The influence of physical stress on response to and resolution of emotional ambiguity

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Julie A. Cantelon

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Committee Members:
Robin B. Kanarek, Ph.D.
Nathan Ward, Ph.D.
F. Caroline Davis, Ph.D.

Abstract

Individuals with high stress jobs (e.g. law enforcement or military personnel) are often tasked with quickly interpreting ambiguous information in order to guide appropriate action. While certain social cues are clear (happy facial expression), others are ambiguous as they do not clearly signal whether an individual feels positive or negative (surprised facial expression) and could be interpreted as either safe or threatening. Previous work has demonstrated shifts in valence bias of ambiguous facial expressions occurs during acute emotional stress states. However, the influence of physical stress on valence bias, or tendency to interpret ambiguity as positive or negative, remains unexplored. Here we examined whether moderate and high levels of physical stress influenced interpretation and resolution of emotional ambiguity. Forty-eight young adults (29 females, ages 18-35) who engaged in regular exercise, completed 40-minutes of steady-state cycling at moderate (65% Heart Rate Reserve, HRR) and high (85% HRR) exercise intensities on two separate days. They completed measures of perceived exertion, affect and arousal, then rated a series of ambiguous (surprised) faces as positive or negative when presented alone, or in context. Physiological response and emotional state significantly differed between moderate and high intensity conditions (all p's < .001). However, there were no significant differences in valence bias, or ability to use contextual cues to resolve ambiguity of surprise between conditions (ps > .1). Importantly, even slight shifts might alter if information is perceived as safe vs. threatening. Thus, individual differences factors that may have affected interpretation of ambiguous social cues during physical stress are discussed.

Keywords: emotional ambiguity, valence bias, acute exercise, acute stress

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The influence of physical stress on response to and resolution of emotional ambiguity

Individuals with high stress occupations, such as law enforcement and military personnel, operate in stressful environments that can be simultaneously physically and emotionally demanding. Under such acutely stressful conditions, these individuals are often tasked with interpreting and resolving ambiguous information to guide appropriate action. Ambiguity is ubiquitous in everyday life and can be present in many forms. For instance, words or images that are vague and have multiple meanings, facial expressions that don't clearly signal how another person is feeling, or behaviors that are open to interpretation (Neta & Tong, 2016; Schoth & Liossi, 2017). As individuals with high stress jobs often operate in threatening environments, resolution of ambiguity and determination of whether people or information encountered are safe or threatening is critical and, in some scenarios, may determine life or death. Thus, under acute stress states, or when a source of threat is unclear, it can be adaptive to view ambiguous stimuli as threatening until contextual information proves otherwise (Cornwell et al., 2011). Consequently, previous work has examined affective decision making in response to ambiguity under *emotional stress* (Brown, Raio & Neta, 2017; Neta et al., 2017; Ito et al., 2017; Park, Vasey, Kim, Hu & Thayer, 2016), but response to and resolution of ambiguity under *physical stress* remains relatively unexplored.

Ambiguity in an affective domain

In the affective domain, responses to ambiguity can be examined using facial expressions of emotion. Facial expressions are biologically relevant signals that provide the perceiver with vital information about emotional state and intentions of others (Schmidt & Cohn, 2001). In addition, facial expressions provide adaptive value as they can signal events, such as threat or reward. As such, they can provide predictive information about one’s immediate environment, which can be used to guide behavior (Whalen, 1998). For individuals with high stress jobs, correct assessment of emotional information extracted from facial expressions is critical as it both modulates social interactions and can be used to determine appropriate action (Elrich, 2000; Mahoney, Hirsch, Hasselquist, Lesher & Lieberman, 2007).

Valence, or whether the emotion being expressed is positive or negative, is one important signal portrayed by facial expressions. This good-bad distinction is fundamental to facial expression interpretation, and not only develops early but is stable across the lifespan (Neta et al., 2009; Tottenham et al., 2014). Thus, some expressions are associated with clearly positive and negative valence, such as happy or angry (Ekman & Friesian, 1976), whereas other expressions are more ambiguous in that they could signal presence of both positive or negative events. For example, an expression of surprise signals that an important event has occurred, yet it does not indicate whether the event is threatening or rewarding (Whalen et al., 2009) As such, surprise is especially ambiguous: it has been predictive of positive (unexpected birthday party) and negative (oncoming car crash) events in the past, and thus, can be interpreted both positively or negatively (Neta, Norris & Whalen, 2009; Tomkins & MCarter, 1964; Whalen, 1998). When presented in isolation without contextual information to disambiguate the valence, this inherent ambiguity in surprised facial expressions can be used to determine an individual's valence bias: the tendency to interpret ambiguity as positive or negative.

