The Exercise and Affect Relationship: Evidence for the Dual-Mode Model and a Modified Opponent Process Theory

Sarah M. Markowitz\(^1\) and Shawn M. Arent\(^2\)

\(^1\)Wells College; \(^2\)Rutgers, the State University of New Jersey

This study examined the relationship between exertion level and affect using the framework of opponent-process theory and the dual-mode model, with the Activation-Deactivation Adjective Checklist and the State Anxiety Inventory among 14 active and 14 sedentary participants doing 20 min of treadmill exercise at speeds of 5% below, 5% above, and at lactate threshold (LT). We found a significant effect of time, condition, Time × Condition, and Time × Group, but no group, Group × Condition, or Time × Group × Condition effects, such that the 5% above LT condition produced a worsening of affect in-task compared with all other conditions whereas, across conditions, participants experienced in-task increases in energy and tension, and in-task decreases in tiredness and calmness relative to baseline. Posttask, participants experienced mood improvement (decreased tension, anxiety, and increased calmness) across conditions, with a 30-min delay in the above LT condition. These results partially support the dual-mode model and a modified opponent-process theory.

**Keywords:** mood, biological threshold, aerobic exercise

A substantial body of evidence shows that a single bout of exercise improves postexercise affect (Landers & Arent, 2007). The dose of exercise needed to produce optimal affective improvement in different individuals, however is not known (Ekkekakis & Petruzzello, 1999). Though support has been found consistently for a relationship between exercise and posttask affective improvement, further research is needed to elucidate the mechanisms of this association, particularly within a theoretical framework (O’Neal, Dunn, & Martinsen, 2000). Two theories regarding the effects of exertion level on affect are the opponent-process theory (Solomon, 1991) and the dual-mode model (Ekkekakis, 2001).

Solomon’s opponent-process theory (1980, 1991; Solomon & Corbit, 1974), posits that the initial physiological or psychological response (the \(a\) process) to a stressor is followed by a secondary or compensatory response (the \(b\) process), which has the opposite valence of the \(a\) process. This \(b\) process is proposed to be generated whenever the input from the \(a\) process reaches a certain threshold. The \(b\)
process has a long latency, increases slowly, lasts a long time, and is strengthened by use (Solomon & Corbit, 1974). As it applies to exercise, the a process may most accurately be described as the sympathetic activation and parasympathetic withdrawal that occurs during exercise, and the b process may be the parasympathetic rebound or vagal “overshoot” that occurs in response to the cessation of the exercise stimulus in an effort to return to homeostasis. However, with high-intensity exercise, some physiological changes (e.g., body temperature, heart rate, catecholamine response, activation of the hypothalamic-pituitary-adrenal [HPA] axis associated with sympathetic arousal) do not cease immediately after exercise. In this situation, some a processes continue, while other b processes begin, potentially producing a washout effect in which the a and b processes overlap and offset one another to some degree (Kaikkonen, Rusko, & Martinmaki, 2008; Terziotti, Schena, Gulli, & Cevese, 2001). Because of these physiological responses, which may be associated with mechanisms driving excess postexercise oxygen consumption (EPOC), it may be necessary to consider a “modified” opponent-process theory as it applies to higher intensities of exercise.

In line with these concepts, Ekkekakis (2001) found that in-task affect was worst for exercisers at the highest intensity, but this same group also got the most affective benefit postexercise, as opponent-process theory would predict. A large body of evidence shows that affect improves postexercise, regardless of the valence of in-task affect, though the magnitude and time-course of these effects may differ as a function of exercise type and intensity. This is a robust finding, applicable across types of exercise, environments, participants, and mood and affect measures (Ekkekakis, 2003). Opponent-process theory appears to primarily account for the postexercise responses seen in those for whom in-task affect is negative. For those in whom in-task affect is positive, and postexercise affect remains positive, it is possible that they did not reach a sufficient threshold to activate a compensatory b process and that the mechanisms by which in-task affective improvement occurs still function. Support for the opponent-process theory as it relates to exercise and affect has generally received mixed support in recent studies (e.g., Lochbaum, Karoly, & Landers, 2004; Bixby & Lochbaum, 2006). Though the opponent-process theory would predict different affective responses for active vs. inactive individuals, studies by Lochbaum et al. (2004) and Bixby and Lochbaum (2006) found similar patterns of response regardless of exercise history. However, Bixby and Lochbaum found that the pattern of responses when collapsed across groups did vary as a function of intensity and were consistent with Solomon’s theory, in contrast to the findings of Lochbaum et al. This may have been due to the fact that Bixby and Lochbaum based exercise intensity on ventilatory threshold rather than simply a percentage of VO₂ max.

A more recent conceptualization of the exercise and affect relation involves the dual-mode model (Ekkekakis, 2003). According to this model, cognitive factors (like self-efficacy, attributions, and thoughts about the social environment) primarily determine affective responses at low to moderate levels of exercise. On the other hand, interoceptive cues related to exercise-induced physiological changes primarily determine affective responses as exercise intensity approaches certain biological thresholds that threaten homeostasis. One such potential threshold is the lactate threshold (LT), which refers to the point at which lactate begins to accumulate in the bloodstream faster than it can be removed (Ekkekakis, 2001). In other words,
lactate production exceeds lactate clearance. This is one marker for a point at which
the body can no longer maintain homeostasis if exertion at this level continues as
the system is no longer able to sustain steady-state exercise.

