems no longer justifiable" ([36], p. 88).

This is a critical methodological issue in studies of the exercise–affect relationship. The reason is that suprathreshold intensities are usually accompanied by a cascade of biochemical, neuroendocrine, autonomic, cardiovascular, and respiratory changes that dramatically transform the internal environment and challenge the maintenance of homeostasis. In turn, homeostatic perturbations are closely linked to affect [37]. Thus, in the present study, the levels of exercise intensity that were compared were determined in relation to the ventilatory threshold.

Theoretical Framework

Most previous dose–response studies on the exercise–affect relationship were descriptive in scope and did not set out to test the postulates of a specific theoretical framework [14]. In the absence of an exercise-specific dose–response model, several authors had speculated that the relationship approximates an inverted-U, with low intensity lacking the potency to change affect, high intensity likely being aversive, and midrange intensities being optimal [38, 39].

At this point, it has become clear that the inverted-U model has several limitations. First, it does not fit empirical findings well. For example, in some studies, low-intensity self-paced walks as short as 4 min have been shown to improve affect [40–42]. At the high end of the intensity spectrum, studies examining affective responses to maximal exercise tests have found that increases in fatigue co-occur with positive changes, such as improvements in self-esteem [43]. Moreover, as noted earlier, midrange intensities such as 60% of maximal aerobic capacity seem to make some participants feel progressively better but others progressively worse [33]. Second, the inverted-U model does not address the large individual differences in affective changes that have been shown to occur in response to the same exercise intensity. Third, the model offers no mechanistic explanation for the postulated pattern of dose–response effects.

The hypotheses examined in the present study were derived from a recently developed conceptual framework named the dual-mode theory (for a detailed analysis of theoretical postulates, see [44–47]). According to this theory, the ventilatory threshold (VT), due to the substantial physiological changes it entails, presents a challenge, to which some individuals (depending on their personality traits and cognitive appraisals) may respond with increases and others with decreases in pleasure. At intensities that exceed the VT, strong interoceptive cues, inherently charged with negative affect, overwhelm individual differences, leading to generalized decreases in affective valence. Thus, based on the dual-mode theory, the hypotheses that were examined in the present study were the following: (a) during exercise below the VT, affective valence would remain mostly positive; (b) during exercise at the VT, affective valence responses would show variability between individuals; (c) during exercise above the VT, affective valence would decline in most individuals (and perceived activation would be highest); and (d) after exercise, affective valence would show a positive change compared to pre-exercise and the end of the bouts, regardless of intensity.

Methods

Participants

Thirty volunteers were recruited through personal communications from the undergraduate and graduate student body of a large university. The sample consisted of 14 women (age, M±SD=21.21±2.04 years; height, M±SD=167.28±9.14 cm; body mass, M±SD=60.59±6.63 kg; body mass index, M±SD=21.69±2.15 $m \cdot kg^{-2}$; maximal oxygen uptake: M±SD=47.71±7.61 $ml \cdot kg^{-1} \cdot min^{-1}$) and 16 men (age, M±SD=21.50±2.45 years; height, M±SD=182.17±5.00 cm; body mass, M±SD=78.50±9.20 kg; body mass index, M±SD=23.63±2.42 $m \cdot kg^{-2}$; maximal oxygen uptake, M±SD=56.59±7.27 $ml \cdot kg^{-1} \cdot min^{-1}$). On average (±SD), the men were physically active for at least 20 min on 4.83±1.40 days per week, and the women were active on 4.82±1.53 days per week. All the women and all but one of the men were physically active on at least 3 days per week. On Borg's [55] Category Ratio ten-point scale of perceived exertion, the men reported averaging 6.87±1.88 units, and the women reported averaging 6.07±1.38 units. The participants were paid $50 each in compensation for their time, and all who were recruited into the study completed all sessions. Before their involvement in the study, the participants read and signed an informed consent form that was approved by the university's Institutional Review Board. They also read and signed a form certifying that they (a) had a physical examination during the previous year that revealed no contraindications to vigorous exercise, (b) had no history of cardiovascular, respiratory, musculoskeletal, metabolic, or mental conditions, (c) were not suffering from any injuries or other ailments, and (d) were not taking any medication.

Measures

Affect was measured from the perspective of the circumplex model. Both multi-item and single-item scales were used, the latter being more appropriate for repeated assessments during exercise.

The Feeling Scale (FS; [27]) is an 11-point, single-item, measure of affective valence. The scale ranges from −5 to +5. Anchors are provided at zero (Neutral) and at all odd integers, ranging from "Very Bad" (−5) to "Very Good" (+5). In a previous work in our laboratory, the FS has exhibited correlations ranging from 0.51 to 0.88 with the Valence scale of the Self Assessment Manikin (SAM; [48]) and from 0.41 to 0.59 with the Valence scale of the Affect Grid (AG; [49]).

The Felt Arousal Scale (FAS) of the Telic State Measure [50] is a six-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 a previous work in our laboratory, the FAS has shown correlations ranging from 0.45 to 0.70 with the Arousal scale of the SAM and from 0.47 to 0.65 with the Arousal scale of the AG.

The Activation Deactivation Adjective Check List (AD ACL; [51]) is a multi-item measure of the bipolar dimensions of Energetic Arousal (EA) and Tense Arousal (TA). Each dimension is represented by ten items. The EA dimension ranges from Energy to Tiredness, whereas the TA dimension ranges from Tension to Calmness. Thayer [52, 53] and Ekkekakis et al. [54] have provided extensive validity and reliability information on the AD ACL. Using stochastic process modeling, Ekkekakis, Hall, and Petruzzello [54] have provided evidence that the structure of the AD ACL conforms to a circumplex in the context of physical activity. Specifically, the Energy items tap the high-activation pleasure quadrant, the Tension items tap the high-activation displeasure quadrant, the Tiredness items tap the low-activation displeasure quadrant, and the Calmness items tap the low-activation pleasure quadrant.

