Dose-response and mechanistic issues in the resistance training and affect relationship

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Abstract:

The purpose of this study was to examine the dose-response gradient of exercise-induced affective change and the role of the stress response as a contributing mechanism. Male and female participants ($N = 31$) completed three different resistance training protocols (40%, 70%, and 100% of 10-repetition maximum [RM]) and a no-treatment control condition. Affective responses were assessed immediately before and at 0–5, 15, 30, 45, and 60 minutes postexercise. Salivary cortisol and heart rate (HR) responses were also assessed during each condition. As predicted, moderate intensity resistance training generally produced the greatest improvements in affect ($p < .05$). HR and cortisol accounted for as much as 27.3% and 5.4% of the affective variance, respectively. Findings support a curvilinear dose-response relationship between intensity and affective responses, with moderate intensity training resulting in immediate, large, and enduring affective benefits. Results also suggest that moderate activation of the stress response positively influences exercise-induced affective change.

Keywords: strength training | anxiety | intensity | stress response

Article:

Recent reviews have provided some basis for concluding that exercise does play a role in promoting improved affect (Arent, Landers, & Etnier, 2000; Landers & Arent, 2001; Mutrie, 2000). However, there is still controversy regarding whether the relationship between exercise and anxiety reduction meets Hill's (1965) criteria for concluding that a "causal" relationship exists. With the exception of Mutrie (2000), researchers have concluded that while many of the criteria for causation are met, there is a paucity of evidence for the dose-response criterion (Arent, Rogers, & Landers, 2001; O'Neal, Dunn, & Martinsen, 2000). Although dose-response intensity effects have been suggested (e.g., Petruzzello & Tate, 1997), there is little direct empirical evidence to accurately establish a dose-response curve for the exercise/affect relationship. This is primarily due to the fact that most studies in this area have not compared more than two levels of intensity. One exception is found in the resistance training literature (O'Connor, Bryant, Veltri, & Gebhardt, 1993), but the conclusions derived from that study are limited because of statistical problems (i.e., missing data limiting within-subjects comparisons) and an inability to compare to other studies in the area due to the lack of a true "high intensity" condition.

Dose-response considerations aside, and despite at least some initially encouraging findings, what research evidence there is for the effects of resistance training on affect is plagued by methodological issues that limit the formulation of a conclusive statement regarding the efficacy of this type of exercise in general. Some of these issues include: (a) poorly defined ranges of intensity and volume due to self-selection of exercise (Koltyn, Raglin, O'Connor, & Morgan, 1995); (b) lack of information on volume or exercise intensity for all exercises (Garvin, Koltyn, & Morgan, 1997); (c) potentially confounded postexercise assessments (Focht & Koltyn, 1999; O'Connor et al., 1993); and (d) lack of control for volume (i.e., total number of repetitions; Kraemer & Ratamess, 2004) due to time constraints or different repetition ranges for different loads (Bartholomew & Linder, 1998; Focht, 2002; Focht & Koltyn, 1999). Though these studies have provided an important foundation for the examination of resistance training's impact on affective responses, the methodological issues must be resolved before an accurate determination can be made about the nature of this relationship.

An initial step in the attempt to correct these problems involves reconsidering and clarifying the concept of strength training "intensity." Previous studies have usually adopted a definition of intensity based solely on the percentage of one-repetition maximum (1-RM) that participants are lifting, which may more accurately be referred to as "load" (Baechle, Earle, & Wathen, 2000; Kraemer & Ratamess, 2004). When participants are using 70% of their 1-RM but performing 10 repetitions, they are likely engaging in high intensity (rather than moderate intensity) strength training, as 70–75% of 1-RM closely approximates 100% of 10-RM (Baechle et al.). Therefore, variables such as whether a participant performed sets to muscular failure, physiological responses, and ratings of perceived exertion (Tuson, Sinyor, & Pelletier, 1995) need to be considered when evaluating the influence of resistance training intensity on affective change. In addition, in order to establish a dose-response curve for strength training intensity, volume (i.e., sets × reps; Kraemer & Ratamess) must be consistent from condition to condition. The use of more precise operational definitions of exercise intensity is important considering that the influence of the intensity of a stressor on affective and behavioral responses has formed the foundation for theories on the stress/affect relationship.

Selye (1950) coined the terms "distress" and "eustress" to reflect the notion that not all challenges to homeostasis were noxious. He contended that brief, moderate, controllable challenges to the organism might result in pleasant experiences. Csikszentmihalyi (1982) built upon this idea with the theory of optimal stimulation. According to this theory, when the challenges of an activity are considered threatening or beyond the individual's capabilities (as might occur with very high intensity exercise), feelings of negative affect and anxiety will be the result. At the other end of the spectrum, if the activity is not challenging enough (as might occur with very low intensity exercise), boredom or disinterest might result. When balanced with the individual's capability, the result of the activity should be an optimal affective experience. One question, however, is whether or not there is an underlying mechanism that drives the affective response to the different levels of challenge or intensity of exercise.

Though many plausible physiological mechanisms (e.g., the cardiac influence model, the beta-endorphin hypothesis, the norepinephrine hypothesis) have been advanced to explain the acute exercise/affect relationship, none has received conclusive support as a primary mechanism (see Landers & Arent, 2001, for review). Part of the problem may stem from the very specific nature of each model or hypothesis. All of these proposed mechanisms are specific indications of a more general activation of the hypothalamic-pituitary-adrenal (HPA) axis and/or the autonomic nervous system (ANS). Furthermore, both the HPA axis and the ANS are activated under stress due to their role in protection of the organism and mobilization of the organism's resources under these conditions. Considering that exercise can serve as a stressor (Borer, 2003), it makes sense to examine the general stress response when trying to establish the underlying reasons for an exercise/affect relationship, particularly when one considers the association of HPA and ANS activation with anxious and depressive symptomology (Filaire, Le Scanff, Duche, & Lac, 1999; Nesse, Cameron, Curtis, McCann, & Huber-Smith, 1984).

It has been suggested (Solomon & Corbit, 1973) that the calming response following the presentation of certain stressors may be mediated by vagal "overshoot" or a rebound response to sympathetic activation (as evidenced by heart rate response) in an attempt to return to homeostasis. In addition, glucocorticoids (i.e., cortisol) released during stress may act on the CNS to influence mood (Schulkin, Gold, & McEwen, 1998), and both the HPA axis and ANS can influence emotional response to stressor exposure (Chrousos & Gold, 1992). Hatfield (1991) contends that this phenomenon holds particular relevance for the affective responses seen following acute exercise. More important, this effect may be influenced by the intensity of the exercise stimulus. At high stressor intensities, circulating hormones can actually produce effects that might be considered anxiogenic (Chrousos & Gold). This may explain the transient anxiety increases seen in some resistance training studies (e.g., Bartholomew & Linder, 1998; Raglin, Turner, & Eksten, 1993), considering that both HPA axis and ANS activation are positively related to the intensity of a resistance training session (Hakkinen & Pakarinen, 1993; Kraemer et al., 1993).