Two studies that examined LT and the implications for the dual-mode model
found evidence in support of the model (Parfitt, Rose, & Burgess, 2006; Rose &
Parfitt, 2007). However, it should be noted that these studies technically used a
lactate value commonly (though somewhat arbitrarily) used to indicate onset of
blood lactate accumulation (OBLA), which was 4 mmol·L⁻¹. When participants
exercised above their OBLA, in-task affect was significantly worse than when
exercising below OBLA, but posttask affect was not significantly different. Fur-
thermore, when allowed to self-select intensity, participants chose to exercise
near their individual OBLA (Parfitt et al., 2006). Rose and Parfitt (2007) found
similar in-task results, such that exercise above OBLA produced the worst in-task
affective responses, and exercise below OBLA and at self-selected speeds pro-
duced the best in-task affective response, compared with exercise at OBLA. Like
much of the recent work in the exercise and affect area that has used the tenets
of the dual-mode model as the driving principles, both of these studies relied on
very basic, but commonly used, measures of affective valence and activation, the
Feeling Scale and Felt Arousal Scale. However, it has been noted by Ekkekakis
and Petruzzello (2000) that the stimulus of exercise itself is multifaceted and can
“induce affective responses emerging from any level of affective processing, from
basic affect to specific emotions” (p. 78). Recent research examining the dose-
response effects of resistance exercise intensity (Arent, Landers, Matt, & Etnier,
2005) found that affect and anxiety were both influenced by intensities that fell
above or below a threshold for activation of the HPA axis. Considering these out-
comes and the contentions of Ekkekakis and Petruzzello, it would seem prudent
to include measures that have shown sensitivity to biological thresholds as well
as that assess the dimensional (i.e., generalized positive and negative affect) and
categorical (i.e., specific emotional responses such as anxiety) levels of affective
change. Furthermore, this would allow for better comparison with previous studies
that have focused primarily on postexercise affective responses as many of them
have relied on categorical measures of emotion or affect.

It has been proposed that individual differences may explain why some people
experience greater affective benefit than others from exercise. Fitness and activity
levels have received some attention as possible key individual difference variables,
though the findings have generally been considered equivocal (Ekkekakis &
Petruzzello, 1999). Several studies have found no differences in mood or affective
responses among individuals of different fitness levels for low or moderate inten-
sity exercise (Reed, Berger, Latin, & La Voie, 1998; Steptoe, Kearsley, & Walters,
1993). At higher intensities of exercise, however, more fit individuals have been
found to experience more affective and anxiolytic benefit than unfit individuals
(Blanchard, Rodgers, Spence, & Courneya, 2001; Tieman, Peacock, Cureton,
& Dishman, 2002). Individuals’ activity level may be an important factor in the
exercise and affect relationship, particularly for high-intensity exercise conditions.
With the increasing attention that the dual-mode model has brought to the concept
of biological thresholds dictating at least part of the affective responses to exercise,
it is important to extend the previous work on individual differences such as fitness
to incorporate these newer concepts.
The Current Study

We sought to test the dual-mode model of exercise and affect in the context of opponent-process theory to determine the relationship between exertion level (as a function of LT) and affect in active and inactive participants. Our main hypothesis was that exertion above LT would worsen in-task affect (as interoceptive cues take over from the physiological changes occurring); for posttask affect, we expected improvement from baseline for all levels of exertion with a delay in affective improvement at exertion above LT due to physiological recovery processes occurring postexercise. Consistent with the tenets of the opponent-process theory and the effects of strengthening the β process with repeated stimulation, it was also predicted that active participants would report greater levels of positive affect and lower levels of negative affect than inactive participants during and following exercise.

Methods

Participants

A total of 28 college-age students (M_age = 21.0 ± 1.82 years) participated. Participants in the active group (n = 14, M_age = 21.1 ± 2.07, males percentage of body fat (%BF) = 10.8 ± 6.18, females %BF = 21.7 ± 5.56) were recruited through varsity and club sports teams, and were screened to determine that they engaged in moderate or strenuous physical activity five days per week for an hour or more. Participants in the inactive group (n = 14, M_age = 20.8 ± 1.58, males BF% = 33.3 ±10.56, females BF% = 34.7 ± 5.42) were recruited from the campus at large, and were screened to determine that they engaged in moderate or strenuous physical activity less than once per week in the past six months. Demographic characteristics are displayed in Table 1. There was a significant difference in LT and %BF (for both males and females, analyzed separately) between active and inactive participants, such that active participants were significantly leaner and had higher LTs than inactive participants. All participants received research credit and/or a chance to win a gift certificate for their participation in addition to feedback about their current state of physical fitness. All participants had a physical examination during the previous year that revealed no contraindications to vigorous physical activity (i.e., had no history of cardiovascular, respiratory, musculoskeletal, metabolic, or mental conditions, and they were not suffering from any injuries or other ailments, and were not taking any medication that would affect exercise tolerance or performance). All participants provided their informed consent, and all procedures were approved by the Rutgers Institutional Review Board and were therefore in accordance with universal ethical principles.

Measures

Physiological Variables. Participants’ LT was determined by a graded maximal treadmill test to exhaustion. Capillary blood samples (5 µL) were taken from the fingertip at rest and at the end of each 4-min stage to analyze blood lactate accumulation. The Lactate Pro (Arkray, Japan) portable analyzer was used to determine whole blood lactate content. The Lactate Pro has previously demonstrated...
a coefficient of variation of less than 3%. Lactate concentration was plotted against treadmill speed to determine the velocity at which lactate threshold (VLT) occurred using the Dmax method (Cheng et al., 1992), the most sensitive and valid measure of velocity at LT (Nicholson & Sleivert, 2001).

Percent body fat was measured through a two-stage procedure. Body volume was measured via air displacement plethysmography using the BOD POD (Life Measurement, Inc., Concord, CA). The error of body volume reading is roughly 0.02%, which allows for calculation of percent body fat with only 0.01% error (Dempster & Aitkens, 1995). Calculated body volume was used to calculate percent body fat using the Siri two-component equation. Height and weight were recorded in conjunction with body composition assessment.