Finally, the Rating of Perceived Exertion (RPE; [55]) was used as a manipulation check to measure perceived effort during exercise. The RPE is a 15-point scale ranging from 6 to 20, with anchors ranging from "No exertion at all" to "Maximal exertion."

Procedures

Participation in the study entailed five laboratory sessions, scheduled on different days. Each session is described below.

Session I

The purpose of the first session was to determine each participant's maximal aerobic capacity and VT through an incremental treadmill test to volitional exhaustion. The analysis of expired gases for this test was done with a metabolic cart (OCM-2 Oxygen Uptake System, AEI Technologies, Pittsburgh, PA, USA). The O_2 and CO_2 analyzers were calibrated before each test. The protocol that was used involved alternating between increases in the speed and grade of a treadmill every minute until each participant terminated the test due to volitional exhaustion. In all cases, the attainment of maximal aerobic capacity was verified by at least two of the following criteria: (a) a peak or plateau in oxygen consumption (changes <2 $ml \cdot kg^{-1} \cdot min^{-1}$) with increasing workload; (b) a respiratory exchange ratio of at least 1.1; and/or (c) reaching age-predicted maximal heart rate (i.e., 220–age).

To determine the maximal oxygen uptake (VO_{2max}), 30-s averages were calculated, and the highest was designated VO_{2max}. The VT was determined by the procedure described by Davis et al. [56]. This procedure entails plotting the ventilatory equivalents for oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2) over the course of the test and identifying the point at which there is a systematic increase in V_E/VO_2 without a corresponding increase in V_E/VCO_2 (see Fig. 1). This technique has been shown to lead to a

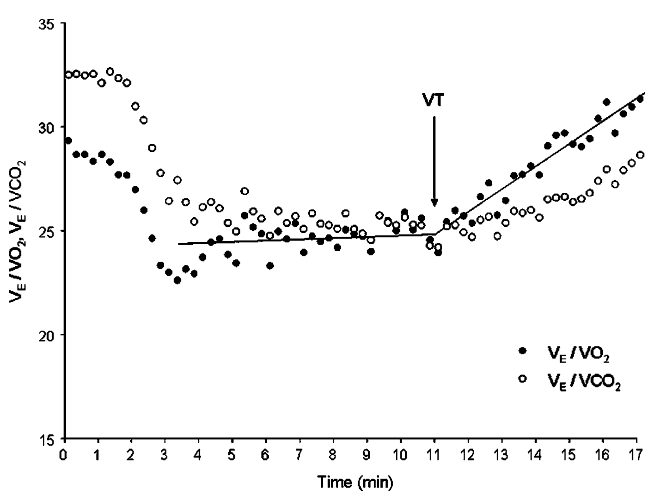

Fig. 1 Illustration of the method used for the detection of the ventilatory threshold (*VT*). The VT occurs at the level of exercise intensity at which there is a systematic increase in the ventilatory equivalent for oxygen (V_E/VO_2) without a concomitant increase in the ventilatory equivalent for carbon dioxide (V_E/VCO_2)

determination of the VT that is more accurate compared to alternative methods [57].

The three exercise intensities that were used in subsequent sessions were determined in relation to the VT as follows: (a) an intensity 20% below the oxygen uptake corresponding to the VT (<VT), (b) an intensity equal to the oxygen uptake corresponding to the VT (@VT), and (c) an intensity 10% higher than the oxygen uptake corresponding to the VT (>VT). The latter intensity was set 10% above the VT because, as noted earlier, suprathreshold intensities challenge the maintenance of a physiological steady-state (show a distinctive physiological "drift" over time). Consequently, a higher intensity could have precluded some individuals from completing the experimental sessions.

Session II

The second session included a series of intensity verification trials. The main reason why these trials were considered necessary was the desire to avoid having the participants wear face masks for the collection of expired gases during the experimental sessions. The one-way valves used in face masks could increase respiratory effort and, therefore, reduce both the ecological validity (i.e., the applicability to exercise without a mask) and the internal validity of the findings (i.e., affective responses being influenced by the mask rather than exercise intensity). Furthermore, although the incremental treadmill tests of Session I involved increases in both speed and grade, using grades higher than 3% during the experimental sessions was considered undesirable from the perspective of ecological validity, as they could introduce substantial differences in biomechanical and muscle recruitment patterns. Finally, the intensity verification trials were deemed necessary, as physiological responses might be somewhat different between incremental and constant-workload protocols.

Thus, during Session II, each participant ran on the treadmill for 5 min at each of the three intensities while ventilatory and heart rate responses were being monitored. After the initial rapid increase in oxygen uptake (first 2–3 min), the treadmill settings were adjusted to elicit the desired level of oxygen uptake (i.e., 20% below, at, and 10% of oxygen uptake above the VT; see Fig. 2). Between the 5-min runs, the participants were allowed to recover for as long as it was necessary for their heart rate to return to within 10 beats$\cdot$min^{-1} of the pre-exercise value.

Sessions III, IV, and V

The third, fourth, and fifth sessions were the experimental sessions. Identical procedures were followed in all three with the exception of the intensity that was used in each (i.e., <VT, @VT, and >VT). The order of intensities was randomized using a computer algorithm. To reduce expectancy effects, the participants were told that they might have to run at any possible combination of a "relatively low," a "moderate," and a "relatively high" intensity, including the possibility of all three sessions being at the same intensity.