Despite the recognized relationship between the HPA axis, ANS, and resistance training intensity, a question still remains as to the optimal stimulus required to produce optimal affective outcomes. Taking the effects of stressor intensity into account, Chrousos and Gold (1992) propose a model that provides for a curvilinear relationship between the activation of the stress system and a sense of well-being. Thus, optimal affective change (particularly for anxiety and other arousal-laden constructs) following exercise should occur at moderate intensity for most people, with relatively little affective benefit occurring at low or high intensities (Chrousos & Gold). This notion is consistent with other theories on the stress/affect relationship (Csikszentmihalyi, 1982; Selye, 1950).

In order to examine stress system response to exercise and infer level of challenge to the organism, researchers can use physiological measures of HPA axis activation and ANS activation (Chrousos & Gold, 1992). Fortunately, this can be done using noninvasive measures such as salivary cortisol (Kirschbaum & Hellhammer, 1994) and heart rate (HR) to examine the level of activation of the HPA axis and ANS, respectively, while helping to prevent unintended changes in affect (particularly anxiety) that might result from blood draws.

In light of these considerations and the aforementioned problems in the resistance training literature, two primary objectives of this study were established. The first objective was to examine the dose-response gradient of affective change by manipulating three distinct levels of weight training intensity based on percentages of each individual's 10-RM while holding sets and repetitions (i.e., volume) constant. The second objective was to examine the role of the stress response, specifically the HPA axis and ANS, as a contributing mechanism to the affective changes following resistance exercise.

Based on the work of Chrousos and Gold (1992), Selye (1950), and Csikszentmihalyi (1982), it was hypothesized that there is a curvilinear relationship between resistance training intensity and postexercise affective response due to activation of the general stress response. Thus it was predicted that there would be a significant curvilinear effect for intensity, with the moderate intensity condition (70% 10-RM) producing the most beneficial changes in anxiety, positive affect (PA), negative affect (NA), energy, tiredness, tension, and calmness over time. It was also predicted that change in average HR (ΔAHR), peak HR (PHR), cortisol, and ratings of perceived exertion (RPE) would demonstrate a linear relationship with exercise intensity. Finally, it was predicted that there would be a significant curvilinear relationship between physiological activation (ΔAHR, PHR, cortisol, and RPE) and improvements in affect.

Method

Participants

Male (n = 15; 22 ± 0.7 yrs; 180.8 ± 1.9 cm; 77.8 ± 2.9 kg) and female (n = 16; 20.8 ± 0.5 yrs; 166.5 ± 1.6 cm; 60.2 ± 1.4 kg) undergraduate students from a major southwestern university took part in the study. In order to be included in the study, all participants had to have been active aerobic exercisers who were not currently weight training. For the purpose of this study, "active aerobic exerciser" was defined as an individual engaging in structured aerobic exercise at least three times per week for 30 minutes at a moderate intensity (e.g., a fast walk) for the last 4 months. Potential participants also had to have refrained from strength training over this same period of time.

These screening criteria were used for a number of reasons. First, it is generally recommended that sedentary individuals should not perform high intensity weight training. Second, active individuals were used in order to control for preexisting aversion to exercise that may be common among sedentary individuals. Third, participants who were not engaging in weight training were used in order to help attenuate the influence of expectancies associated with different modes of resistance training or preferred modes that resistance-trained individuals may have developed. This also prevented negative affective responses that might have resulted from the study requirement of having to stop a current weight training program, as regular exercisers often experience increased mood disturbance if forced to refrain from their regular program (Allen, 1990). In addition to these criteria, participants also had to have been free of any chronic disease (bone, joint, or other) affecting the ability to weight train, and also be free of any history of major psychological disorders. Female participants had to have been using oral contraceptives, so as to limit hormonal fluctuations associated with menstrual phases (Altemus, Roca, Galliven, Romanos, & Deuster, 2001). Written informed consent was obtained from each individual prior to participation in the study.

Procedures

Frequency, duration, and mode of physical activity were screened verbally using the Exercise Habits portion of the Lifestyle Evaluation Questionnaire (Heyward, 1998). In addition, potential participants were asked to rate their average physical activity intensity using Borg's (1998) 15-point Rating of Perceived Exertion (RPE) scale. Based on the inclusion criteria established, they had to rate their typical exercise intensity as at least a "12" to be included. Potential participants were then asked how many months they had been participating at this level. Based on the responses, those who had been participating in the required level of endurance activity and had refrained from participating in a structured weight training program were eligible for inclusion in the study.

After completing an initial familiarization and strength testing session, all participants completed a no-treatment control condition and three strength training sessions. These conditions were presented in counterbalanced order, each presented 3–7 days (at least 72 hrs) apart to allow adequate recovery and time for delayed onset muscle soreness (DOMS) to subside. The no-treatment control condition consisted of watching a 45-minute video on the history of strength training and bodybuilding. All women completed their sessions during the 21-day pill phase of their menstrual cycle so that the hormonal dose from the oral contraceptives would be consistent.

During the initial testing session, 10 repetitions maximum (10-RM) were determined for each of six upper body exercises for each participant. The 10-RM is considered to be a safer and more valid means of strength testing than the 1-RM in people not accustomed to weight training (Baechle et al., 2000). Furthermore, the 1-RM test is contraindicated for most unijoint, small muscle lifts (e.g., biceps curls, triceps extensions). The exercises included bench press, lat pulldown, shoulder press, seated rows, triceps extensions, and biceps curls. These six exercises target the major muscle groups of the upper body and represent a typical push/pull upper body resistance training workout. Participants first warmed up on a stationary bicycle for 5 minutes prior to strength testing in order to increase blood flow and prepare them for the maximal tests. The 10-RM for each exercise was determined as described by Baechle et al. (2000). Participants performed progressively heavier warm-up sets. Additional weight was added until a weight allowing *only* 10 repetitions (completed in good form) was determined. A rest period of 2 to 4 minutes was allowed between attempts in order to ensure adequate recovery. This same procedure was followed so as to establish the 10-RM for each of the six lifts. Each 10-RM was determined within three attempts.

The exercise sessions consisted of the same six upper-body exercises (completed in the same order as during maximal testing) performed as follows on separate days: (a) three sets of each exercise performed at 40% of the predetermined 10-RM for 10 reps; (b) three sets of each exercise performed at 70% of the predetermined 10-RM for 10 reps; or (c) three sets of each exercise performed at 100% of the predetermined 10-RM for 10 reps. Participants rested for 90 seconds between sets. According to Wathen (1994), 40%, 70%, and 100% of a given RM would constitute low, moderate, and high intensities, respectively. These conditions have never been compared to each other based on the particular hormonal and psychological variables included in this study, and will provide for a test of the fit of the curvilinear dose-response model proposed by Chrousos and Gold (1992).

Participants were allowed to withdraw at any time, without penalty, if they experienced adverse effects from any of the treatments. Furthermore, all testing occurred between 10 a.m. and 3 p.m. in order to minimize diurnal variations and maximize acute cortisol changes. These midday hours have been found to be relatively stable periods of cortisol secretion (Altemus, Deuster, Galliven, Carter, & Gold, 1995; Sachar, 1975). This is also when cortisol changes following stressor exposure (such as exercise) have been found to be largest and most distinct (Altemus et al.). As an additional control, each participant completed all of his/her conditions at the same time of day. In order to further control for the effects of food intake on cortisol secretion, participants were asked to refrain from eating for at least 60 minutes prior to baseline sampling.