**Affect Measures.** *Activation-Deactivation Adjective Checklist (AD-ACL; Thayer, 1989).* The short form of the AD-ACL is a brief self-report measure that comprises four subscales (Energy, Tiredness, Tension, and Calmness). Each subscale includes five adjectives (rated on a 4-point continuum from definitely feel to definitely do not feel). It has been widely used in psychophysiological research, with test–retest reliabilities at .89 (energy), .89 (tiredness), .93 (tension), and .79 (calmness) (Thayer, 1989). The AD-ACL was used to assess the dimensional qualities of exercise-induced affect.

*State-Trait Anxiety Inventory: State Anxiety Scale (SAI; Spielberger, Gorsuch, Luschene, Vagg, & Jacobs, 1983).* The SAI is a brief self-report measure of 20 items (rated on a 4-point continuum from not at all to very much so) concerning the amount of anxiety currently experienced. It has been widely used in psychological research, with an internal consistency alpha during recovery from exercise from .66 to .80 (Ekkekakis, Hall, & Petruzzello, 1999), and adequate test–retest reliability (Spielberger et al., 1983). The SAI was used to assess a categorical measure of affect.

*Rating of Perceived Exertion (RPE; Borg, 1998).* The RPE is a 15-point single-item scale (ranging from 6 to 20, anchored at 6 for very, very light and 20 for maximal exercise, or very, very hard). Correlations between RPE and heart rate across the stages of a graded exercise test have ranged between 0.85 and 0.94 (Noble & Robertson, 1996).

---

**Table 1  Characteristics of Active and Inactive Participants**

<table>
<thead>
<tr>
<th>Group</th>
<th>Active</th>
<th>Inactive</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Male</td>
<td>57</td>
<td>50</td>
<td>54</td>
</tr>
<tr>
<td>% Caucasian*</td>
<td>92</td>
<td>57</td>
<td>73</td>
</tr>
<tr>
<td>Means (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age in years</td>
<td>21.1 (2.1)</td>
<td>20.8 (1.6)</td>
<td>21.0 (1.8)</td>
</tr>
<tr>
<td>Males %BFb</td>
<td>10.8 (6.2)</td>
<td>33.3 (10.6)</td>
<td>21.3 (14.2)</td>
</tr>
<tr>
<td>Females %BFb</td>
<td>21.7 (5.6)</td>
<td>34.7 (5.4)</td>
<td>28.8 (8.5)</td>
</tr>
<tr>
<td>LT in km⋅h⁻¹b</td>
<td>12.3 (1.6)</td>
<td>6.2 (0.7)</td>
<td>9.2 (3.1)</td>
</tr>
</tbody>
</table>

*aEthnicity data is missing from two participants (two active).  
b*p < .001 between active and inactive participants.*
Procedures

**Lactate Threshold Assessment.** After granting informed consent, participants completed a demographics questionnaire and were weighed and measured. They then underwent the BOD POD procedure and the exercise performance test (consisting of a graded maximal treadmill test to exhaustion). Participants completed a series of 4-min stages with 1-min rest intervals between stages for the sampling of capillary blood to determine blood lactate values. Stage 1 speed was set at 8.0 km·h⁻¹ for active males, 6.0 km·h⁻¹ for active females, and 4.0 km·h⁻¹ for the inactive individuals, while grade was set at 1% for all groups. Speed was increased by 2.0 km·h⁻¹ with each incremental stage for active males, 1.6 km·h⁻¹ for active females, and 1.4 km·h⁻¹ for inactive individuals. Grade was maintained at 1% throughout the test to maintain biomechanical demands that would be used during the exercise protocol as well as to mimic the energetic cost of outdoor running (Jones & Doust, 1996). This process continued until volitional exhaustion. These speeds and increments from stage-to-stage were used to establish a sufficient sampling of steady-state efforts for accurate calculation of the third-order polynomial curve used in the $D_{\text{max}}$ method of LT assessment. Using this approach, the average numbers of stages attained were as follows: active males = 7.2; active females = 7.5; inactive males = 7.2; inactive females = 6.8. Heart rate was continuously monitored using a Polar S810 HR monitor (Polar Electro Co., Woodbury, NY).

**Experimental Testing** Participants came to the laboratory for experimental testing on three separate occasions; the order of testing was randomly assigned and all testing was done at the same time of day (within 2 hr) across the conditions for each subject. While wearing a heart-rate monitor, participants engaged in 20 min of treadmill walking or running at either 5% below, 5% above, or at their LT, after warming up for 5 min at half of LT speed. After completing the exercise task, participants rested quietly for 60 min. During the rest period, they stayed in the experimental testing room, sitting at a table in the opposite corner of the room, where they were permitted to read or study. They completed the AD-ACL and SAI at eight time points: immediately preexercise (t0), 8 min into exercise (t8), 16 min into exercise (t16), immediately postexercise (p0), 15 min postexercise (p15), 30 min postexercise (p30), 45 min postexercise (p45), and 60 min postexercise (p60). Participants also communicated RPE at times t8 and t16. At times t0, p0, p15, p30, p45, and p60, they completed the questionnaires with pen and paper. During in-task assessments (t8 and t16), participants viewed a poster-sized version of all questionnaires and responded verbally while a laboratory assistant recorded their answers. Total assessment time at each interval lasted approximately 90 s. The in-task intervals were chosen to allow for achievement of steady state (t8) in the below and at LT conditions as well as to provide for an assessment (t16) close to the end of exercise but not influenced by the expectancy of stopping upon completion of the questionnaire.