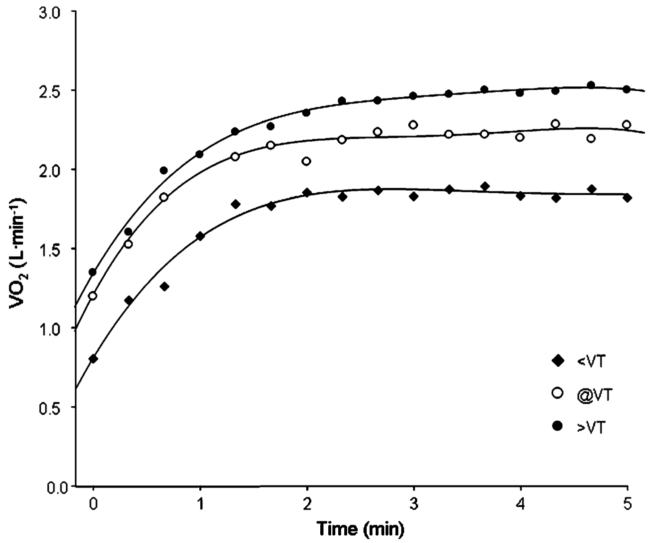

Fig. 2 Illustration of the oxygen uptake ($\dot{V}O_2$) data obtained during the intensity verification trials (Session II) from a representative participant

Upon arrival at the laboratory, the participants were asked to complete the battery of pre-exercise self-report measures (FS, FAS, and AD ACL). The same experimenter conducted all the tests and gave the same explanations to all the participants who asked for clarifications. The participants were then fitted with a heart rate transmitter on their chests (Smart Edge, Polar Electro Oy, Finland). Then, they warmed-up by walking on the treadmill for 5 min at 4.8 km$\cdot$h^{-1} and 0% grade. During the last 15 s of the walk, the participants were shown a poster that displayed the scales for perceived exertion (RPE), affective valence (FS), and perceived activation (FAS) and were asked to indicate their responses either verbally or by pointing to the appropriate numbers. When the 5-min warm-up period was completed, the speed and grade of the treadmill were increased to the levels that corresponded to the intensity that had been selected for the day. This speed and grade were maintained constant for the next 15 min. The RPE, FS, and FAS were assessed again during the last 15 s of min 3, 6, 9, 12, and 15.

Immediately after each run, the treadmill was stopped, and a droplet of blood was obtained using a finger prick. The samples were analyzed immediately for lactate (Accusport, Boehringer Mannheim, Indianapolis, IN, USA). After the blood draw (approximately a 2-min interruption), the treadmill was restarted and the participants were allowed to cool-down by walking for 5 min at 4.8 km$\cdot$h^{-1} and 0% grade. During the last 15 s of the cool-down, they were asked again to provide ratings for the RPE, FS, and FAS. At the end of the 5-min cool-down, the participants stepped off the treadmill, sat on a chair, completed a post-exercise AD ACL, and remained seated for 20 min. During this recovery period, they responded to the FS, FAS, and AD ACL two more times, at min 10 and at 20 post-exercise.

Statistical Analyses

Three sets of analyses were performed. First, changes in affective valence (FS), perceived activation (FAS), Energetic Arousal and Tense Arousal (AD ACL) were examined from pre- to the three post-exercise time points (i.e., end of the cool-down, and the 10th and 20th min of recovery). This analysis was intended to simulate previous studies involving pre- to post-exercise assessments of affect. Second, changes in FS and FAS were examined during exercise (pre-exercise, end of the warm-up, and the 3rd, 6th, 9th, 12th, and 15th min of the runs). Third, the immediate post-exercise changes in FS and FAS were examined, from the end of the runs to the end of the cool-downs.

Changes were examined with intensity by time repeated-measures analyses of variance (ANOVAs). Initially, gender was also included as a between-subject factor in all analyses involving the dependent variables (FS, FAS, EA, and TA). However, none of the gender main effects or interactions (gender by intensity, gender by time, and gender by intensity by time) reached statistical significance, so gender was omitted. In addition, the effect of the phase of the menstrual cycle (follicular versus luteal) was examined among the 14 women, but it was not found to influence any of the dependent variables. When the assumption of sphericity was violated in the repeated-measures ANOVAs, the degrees of freedom were adjusted using the conservative Greeenhouse–Geisser correction and the adjusted degrees of freedom are presented. When statistically significant effects were found, they were followed by Bonferroni-corrected multiple pairwise comparisons and adjusted p values are reported (each directly comparable to 0.05). Finally, effect sizes $[d=(M_i-M_j)/SD_{pooled}]$ are also reported for select contrasts.

Results

Intensity Manipulations

The manipulation of exercise intensity was successful in inducing significantly different physiological responses across the three conditions. First, a repeated-measures ANOVA for the three exercise intensity conditions on the blood lactate levels was significant, $F(2, 58)=27.17$, $p<0.001$, $\eta^2=0.484$. The average blood lactate levels (±SD) were 3.48±1.15, 4.26±1.56, and 5.75±1.82 $mmol \cdot l^{-1}$ after the <VT, @VT, and >VT intensity conditions, respectively. All the pairwise comparisons between conditions were significant.

Second, a 3 (intensity conditions) by 6 (time points: warm-up, min 3, 6, 9, 2, 15) repeated-measures ANOVA on the heart rate data showed a significant main effect of intensity condition [$F(2, 54)=101.06$, $p<0.001$, $\eta^2=0.789$], a significant main effect of time [$F(1.90, 51.25)=1,797.65$, $p<0.001$, $\eta^2=0.985$], and a significant intensity condition by time interaction, $F(3.35, 90.32)=38.62$, $p<0.001$, $\eta^2=0.589$. The average heart rates (±SD) at the end of the runs were 162.14±13.47, 172.77±11.15, and 182.83±10.67 $beats \cdot min^{-1}$, for the <VT, @VT, and >VT intensity conditions, respectively. All the pairwise comparisons between conditions at that time point were significant (see Fig. 3).

