Higher chronic psychological stress is associated with blunted affective responses to strenuous resistance exercise: RPE, pleasure, pain

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A B S T R A C T
The aim of this study was to determine whether mental stress moderates perceptions of muscular pain, exertion, pleasure and arousal during a bout of strenuous resistance exercise. Two hundred and ten undergraduate students recruited from resistance exercise classes were screened with the Perceived Stress Scale (PSS). Fifty-seven individuals (age = 20.1 ± 1.2 y) were invited to complete the Undergraduate Stress Questionnaire (USQ), a measure of life event stress, and fitness testing. They later performed a two-phase, acute heavy-resistance exercise protocol: first phase: 10-repetition maximum (RM) leg press test; second phase: six sets at 80%–100% of 10-RM. During exercise, participants responded to the Feeling Scale (pleasure), Felt Arousal Scale, Omni-RPE and the Pain Intensity Scale. Affective responses and heart rate were analyzed with a hierarchical linear modeling (HLM) growth curve analysis. USQ moderated the trajectories of affective responses and heart rate during exercise. Higher stress (USQ) levels were significantly related to lower rise in RPE (time², p < .002; time³, p < .001) and heart rate (time², p < .001; time³, p < .001). USQ had a main effect on pleasure and arousal (time², p = .048; time³, p = .024). Relationships held even after adjusting for covariates, such as depression. Future research should determine if differential responses to exercise by stress have implications for behavioral interventions and mental health outcomes.

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Introduction

Resistance training, like aerobic exercise, protects against chronic conditions such as hypertension, diabetes, and acute illness (Ciccolo, Carr, Krupel, & Longval, 2010; Grontved, Rimm, Willett, Andersen, & Hu, 2012). Furthermore, there is evidence for a dose response. Larger volumes of training are associated with greater benefits, especially for muscular fitness and bone health (Grontved et al., 2012; Steib, Schoene, & Pfeifer, 2010). These benefits extend to mental health as moderate intensity resistance exercise has a salutary effect on mood post-exercise (Bibeau, Moore, Mitchell, Vargas-Tonsing, & Bartholomew, 2010). Consequently, the current ACSM guidelines advocate the use of resistance training to optimize physical and mental health (Garber et al., 2011). Despite potential gains in fitness, health and enhanced hedonic tone, people paradoxically fail to engage in exercise, particularly activity of a more intense nature. Indeed, only 29.3% of the United States population engages in resistance training at the recommended level of 2 or more days a week (Centers for Disease Control, 2013).
Many factors may impact exercise avoidance with evidence supporting the notion that the experience of discomfort during exercise affects future exercise behavior (Cook, 2006; Hall, Ekkekakis, & Petruzzello, 2002). In fact, the experience of greater displeasure during exercise predicts less physical activity at time points 3, 6 and 12 months later (Kwan & Bryan, 2010; Williams et al., 2008). This phenomenon has a biological basis, as the experience of aversive muscular sensations dampens the reward pathways for physical activity (de Geus & de Moor, 2011). Complicating the matter is the fact that exercise close to maximum capacity (i.e., above lactate threshold) produces feelings of displeasure and aversive sensations (Ekkekakis, Parfitt, & Petruzzello, 2011). Furthermore, with increasing intensity both aerobic and resistance training results in a quadratic rise in both effort sense and muscular pain (Cook, 2006; Hollander et al., 2003). High intensity resistance training, in particular, is associated with decrements in mood and exacerbated anxiety, negative affect and tense arousal (Arent, Landers, Matt, & Etnier, 2005; Bartholomew & Linder, 1998; Raglin, Turner, & Eksten, 1993). Unpleasant sensations are magnified when resistance training is unaccustomed or of very high volume (workload), short rest periods are used, movements are focused on slow, eccentric contractions or any combination of these factors (Bibeau et al., 2010; Hollander et al., 2002). Exercise is certain an acute stressor of both a physical and psychological nature.

A relatively recent line of inquiry centers on how affective responses to exercise vary by the experience of mental stress (Azevedo et al., 2006; Webb et al., 2013). Psychological stress is similar to exercise in that it results in magnified somatic sensations, like arousal (Schulz et al., 2013). However, acute mental stress (Rief & Barsky, 2005), injections of cortisol (Miller, McKinney, Kanter, Korte, & Lóvallo, 2011) and exercise may all initially dampen affective responses, such as pain, perhaps by increasing β-endorphin (Tsigos & Chrousos, 2002), a phenomenon that has been evolutionarily conserved (Sapolsky, 2004). When acute mental stress is experienced concurrent to the physical stress of exercise (a “dual challenge”) perceptions of state anxiety, effort sense and mental workload become exaggerated, resulting in greater cortisol and cardiovascular responses (Azevedo et al., 2006; Webb et al., 2013).