**Statistical Analysis** Descriptive statistics of demographic variables (age, gender, and ethnicity) and physiological variables (LT and %BF) were examined to characterize the sample (see Table 1), and comparisons between active and inactive participants were made. As a manipulation check, an ANOVA to determine whether there was a difference in RPE in the various conditions was also performed, with post hoc univariate comparisons with Bonferroni corrections.
To examine the affective response to the different levels of exertion across groups, conditions, and time, a $2 \times 3 \times 8$ (Activity Group $\times$ Condition $\times$ Time Point) MANOVA was performed. Univariate follow-ups for each measure were used in the event of significant multivariate findings. Planned simple contrasts of time within condition were used to determine if there was a difference from baseline for each time point as a function of the intensity of exercise.

For each univariate analysis, the Huynh–Feldt epsilon was examined for the general model to evaluate sphericity. If the Huynh–Feldt epsilon exceeded .75, sphericity was considered to have been met and the unadjusted statistic was used. If epsilon was less than .75, the adjusted Huynh–Feldt statistic was used to test significance. Effect sizes (ES) were calculated to assess magnitude of change where appropriate using Hedges’s $g$ formula for ES computation. Data are expressed as mean $\pm$ SD and statistical significance was set at the $p \leq .05$ level.

**Results**

**Manipulation Check**

As a manipulation check, two-way ANOVA was performed and determined that there was a significant effect of condition, $F(2, 78) = 8.984, p < .001$, and group, $F(1, 78) = 5.434, p = .022$, such that active participants reported higher RPE than inactive participants, but not Condition $\times$ Group, $F(2, 78) = .533, p = .589$, on RPE. Post hoc Bonferroni analyses indicated that there was a significant difference in RPE between the above LT and below LT conditions ($M_{\text{difference}} = 2.46 \pm .582, p < .001$), such that when participants were in the above LT condition, they reported higher RPE. See Table 2.

**Table 2** Ratings Means (SD) of Perceived Exertion by Condition and Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Active Group</th>
<th>Inactive Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below LT*</td>
<td>12.3 (1.4)</td>
<td>10.5 (1.9)</td>
</tr>
<tr>
<td>At LT</td>
<td>13.0 (1.5)</td>
<td>12.1 (3.1)</td>
</tr>
<tr>
<td>Above LT*</td>
<td>14.1 (1.4)</td>
<td>13.5 (3.1)</td>
</tr>
<tr>
<td>Total</td>
<td>13.1 (1.6)$^b$</td>
<td>12.0 (3.0)$^b$</td>
</tr>
</tbody>
</table>

*Each group in the Above LT condition has significantly greater RPE than in the Below LT condition, at $p < .05$.

$^b$Active group has significantly greater RPE than inactive group, at $p < .05$.

**Main Hypothesis**

Results of the $2 \times 3 \times 8$ (Group $\times$ Condition $\times$ Time Point) MANOVA revealed a significant main effect for time, Wilks’s $\Lambda = .146, F(35, 751.2) = 12.422, p < .001$, condition, Wilks’s $\Lambda = .376, F(10, 96) = 6.063, p < .001$, Time $\times$ Group, Wilks’s $\Lambda = .733, F(35, 751.2) = 1.648, p = .011$, and Time $\times$ Condition, Wilks’s $\Lambda = .474, F(70, 1718) = 4.173, p < .001$, but no significant group effect, or Group $\times$ Condition or Time $\times$ Group $\times$ Condition interaction effects, $ps > .41$. 
Energy. For the energy subscale of the ADACL, there was a significant effect of time, $F(2.1, 54.4) = 40.562, p < .001$, a trend for condition, $F(1.9, 48.6) = 3.204, p = .053$, but no Time × Condition or Time × Group interactions, $ps > .27$, indicating that there was a difference in affective response across time points and across conditions (see Figure 1).

When participants were in the 5% below LT condition, there was a significant effect of time, $F(2.5, 21) = 26.199, p < .001$. Simple contrasts indicate that there was a significant increase in energy from baseline in the 5% below LT condition at 8 min in-task, $F(1, 21) = 33.459, p < .001$, 16 min in-task, $F(1, 21) = 46.080, p < .001$, immediately posttask, $F(1, 21) = 50.998, p < .001$, and 15 min posttask, $F(1, 21) = 8.607, p = .007$, but not at 30, 45, or 60 min posttask, $ps > .27$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, $ES = 1.08$; 16 min in-task, $ES = 1.33$; immediately posttask, $ES = 1.58$; 15 min posttask, $ES = 0.36$; 30 min posttask, $ES = 0.18$; 45 min post task, $ES = 0.12$; 60 min posttask, $ES = –0.07$.

When participants were in the LT condition, there was a significant effect of time, $F(2.9, 21) = 21.879, p < .001$. Simple contrasts indicate that there was a significant increase in energy from baseline in the LT condition at 8 min in-task, $F(1, 21) = 26.020, p < .001$, 16 min in-task, $F(1, 21) = 32.661, p < .001$, immediately posttask, $F(1, 21) = 35.282, p < .001$, and 15 min posttask, $F(1, 21) = 4.512, p = .043$, but not at 30, 45, or 60, min posttask, $ps > .18$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, $ES = 1.19$; 16 min in-task, $ES = 1.37$; immediately posttask, $ES = 1.00$.
1.65; 15 min posttask, ES = 0.46; 30 min posttask, ES = 0.28; 45 min posttask, ES = 0.11; 60 min posttask, ES = –0.08.