Third, a 3 (intensity conditions) by 6 (time points: warm-up, min 3, 6, 9, 12, 15) repeated-measures ANOVA on the perceived exertion (RPE) data showed a significant main effect of intensity condition [$F(2, 58)=70.99$, $p<0.001$, $\eta^2=0.710$], a significant main effect of time [$F(2.08, 60.19)=225.64$, $p<0.001$, $\eta^2=0.886$], and a significant intensity condition by time interaction, $F(5.23, 151.53)=28.32$, $p<0.001$, $\eta^2=0.494$. At the conclusion of the runs, the average ratings of perceived exertion (±SD) were 11.17±2.17, 13.53±2.18, and 15.47±2.15, for the <VT, @VT, and >VT intensity conditions, respectively. All the pairwise comparisons between conditions at that time point were significant (see Fig. 4).

Affective Changes from Pre- to Post-exercise

A 3 (intensity conditions) by 4 (time points: pre-exercise, end of cool-down, min 10 and 20 of recovery) repeated-measures ANOVA on the ratings of affective valence (FS) showed only a significant main effect of time, $F(2.09, 60.66)=9.14$, $p<0.001$, $\eta^2=0.240$ (see Fig. 5a, c). Regardless of exercise intensity, there was an improvement in valence from pre-exercise to all time points post-exercise (for all pre-post comparisons, $p<0.01$). A similar analysis for the ratings of perceived activation (FAS) also showed

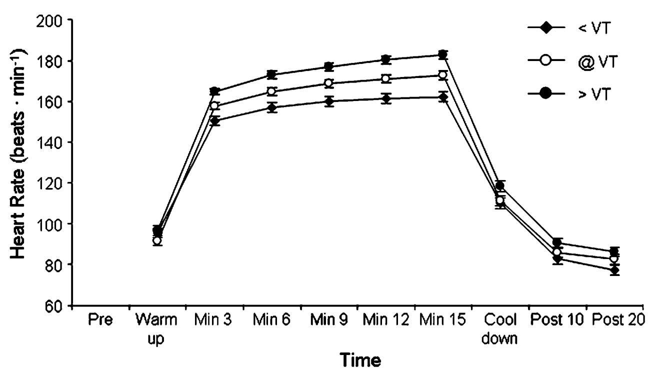

Fig. 3 Heart rate responses (M±SE) during the three exercise intensity conditions

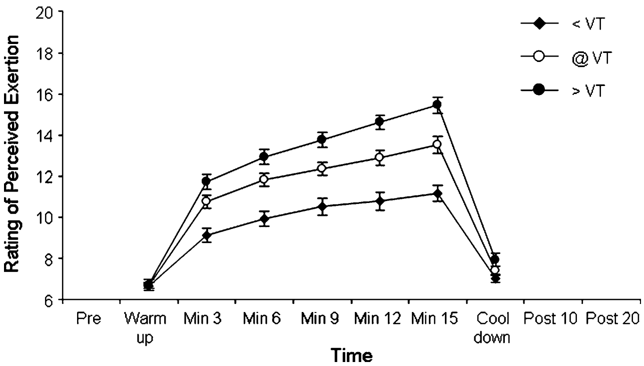

Fig. 4 Ratings of perceived exertion (M±SE) during the three exercise intensity conditions

only a significant main effect of time, $F(2.17, 63.05)=33.93$, $p<0.001$, $\eta^2=0.539$ (see Fig. 5b, c). Regardless of intensity, there was an increase in perceived activation from pre-exercise to the end of the cool-down ($p_{adj}<0.001$) and decreases thereafter, from the cool-down to min 10 of recovery ($p_{adj}<0.001$) and from min 10 to 20 of recovery ($p_{adj}<0.01$). This post-exercise decrease in perceived activation led to a significantly lower level compared to pre-exercise ($p_{adj}<0.05$).

The analysis of the Energetic Arousal (EA) and Tense Arousal (TA) scales of AD ACL for the same time points yielded similar results. Specifically, only the time main effect was significant for EA [$F(2.06, 59.58)=23.91$, $p<0.001$, $\eta^2=0.452$] and TA [$F(2.07, 60.07)=11.32$, $p<0.001$, $\eta^2=0.281$]. Regardless of exercise intensity, EA increased from pre-exercise to the end of the cool-down ($p_{adj}<0.001$) and then decreased from the end of the cool-down to min 10 of recovery ($p_{adj}<0.001$), but at that time, it was still higher than the pre-exercise level ($p_{adj}<0.05$). Similarly, regardless of exercise intensity, TA increased to a non-significant degree from pre-exercise to the end of the cool-down and decreased thereafter. Both at min 10 ($p_{adj}<0.001$) and at min 20 of recovery ($p_{adj}<0.001$), TA was lower than its level after the cool-down.