Valence bias varies widely across individuals, allowing for examination of individual differences in interpretation of ambiguity (Kim, Somerville, Johnstone, Alexander, & Whalen, 2003; Neta, Norris, & Whalen, 2009; Neta, Kelley & Whalen, 2013). Despite these individual differences in propensity to interpret emotional ambiguity positively or negatively, an "initial-negativity hypothesis" has been proposed (Neta & Whalen, 2010). When interpreting surprise, behavioral and psychophysiological studies have demonstrated that the initial, automatic response is negative, marked by faster reaction times and higher amygdala activity (Kim et al., 2003; Neta, Kelley & Whalen, 2013; Neta & Whalen; 2010; Neta & Tong, 2016; Petro, Tong, Henley & Neta, 2018). This early negative appraisal is consistently demonstrated and generalizes to other types of stimuli (e.g. scenes), even in those who ultimately rate the expression as positive (Neta et al. 2009; Neta & Tong, 2016).

Valence bias of ambiguity

A growing body of work suggests both attentional deployment and/or top-down regulatory control may be processes critical to interpretation of ambiguous social cues. Interestingly, it has been proposed that cognitive biases in attention and interpretation may stem from a shared processing mechanism (Mathews et al., 1997; Williams et al., 1997). This notion stems from models of anxiety proposing that both hypervigilance to threat and negative interpretive biases result from competition between bottom-up (early threat processing) and top-down (cognitive control) processing (Bishop, 2007; Mathews & Mackintosh, 1998). Thus, it is possible that shifts in attention might have broader cognitive consequences, impacting downstream interpretive processes (Bowler et al., 2017). As such, previous work has demonstrated that successful redirection of attention, either towards positive or away from negative information, results in subsequent transfer effects on interpretation of emotional ambiguity (Bowler et al., 2017; White, Suway, Pine, Bar-Haim & Fox, 2011).

Given that the initial interpretation of surprise is ubiquitously negative, additional regulatory processing is necessary to shift interpretation to positive. Indeed, previous work has suggested that cognitive control processes and recruitment of the prefrontal cortex (PFC) are required during resolution of ambiguity (Neta et al., 2013; Neta et al., 2014). In young adults, more positive interpretations of surprise are associated with greater activity in the medial prefrontal cortex (mPFC), suggesting regulatory influence is needed to override the initial negativity default (Kim et al., 2003). As the PFC is involved in both domain general and domain specific cognitive control, such as the cognitive control of emotion (Buhle et al., 2014), recent work has started to examine the relationships between valence bias and emotion regulation. Specifically, given the dual valence representation of surprise (can be interpreted both positively and negatively), it is likely that overriding an initial negative appraisal involves reinterpretation of the expression, as opposed to distancing or suppressing this negative interpretation (Neta, Norris & Whalen, 2009; Neta, Tong, Brown & Davis, under review). This reevaluation, or cognitive reappraisal, has been associated with top-down cognitive control circuitry involving the prefrontal, parietal, and anterior cingulate cortical regions (Ochsner & Gross, 2005). Recent neuroimaging results demonstrate significant shared activation between these regions involved cognitive reappraisal and those involved when positive valence biases emerge (Petro, Tong, Henley & Neta, 2018). Taken together, extant work indicates that interpreting ambiguity in a positive light occurs with engagement of regulatory control.

Emotional stress and valence bias

Recent work has suggested that stress exposure alters decisions made in response to uncertainty (ambiguity) (Starcke & Brand, 2016). Acute emotional stress is associated with increased negative affect, reduced cognitive control and flexibility, and reduced regulation of negative emotion (Plessow, Kiesel & Kirschbaum, 2012; Raio et al., 2013; Schwabe & Wolfe, 2011). Furthermore, elevated stress hormones, such as catecholamines (i.e. dopamine, noradrenaline) and glucocorticoids (i.e., cortisol) reduce PFC activity and increase amygdala activity, resulting in diminished regulatory control but increased threat detection (Hermans, Henckens, Joels, & Fernandez 2014; Shields, Sazma & Yonelinas, 2016). As such, research examining valence bias in individuals with depression and anxiety has demonstrated that prolonged stress states can lead to negative appraisals of facial emotional ambiguity (Ito et al., 2017; Park et al., 2016). More recently, work has begun to examine the influence of acute emotional stress states on the interpretation of surprise. First, work by Brown & colleagues (2017) demonstrated that following acute stress exposure, individuals with the highest levels of perceived stress and salivary cortisol, relative to baseline, provided more negative ratings for surprise. Furthermore, negative interpretations were associated with greater difficulty engaging in goal-directed behavior, such as regulating negative emotion. Although results did not yield significant differences in valence bias between stress and control conditions, sensitivity to detect changes due to acute stress may have been contingent upon both the stress manipulation chosen and use of a between-participants design (Giles et al., 2014). However, initial results highlight the possibility that stress reactivity may impair the subsequent higher-order processing required to eventually arrive at positive appraisals of ambiguous social cues.