When participants were in the 5% above LT condition, there was also a significant effect of time, \( F(3.6, 21) = 26.531, p < .001 \). Simple contrasts indicate that there was a significant increase in energy from baseline in the 5% above LT condition at 8 min in-task, \( F(1, 21) = 22.594, p < .001 \), 16 min in-task, \( F(1, 21) = 23.811, p < .001 \), and immediately posttask, \( F(1, 21) = 35.940, p < .001 \), but not at 15, 30, 45, or 60 min posttask, \( ps > .12 \). Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, \( ES = 1.17 \); 16 min in-task, \( ES = 1.27 \); immediately posttask, \( ES = 1.50 \); 15 min posttask, \( ES = 0.23 \); 30 min posttask, \( ES = 0.06 \); 45 min posttask, \( ES = -0.02 \); 60 min posttask, \( ES = -0.32 \).

**Tiredness.** For the tiredness subscale of the ADACL, there was a significant effect of time, \( F(3.9, 101.9) = 9.159, p < .001 \), and Time × Condition, \( F(9.1, 157.9) = 3.692, p = .02 \), but not condition, or Time × Group, \( ps > .21 \), indicating that there was a difference in affective response across time points as a function of condition (see Figure 2).

When participants were in the 5% below LT condition, there was a significant effect of time, \( F(3.8, 21) = 6.810, p < .001 \). Simple contrasts indicate that there was a significant decrease in tiredness from baseline in the 5% below LT condition at 8 min in-task, \( F(1, 21) = 19.901, p < .001 \), 16 min in-task, \( F(1, 21) = 21.613, p < .001 \), immediately after, \( F(1, 21) = 19.852, p < .001 \), 15 min, \( F(1, 21) = 15.838 \),

![Figure 2](image_url) — Tiredness by condition across time (± SE).
p < .001, 30 min, $F(1, 21) = 8.799, p = .006$, and 60 min, $F(1, 21) = 7.759, p = .010$, posttask, but not at 45 min posttask, $p = .122$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = –0.67; 16 min in-task, ES = –0.80; immediately posttask, ES = –0.78; 15 min posttask, ES = –0.73; 30 min posttask, ES = –0.57; 45 min posttask, ES = –0.32; 60 min posttask, ES = –0.46.

When participants were in the LT condition, there was a significant effect of time, $F(3.2, 21) = 3.200, p = .025$. Simple contrasts indicate that there was a significant decrease in tiredness from baseline in the LT condition at 8 min in-task, $F(1, 21) = 4.276, p = .048$, immediately posttask, $F(1, 21) = 15.145, p = .001$, and 15 min posttask, $F(1, 21) = 5.076, p = .033$, but not at 16 min in-task, or 30, 45, or 60 min posttask, $ps > .11$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = –0.36; 16 min in-task, ES = –0.25; immediately posttask, ES = –0.70; 15 min posttask, ES = –0.34; 30 min posttask, ES = –0.29; 45 min posttask, ES = –0.18; 60 min posttask, ES = –0.16.

When participants were in the 5% above LT condition, there was a significant effect of time, $F(4.2, 21) = 7.412, p < .001$. Simple contrasts indicate that there was a significant decrease in tiredness from baseline in the 5% above LT condition at 8 min in-task, $F(1, 21) = 12.614, p = .001$, 16 min in-task, $F(1, 21) = 5.910, p = .022$, immediately after, $F(1, 21) = 11.115, p = .002$, and 60 min posttask, $F(1, 21) = 4.783, p = .038$, but not at 15, 30, or 45 min posttask, $ps > .17$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = –0.58; 16 min in-task, ES = –0.45; immediately posttask, ES = –0.68; 15 min posttask, ES = 0.28; 30 min posttask, ES = –0.02; 45 min posttask, ES = –0.31; 60 min posttask, ES = –0.41. There was a trend toward increased tiredness within the first 15 to 30 min posttask, particularly compared with the other conditions (see Figure 2).

**Tension.** For the tension subscale of the ADACL, there was a significant effect of time, $F(3.1, 80.7) = 29.870, p < .001$, condition, $F(1.6, 41.9) = 7.234, p = .004$, Time × Condition, $F(3.3, 86.8) = 3.123, p = .026$, and Time × Group, $F(3.1, 80.7) = 4.624, p = .004$, indicating that there was difference in tension over time as a function of condition and as a function of activity status (see Figures 3 and 4).

When participants were in the 5% below LT condition, there was a significant effect of time, $F(3.4, 21) = 10.667, p < .001$. Simple contrasts indicate that there was a transient but significant increase in tension from baseline in the 5% below LT condition immediately posttask, $F(1, 21) = 5.688, p = .024$, and a significant decrease in tension from baseline at 15 min, $F(1, 21) = 5.626, p = .025$, 30 min, $F(1, 21) = 5.836, p = .023$, and 45 min, $F(1, 21) = 8.083, p = .008$, posttask, but no significant difference from baseline at 8 or 16 min in-task, or 60 min posttask, $ps > .09$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = 0.27; 16 min in-task, ES = 0.30; immediately posttask, ES = 0.53; 15 min posttask, ES = –0.38; 30 min posttask, ES = –0.43; 45 min posttask, ES = –0.40; 60 min posttask, ES = –0.31.

When participants were in the LT condition, there was a significant effect of time, $F(1.9, 21) = 12.787, p < .001$. Simple contrasts indicate that there was a significant increase in tension from baseline in the LT condition at 8 min in-task,
Figure 3 — Tension by condition across time (± SE).