When stress is chronic, in other words, unremitting and irreversible over a longer time period, physical (Chida & Hamer, 2008; Pike et al., 1997) and mental (Delvaux, 1999; McGonagle & Kessler, 1990) responses to acute stress become dysregulated. Those with trait anxiety display exaggerated response to an acute stressor (i.e., public speaking) (Duncou, Makatsori, Fickova, Selko, & Jezova, 2006). However, exposing individuals reporting higher levels of chronic stress to acute psychological perturbations in the laboratory (e.g., mental arithmetic, exposure to very sad and gloomy music, recall of previous negative life events) results in differential outcomes. Interestingly, chronic stress may be related to lower (blunted) acute stress reactivity (Allen, Bocek, & Burch, 2011; Lethbridge & Allen, 2008). A recent review from Lóvallo (2013) concludes that chronic stress, particularly cumulative adverse life event stress, may dysregulate cardiovascular stress reactivity in either direction: exaggerated or blunted. Chronic stress results in perceptions of greater workload during laboratory stressors (Evans, Allen, Tafalla, & Omeara, 1996), and those with chronic stress report greater somatic arousal (Melamed et al., 1999) and activation (Ekstedt et al., 2006) when exposed to non-laboratory stressors. Unlike acute stress, indicators of chronic stress, such as exposure to early-life major stressors (Ashkinazi & Vershinina, 1999; Green, Chen, Alvarez, Ferrari, & Levine, 2011; Imbe, Iwai-Liao, & Senha, 2006; Rhudy & Meagher, 2000), chronic work strain (Lundberg, 2002; Saastamoinen, Laaksonen, Leino-Arjas, & Labelma, 2009; Wahlstrom, Hagberg, Toomingas, & Tornqvist, 2004) and long-term caregiving stress (Tonga & Duger, 2008) are related to hyperalgesia, increased pain sensitization, low back pain and exacerbated muscular tension. Interestingly, data with PTSD patients finds that pain sensitization is lower compared to healthy controls (Kraus et al., 2009), and chronic stress is associated with both enhanced and diminished visceral perceptions (Delvaux, 1999). Given these observations, the confluence of chronic mental stress and an acute bout of exercise, itself an acute stressor, cannot be expected to have the same impact on affective responses as pairing an acute mental and physical stressor.

Interestingly, few studies have examined the interaction of chronic mental stress and acute exercise stress on affective responses. Those reporting higher levels of chronic stress recover from fatigue and soreness more slowly in a four-day period after resistance exercise and experience a delayed rebound of perceived energy (Stults-Kolehmainen, Bartholomew, & Sinha, 2014). In non-controlled settings, Lutz, Stults-Kolehmainen, and Bartholomew (2010) found that experiences of life event stress over a six-week period were related to lower workout session ratings of perceived exertion (RPE). This same study reported that dampened PA was related to higher stress for subjects newly adopting exercise. Coping with chronic stress consumes self-control strength, rendering individuals less likely to monitor and regulate behavior (Hagger, Wood, Stiff, & Chatzisarantis, 2009). Oaten and Cheng (Oaten & Cheng, 2005) found that students during final examinations had impaired performances on the Stroop test following a regulatory-depleting task (e.g., thought suppression). These students also were less physically active than a control group who were not in the midst of examination stress. None of these studies, however, examined affective responses during exercise or the stressfulor, which may explain these associations.

Given this gap in the literature, the purpose of this study was to examine the relationship of chronic stress with affective responses to exercise. The significance of this topic is magnified by fact that physical exercise adaptations (Stults-Kolehmainen & Bartholomew, 2012; Stults-Kolehmainen et al., 2014) and physical activity behaviors are consistently related to both subjective (perceived) and objective (i.e., life event) forms of chronic stress. A recent systematic review discovered that the majority of high quality prospective studies examining the effect of chronic stress on PA found an inverse association (Stults-Kolehmainen & Sinha, 2014). Few studies explored potential mechanisms for these effects. If psychological stress is related to altered affective responses, this would justify a prospective model in which the effects of stress on physical activity may be mediated by affective responses. We hypothesized that chronic mental stress, measured with surveys of life event stress and perceived stress, would be related to altered mental strain (i.e., arousal, displeasure, RPE and pain) during an acute, high resistance exercise protocol (AHREP). Given the equivocal nature of the stress and affect literature, directionality of the association was not predicted (Delvaux, 1999; Lóvallo, 2013). Because post-exercise affective responses are inconsistently related to stress, a secondary and peripheral aim of this investigation was to examine the relationship between stress and negative and positive affect in the recovery period 20 min post-exercise after adjusting for baseline affective state (Allen et al., 2011).

Methods

Subjects

Students in resistance training classes (n = 210) completed an online screening instrument for subjective stress (Perceived Stress Scale, PSS) (Cohen & Williamson, 1988) and depression (Center for Epidemiological Studies Depression Scale, CES-D) (Ensel, 1986). To
ensure sufficient variability in stress measures, respondents reporting higher (1/2 standard deviation above population mean, determined from pilot data described below) and lower stress (1/2 standard deviation below population mean) on the PSS were invited to participate in the remainder of the study. We excluded individuals scoring high for depression (≥27 on the CES-D), however, to protect against both severe loss of motivation and psychomotor retardation, yet effectively exhaust our participants during strenuous exercise (AHREP; explained below). More details about subject recruiting have been published elsewhere (Stults-Kolehmainen & Bartholomew, 2012; Stults-Kolehmainen et al., 2014). All participants signed an informed consent before beginning any laboratory procedures. This study was approved by the Institutional Review Board of The University of Texas at Austin in accordance with the Declaration of Helsinki.