Affective Changes During Exercise

A 3 (intensity conditions) by 7 (time points: pre-exercise, warm-up, min 3, 6, 9, 12, and 15) repeated-measures ANOVA on the ratings of affective valence (FS) showed that the effect of intensity condition [$F(2, 58)=15.68$, $p<0.001$, $\eta^2=0.351$], the effect of time [$F(1.69, 48.93)=14.86$, $p<0.001$, $\eta^2=0.339$], and their interaction [$F(4.20, 121.71)=6.04$, $p<0.001$, $\eta^2=0.172$] were significant (see Fig. 5a, c). There were no significant differences between the conditions before the beginning of exercise or at the end of the warm-up. However, differences between the conditions developed during the runs. Specifically, the <VT and @VT conditions differed at min 3 ($p_{adj}<0.05$, $d=0.39$), min 12 ($p_{adj}<0.05$, $d=0.52$), and min 15 ($p_{adj}<0.05$, $d=0.56$). The @VT and >VT conditions differed at min 12 ($p_{adj}<0.01$, $d=0.79$) and min 15 ($p_{adj}<0.01$, $d=0.70$). Finally, the <VT and >VT conditions differed throughout the runs, with the differences getting progressively larger from min 3 ($p_{adj}<0.01$, $d=0.61$) to min 15 ($p_{adj}<0.001$, $d=1.27$).

The average ratings of affective valence in the <VT condition showed a relatively small and non-significant decrease from the end of the warm-up to min 15 ($d=0.51$). The decrease in the @VT condition during the same period was larger but still non-significant ($p_{adj}=0.056$, $d=0.76$). However, in the >VT condition, the decrease reached statistical significance as early as min 6 ($p_{adj}<0.05$, $d=0.53$) and grew increasingly larger through min 15 ($p_{adj}<0.001$, $d=1.22$).

A trend analysis was also performed to examine whether the changes in affective valence in each condition fit a quadratic pattern. The quadratic trend was not significant in the <VT [$F(1, 29)=3.70$, $p=0.06$, $\eta^2=0.113$] or the @VT [$F(1, 29)=1.95$, $p=0.17$, $\eta^2=0.063$] conditions, but was significant in the >VT condition, $F(1, 29)=9.80$, $p<0.01$, $\eta^2=0.253$.

A 3 (intensity conditions) by 7 (time points: pre-exercise, warm-up, min 3, 6, 9, 12, and 15) repeated-measures ANOVA was also performed on the FAS ratings of perceived activation (see Fig. 5b, c). This analysis also showed a significant main effect of intensity [$F(2, 58)=10.23$, $p<0.001$, $\eta^2=0.261$], a significant main effect of time [$F(1.40, 40.67)=60.07$, $p<0.001$, $\eta^2=0.674$], and a significant interaction [$F(4.64, 134.63)=5.11$, $p<0.001$, $\eta^2=0.150$]. There were no significant differences between the conditions before the beginning of exercise or at the end of the warm-up. However, differences between the conditions developed during the runs. Specifically, the <VT and @VT conditions differed at min 12 ($p_{adj}<0.01$, $d=0.58$), and min 15 ($p_{adj}<0.01$, $d=0.64$). The @VT and >VT conditions differed at min 12 ($p_{adj}<0.05$, $d=0.39$). Finally, the <VT and >VT conditions differed throughout the runs, with the differences getting progressively larger from min 3 ($p_{adj}<0.05$, $d=0.39$) to min 15 ($p_{adj}<0.01$, $d=0.87$).

The increases in FAS ratings compared to the end of the warm-up were significant after min 3 for all intensity conditions, <VT ($p_{adj}<0.001$, $d=0.48$), @VT ($p_{adj}<0.001$, $d=0.75$), and >VT ($p_{adj}<0.001$, $d=0.93$). Thereafter, the increases grew progressively larger until min 15, with the increase ranging from <VT ($d=1.05$) to @VT ($d=1.80$), and to >VT ($d=2.02$).

Patterns of Interindividual Variability

To examine the pattern of interindividual variability in affective valence responses across the three intensity conditions, FS change scores were computed from the end