Figure 4 — Tension by group across time (± SE).
When participants were in the 5% above LT condition, there was a significant effect of time, $F(2.4, 21) = 10.234, p < .001$. Simple contrasts indicate that there was a significant increase in tension from baseline in the 5% above LT condition at 8 min in-task, $F(1, 21) = 12.495, p = .001$, 16 min in-task, $F(1, 21) = 15.225, p = .001$, 0 min posttask, $F(1, 21) = 38.562, p < .001$, 15 min, $F(1, 21) = 8.655, p = .007$, and 30 min, $F(1, 21) = 5.959, p = .021$, posttask, before returning back toward baseline levels at 45 and 60 min posttask, $ps > .14$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, $ES = 1.22$; 16 min in-task, $ES = 1.33$; 0 min posttask, $ES = 1.02$; 15 min posttask, $ES = 0.76$; 30 min posttask, $ES = 0.59$; 45 min posttask, $ES = -0.15$; 60 min posttask, $ES = -0.28$.

To examine the significant Time × Group interaction, data were collapsed across conditions for each group. Within the inactive group, there was a significant effect of time on tension, $F(2.3, 92.4) = 16.021, p < .001$. Simple contrasts indicate that there was a significant increase in tension from baseline at 8 min in-task, $F(1, 41) = 11.36, p = .002$, 16 min in-task, $F(1, 41) = 11.403, p = .002$, and immediately posttask, $F(1, 41) = 8.535, p = .006$, and a significant decrease in tension at 45 min, $F(1, 41) = 9.848, p = .003$, and 60 min, $F(1, 41) = 15.669, p < .001$, posttask, but no significant difference from baseline at 15 or 30 min posttask. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, $ES = 0.44$; 16 min in-task, $ES = 0.49$; immediately posttask, $ES = 0.60$; 15 min posttask, $ES = -0.12$; 30 min posttask, $ES = -0.31$; 45 min posttask, $ES = -0.44$; 60 min posttask, $ES = -0.61$. Within the active group, there was a significant effect of time on tension, $F(5, 204.3) = 16.1, p < .001$. Simple contrasts indicate that there was a significant increase in tension from baseline at 8 min in-task, $F(1, 41) = 15.713, p < .001$, 16 min in-task, $F(1, 41) = 16.507, p < .001$, and immediately posttask, $F(1, 41) = 22.069, p < .001$, followed by a significant decrease in tension at 45 min posttask, $F(1, 41) = 4.133, p = .049$, but no significant difference from baseline at 15, 30, or 60 min posttask. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, $ES = 0.44$; 16 min in-task, $ES = 0.49$; immediately posttask, $ES = 0.64$; 15 min posttask, $ES = 0.06$; 30 min posttask, $ES = -0.03$; 45 min posttask, $ES = -0.18$; 60 min posttask, $ES = -0.20$.

**Calmness.** For the calmness subscale of the ADACL, there was a significant effect of time, $F(2.5, 64) = 46.242, p < .001$, condition, $F(1.8, 45.5) = 15.8114, p < .001$, and Time × Condition, $F(4, 103) = 5.781, p < .001$, but not Time × Group, $p = .502$, indicating that there was a difference in calmness over time as a function of condition (see Figure 5).
When participants were in the 5% below LT condition, there was a significant effect of time, $F(2.7, 21) = 35.189, p < .001$. Simple contrasts indicate that there was a significant decrease in calmness from baseline in the 5% below LT condition at 8 min in-task, $F(1, 21) = 26.537, p < .001$, 16 min in-task, $F(1, 21) = 44.382, p < .001$, and immediately posttask, $F(1, 21) = 19.186, p < .001$, followed by a significant increase in calmness at 30 min, $F(1, 21) = 6.301, p = .018$, 45 min, $F(1, 21) = 6.506, p = .017$, and 60 min, $F(1, 21) = 5.070, p = .033$, posttask, but no significant difference from baseline at 15 min posttask, $p = .199$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = –1.05; 16 min in-task, ES = –1.26; immediately posttask, ES = –0.93; 15 min posttask, ES = 0.24; 30 min posttask, ES = 0.45; 45 min posttask, ES = 0.53; 60 min posttask, ES = 0.49.

When participants were in the LT condition, there was a significant effect of time, $F(2.9, 21) = 22.887, p < .001$. Simple contrasts indicate that there was a significant decrease in calmness from baseline in the LT condition at 8 min in-task, $F(1, 21) = 18.280, p < .001$, 16 min in-task, $F(1, 21) = 17.168, p < .001$, and immediately posttask, $F(1, 21) = 23.585, p < .001$, followed by a significant increase in calmness at 30 min, $F(1, 21) = 6.051, p = .021$, 45 min, $F(1, 21) = 6.202, p = .019$, and 60 min, $F(1, 21) = 16.829, p < .001$, posttask, but no significant difference from baseline at 15 min posttask, $p = .396$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = –1.02; 16 min in-task, ES = –1.01; immediately posttask, ES = –1.03;
15 min posttask, ES = 0.13; 30 min posttask, ES = 0.43; 45 min posttask, ES = 0.48; 60 min posttask, ES = 1.56.

When participants were in the 5% above LT condition, there was a significant effect of time, $F(3, 21) = 21.145, p < .001$. Simple contrasts indicate that there was a significant decrease in calmness from baseline in the 5% above LT condition at 8 min in-task, $F(1, 21) = 16.508, p < .001$, 16 min in-task, $F(1, 21) = 19.131, p < .001$; 0 min, $F(1, 21) = 38.624, p < .001$, 15 min, $F(1, 21) = 7.177, p = .012$, and 30 min, $F(1, 21) = 10.527, p = .003$, posttask, and a significant increase in calmness at 45 min, $F(1, 21) = 15.663, p < .001$, and 60 min, $F(1, 21) = 10.542, p = .003$, posttask. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = –1.16; 16 min in-task, ES = –1.21; immediately posttask, ES = –1.24; 15 min posttask, ES = –0.75; 30 min posttask, ES = –0.86; 45 min posttask, ES = 0.77; 60 min posttask, ES = 0.78.