**Procedures**

**Overview**

Participants made 2 visits to the laboratory for testing, the first of which occurred approximately 1–2 weeks after screening. Participants were re-administered the PSS (paper/pencil version) at the first visit and the Undergraduate Stress Questionnaire (USQ), a measure of life event stress. To ensure safety, at each visit participants completed a brief warm-up on a cycle ergometer along with a standardized set of light lower body stretches. At the first visit, participants completed a battery of fitness and body composition tests (described below) and were familiarized with all study protocols. After 5–14 days subjects returned for a strenuous exercise protocol (AHREP; explained below). To control for various factors affecting exercise performance and perceptions, participants were instructed to perform only light recreational exercise during the 48 h period before laboratory testing. They were also instructed to abstain from various substances during this time period (e.g., anti-inflammatories; supplements). Caffeine and food intake were prohibited within a 2-h period before the AHREP protocol. Additional procedural detail is supplied by Stults-Kolehmainen and Bartholomew (2012).

**Acute heavy-resistance exercise protocol**

A two-stage, acute heavy-resistance exercise protocol (AHREP) was developed to reliably produce quantifiable decrements in muscular function for a cohort of students in resistance training classes (see Stults-Kolehmainen and Bartholomew (2012) for a graphical representation). The first stage was a “ramping phase,” which is similar to a strength test to determine 10 repetition maximum (RM) capacity. This consisted of a variable number of sets of 10 repetitions, each performed with an increasing load until a full set could no longer be completed. The cadence of the movement was kept steady with a metronome, as 3 s eccentric action/2 s concentric action with a 1 s isometric hold at full extension (without locking the knees). Two minutes were provided for rest between each set. After the last set, 3 min of rest were provided before the beginning of the “burnout phase.” In this phase six sets of leg presses were performed, each to volitional exhaustion (10 ± 2 reps). The load of the first set was the just-determined 10-RM capacity, and the second set’s load was 90% of this value. If the subject was able to perform ≥10 reps during the second set, sets 3–6 were maintained at this weight. Otherwise, the load was reduced to 80%. Participants were given strong verbal encouragement throughout the protocol.

**Assessment schedule**

Participants completed the psychological instruments for outcomes of interest (Omni-RPE, pain, feeling, arousal) before the AHREP, at odd-numbered sets and after the last set of the first phase. They completed these scales at sets 1, 3, 5 and 6 during the burnout phase.

**Measures**

**Psychological assessments: stress**

Perceived chronic mental stress was measured with the Perceived Stress Scale: 10-Item Version (PSS). The PSS measures the degree to which situations in one’s life are appraised as stressful, with scores ranging from 0 to 40 (Cohen & Williamson, 1988). It is correlated with both quantity of life event stressors (r = .32) and the negative impact of these events (r = −.27) (Cohen & Williamson, 1988). A large national sample of young adults, ages 18–29 years (N = 645), had a mean PSS of 14.2 (SD = 6.2). Pilot data for this study (paper/pencil format) was collected from 357 undergraduate students in weight-training classes. These students had a mean PSS score of 14.4 (SD = 5.5) at the beginning of a semester and 17.8 (SD = 6.1) in their final examination period. The internal consistency for this earlier sample (Cronbach’s α) was .76. This was supplemented by an unweighted version of the Undergraduate Stress Inventory (USQ), which was used to measure school and non-school related life event stress that occurred in the month prior to evaluation (Crandall, Preisler, & Aussprung, 1992). The objective form is a checklist that has 83 items representing common stressors for undergraduates. The USQ correlates well with other stress inventories; e.g. r = .79 with Subjective Distress Scale, and r = .97 with the Objective Stressor Scale (Crandall et al., 1992).

**Psychological assessments: affective responses**

Muscular pain during exercise was measured with the Pain Intensity Scale (Cook, O’Connor, Eubanks, Smith, & Lee, 1997; Cook, O’Connor, Oliver, & Lee, 1998). The category/ratio scale has 12 responses with 0 being “no pain at all,” 5 being “somewhat strong pain,” and 10 being “extremely intense pain (almost unbearable).” Respondents were permitted to select a numeric value above 10 to properly anchor maximal pain. The scale is correlated with visual analog scale (VAS) measures of pain (r = .74-.94), has high reliability (ICC = .88–.98) and is highly reproducible with different samples performing the same test (Cook et al., 1997, 1998). Detailed written instructions for the participants were adapted from Cook et al. (1997), and subjects were instructed to focus their ratings on the working muscles of the lower body. The Feeling Scale (FS) (Hardy & Rejeski, 1989) was used as a single-item measure of affective valence (pleasure/displeasure). This is an 11-point bi-polar measure ranging from –5 to +5. The anchors include “very bad” at –5 to “neutral” at 0 to “very good” at +5. The FS exhibits correlations ranging from .51 to .88 with the valence scale of the Self-Assessment Manikin (SAM; Lang, 1980) and from .41 to .59 with the valence scale of the Affect Grid (AG; Russell, Weiss, & Mendelsohn, 1989). Perceived arousal (activation) was measured with the Felt Arousal Scale (FAS) of the Telic State Measure (Svebak & Murgatroyd, 1985). This single-item, 6-point scale ranges from 1 to 6 with anchors including “low arousal” at 1 to “high arousal” at 6. Correlations of the FAS with the SAM arousal scale range from .43 to .70. Correlations with the arousal scale of the AG range from .47 to .65. Rating of perceived exertion (RPE) was measured with the Omni Scale for resistance exercise (Legally & Robertson, 2006) with instructions modified to conform with Borg (1990). Lastly, participants also completed the Positive and Negative Affect Scale (PANAS) (Watson, Clark, & Tellegen, 1988). The PANAS inquires about feelings at the present moment, both positive (e.g., enthusiasm, high energy and alertness) and negative (e.g., distress, anger, guilt). Each subscale has 10 items with high internal consistencies.
(Cronbach's α = .86—.90 for positive affect and .84—.87 for negative affect).