Dependent Variables

Rating of Perceived Exertion. To assess the participant's perception of the intensity of the workout, Borg's (1998) 15-point RPE scale was used three times for each condition. The first two assessments occurred after the second and fourth exercises, respectively, with the final assessment occurring immediately following the workout. The assessments occurred every 15 minutes during the control condition. This scale ranges from 6 (no exertion at all) to 20 (maximal exertion). The three assessments were combined to get an average RPE for each condition.

Salivary Cortisol. Saliva samples were collected immediately before and after each condition, as well as at 30 and 60 minutes of recovery. These samples were collected using the Salivette sampling device, which is composed of a small polyester swab inside a centrifugation tube (Sarstedt Inc., Rommelsdorf, Germany). The participants were asked to chew on the swab for at least 45–60 seconds, which has been recommended for sufficient sampling volume (Kirschbaum & Hellhammer, 1994). Once the samples were returned to the laboratory, they were stored at –80 °C until analysis. Cortisol was analyzed using a coated-tube RIA from commercially available kits (ICN Pharmaceuticals, Costa Mesa, CA).

Heart Rate. Heart rate (HR) was monitored for 5 minutes before beginning each condition, throughout the condition, and for the entire 60-minute recovery period to assess ANS activation. HR was assessed using the Polar Vantage XL monitor (Polar Electro Co., Woodbury, NY) at 5-second intervals and downloaded using Polar HR monitor software for computer analysis. ΔAHR from baseline and peak HR (PHR) were assessed for each condition.

Affective Assessments. State anxiety, arousal/activation, and positive and negative affect were assessed using the STAI (Spielberger, Gorsuch, Luschene, Vagg, & Jacobs, 1983), AD-ACL (Thayer, 1989), and PANAS (Watson, Clark, & Tellegen, 1988), respectively, immediately before and at 0–5, 15, 30, 45, and 60 minutes following exercise. The STAI consists of 20 questions to which participants respond regarding their anxiety level. Internal consistency α for the STAI during recovery from exercise has been reported to range from .66 (Rejeski, Hardy, & Shaw, 1991) to .80 (Ekkekakis, Hall, & Petruzzello, 1999), and test-retest reliability has been adequate (R = .60; Spielberger et al.). The AD-ACL is composed of two primary dimensions:

energetic arousal and tense arousal. Each dimension is further divided into energy/tiredness, and tension/calmness, respectively. Test-retest reliabilities have been reported as .89 (energy), .89 (tiredness), .93 (tension), and .79 (calmness) (Thayer, 1989). The PANAS consists of 20 adjectives, with 10 representing negative affect and 10 representing positive affect. Internal consistency α's range from .86 to .90 for PA and .84 to .87 for NA, with test-retest reliabilities of .54 and .45 for PA and NA, respectively (Watson et al., 1988). Each question for the STAI, AD-ACL, and PANAS is answered with regard to how the participant feels "at that moment."

Statistical Analysis

In order to assess Prediction 1, we calculated area under the response curve (AUC) for each affective construct using the trapezoidal method and then adjusted for baseline values (DAUC). Rather than relying simply on time-point to time-point assessments, use of DAUC provides the summary function needed to examine the overall positivity or negativity of the participants' affective responses in order to adequately assess the dose-response curve postulated to exist by Chrousos and Gold (1992). It also has the advantage of taking time intervals into account, which is not considered when simply computing mean changes. Previous studies (e.g., DiLuigi, Guidetti, Baldari, & Romanelli, 2003; Roberts, Wessely, Chalder, Papadopoulos, & Cleare, 2004) have used AUC analyses to examine hormonal responses related to stress, affect, and exercise.

A 4 × 2 (condition × gender) MANOVA with repeated measures on the first factor was used to assess effects on DAUC anxiety, DAUC PA, DAUC NA, DAUC energy, DAUC tiredness, DAUC tension, and DAUC calmness. Univariate follow-up tests were conducted where appropriate, and linear, quadratic, and cubic trends were assessed. In order to test Prediction 2, we used separate repeated-measures univariate ANOVAs to assess ΔAHR, PHR, cortisol, and RPE responses to resistance training intensity. Follow-up trend analyses were also conducted. Prediction 3 was tested with separate hierarchical regression analyses using the polynomial trends for ΔAHR, PHR, DAUC cortisol, and RPE as the predictor variables to assess the relationship between each physiological activation variable and the DAUCs for the affective variables of anxiety, PA, NA, energy, tiredness, tension, and calmness.

For each univariate analysis, examination of the Huynh-Feldt epsilon for the general model was used to test the assumption of sphericity. If this statistic was larger than .75, sphericity was considered to have been met and the unadjusted univariate statistic was used. When epsilon was less than .75, it was considered a violation of the assumption of sphericity and the Huynh-Feldt (H-F) adjusted statistic was used to test significance. Due to the use of repeated measurements in the regression analyses, within-subjects clustering effects were assessed and adjusted significance tests were used where appropriate as outlined by Donner and Cunningham (1984) and Scott and Holt (1982).

Results

Physiological Activation as a Function of Intensity

Repeated-measures univariate ANOVAs revealed a significant effect of condition on ΔAHR, $F(3, 90) = 110.29$, $p < .001$, PHR, $F(3, 90) = 153.12$, $p < .001$, and RPE, $F(3, 90) = 711.036$, $p < .001$. Follow-up trend analyses revealed a significant linear relationship between ΔAHR and exercise intensity, $F(1, 30) = 148.77$, $p < .001$, and between PHR and exercise intensity, $F(1, 30) = 328.67$, $p < .001$. There was also a significant linear trend for the effects of intensity on RPE, $F(1, 30) = 2708.94$, $p < .001$. Means and standard deviations for ΔAHR, PHR, and RPE are listed in Table 1.

Table 1. Descriptive Statistics (M ± SD) for ΔAHR, PHR, and RPE as a Function of Condition

	Condition			
Variable	**Control**	**Low intensity**	**Mod. intensity**	**High intensity**
ΔAHR (bpm)	7.32	12.03	24.82	44.19
	±7.62	±6.59	±8.87	±14.15
PHR (bpm)	106.03	119.10	139.65	169.13
	±15.16	±13.39	±12.97	±15.26
RPE	6.00	8.31	12.39	17.14
	±0.00	±1.42	±1.11	±1.04

A repeated-measures univariate ANOVA was also conducted on cortisol secretion as a function of exercise intensity. In order to do this, the area under the cortisol response curve (AUC) was calculated and then adjusted for baseline values (DAUC). There was a significant effect of condition on cortisol secretion, $F(1.24, 37.08) = 5.86$, $p < .05$. Polynomial analyses indicated a significant quadratic trend for the effects of exercise intensity on cortisol DAUC, $F(1, 30) = 7.233$, $p = .012$, with high intensity training producing the only significant increase in cortisol secretion over the duration of exercise and recovery periods. Cortisol means and standard deviations are listed in Table 2.