**Anxiety Scores.** For anxiety scores measured by the SAI, there was a significant effect of time, $F(3.2, 84.5) = 30.137, p < .001$, condition, $F(1.4, 36.3) = 8.212, p = .003$, and Time × Condition, $F(4.5, 117.4) = 13.910, p < .001$, but not Time × Group, $p = .345$, indicating that there was a difference in anxiety scores across time as a function of condition (see Figure 6).

When participants were in the 5% below LT condition, there was a significant effect of time, $F(3.4, 21) = 16.543, p < .001$. Simple contrasts indicate that there was not a significant difference in anxiety scores from baseline in the 5% below LT condition at 8 or 16 min in-task, $ps > .15$, but that there was a significant decrease from baseline immediately post, $F(1, 21) = 6.234, p = .019$, as well as at 15 min,
When participants were in the LT condition, there was a significant effect of time, $F(3, 21) = 21.995, p < .001$. Simple contrasts indicate that there was not a significant difference from baseline in the LT condition at 8 or 16 min in-task, or immediately posttask, $ps > .22$, but there was a significant decrease from baseline at 15 min, $F(1, 21) = 9.024, p = .006$, 30 min, $F(1, 21) = 16.223, p < .001$, 45 min, $F(1, 21) = 17.301, p < .001$, and 60 min, $F(1, 21) = 48.606, p < .001$, posttask. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = 0.20; 16 min in-task, ES = 0.04; immediately posttask, ES = –0.20; 15 min posttask, ES = –0.63; 30 min posttask, ES = –0.78; 45 min posttask, ES = –0.95; 60 min posttask, ES = –1.43.

When participants were in the 5% above LT condition, there was a significant effect of time, $F(3, 21) = 25.194, p < .001$. Simple contrasts indicate that there was a significant increase in anxiety scores from baseline in the 5% above LT condition at 8 min in-task, $F(1, 21) = 5.089, p = .032$, 16 min in-task, $F(1, 21) = 7.922, p = .009$, and 15 min, $F(1, 21) = 10.447, p = .003$, and 30 min, $F(1) = 10.891, p = .003$, posttask, followed by a significant decrease in anxiety scores from baseline at 45 min, $F(1, 21) = 15.860, p < .001$, and 60 min, $F(1, 21) = 42.092, p < .001$, posttask, but not immediately posttask, $p = .492$. Effect sizes, representing magnitude of change at each time point compared with baseline were as follows: 8 min in-task, ES = 0.38; 16 min in-task, ES = 0.57; immediately posttask, ES = 0.13; 15 min posttask, ES = 0.51; 30 min posttask, ES = 0.81; 45 min posttask, ES = –0.84; 60 min posttask, ES = –1.50.

**Discussion**

Our results provide partial support for the dual-mode model in the context of opponent-process theory, such that 5% above LT condition produced a worsening of affect in-task compared with all other conditions (with increased anxiety scores relative to baseline in-task in the 5% above LT condition, compared with nonsignificantly reduced anxiety scores relative to baseline in-task in the other two conditions). Across conditions, participants experienced in-task increases in energy and tension, and in-task decreases in tiredness and calmness relative to baseline, all indicative of increased activation, as would be expected in-task.

Contrary to what opponent-process theory would suggest, exertion 5% above LT produced increased tension and anxiety scores from 0 to 30 min posttask, compared with decreased tension and anxiety scores from 0 to 30 min posttask in the other two conditions, relative to baseline. Similarly, calmness decreased in-task for all conditions, but was not significantly different from baseline at 15 min posttask and decreased from baseline at 30 min posttask in the LT and 5% below LT conditions, whereas it was decreased from baseline at 15 and 30 min posttask in the 5% above LT condition. These results can be explained, however, by the extended
recovery time needed for physiological processes such as body temperature, respiration, and cortisol to return to baseline following high levels of exertion resulting from excess postexercise oxygen consumption (Gaesser & Brooks, 1984). After 30 min posttask, when in the 5% above LT condition, participants experienced comparable reductions in tension and anxiety, and increases in calmness, scores as in the other conditions. This is evidence in support of a “modified” opponent-process theory, which would take into account the extended (30-min) recovery time needed for exertion above LT, as shown by the response pattern in the tension, calmness, and anxiety in this sample. Across conditions, participants experienced increased energy and decreased tiredness posttask, relative to baseline, suggesting overall affective improvement posttask, as predicted.

No Group × Condition interaction was found, so the study does not necessarily support previous evidence that active participants experience more affective benefit at higher levels of exertion than inactive participants (Blanchard et al., 2001; Tieman et al., 2002). However, it is also possible that LT when defined as in the current study provides a useful biological threshold that accounts for fitness differences by controlling for anaerobic metabolic responses. This may also help explain the results of Bixby and Lochbaum (2006) who found that exercise history did not appreciably influence affective responses, particularly during recovery. As in the current study, intensity was assigned based on a threshold (i.e., ventilatory threshold) rather than just as a percentage of VO₂max. In the current study, there was evidence that there was a difference in fitness between the groups, as the active group was significantly leaner and had significantly higher LT than the inactive group. There was also limited support that there was a difference in overall response between the groups. For example, inactive participants reported a greater increase in in-task tension relative to baseline, compared with active participants. Perhaps this level of exertion was unfamiliar to them, and as a novel experience, it resulted in more tension than in the more experienced, fitter, active participants (see Figure 4).