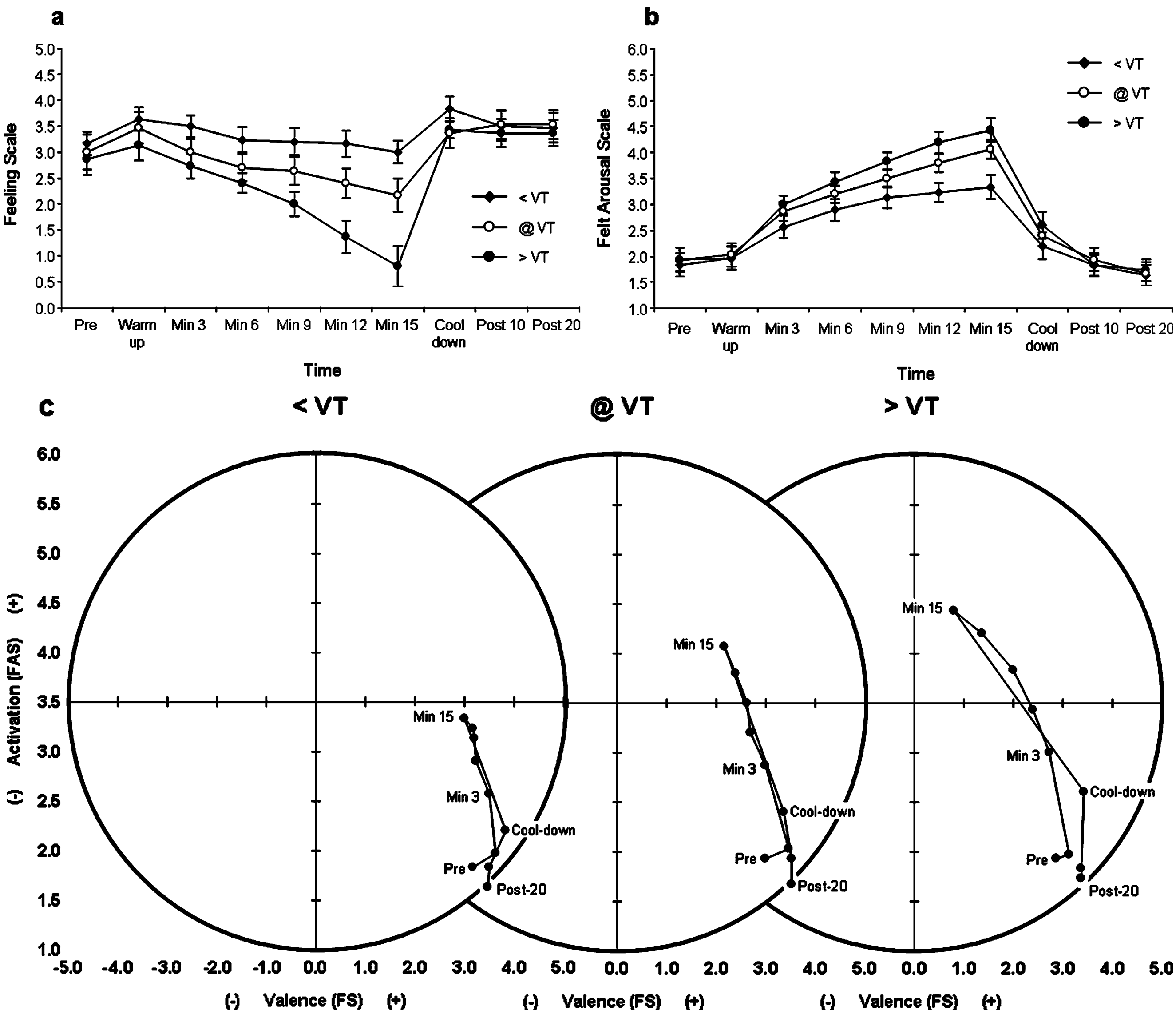

Fig. 5 Feeling Scale (*FS*) and Felt Arousal Scale (*FAS*) responses (*M*±SE) during the three exercise intensity conditions, plotted separately (**a** and **b**) and as an affective circumplex (**c**)

of the warm-up to min 15 for each condition. The <VT condition resulted in the lowest percentage of participants reporting a decline in affective valence. The @VT condition resulted in the lowest percentage of participants reporting no changes. Furthermore, the @VT condition was the only one that resulted in some participants reporting considerable improvements in FS (up to 5 units), and at the same time, other participants reporting considerable declines (up to 6 units). Finally, the >VT condition resulted in the highest percentage of participants reporting declines in FS and in the largest average decline.

Specifically, in the <VT condition, 2 individuals (7%) showed an increase in FS ratings by an average of 1.50±.71 units (range 1 to 2), 15 individuals (50%) showed no change, and 13 individuals (43%) showed a decrease by an average of 1.69±1.11 units (range 1 to 5). In the @VT condition, 4 individuals (13%) showed an increase by an average of 2.75±2.06 units (range 1 to 5), 3 individuals (10%) showed no change, and 23 individuals (77%) showed a decrease by an average of 2.17±1.27 units (range 1 to 6). Finally, in the >VT condition, 3 individuals (10%) showed an increase by an average of 2.00±1.73 units (range 1 to 4), 3 individuals (10%) showed no change, and 24 individuals (80%) showed a decrease by an average of 3.17±1.90 units (range 1 to 8).

Immediate Post-exercise Affective Changes

A 3 (intensity conditions) by 2 (time points: end of run, end of cool-down) ANOVA on affective valence ratings (FS) showed a significant effect of exercise intensity [$F(2, 58)=14.66$, $p<0.001$, $\eta^2=0.336$], a significant effect of time [*F*

(1, 29)=43.39, $p<0.001$, $\eta^2=0.599$], and a significant interaction [$F(2, 58)=14.26$, $p<0.001$, $\eta^2=0.330$]. The average improvements (±SD) in FS were 0.83±1.34, 1.20±1.52, and 2.63±2.17 units after the <VT, @VT, and >VT conditions, respectively. These changes were significant for all three conditions, <VT ($p_{adj}<0.01$, $d=0.67$), @VT ($p_{adj}<0.001$, $d=0.73$), and >VT ($p_{adj}<0.001$, $d=1.60$). Although there were differences between the conditions in the degree of improvement in FS, these were a function only of the differences at the end of the runs, not at the end of the cool-downs. Although all pairwise comparisons between intensity conditions were significant at the end of the runs, none was significant at the end of the cool-downs (d from 0.05 to 0.37). The changes in valence during the runs and those during the cool-downs were strongly correlated (−0.83, −0.82, −0.82, for <VT, @VT, and >VT, respectively).

A 3 (intensity conditions) by 2 (time points: end of run, end of cool-down) ANOVA on ratings of perceived activation (FAS) also showed a significant effect of exercise intensity [$F(2, 58)=9.17$, $p<0.001$, $\eta^2=0.240$], a significant effect of time [$F(1, 29)=52.03$, $p<0.001$, $\eta^2=0.642$], and a significant interaction [$F(2, 58)=5.21$, $p<0.01$, $\eta^2=0.152$]. The average decreases (±SD) were 1.13±1.16, 1.67±1.30, and 1.83±1.62 units after the <VT, @VT, and >VT conditions, respectively. These changes were significant for all three conditions, <VT ($p_{adj}<0.001$, $d=0.82$), @VT ($p_{adj}<0.001$, $d=1.58$), and >VT ($p_{adj}<0.001$, $d=1.41$). Although two of the three pairwise comparisons between the intensity conditions were significant at the end of the runs, none of them was significant at the end of the cool-downs (d from 0.16 to 0.28).