As affective responses to exercise may vary with one’s perceived tolerance for higher intensity work, the tolerance sub-scale of the Preference for and Tolerance of Exercise Intensity Questionnaire (PRETIE-Q) was also completed (Ekkekakis, Lind, Hall, & Petruzzello, 2007). This scale has eight items with four that assess tolerance for higher intensity exercise (e.g., “I always push through muscle soreness and fatigue when working out.”) and four that tap low exercise tolerance (e.g., “during exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off.”). Every statement has a 5-item response with anchors ranging from “I totally disagree” at 1, to “neither agree nor disagree” at 3, to “I strongly agree” at 5. Low tolerance items are reversed-scored. Internal consistency ranges from α = .82 to α = .87. Test–retest reliability (after 3 and 4 months) ranges from α = .85 to α = .72, respectively (Ekkekakis et al., 2007).

**Fitness and performance assessments**

Aerobic capacity (VO2peak) was determined with an incremental protocol test on an Excalibur Sport electronically-braked cycle ergometer (Lode BV, Groningen, The Netherlands) (Storer, Davis, Caiozzo, & Barthalomew, 1993) to heart rate was recorded with a Polar-OY (Kempele, Finland) telemetric heart rate monitor. Body composition was determined from Dual energy X-ray absorptiometry (Lunar DXA, G.E., Madison, WI). To assess lower and upper body movements with a standard bench and a plate-loaded, 45° Cybex machine. Strength was determined from muscular failure at 3–5 repetitions in the last set, and 1-RM measures were determined from coefficients reported by Bryzcki (1993).

Maximal Isometric Force (MIF) was determined on a modified leg press machine nearly identical to the machine used for leg press strength and the AHREP. Participants were given three trials to press maximally against the sled platform at a 110-degree knee joint angle for 4 s. Vertical jump power was determined from a squat jump measured with a Vertec apparatus (Sports Imports, Inc., Columbus, OH) and calculated from the equation by Sayers, Harackiewicz, Harman, Frykman, and Rosenstein (1999). Maximal cycling power was determined from a modified Monark cycle ergometer fitted with an optical sensor to determine velocity of the flywheel (Martin, Wagner, & Coyle, 1997). For power assessments, participants were given three trials for each measurement period to achieve peak power. Additional details for all fitness and performance tests are provided by Stults-Kolehmainen and Barthalomew (2012).

**Statistical analyses**

Descriptive statistics (M and SD) were calculated for USQ (the main predictor of interest) and PSS scores at the first visit (PSS-V1), and Pearson’s Product correlations were calculated between predictor variables. Kolmogorov–Smirnov (K–S) tests were conducted to determine normality of stress measures at the first laboratory visit. It was determined a priori that both stress scales would be modeled as linear/continuous variables if their distributions at the first visit met normality requirements (which for PSS would indicate regression to the mean from the online survey). Keeping with previous publications, it was determined that separate multivariate analyses would be conducted for each measure of stress (Stults-Kolehmainen & Barthalomew, 2012; Stults-Kolehmainen et al., 2014). A model-building approach was utilized. A two-level (observations, level 1 nested within persons, level 2) hierarchical linear modeling (HLM) growth curve analysis (Raudenbush & Bryk, 2002) was used to detect differences in affective trajectories by stress variables, both USQ and PSS (mean of PSS from first and second visits to the laboratory) over the AHREP protocol. Outcome measures were feeling (pleasure—displeasure), arousal, RPE and pain assessed over the AHREP protocol. Initial HLM analyses modeled time as linear. Stress measures were added as covariates at the level 2 to determine if these variables moderated the recovery curves. Additional intercepts-and-slopes-as-outcomes analyses were conducted to determine the best functional form of time (linear, quadratic, and exponential) for each variable’s growth curve analyses. Functions of time significant below a p value of .05 were retained for further moderation analyses. Additional models were produced with the inclusion of 6 variables (depression, relative aerobic capacity, self-reported tolerance for exercise intensity, gender, workload [kg] and body fat%) that could influence stress and outcome variables associations (Allen et al., 2011). Effect sizes were calculated using Cohen’s f². Finally, separate models were created for: a) the entire AHREP protocol and b) the first (ramping) stage of the protocol. Analyses were conducted with SAS 9.3 (Cary, NC, USA). p Values < .05 were deemed significant.