Table 2. Descriptive Statistics (M ± SD) for Salivary Cortisol (µg/dl) as a Function of Condition and Time

	Time of Assessment			
Condition	**Pre**	**0 min. post**	**30 min. post**	**60 min. post**
Control	0.311	0.266	0.242	0.217
	±0.235	±0.197	±0.153	±0.148
Low intensity	0.314	0.269	0.235	0.209
	±0.179	±0.160	±0.099	±0.121
Moderate intensity	0.336	0.291	0.226	0.207
	±0.194	±0.149	±0.128	±0.125
High intensity	0.310	0.416	0.505	0.314
	±0.153	±0.299	±0.325	±0.223

Overall Affective Responses (Area Under the Curve)

Results of the 4 × 2 (condition × gender) MANOVA with repeated measures on the first factor indicated a significant main effect for condition, Wilks' $\lambda = .325$, $F(21, 233.14) = 5.318$, $p < .001$. The multivariate main effect for gender and the multivariate condition × gender interaction were not significant ($p > .18$). Due to the lack of a significant effect for gender, data were collapsed across males and females for the remainder of the analyses. Univariate follow-up tests were conducted for each affective variable due to the significant multivariate effect for condition.

Anxiety. A significant condition effect was found for DAUC anxiety, $F(1.91, 57.39) = 30.13$, $p < .001$. Polynomial contrast analyses revealed a significant cubic trend, $F(1, 30) = 48.45$, $p < .001$, with moderate intensity resistance training producing the largest reductions in anxiety over the recovery period (see Figure 1).

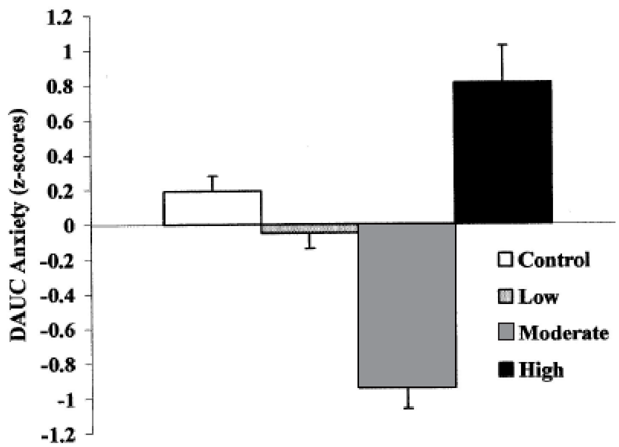

Figure 1. DAUC anxiety *z*-scores as a function of condition.

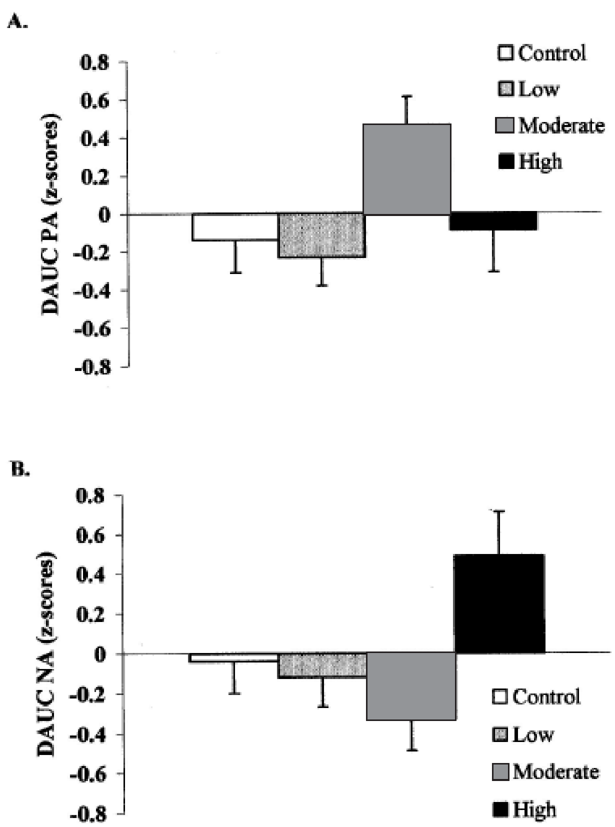

Figure 2. (A) DAUC positive affect *z*-scores and (B) DAUC negative affect *z*-scores as a function of condition.

PA. A significant effect of condition on DAUC PA was found, $F(3, 90) = 4.876$, $p = .003$. Polynomial contrast analyses revealed a significant cubic trend, $F(1, 30) = 17.593$, $p < .001$, with moderate intensity resistance training producing the only increase in PA over the duration of the recovery period (see Figure 2A). Low intensity training resulted in the largest total decrease in PA.

NA. A significant effect of condition on DAUC NA was found, $F(3, 90) = 5.008$, $p = .003$. Polynomial contrast analyses revealed a significant quadratic trend, $F(1, 30) = 12.868$, $p = .001$, with moderate intensity resistance training producing the largest decrease in NA over the duration of the recovery period (see Figure 2B). High intensity training resulted in the only increase in total NA.

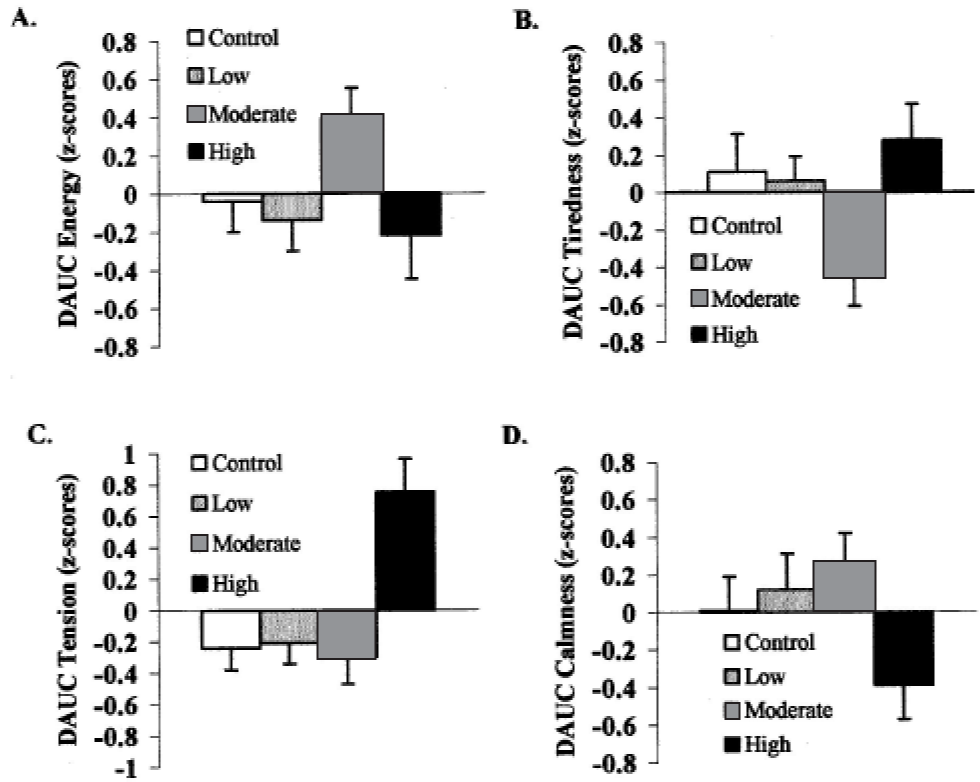

Figure 3. (A) DAUC energy *z*-scores, (B) DAUC tiredness *z*-scores, (C) DAUC tension *z*-scores, and (D) DAUC calmness *z*-scores as a function of condition.