Discussion

The exercise psychology research literature contains two conclusions that, when juxtaposed, may appear paradoxical. On the one hand, reviewers have pointed out that "both survey and experimental research…provide support for the well-publicized statement that '*exercise makes you feel good*'" ([58], p. 413, italics in the original). The intensity of exercise is not commonly considered as a factor that can modify the seemingly ubiquitous positive effects [14]. On the other hand, "the mean dropout rate from supervised exercise programs reported around the world has remained at roughly 50% over the past 20 years" ([5], p. 63). As both intuition and research from other domains suggest that people are generally inclined to pursue activities that make them feel better and avoid activities that make them feel worse [15–17], how can these apparently incompatible conclusions be reconciled?

One possible explanation is that exercise can also make some people feel worse, and the intensity of exercise probably contributes to such negative changes to a larger degree than previously recognized. The present study reexamined the relationship between exercise intensity and affective responses based on the premise that a critical overhaul of the conceptual and methodological platform was necessary for the nature of the dose–response relationship to be revealed. Specifically, (a) affective responses were examined from a dimensional perspective, using the circumplex model, (b) affect was assessed repeatedly during and after exercise, (c) affective change was considered both at the group and the individual level, (d) exercise intensity was standardized in relation to the VT, and (e) hypotheses based in the dual-mode theory were tested. We believe that the data reported in this study form the basis for solving the 40-year-old enigma of the intensity–affect relationship and open the door to the systematic investigation of the long-theorized intensity–affect–adherence causal chain.

Most findings were consistent with predictions. Analyses of change from pre- to post-exercise showed significant shifts toward higher activation and more positive valence (a combination characteristic of such affective states as perceived energy and vigor), regardless of exercise intensity. This absence of a dose–response effect when affective changes are assessed from pre- to post-exercise is consistent with most studies based on this assessment protocol [14].

The picture, however, was very different when affective changes were examined during the exercise bouts. On average, affective valence did not exhibit a significant decline when the intensity was below or even at the VT, but it did show a significant, quadratic, and relatively homogeneous decline (80% of the sample) as early as the sixth minute of the exercise bout when the intensity was just 10% above the VT. This decline in valence happened in conjunction with a larger increase in perceived activation than seen in the other two intensity conditions. In combination, the valence and activation responses indicate that, during the >VT condition, the participants experienced an affective state that was closer to the high-activation displeasure circumplex quadrant (characteristic of tension and distress) than during the other two conditions (see Fig. 5c). Importantly, this difference in affective responses occurred while the average difference in heart rate separating the three intensity conditions was only about 10 beats$\cdot$min^{-1}.

These results help to refine previous findings of a negative relationship between exercise intensity and affect [25, 27–30]. The data show that the relationship is not negative throughout the entire range of exercise intensity but rather that affective valence begins to decline once the intensity exceeds the VT. In other words, the dose–response relationship is not linear, but instead, the VT appears to be a "turning point" toward reduced affective positivity.

Additional evidence for this phenomenon has come from studies involving incremental exercise protocols (in which the workload was increased every few minutes until the participants terminated the test due to volitional exhaustion; see [26, 59]). Such protocols, however, may have limited internal validity (as they cannot tease apart the influence of the ventilatory-threshold intensity per se from that of fatigue accumulated from the earlier stages) and external validity (as they do not resemble the pattern of common exercise bouts).

The only previous study that examined affective responses to constant-workload exercise and involved intensities set in relation to the VT also yielded similar results. Bixby et al. [60] examined 14 women (mean age, 23.1 years; mean VO_{2max}, 37.1 ml·kg^{-1}·min^{-1}) and 13 men (mean age, 23.6 years; mean VO_{2max}, 40.9 ml·kg^{-1}·min^{-1}) who exercised on a cycle ergometer for 30 min either at 75% of the heart rate associated with the VT or at a heart rate "just below" that associated with the VT. During the below-VT condition, responses on a "best mood" versus "worst mood" visual analogue scale improved significantly at min 20 and 30, whereas during the VT condition the responses were significantly worse-than-baseline throughout the bout.

Two additional studies have shown that the so-called onset of blood lactate accumulation (OBLA), conventionally defined as an exercise intensity resulting in a buildup of 4.0 mmol·l^{-1} of lactate in the blood, is associated with a decline in affect. Given that the absolute levels of lactate in response to exercise can vary greatly between individuals, the concept of the OBLA is considered controversial and its relationship to the VT is unclear (recall, however, that blood lactate concentration was 4.26±1.56 mmol·l^{-1} after the @VT condition and 5.75±1.82 mmol·l^{-1} after the >VT condition in the present study). Nevertheless, it is interesting that these studies, despite using very different samples and exercise protocols, produced similar results. Specifically, Acevedo et al. [61] examined 11 competitive male distance runners (mean age, 22.6 years; mean VO_{2max}, 67.7 ml·kg^{-1}·min^{-1}). They ran for 5 min at intensities 10% below, at, and 10% above OBLA. FS declined significantly and became negative only from OBLA to 10% above OBLA. Parfitt et al. [62] examined 12 sedentary men (age, 36.5 years; mean VO_{2max}, 34.1 ml·kg^{-1}·min^{-1}). They exercised on a treadmill for 20 min (on different days) at an intensity corresponding to 2 mmol·l^{-1} of lactate, 4 mmol·l^{-1} of lactate, or at a self-selected pace (which was between the other two). Affective valence, measured by the FS, became less positive and ultimately negative at the 4 mmol·l^{-1} lactate condition (which, due to the absence of a physiological steady-state, actually culminated at 7.17 mmol·l^{-1}) but remained positive and stable in the other two conditions (in which lactate levels remained stable).