**Results**

**Descriptive statistics**

The final sample included 57 participants who were 18–23 years of age (M = 20.12, SD = 1.21) including 15 women and 42 men. Of these participants, 33 scored lower for stress and 24 scored higher for stress from the online PSS screening (PSS-O). PSS scores from the first visit, which was a paper/pencil questionnaire, also indicated sufficient variability to test hypotheses (PSS-V1; M = 14.5, SD = 7.8, range 0–32). PSS-V1 was distributed normally, K–S (57) = .11, p = .078, which indicated regression to the mean from the online version of the survey. PSS-O had a positive linear relationship with PSS-V1 (r = .74, p < .001). Undergraduate Stress Questionnaire (USQ) scores also had sufficient variability (M = 22.6, SD = 10.4, range 1–50) and had a normal distribution, K–S (57) = .09, p = .200. Hence, hypothesis testing was conducted with both stress measures modeled as continuous linear variables in HLM analyses. PSS-V1 had a positive linear relationship with USQ (r = .56, p = .002). The correlations between PSS and USQ with negative affectivity (from the first visit) were similar (r = .57 vs. r = .55, respectively). See Appendix A for supplementary data.

PSS-V1 was related significantly to bench press 1RM (r = .28, p = .037) and workload relative to body mass (i.e., total mass lifted per body mass; r = .27, p = .046). Both USQ and PSS-V1 were related to total repetitions during the AHREP (USQ: r = .31, p = .020; PSS: r = .33, p = .013). Stress measures were not related to other fitness variables, absolute workload (total mass lifted), peak heart rate, or average heart rate in the burnout phase of the AHREP. The AHREP resulted in decreases in MIF (46.5%), squat jump (16.7%) and cycle power (18.6%).

**Life event stress models with linear time**

Over the entire AHREP, USQ scores moderated the relationships (as demonstrated by interactions between these variables) between time and RPE (p = .005) and heart rate (p = .002), but not pain, pleasure or arousal. USQ had a main effect for RPE (p = .002). These models are presented in Table 1, which shows that all effect sizes for stress were small (Cohen’s f² < .04). Overall, USQ was related to blunted affective responses.

In these models, USQ had a significant main effect on FS (p = .010). When the non-significant interaction was eliminated from the model, the main effect remained [β = −0.035, SE = −0.009, t(51) = −3.89, p < .001] even after adjusting for covariates
Table 1

<table>
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<th>Outcome</th>
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<td>Stress</td>
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<tr>
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<td>Intercept</td>
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<td>Time</td>
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</table>

\( ^4 \) Only models with linear time are presented. USQ = Undergraduate Stress Questionnaire (life event stress). PSS = Perceived Stress Questionnaire (subjective stress).

HR = heart rate. RPE = rating of perceived exertion. FS = Feeling Scale. FAS = Felt Arousal Scale.

(tolerance for exercise intensity, workload, body fat%, VO2peak, gender, depression; \( p < .001; f^2 = .02 \)). This relationship held even when only examining the ramping stage of the AHREP (\( p = .005 \)). USQ had no main effect and no significant interactions with time on perceived arousal/activation. However, when adjusted by covariates (tolerance for exercise intensity, workload, body fat%, VO2peak, gender, depression) a main effect was detected [\( \beta = -.027, SE = .007; t(44) = -4.05, p < .001; f^2 = .1 \)]. This relationship held even when only examining the ramping stage of the AHREP (\( p = .006 \)).

Life event stress models with additional functions of time

Visual inspection of the raw data revealed that RPE, heart rate and pain increased curvilinearly. Therefore, analyses were rerun with time modeled with squared and cubed terms. For RPE, interactions between time and stress were significant in a model including squared [\( \beta = -.002, SE = .001; t(533) = -3.08, p = .002 \)] and cubed [\( \beta = 1.0E^{-4}, SE = 4.0E^{-5}, t(533) = 3.38, p < .001 \)]. After adjusting this model for covariates (tolerance for exercise intensity, workload, body fat%, VO2peak, gender, depression) interactions remained significant (\( p = .004; .002; f^2 = .01; .02 \)). In this final model, the main effect of USQ was also significant (\( p = .008; f^2 = .01 \)). See Fig. 1 (panel F) for the final model, in which the curves are generated from imputed values for stress at the mean and approximately 1 standard deviation above and below the mean. Similar models that included data only from the ramping stage of the AHREP produced similar results (\( p < .001 \)). At baseline, RPE did not statistically differ by stress when using a simple median split (higher stress: 2.5 ± 1.8; lower stress: 1.7 ± 1.0; \( p = .059 \)).

The USQ and time interactions were significant for heart rate as well. Models that included squared [\( \beta = -.022, SE = .006, t(629) = -3.51, p < .001 \)] and cubed [\( \beta = .002, SE = 4.0E^{-3}, t(629) = 3.74, p < .001 \)] time also had significant interactions. Higher levels of stress were associated with a flatter and more blunted heart rate response. These relationships held even after adjusting for covariates (tolerance for exercise intensity, workload, body fat%, VO2peak, gender, depression; \( p = .001; .001; f^2 = .02; .02 \)). In this adjusted model, the main effect of USQ was significant (\( p = .005; f^2 = .01 \)). See Fig. 1 (panel B). Similar models that limited time to the ramping stage of the AHREP produced similar results (\( p < .001 \)). Using a simple median split, higher stress was associated with a higher baseline heart rate (higher stress: 102.0 ± 12.2; lower stress: 93.2 ± 10.6 bpm; \( p = .011, \eta^2 = .13 \)).