Arousal/Activation. Significant effects of condition on DAUC energy, $F(3, 90) = 2.93$, $p < .05$; DAUC tiredness, $F(3, 90) = 3.49$, $p < .02$; DAUC tension, $F(3, 90) = 9.775$, $p < .001$; and DAUC calmness, $F(3, 90) = 2.92$, $p < .05$, were found. Polynomial contrast analyses revealed significant cubic trends for energy, $F(1, 30) = 10.47$, $p < .01$, and tiredness, $F(1, 30) = 8.21$, $p < .01$. Polynomial contrast analyses also revealed significant quadratic trends for tension, $F(1, 30) = 13.343$, $p < .001$, and calmness, $F(1, 30) = 4.986$, $p < .05$. Moderate intensity resistance training produced the only increase in energy (see Figure 3A) and decrease in tiredness (see Figure 3B) over the duration of the recovery period. The control condition, low intensity training, and high intensity training resulted in similar overall reductions in energy and increases in tiredness. Moderate intensity training also resulted in the greatest total increase in calmness (see Figure 3D) over the duration of the recovery period; only high intensity training resulted in overall decreases in calmness. High intensity resistance training also produced the only increase in tension (see Figure 3C) over the duration of the recovery period; the control condition, low intensity training, and moderate intensity training all resulted in similar total decreases in tension.

Predictors of the Affective Response

Δ*AHR*. Separate hierarchical regression analyses were performed using each affective variable's DAUC (anxiety, PA, NA, energy, tiredness, tension, and calmness) as the criterion variables. After centering the ΔAHR variable, we entered the linear function of ΔAHR as a predictor at Step 1, followed by the quadratic function of ΔAHR at Step 2, and finally the cubic function of change in AHR at Step 3. A significant cubic trend was found for ΔAHR and anxiety, F change (1, 120) = 5.612, $p < .02$. This cubic trend accounted for 27.3% of the variance in anxiety. A significant quadratic trend was found for ΔAHR and NA, F change (1, 121) = 12.782, $p < .01$. This quadratic trend accounted for 13.8% of the variance in NA. A significant quadratic trend was also found for ΔAHR and tension, F change (1, 121) = 5.778, $p < .02$, accounting for 14.7% of the variance. The quadratic function of ΔAHR was also found to significantly predict 7.6% of the variance in calmness, F change (1, 121) = 5.921, $p < .02$. ΔAHR did not predict a significant amount of variance in PA, energy, or tiredness ($p > .19$).

PHR. Separate hierarchical regression analyses were performed using each affective variable's DAUC (anxiety, PA, NA, energy, tiredness, tension, and calmness) as the criterion variables. After centering the PHR variable, we entered the linear function of PHR as a predictor at Step 1, followed by the quadratic function of PHR at Step 2, and finally the cubic function of PHR at Step 3. A significant quadratic trend was found for PHR and anxiety, F change (1, 121) = 10.773, $p = .001$. This quadratic trend accounted for 11.0% of the variance in anxiety. The cubic trend for PHR accounted for a significant amount of variance in PA, F change (1, 120) = 8.223, $p < .01$, $R^2 = .048$. A significant positive linear trend was found for PHR and NA, F change (1, 122) = 7.978, $p < .01$, $R^2 = .054$, and PHR and tension, F change (1, 122) = 18.573, $p < .011$, $R^2 = .125$. A significant though small amount of variance in energy was accounted for by the cubic trend for PHR, F change (1, 120) = 5.278, $p = .023$, $R^2 = .032$. The PHR cubic trend also accounted for 8.4% of the variance in tiredness, F change (1, 120) = 9.037, $p = .003$. PHR did not predict a significant amount of variance in calmness ($p > .075$).

Cortisol. Examination of scatter plots indicated that one participant might have been an outlier due to highly elevated cortisol levels (based on cortisol DAUC). Regression diagnostics were run, and values for studentized deleted residuals, centered leverage, and DFBeta Intercept indicated that the cortisol data for this participant were artificially altering the fit of the regression line. Therefore the data for this participant were removed from regression analyses utilizing cortisol data. The remaining data consisted of cortisol values and affective responses from 16 females and 14 males.

Separate hierarchical regression analyses were performed using each affective variable's DAUC (anxiety, PA, NA, energy, tiredness, tension, and calmness) as the criterion variables. After centering the cortisol DAUC variable, we entered the linear function of cortisol DAUC as a predictor at Step 1, followed by the quadratic function of cortisol DAUC at Step 2, and finally the cubic function of cortisol DAUC at Step 3. A significant linear trend was found for cortisol

DAUC and anxiety, F change (1, 118) = 7.781, p = .006. This linear trend accounted for 5.4% of the variance in anxiety. The linear trend for cortisol DAUC also accounted for a significant amount of variance in PA, F change (1, 118) = 5.356, p = .022, R^2 = .035. A significant linear trend was found for cortisol DAUC and energy, F change (1, 118) = 6.460, p = .012, R^2 = .044; cortisol DAUC and tiredness, F change (1, 118) = 5.610, p = .019, R^2 = .037; and cortisol DAUC and tension, F change (1, 118) = 4.927, p = .028, R^2 = .032. However, the quadratic trend for cortisol DAUC and energy was nearly significant, F change (1, 117) = 3.884, p = .051, R^2 = .067, as was the linear trend for cortisol DAUC and calmness, F change (1, 118) = 3.435, p = .066, R^2 = .020. Cortisol DAUC did not predict a significant amount of variance in NA (p > .15).

RPE. Separate hierarchical regression analyses were performed using each affective variable's DAUC (anxiety, PA, NA, energy, tiredness, tension, and calmness) as the criterion variables. After centering the RPE variable, we entered the linear function of RPE as a predictor at Step 1, followed by the quadratic function of RPE at Step 2, and finally the cubic function of RPE at Step 3. A significant quadratic trend was found for RPE and anxiety, F change (1, 121) = 39.892, p < .001, with RPE accounting for 25.6% of the variance in anxiety. The quadratic trend for RPE also accounted for a significant amount of variance in NA, F change (1, 121) = 6.524, p = .012, R^2 = .06, tension, F change (1, 121) = 7.101, p < .01, R^2 = .133, and calmness, F change (1, 121) = 4.925, p = .028, R^2 = .04. The quadratic trend for RPE and tiredness was nearly significant, F change (1, 121) = 3.661, p = .058, but RPE only accounted for 1.3% of the variance in tiredness. RPE did not predict a significant amount of variance in PA or energy (p > .20).