Notwithstanding the considerable differences between these studies, they all seem to converge on certain important conclusions: (a) exercise intensity clearly influences affective responses and (b) a physiological landmark (VT or OBLA) seems to be the "turning point" beyond which affective valence starts to decline. This link between physiological function and affect is consistent with the postulated adaptational role of affect in the context of exercise as outlined in the dual-mode theory [44–47] and similar formulations [37].

Consistent with the hypothesis that the termination of exercise would be followed by a rapid improvement in valence, the results of the present study showed marked improvements in affective valence during the immediate post-exercise period (an approximately 2-min-long pause for the collection of blood samples and a 5-min cool-down walk). These improvements were responsible for the elimination of dose–response effects in affective valence. Remarkably, at the end of the cool-down, the three intensity conditions were separated by less than one-half FS unit. This finding underscores the importance of assessing affect repeatedly during and after the exercise bout in studies investigating intensity effects (also see [60]).

It is noteworthy that, although the <VT intensity did not lead to a significant group-level decline in affective valence and elicited a rating of perceived exertion of no more than 11.17 on a scale from 6 to 20, this intensity was associated with declines in affective valence in 43% of the sample (decreases in FS of 1.69±1.11 units, with a range from 1 to 5). Regardless of whether these changes are caused by aversive interoceptive cues (as is probably the case with higher-intensity exercise) or by cognitive factors (e.g., self-efficacy, cognitive antecedents of social physique anxiety, attitudes, coping, and goal orientations), the fact that four out of ten participants reported feeling slightly to substantially worse during exercise below the VT warrants attention. On a related note, it should be pointed out that the few studies that have examined the effects of low-intensity physical activity, such as self-paced walking, have shown significant positive affective changes (i.e., increases in energy and decreases in tension and tiredness) both during and for a period after the activities [40–42]. Therefore, it seems that, contrary to the inverted-U model, exercise stimuli toward the low end of the intensity spectrum may be associated with significant positive affective changes not only after but also during the activity. Importantly, these seem to be shared by the majority of participants [46]. As exercise intensity increases, particularly proximally to the VT, whether affective responses will remain positive may depend on individual differences in the preference for or tolerance of the interoceptive symptoms associated with metabolic strain [63–65].

One limitation of the present study that future studies should address is the fact that the sample consisted of young, healthy, physically active, and moderately to highly fit individuals. Therefore, the findings cannot be assumed to generalize to other populations (or modes of exercise) without further empirical study. However, this limitation should be viewed in the context of the following considerations. First, determining exercise intensity in relation to the VT probably achieves a better standardization of the physiological demands of exercise than percentages of maximal capacity. Thus, exercise stimuli should be comparable, at least in terms of metabolic demands, whether the threshold occurs at 80% of maximal capacity (as may be the case with a young and physically fit individual) or 50% (as may be the case with an elderly person). Second, it is reasonable to assume that, if anything, the responses of older or less physically fit individuals to an exercise intensity that exceeds the VT would be even less positive than those reported by the participants in this study.

In closing, let us return to the implications of the intensity–affect link for exercise adherence and public health. A growing number of studies in the domain of exercise now substantiate what hedonic theories of motivation have claimed for millennia: In the long run, human nature is bound to gravitate toward behavioral choices that increase pleasure and avoid behavioral choices that consistently decrease pleasure [18–21]. Furthermore, it is reasonable to assume that, among multiple pleasant alternatives, people will tend to choose those more likely to maximize pleasure. Against this backdrop, a perusal of the popular media reveals that exercise is portrayed as a "bitter pill" that one must tolerate if any hopes of accruing significant benefits are to materialize. For example, according to a best-selling book, people should exercise "at the highest intensity that is safe" ([66], p. 108). Exercise and health professionals are cautioned that "when most people are left to their own devices, they will adopt an exercise intensity that is too low" (p. 109), and therefore, they should push people harder. According to the same source, the appropriate exercise intensity is one that induces "a definite feeling of fatigue" (p. 113) and takes people "past [their] level of comfort" (p. 115). In other words, the "no pain, no gain" adage long espoused by overzealous high-school coaches is alive and well and has evidently made significant inroads into the public health arena.

The present study demonstrated that, for healthy individuals without an exercise-limiting condition, an exercise intensity up to the level of the ventilatory threshold does not induce significant and generalized decreases in pleasure. This finding becomes even more important in light of other data, showing that the intensity of the ventilatory threshold is not only effective for improving fitness and health but also that higher intensities (exceeding the ventilatory or lactate threshold) do not seem to confer any additional fitness or health benefits to previously untrained individuals ([67, 68]; also [59] and Discussion therein). Although supra-threshold training might be beneficial for some competitive athletes, in the domain of public health, an intensity that exceeds the ventilatory threshold may increase the "pain" (i.e., reduce pleasure) but it is unlikely to produce added physiological "gain."

It is important to point out that, in the present study, the average treadmill speeds used in the @VT and >VT conditions differed by less than one-half mile per hour, a difference that is—at least initially—hardly perceptible by most individuals. Because many novice exercisers may lack the self-monitoring skills necessary to accurately gauge and regulate their intensity (and many exercise professionals may have a propensity to "push harder"), deviations of such small magnitude are probably not uncommon in practice. Thus, an important direction for future research would be to develop and test intervention strategies designed to teach beginner exercisers to recognize the perceptual and affective cues associated with the transition to supra-threshold intensities [69]. Furthermore, it is crucial to extend this research by examining whether intensity-dependent differences in affective responses in turn influence adherence, particularly over the critical first few months of exercise participation. Of particular interest would be to examine whether the different parts of the exercise experience, such as the positive or negative affective "peak" during the bout or the affective state at the "end" of the bout (i.e., during the cool-down or recovery), have different predictive value for future exercise behavior [16].

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