Perceived stress models

Models examining associations between mean perceived stress and time on affective responses to exercise showed similar trends. For RPE, perceived stress had both a main effect (\( p = .002 \)) and interacted with linear time (\( p = .001 \)). Models with squared [\( \beta = -.004, SE = .001, t(533) = -3.65, p < .001 \); and cubed [\( \beta = 3.0E^{-4}, SE = 9.0E^{-3}; t(533) = 3.75, p < .001 \)] time also had significant interactions. These held even after adjusting for covariates (\( p < .001; f^2 = .01 \)). See Fig. 1 (panel E). Models which limited time to the ramping stage of the AHREP produced similar results (\( p < .001 \)). For heart rate, final PSS models were similar (model with covariates: main effect of stress, \( p = .020 \); stress x time interactions, \( p < .001 \)). A blunted response was observed for those reporting higher levels of stress.

Mean PSS interacted with squared [\( \beta = -.004, SE = .002, t(570) = -1.98, p = .048 \)] and cubed [\( \beta = 3.2E^{-5}, SE = 1.4E^{-4}, t(570) = 2.27, p = .024 \)] to predict muscular pain, a finding not seen with USQ. Higher levels of stress were associated with lower ratings of pain. However, only the cubed time x stress interaction was significant after adjusting for covariates (tolerance for exercise intensity, workload, body fat%, VO2peak, gender, depression; \( p = .044, f^2 = .01 \)) while the squared time x stress interaction neared significance (\( p = .072, f^2 = .01 \)). In this adjusted model, the main effect of PSS was also significant (\( p = .035, f^2 = .01 \)). See Fig. 1 (panel C). In the ramping stage of the AHREP, an interaction between perceived stress and linear time approached significance [\( \beta = -.018, SE = .009, t(238) = -1.91, p = .058 \)].

Results for pleasure/displeasure (e.g., main effects of stress; \( p < .001 \)) and arousal (no main effect) were similar when mean PSS was entered into models instead of USQ. PSS was significant (\( p < .001, f^2 = .01 \)) when covariates were added to models for both outcomes. To further investigate whether PSS was
associated with pleasure at specific time points, a $2 \times 5$ factorial ANOVA was also conducted. This analysis suggested that there was a main effect of stress, $F(1, 55) = 4.155$, $p = .047$, $\eta^2 = .09$, and time, $F(1, 55) = 6.707$, $p < .001$, $\eta^2 = .39$, but no significant time × stress interaction, $F(1, 55) = .871$, $p = .490$. Higher stress was associated with lower pleasure. See Fig. 2.

**Negative affect post-exercise**

Linear regression modeling was used to explore whether stress was associated with affect 5 and 20 min after the AHREP. Results showed that the USQ predicted negative affect (NA) scores at 5 min, $F(1, 38) = 17.49$, $p < .001$, and 20 min, $F(1, 36) = 15.35$, $p < .001$, explaining 31.5% and 29.9% of the variance, respectively. Specifically, a 1-point increase in USQ scores predicted a .2 increase in NA, $t(39) = 4.18$, $p < .001$, at 5 min and a .19 increase in NA, $t(36) = 3.92$, $p < .001$, at 20 min. When baseline negative affect and depression (CES-D) scores were entered into the regression in the first block relationships were maintained at both time points, $F(1, 38) = 8.44$, $p < .001$, $F(1, 36) = 9.04$, $p < .001$. The variance explained increased for these models (41.3% and 44.4%, respectively). USQ remained a significant predictor at both time points, $t(39) = 2.319$, $p = .026$; $t(36) = 2.201$, $p = .035$. A median split of USQ shows that those reporting lower stress also consistently report lower negative affect at baseline (means ± SD: 12.7 ± 3.8 vs. 17.0 ± 4.6; $p = .003$), 5 min post (13.7 ± 3.0 vs. 16.4 ± 4.2; $p = .025$) and 20 min post-exercise (12.3 ± 2.4 vs. 14.8 ± 4.4; $p = .031$). USQ did not predict positive affect post-exercise, and models substituting PSS instead of USQ did not predict affect when adjusting for baseline affective state.

![Fig. 1. Predicted values of heart rate, pain and rating of perceived exertion (RPE) across the acute high resistance exercise protocol (AHREP workout) as moderated by perceived stress (PSS; left panels) and life event stress (USQ; right panels).](image-url)
**Discussion**

These data demonstrate that affective responses to high intensity, high volume resistance exercise vary by self-report of chronic psychological stress in a population of undergraduate weight-training class students. In fact, growth curve analyses revealed that both life event stress (measured with the USQ) and perceived stress (measured with the PSS) were associated with the slope of change for RPE and heart rate. Higher stress was associated with higher baseline levels of these variables, such as depression, fitness, body composition, gender, tolerance for exercise intensity and workload. Notably, muscular pain was not predicted by life event stress, but was by perceived stress. In a secondary analysis, life event stress (but not perceived stress) was associated with higher levels of negative affect 5 and 20 min post-exercise. This association was independent of baseline life event stress and depression. These findings are unique given that the current literature has almost exclusively focused on the anxiolytic and stress-alleviating effects of exercise (Stults-Kolehmainen & Sinha, 2014), as opposed to the associations of stress with exercise responses.