Discussion

The purpose of this study was to examine the dose-response gradient of affective change to varying intensities of resistance training as well as to examine the role of the stress response as a contributing mechanism to affective changes following resistance exercise. Fulfillment of these objectives was predicated on the ability to accurately and appropriately manipulate weight training intensity as a function of each individual's 10-RM while holding volume constant. As expected, ΔAHR, PHR, cortisol secretion, and RPE differed between intensity conditions. For most of these variables, the relationship with intensity was linear. Furthermore, the greatest values for these intensity-related variables (except for cortisol) were seen in the high intensity (100% 10-RM) condition, followed by the moderate intensity (70% 10-RM) condition, then the low intensity (40% 10-RM) condition, and finally the control condition. Cortisol secretion was only increased in the high intensity condition, suggesting a threshold effect for HPA-axis activation as a result of resistance training. This finding is consistent with previous research on the response of the stress system to varying stressor intensities (Chrousos & Gold, 1992).

Analysis of DAUC for each affective variable provided strong support for the prediction of a curvilinear relationship between intensity and postexercise affective response. Significant curvilinear trends for intensity were found for all affective variables. As predicted, moderate intensity strength training produced the greatest improvements in anxiety, PA, NA, energy, tiredness, and calmness. Similar improvements in tension were seen with moderate intensity, low intensity, and control conditions. High intensity training resulted in increased anxiety, NA, tiredness, and tension, and decreased energy and calmness. Similarly, low intensity exercise was generally ineffective in producing beneficial changes in affect, and was typically no different than the control condition.

These findings also suggest that affective change following resistance training occurs at both a dimensional (i.e., the dimensions of PA and NA) and categorical (i.e., anxiety) level. This supports the contention by Ekkekakis and Petruzzello (2000) that, because exercise is a "multifaceted stimulus," it has the ability to "induce affective responses emerging from any level of affective processing, from basic affect to specific emotions" (p. 78).

The relative lack of significant findings for low intensity resistance training and the control condition does little to support the distraction hypothesis (Bahrke & Morgan, 1978) and is consistent with findings from previous meta-analytic reviews on the exercise/affect relationship (Arent et al., 2000; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991). The distraction hypothesis posits that exercise acts as a time-out from daily stressful events. It may be inferred from this hypothesis that the intensity of the exercise should be irrelevant. Interestingly, in the current study a number of participants actually indicated displeasure or boredom with the low intensity condition. Combined with the lack of significant findings for the control condition, this would suggest that exercising at a sufficient intensity provides for more than a simple distraction from daily hassles.

These findings may hold particular relevance for studies designed to examine the phenomenon of exercise adherence. Previous research (Rejeski, 1994) has indicated that whether or not participants continue to engage in a structured exercise program may be influenced by affective responses to initial exercise bouts. Based on the results of the current study, researchers clearly must consider important intensity-related variables when designing studies that employ resistance training exercise. In addition to considering the negative affective symptoms that apparently accompany very high intensity strength training, researchers must also realize the insufficient stimulation provided by low intensity training. Simply going through the motions of strength training apparently does very little to promote a positive affective experience, and would also do little to promote substantial fitness improvements.

In order to determine the impetus behind the demonstrated dose-response effects in the current study, we examined potential underlying physiological mechanisms. As hypothesized, measures of autonomic activation were significant predictors of most changes in exercise-induced affect, particularly changes in "negative" affective constructs. The demonstrated relationships, as expected, were curvilinear in nature. These curvilinear trends provide support for the proposed relationship between activation of the stress system and a sense of well-being (Chrousos & Gold, 1992). These trends explained a considerable amount of variance in many affective constructs, most notably anxiety (27.3%). However, the relative lack of predictive ability of these physiologically-based mechanisms for changes in "positive" affect (i.e., PA, energy) would suggest that there may be other important mechanisms underlying the exercise/affect relationship. This was particularly surprising considering that these constructs were changed in a similar fashion to the negative affective constructs as a function of the intensity condition.

These results, though, are consistent with previous research (McGowan, Talton, & Thompson, 1996) which found significant correlations between average exercise heart rate and mood disturbance, but did not find similar significant correlations when examining changes in vigor following weight training. Other studies have had similar difficulties trying to relate changes in PA to physiological mechanisms (Hatfield, Goldfarb, Sforzo, & Flynn, 1987; Kraemer, Dzewaltowski, Blair, Rinehardt, & Castracane, 1990). However, these findings may fit within the models proposed by Selye (1950) and Csikszentmihalyi (1982) based on the notion of an optimal challenge or optimal stimulation that moderate intensity training might provide (vs. high or low intensity exercise) in order to produce pleasant experiences following physical activity. These types of "optimal experiences" may impart a sense of mastery, which may in turn provide for improvements in positive affective constructs. Though the examination of the role of efficacy beliefs in the affective responses to exercise was not the purpose of the current study, future research may want to consider including assessments of this potential mechanism.

It may also be the case that changes in positive affect are influenced to a greater degree by individual interpretations of the exercise experience (Tuson et al., 1995). It is possible that changes in positive affective items such as *strong*, *proud*, and *inspired* are brought about by cognitive appraisals based on exteroceptive cues associated with the exercise bout. On the other hand, negative affective items such as *tense* and *jittery* may be influenced to a greater degree by interoceptive cues associated with the physiological demands of exercise. This might explain why the stress-response variables examined in this study were better predictors of negative affective changes than of positive affective changes. The result could be similar changes in positive and negative affect following a given exercise intensity, but for different reasons. The enduring activation of internal processes in the high intensity condition would therefore potentially account for the overall increases in affective constructs such as anxiety and NA, and the overall decreases in calmness. This is consistent with previous research that has linked interoception and anxiety disorders (e.g., Richards, Cooper, & Winkelman, 2003), which may also explain the slightly greater predictive utility of the physiological measures for state anxiety responses. The differential influence of exteroceptive and interoceptive cues is also consistent with the dual-mode model proposed by Ekkekakis (2003) to explain the exercise/affect relationship.

The interpretation of the exercise experience and the impact on PA responses might also be influenced by preexisting individual differences. For example, previous research (Larsen & Ketelaar, 1991) has suggested that personality variables such as extraversion and neuroticism may differentially impact individual responses to emotion-eliciting stimuli (i.e., exercise). Despite the intuitive appeal of this explanation, it is important to recognize that personality variables have not yet received conclusive support for their role in determining positive affective outcomes, and that the purpose of the current study was not to explicitly test these mechanisms. Furthermore, the curvilinear dose-response relationship between intensity and affective change was seen in most individuals. Despite individual differences in the magnitude of affective change within conditions, moderate intensity training generally produced the greatest improvements while high intensity training produced the largest decrements. This may partly be a function of the relatively homogeneous sample used in the current study.