The active participants reported higher RPE overall than the inactive participants, despite the fact that both groups were exercising at the same intensity relative to their LT. This experience of higher exertion could have influenced their reaction to the task, particularly their thoughts, which according to the dual-mode model could influence affect in the below LT condition. There was not, however, a condition by group interaction effect in evidence here. The differences in tension between the groups are not accounted for by the difference in RPE, as we would expect higher RPE to be associated with greater increased tension, whereas the inactive group experienced a greater increase in tension. While it is possible that the differences in RPE between the groups could have influenced their affective response, there is no particular reason to assume that that is the case. Furthermore, the slight differences in RPE make intuitive sense given that the active group was exercising at a higher absolute intensity and a greater percentage of their VO₂max.

Based on the current data as well as the known physiological responses that continue into recovery following higher intensities of exercise, it appears that we may need to consider a “modified” opponent-process theory for examining psychological effects of exercise. This modified model would need to take into account the fact that the a process would not stop immediately upon removal of the stimulus (i.e., exercise) and that this would then impact the time-course and potentially the magnitude of the b process. This is particularly evident in the pattern of affective
response for tension, calmness, and anxiety scores in this study. When participants were in the 5% above LT condition, they experienced increased tension in-task and for 30 min posttask without significant changes from baseline at any time post-task (as opposed to decreased tension from 15 min posttask onward in other two conditions), decreased calmness in-task and for 30 min posttask (as opposed to no difference from baseline at 15 min posttask, and increases in calmness at 30 min posttask in the other two conditions), and increased anxiety scores in-task and for 30 min posttask (as opposed to decreased anxiety scores from immediately posttask in the 5% below LT condition or 15 min posttask onward for the LT condition).

Despite the criticism that use of the SAI has received over the years (e.g., Ekkekakis et al., 1999; Ekkekakis & Petruzzello, 2000), the potential utility of the scale when used in conjunction with other affective measures and/or physiological measures has been primarily dismissed or overlooked. According to Spielberger (1985), the SAI can “facilitate [emphasis added] distinguishing the physiological concomitants of anxiety as an emotional state from arousal due to physical exertion . . .” (p. 14). Given that the SAI, energy, and tension subscales did not all share the same pattern of results, in both direction and magnitude, it is likely that the state anxiety scores in this study do in fact reflect a noxious challenge to the organism that induces a threat to well-being. In other words, the responses seen do not simply reflect arousal. In support of this notion, Arent et al. (2005) found the overall postexercise anxiety scores to be related to cortisol responses following HPA axis activation during high-intensity resistance training. As Holsboer (1999) and others have established, corticotropin-releasing hormone has been found to be anxiogenic, and this would be consistent with the increases in state anxiety scores that have been seen with exercise intensities requiring enhanced activation of the stress response. In both studies, anxiety scores increased at these higher intensities that required pronounced perturbation of physiological homeostasis which can impart a tremendous strain on the organism. This is not particularly surprising when one considers that Lazarus (1998) has contended that “psychological stress, overall, refers to demands (or conflicts among them), that tax or exceed available resources (internal and external) as appraised by the person involved [emphasis added]” (p. 198). In addition, Lazarus acknowledges that a “stressful appraisal produces negatively toned emotions such as anxiety . . .” (p. 198). Rice (1992) indicates that anxiety resembles a general state of apprehension, and that distinguishing anxiety from stress is nearly impossible as both of them refer to the “subjective psychological result of environmental pressure” (p. 8). During high-intensity exercise, “apprehension” can certainly occur with increased homeostatic challenge due to progressively increasing contribution of anaerobic metabolism or secretion of the stress hormones associated with enhanced activation of the HPA axis that would arise to meet metabolic demands, followed by reduction in apprehension after the task has been completed. The data from this study support this model, particularly given the large effect sizes for decreased anxiety 60 min posttask, compared with either nonsignificant or small effect size changes for energy and tension at this time point.

Much of the criticism of the SAI in exercise research is based only on the 8-item short version. There are a number of differences between the 8- and 20-item versions and this warrants further consideration. While this debate is clearly far from concluded, it would be shortsighted to overlook the potential utility of a measure
such as the SAI to assess symptoms of anxiety that may occur above and beyond the symptoms of just physiological arousal due to exercise (Spielberger, 1985). It is also possible that lower scores on the SAI should be interpreted as reflecting a “state of well-being” (Spielberger, 1985, p. 15). Perhaps the debate over the semantic issues of assessing “state anxiety” has failed to consider what reductions in scores on the SAI actually reflect with regards to the well-being of the individual.

Although the study has the strength of full dimensional and categorical measures used in-task, it is limited by its relatively small sample size. Furthermore, the artificial setting of the laboratory allows for more precise control and manipulation of variables that may affect responses, but reduces external validity. People tend to exercise in social settings, such as gymnasiums, or outdoors, as opposed to the less stimulating laboratory setting. After exercising, people generally do not sit quietly for 60 min, but rather continue on with their day. It is therefore important to recognize that the findings regarding exertion level and affective improvement may not apply in more naturalistic exercise settings. Extension of this work in naturalistic settings is recommended. Further directions for this line of research should include further tests of the “modified” opponent-process theory, as well as further investigation into the dual-mode model, such as examining how cognitions influence affect at lower levels compared with higher levels of exertion.

These results suggest that maximal affective benefit in-task and for 30 min posttask is achieved through exercise at or 5% below LT. Exercise above LT, on the other hand, produces comparable affective improvement after 30 min posttask, preceded by worsening of affect in-task and during 30 min of recovery. Awareness of this information could be useful to individuals beginning an exercise routine; if they know what changes to expect at what intervals, they can choose a level of exercise that will help them achieve their preferred psychological state, and possibly be more likely to adhere to an exercise program.

References


*Manuscript received: November 25, 2009*  
*Revision accepted: July 20, 2010*