The most important finding from this study was the consistent pattern of associations between indicators of mental stress and affective responses to exercise. Overall, higher stress was related to attenuated reports of effort/exertion, pleasure, exertion and—in adjusted models with perceived stress—muscular pain. These results are counter-intuitive, as one might suspect that chronic stress is related to exacerbated physical sensations (Melamed et al., 1999). It should be noted that results were not influenced by ceiling or basement effects (e.g., heart rates did not approach maximum in this young, healthy population; affective valance did not did not come close to minimum), except with the possibility of RPE. Several other explanations of blunted responsiveness exist, most of which are purely speculative. The simplest interpretation is that stressed individuals may underrate aversive sensations due to a contrast effect or other cognitive bias (Gilovich, Griffin, & Kahneman, 2002). However, chronic stress is associated with desensitization and habituation to stressful stimuli (Hauger, Lorang, Irwin, & Aguiler, 1990) whereas those higher in stress become accustomed to higher levels of displeasure in daily life and, as a result, are less responsive to a noxious stimulus (Herman, 2013). Lack of responsibility has physiological underpinnings. Exposure to unremitting stress results in known suppression of primary sensory pathways, deficits in multi-modal sensory integration (Girotti et al., 2006) and dampened neural activity in the dacytgyrus of the hippocampus, perhaps due to large increases in HSP70 expression (Filipovic et al., 2013) and activation of extracellular signal-regulated kinase (ERK) or decreased histone acetylation (Feinland, Harris, Lam, & Schrader, 2014). With chronic stress exposure changes also occur to the prefrontal cortex, which alter one’s ability to selectively attend to stimuli (Arnsten, 2009).

The current data support the notion that stress is associated with an over-extended, exhausted and perhaps ineffectual pattern of functioning during and after exercise. HLM analyses in this report revealed a similar pattern of flatter effort sense and cardiovascular responses for those reporting higher stress. In other words, higher stress is associated with relatively higher baseline levels of these factors and less elevation across the workout. Arousal was also lower for those reporting higher stress. Findings from the current study appear to be consistent with recent investigations that conclude that chronic stress is associated with poor responsiveness to acute stressors (Filipovic et al., 2013; Pruenszer et al., 2013), even in young healthy populations (Allen et al., 2011; Clements & Turpin, 2000; Ginty & Conklin, 2011; Lavallo, 2013; Peters, Godaert, Ballieux, & Heijnen, 2003). This may be an indication of poor ability to “ramp up” in the face of a physical stressor. Previous reports link chronic stress with poor muscular recovery shortly after resistance exercise and altered sensations over 24–96 h post-exercise (Stults-Kolehmainen & Bartholomew, 2012; Stults-Kolehmainen et al., 2014). A healthy response to acute stress is a robust reaction followed by quick recuperation, the lack of which are hallmarks of a dysregulated and exhausted stress response, also known as allostatic load (McEwen, 2007). These data support the tenets of this model of stress.

![Fig. 2. Association of subjective stress (Perceived Stress Scale) with pleasure/displeasure (Feeling Scale) across five resistance training time points. *p < .05.](image-url)
Cognitive explanations for these phenomena also have precedence (Blascovich & Tomaka, 1996). In short, to cope with aversive sensations those under higher chronic stress may cognitively and emotionally withdraw from acute stressors as a defense mechanism. Such a response is often construed as avoidant coping, a signal of which may be underrated sensations (Lake, 2009). Indeed, chronically stressed individuals exhibit more symptoms of dissociation, or detachment from physical sensations, which in turn is associated with altered perceptions of exertion (Masters & Ogles, 1998; Morgan et al., 2001). Suppressing emotions, overriding negative thoughts, and underrating, ignoring or denying aversive physical sensations are effective methods (attentional strategies) of retaining control over a situation, which may be otherwise uncontrollable, thus diminishing the possibility of threat, modulating arousal, regulating distress and protecting the self (Hasenbring, Hallner, & Klasen, 2001; Henry, 1992; Krohne, 1989; Stemmler, Aue, & Wacker, 2007; Webb, Miles, & Sheeran, 2012).