These relatively consistent patterns are congruent with previous findings regarding the degree of individual variability in post-exercise affective responses (e.g., Ekkekakis, 2003; Van Landuyt, Ekkekakis, Hall, & Petruzzello, 2000). However, this is not to suggest that greater variability would not emerge when examining responses *during* exercise (Ekkekakis; Van Landuyt et al.). Future research may be designed with the expressed intent of testing the above concepts, including mastery, interoceptive vs. exteroceptive cues, and individual variability, in order to provide a more complete examination of mechanisms underlying the exercise/affect relationship.

Although cortisol provided some predictive utility for exercise-induced affective changes, the percent of variance accounted for was typically small and the relationships were linear in nature rather than curvilinear. The findings suggest that once resistance exercise crosses an intensity threshold that requires activation of the HPA-axis, the experience is no longer optimal and may induce decrements in affect. In fact, this may indicate that a high intensity exercise stimulus such as that used in this study crosses the line from eustress to distress (Selye, 1950; Singh, Petrides, Gold, Chrousos, & Deuster, 1999).

These results may also indirectly suggest that β-endorphins do not play a major role in promoting positive exercise-induced affective changes, at least not for resistance exercise. Despite the fact that β-endorphins have been found to increase during resistance training (e.g., Kraemer et al., 1993), the increase was typically only demonstrated when using a protocol very similar to the high-intensity condition used in the current study. This would indicate that β-endorphin release is associated with the protocol that produced the most pronounced affective *decrements*. It may be that, despite inhibitory effects of β-endorphin on stress-related responses, some of these effects are relatively unimportant (Allen, 1990). Though this was not directly assessed in the current study, it should be considered in future studies attempting to examine underlying mechanisms in the exercise/affect relationship.

Overall, the results of this study indicate that, when defined and controlled appropriately, moderate intensity resistance training produces beneficial affective changes at both a dimensional and categorical level. Furthermore, accurately defining intensity allowed for the establishment of a curvilinear dose-response pattern of postexercise affective change. In addition, HR and cortisol responses were significant predictors of changes in the negative affective constructs, suggesting that the ANS and HPA axis are viable mechanisms underlying exercise-induced affective changes. The lack of predictive ability for these stress systems on positive affective construct changes suggests that other psychologically-based determinants may be serving as underlying mechanisms in the exercise/affect relationship.

Future research should focus on establishing the efficacy of these mechanisms and other potential physiological influences. Attention should also focus on the potential influence of resistance training experience on affective responses. Neuroendocrine and neuromuscular adaptations that occur as a result of resistance training may impact the individual's perception of an optimal stressor for inducing affective changes. In addition, Chrousos and Gold (1992) have suggested that there may be a family of dose-response curves relating stressor intensity and a sense of well-being depending on whether the individual's stress system is normally reactive, hyperreactive, or hyporeactive. This prospect deserves further examination in populations suffering from dysregulation of the stress response.

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References

Allen, M.E. (1990). Endorphin's role as a mood modifier. *Annals of Sports Medicin*e, **5**, 89-95.

Altemus, M., Deuster, P., Galliven, E., Carter, S., & Gold, P.W. (1995). Suppression of hypothalamic-pituitary adrenal axis responses to stress in lactating women. *The Journal of Clinical Endocrinology & Metabolism*, **86**, 2954-2959.

Altemus, M., Roca, C., Galliven, E., Romanos, C., & Deuster, P. (2001). Increased vasopressin and adrenocorticotropin responses to stress in the midluteal phase of the menstrual cycle. *The Journal of Clinical Endocrinology & Metabolism*, **86**, 2525-2530.

Arent, S.M., Landers, D.M., & Etnier, J.L. (2000). The effects of exercise on mood in older adults: A meta-analytic review. *Journal of Aging and Physical Activity*, **8**, 407-430.

Arent, S.M., Rogers, T.J., & Landers, D.M. (2001). The effects of physical activity on selected mental health variables: Determining causation. *Sportwissenschaft*, **31**, 239-254.

Baechle, T.R., Earle, R.W., & Wathen, D. (2000). Resistance training. In T.R. Baechle & R.W. Earle (Eds.), *Essentials of strength training and conditioning* (2nd ed., pp. 395-423). Champaign, IL: Human Kinetics.

Bahrke, M.S., & Morgan, W.P. (1978). Anxiety reduction following exercise and meditation. *Cognitive Therapy Research*, **2**, 323-333.

Bartholomew, J.B., & Linder, D.E. (1998). State anxiety following resistance exercise: The role of gender and exercise intensity. *Journal of Behavioral Medicine*, **21**, 205-219.

Borer, K.T. (2003). *Exercise endocrinology*. Champaign, IL: Human Kinetics.

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

Chrousos, G.P., & Gold, P.W. (1992). The concepts of stress and stress system disorders: Overview of physical and behavioral homeostasis. *Journal of the American Medical Association*, **267**, 1244-1252.

Csikszentmihalyi, M. (1982). Toward a psychology of optimal experience. In L. Wheeler (Ed.), *Review of personality and social psychology: Vol. 3* (pp. 13-36). Beverly Hills, CA: Sage.

DiLuigi, L., Guidetti, L., Baldari, C., & Romanelli, F. (2003). Heredity and pituitary response to exercise-related stress in trained men. *International Journal of Sports Medicine*, **24**, 551-558.

Donner, A., & Cunningham, D.A. (1984). Regression analysis in physiological research: Some comments on the problem of repeated measurements. *Medicine & Science in Sports & Exercise*, **16**, 422-425.

Ekkekakis, P. (2003). Pleasure and displeasure from the body: Perspectives from exercise. *Cognition and Emotion*, **17**, 213-239.

Ekkekakis, P., Hall, E.E., & Petruzzello, S.J. (1999). Measuring state anxiety in the context of acute exercise using the state anxiety inventory: An attempt to resolve the brouhaha. *Journal of Sport & Exercise Psychology*, **21**, 205-229.

Ekkekakis, P., & Petruzzello, S.J. (2000). Analysis of the affect measurement conundrum in exercise psychology: I. Fundamental issues. *Psychology of Sport and Exercise*, **1**, 71-88.

Filaire, E., Le Scanff, C., Duche, P., & Lac, G. (1999). The relationship between salivary adrenocortical hormones changes and personality in elite female athletes during handball and volleyball competition. *Research Quarterly for Exercise and Sport*, **70**, 297-302.

Focht, B.C. (2002). Pre-exercise anxiety and the anxiolytic responses to acute bouts of self-selected and prescribed intensity resistance exercise. *Journal of Sports Medicine and Physical Fitnes*s, **42**, 217-223.

Focht, B.C., & Koltyn, K.F. (1999). Influence of resistance exercise of different intensities on state anxiety and blood pressure. *Medicine & Science in Sports & Exercise*, **31**, 456-463.

Garvin, A.W., Koltyn, K.F., & Morgan, W.P. (1997). Influence of acute physical activity and relaxation on state anxiety and blood lactate in untrained college males. *International Journal of Sports Medicine*, **18**, 470-476.

Hakkinen, K., & Pakarinen, A. (1993). Acute hormonal responses to two different fatiguing heavy-resistance protocols in male athletes. *Journal of Applied Physiology*, **74**, 882-887.