Such an explanation might inform how chronic stress relates to efforts for physical activity. Chronic stress is frequently associated with impaired motivational drive and reduced locomotion (Rygula et al., 2005; Stults-Kolehmainen & Sinha, 2014). Self-regulatory resources needed to control complex physical activity behaviors may be overly taxed when inhibitory processes to cope with chronic and acute stress are actively upregulated (Oaten & Cheng, 2005). Thus, one might expect that those under stress might lack the ability to maintain exercise efforts. Under natural conditions (i.e., the gymnasium) this might be true, but in a contrived laboratory situation, where regulation is provided externally, it may not. Indeed, stress was not associated absolute workload completed during the AHREP workout, but was positively associated with workload relative to body mass and total repetitions. Several important points emanate from this observation. First, a lack of actual effort (and not simply perceived effort) cannot explain why magnified psychological stress is associated with attenuated psychophysiological responses in the current study. Second, this observation makes sense in the context of evolutionary processes. Suppressing aversive sensations is a known strategy to endure the stresses of everyday life (Hasenbring et al., 2001). Such process might be evolutionarily conserved so stressed individuals may deal with prolonged physical struggles and maintain needed energy expenditure, thus facilitating endurance (Herman, 2013). Interestingly, those who tend to dissociate during exercise exhibit greater levels of endurance (Masters & Ogles, 1998). Moreover, it’s well documented that stress may spur greater activity in some situations (Schwerdtfeger, Eberhardt, Chmitorz, & Schaller, 2010; Stults-Kolehmainen & Sinha, 2014).

As mentioned previously, the experience of aversive sensations during exercise has an impact on future exercise participation (Hall et al., 2002). Consequently, blunted reward processing and hedonic capacity associated with chronic stress may have implications for physical activity enjoyment, motivation, and adherence (Pizzagalli, Bogdan, Ratner, & Jahn, 2007; Rygula et al., 2005). In the current investigation, those reporting higher stress felt worse during and after exercise. Conflicting evidence comes from Stults-Kolehmainen and Bartholomew (2012), who found that perceived energy, fatigue and soreness (but not negative affect, per se) did not vary by stress immediately before or after exercise or during 60 min of recovery. In the period post-strenuous exercise perhaps all individuals felt tired and sore, but stressed individuals may have interpreted these sensations in a more threatening manner, resulting in increased negative affect.

How one interprets sensations, however, may be more important than how one feels. Misgauging affective responses to exercise may have implications for the management of health behaviors and for changes in mental and physical health states (Lake, 2009; Lavello, 2011). For instance, those with blunted emotional responses to acute psychological perturbations have a greater risk for depression relapse a year later (Lethbridge & Allen, 2008). Therefore, it should be determined whether differential affective responses by stress may have implications for interventions aimed at enhancing physical activity and improving mental health. If this is the case, PA interventions may benefit from combining stress management and body awareness techniques, like mindfulness-based stress reduction, with exercise programming (Stults-Kolehmainen, 2013).

Despite the novelty and strengths of the current study, there were also a number of limitations. Strengths included screening a large number of students to ensure variability in chronic stress, excluding individuals scoring high for depression, and implementing a protocol to engage participants in strenuous exercise relative to their current level of fitness. As for limitations, it would have been useful to measure stress hormone responses, such as cortisol and epinephrine (Duncko et al., 2006). Avoidant forms of coping are often associated with a bifurcation of responses from the hypothalamic–pituitary–adrenal (HPA) and sympathetic–adrenal–medullary (SAM) systems, which may explain why cardiovascular responses may be blunted in the face of an acute, strong and novel stressor (Henry, 1992). Lactate samples were not collected to verify metabolic strain, which is the primary determinant of affective responses to exercise (Ekkekakis et al., 2011). However, average heart rates exceeded 160 beats per minute in the burnout stage of the workout, which indicates that the participants likely were experiencing significant physiological strain. Respondents did not rate their sense of control during the protocol and the perceived stressfulness (e.g., threat) and predictability of the protocol itself, factors that likely modulate psychophysiological responses during a laboratory stressor (Henry, 1992; Peters et al., 2003).

Certain enduring characteristics of the participants were not known, such as motivation for exercise, goal-orientation or personality factors like trait neuroticism, which is related to affective reactivity during acute psychosocial stressors (Verschoor & Markus, 2011), or exercise dependency, which is associated with blunted exercise responses (Heaney, Ginty, Carroll, & Phillips, 2011). Efforts should be taken to ascertain factors that may lead to resiliency in the face of stress, such as exercise stage-of-change (Lutz et al., 2010), serotonin (5-HTTLPR) genotypes (Markus & De Raedt, 2011), and utilization of exercise to cope with stress, a factor associated with detached emotional processing (Masters & Ogles, 1998). Finally, there was no control condition or comparison with other modes of exercise, such as aerobic exercise at a matched level of intensity or caloric expenditure. These limitations, however, provide fodder for further lines of inquiry.

This investigation—the first of its kind—demonstrates that self-reports of chronic psychological stress are associated with blunted affective responses during exercise. The relationship between stress and affect varied, however, for each outcome and by the type of stress reported. Participants reporting lower life event stress and perceived stress responded with greater RPE (exertion), pleasure and arousal during the AHREP workout and had a higher heart rate. Lastly, life event stress predicted negative affect post-exercise. These relationships could not be explained by depression, but when controlling for this factor pain was associated with perceived stress. A hallmark of chronic stress overload is an exhausted and/or dysregulated stress response system, including diminished responses to acute, physical stressors, which this report extends to strenuous exercise. Therefore, these data, combined with results showing that stress is related to poor recovery after exercise (Stults-Kolehmainen & Bartholomew, 2012), support the model of allostatic load (McEwen, 2007), which may have implications for health behaviors, such as physical activity.