Hatfield, B.D. (1991). Exercise and mental health: The mechanisms of exercise-induced psychological states. In L. Diamant (Ed.), *Psychology of sports, exercise, and fitness* (pp. 17-49). New York: Hemisphere.

Hatfield, B.D., Goldfarb, A.H., Sforzo, G.A., & Flynn, M.G. (1987). Serum beta-endorphin and affective responses to graded exercise in young and elderly men. *Journal of Gerontology*, **42**, 429-431.

Heyward, V.H. (1998). *Advanced fitness assessment and exercise prescription* (3rd ed.). Champaign, IL: Human Kinetics.

Hill, A.B. (1965). The environment and disease: Association or causation? *Proceedings of the Royal Society of Medicine*, **58**, 295-300.

Kirschbaum, C., & Hellhammer, D.H. (1994). Salivary cortisol in psychoneuroendocrine research: Recent developments and applications. *Psychoneuroendocrinology*, **19**, 313-333.

Koltyn, K.F., Raglin, J.S., O'Connor, P.J., & Morgan, W.P. (1995). Influence of weight training on state anxiety, body awareness, and blood pressure. *International Journal of Sports Medicine*, **16**, 266-269.

Kraemer, R.R., Dzewaltowski, D.A., Blair, M.S., Rinehardt, K.F., & Castracane, V.D. (1990). Mood alteration from treadmill running and its relationship to beta-endorphin, corticotrophin, and growth hormone. *Journal of Sports Medicine and Physical Fitness*, **31**, 241-246.

Kraemer, W.J., Dziados, J.E., Marchitelli, L.J., Gordon, S.E., Harman, E.A., Mello, R., Fleck, S.J., Frykman, P.N, & Triplett, N.T. (1993). Effects of different heavy-resistance exercise protocols on plasma beta-endorphin concentrations. *Journal of Applied Physiology*, **74**, 450-459.

Kraemer, W.J., & Ratamess, N.A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine & Science in Sports & Exercise*, **36**, 674-688.

Landers, D.M., & Arent, S.M. (2001). Physical activity and mental health. In R.N. Singer, H.A. Hausenblaus, & C. Janelle (Eds.), *The handbook of sport psychology* (2nd ed., pp. 740-765). New York: Wiley.

Larsen, R.L., & Ketelaar, T. (1991). Personality and susceptibility to positive and negative emotional states. *Journal of Personality and Social Psychology*, **61**, 132-140.

McGowan, R.W., Talton, B.J., & Thompson, M. (1996). Changes in scores on the profile of mood states following a single bout of physical activity: Heart rate and changes in affect. *Perceptual and Motor Skills*, **83**, 859-866.

Mutrie, N. (2000). The relationship between physical activity and clinically defined depression. In S.J.H. Biddle, K.R. Fox, & S.H. Boutcher (Eds.), *Physical activity and psychological well-being* (pp. 46-62). London: Routledge.

Nesse, R.M., Cameron, O.G., Curtis, G.C., McCann, D.S., & Huber-Smith, M.J. (1984). Adrenergic function in patients with panic anxiety. *Archives of General Psychiatry*, **41**, 771-776.

O'Connor, P.J., Bryant, C.X., Veltri, J.P., & Gebhardt, S.M. (1993). State anxiety and ambulatory blood pressure following resistance exercise in females. *Medicine & Science in Sports & Exercise*, **25**, 516-521.

O'Neal, H.A., Dunn, A.L., & Martinsen, E.W. (2000). Depression and exercise. *International Journal of Sport Psychology,* **31**, 110-135.

Petruzzello, S.J., Landers, D.M., Hatfield, B.D., Kubitz, K.A., & Salazar, W. (1991). A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. *Sports Medicine*, **11**, 143-182.

Petruzzello, S.J., & Tate, A.K. (1997). Brain activation, affect, and aerobic exercise: An examination of both state-independent and state-dependent relationships. *Psychophysiology*, **34**, 527-233.

Raglin, J.S., Turner, P.E., & Eksten, F. (1993). State anxiety and blood pressure following 30 min of leg ergometry or weight training. *Medicine & Science in Sports & Exercise*, **25**, 1044-1048.

Rejeski, W.J. (1994). Dose-response issues from a psychosocial perspective. In C. Bouchard, R.J. Shepherd, & T. Stephens (Eds.), *Physical activity, fitness, and health: International proceedings and consensus statement* (pp. 1040-1055). Champaign, IL: Human Kinetics.

Rejeski, W.J., Hardy, C.J., & Shaw, J. (1991). Psychometric confounds of assessing state anxiety in conjunction with acute bouts of vigorous exercise. *Journal of Sport & Exercise Psychology*, **13**, 65-74.

Richards, J.C., Cooper, A.J., & Winkelman, J.H. (2003). Interoceptive accuracy in nonclinical panic. *Cognitive Therapy & Research*, **27**, 447-461.

Roberts, A.D., Wessely, S., Chalder, T., Papadopoulos, A., & Cleare, A.J. (2004). Salivary cortisol response to awakening in chronic fatigue syndrome. *British Journal of Psychiatry*, **184**, 136-141.

Sachar, E.J. (1975). Twenty-four-hour cortisol secretory patterns in depressed and manic patients. *Progress in Brain Research*, **42**, 81-91.

Schulkin, J., Gold, P.W., & McEwen, B.S. (1998). Induction of corticotropin-releasing hormone gene expression by glucocorticoids: Implication for understanding the states of fear and anxiety and allostatic load. *Psychoneuroendocrinology*, **23**, 219-243.

Scott, A.J., & Holt, D. (1982). The effect of two-stage sampling on ordinary least squares methods. *Journal of the American Statistical Association*, **77**, 848-854.

Selye, H. (1950). *Stress*. Montreal: Acta Medical.

Singh, A., Petrides, J.S., Gold, P.W., Chrousos, G.P., & Deuster, P.A. (1999). Differential hypothalamic-pituitary-adrenal axis reactivity to psychological and physical stress. *The Journal of Clinical Endocrinology & Metabolism*, **84**, 1944-1948.

Solomon, R.L., & Corbit, J.D. (1973). An opponent-process theory of motivation: II. Cigarette addiction. *Journal of Abnormal Psychology*, **81**, 158-171.

Spielberger, C.D., Gorsuch, R.L., Luschene, R., Vagg, P.R., & Jacobs, G.A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists.

Thayer, R.E. (1989). *The biopsychology of mood and arousal*. New York: Oxford University Press.

Tuson, K.M., Sinyor, D., & Pelletier, L.G. (1995). Acute exercise and positive affect: An investigation of psychological processes leading to affective change. *International Journal of Sport Psychology*, **26**, 138-159.

Van Landuyt, L.M., Ekkekakis, P., Hall, E.E., & Petruzzello, S.J. (2000). Throwing the mountains into the lakes: On the perils of nomothetic conceptions of the exercise-affect relationship. *Journal of Sport & Exercise Psychology*, **22**, 208-234.

Wathen, D. (1994). Load assignment. In T.R. Baechle (Ed.), *Essentials of strength training and conditioning* (pp. 435-446). Champaign, IL: Human Kinetics.

Watson, D., Clark, L.A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, **54**, 1063-1070.