Second, recent results from our lab revealed that interpretation of surprise is altered under threat of unpredictable shock (TOS) (Neta et al., 2017). In TOS, participants receive mild, unpredictable electric shocks while performing an unrelated cognitive task. While TOS is not extremely stressful, the unpredictability of threat in this context induces an anxiety state that facilitates heightened vigilance, which can elicit both adaptive and maladaptive effects on cognitive and affective processing (Robinson, Krimsky & Grillon, 2013; Robinson, Vytal, Cornwell & Grillon, 2013b). Our results demonstrated that individuals reporting heightened arousal rated surprise more negatively under shock versus safe conditions. Specifically, those individuals who demonstrated a more positive valence bias at baseline were more likely to interpret surprise negatively during TOS. This again suggests that regulatory control is needed to override the prepotent negative interpretation of surprise (Neta & Whalen, 2010;

Neta, Davis & Whalen, 2011; Neta & Tong, 2016), yet this mechanism may be disrupted under acute stress. This shift to negativity, which was correlated with increased emotional arousal, is consistent with findings suggesting hypervigilance to threat promotes harm avoidance (Shackman, Maxwell, McMenamin, Greischar & Davidson, 2011a). Thus, negative interpretations are likely adaptive in situations in which threat detection is critical for survival.

Exercise as a physical stressor

Prolonged stress exposure is known to have deleterious effects on cognition and behavior, often increasing risk for developing mood and anxiety disorders (Marin et al., 2011). As previously discussed, emotional stress states can influence interpretation of emotional ambiguity, however, stress can be both physical and emotional in nature. Individuals with high stress occupations, such as law enforcement and military personnel, operate in stressful environments that can be simultaneously physically and emotionally demanding. At the same time, these individuals must quickly and accurately judge whether individuals encountered pose potential threat, in order to predict other's behavior and inform their own behavior. Thus, understanding interpretation of ambiguous facial expressions in social contexts that co-occur with high levels of physiological exertion, such as those experienced by military personnel and emergency first responders has important implications for real-world social behavior.

Though often deemed beneficial to health, physical exercise can be considered acutely stressful as it disrupts bodily homeostasis and can lead to dehydration, heat stress, metabolic depletion and central fatigue (Blomstrand et al., 1991; Brisswalter, Collardeau & Rene, 2002; Cheuvront, & Haymes, 2001; Grego et al., 2004, Hancock, 1986). Consequnetly, although exercise is generally believed to make people "feel good", the physiological stress of exercise can result in variable changes in emotional state (Acevedo & Ekkekakis, 2006; Ekkekakis, 2013). When emotional, or affective state, is examined during acute bouts of exercise, it is commonly characterized in terms of two orthogonal dimensions: valence and arousal (Lang, Bradley, & Cuthbert, 1997). Emotional valence describes the direction of the experience ranging from "positive/pleasant" to "negative/unpleasant", whereas emotional arousal describes the activation or intensity of the emotional experience ranging from "high to low" (Bradley & Lang, 1999).

The dual-mode theory suggests a dose-response relationship exists between the intensity of the exercise performed and the pleasure-displeasure experienced (Ekkekakis, 2003; Ekkekakis, Petruzzello & Parfitt, 2011; Ekkekakis, Hargreaves & Parfitt, 2013). As such, extant literature has demonstrated that at low or moderate intensities, below the ventilatory threshold (VT), affective responses are mostly positive (pleasant). Affective responses become variable near VT, also called the lactate threshold (LT), or the point at which ventilation becomes disproportionately high with respect to oxygen consumption. Anecdotally, this represents the point where exercise changes from "moderate" to "heavy" (Rating of Perceived Exertion (RPE) approximately 12-13 out of 20) (Ekkekakis, Hall & Petruzzello, 2002; Stojiljković et al., 2004). The threshold at which exercise changes from "heavy" to "severe" (RPE approximately 15-16) is called the respiratory compensation point (RCP), sometimes called the second ventilatory threshold (VT_2) (Green, Crews, Bosak & Peveler, 2003; Neder & Stein, 2006). At intensities above VT (proximal to RCP and exhaustion), affective responses are uniformly negative (unpleasant) (Ekkekakis, Hall & Petruzzello, 2004, 2008). Moreover, intensity, rather than duration or total work, drives these changes in affective responses (Daley & Welch, 2004; Kilpatrick et al., 2007). Hence, exercise at lower intensities is likely adaptive and pleasant, whereas negative affective responses elicited due to high intensities likely represent a primitive "alarm" function signaling homeostatic perturbations that are maladaptive and not supportive of continued behavior (Hall, Ekkekakis & Petruzzello, 2002).

Physical stress and valence bias

Although research has not yet examined valence bias in relation to physical stress, work examining emotional and cognitive processing during exercise can shed light on how valence bias might shift. First, physical stress may lead to shifts in attentional deployment. Specifically, exercise at increasing intensities may shift internal (associative) focus of attention at the expense of attentional resources available for external (dissociative) focus (Tennebaum, 2007), liken to shifts from bottom-up processing vs. top-down processing. In support of this notion, at intensities above VT individuals often report increases in associative thoughts relating to physical sensations, or interoceptive cues that accompany the metabolic changes due to exercise (i.e., breathing rhythm, muscle fatigue, heart rate, and temperature) (Da Silva et al., 2017; Ekkekakis, Parfitt &

Petruzzello, 2011). Thus, the increased physiological demand at higher exercise intensities may bias attention toward internal state and subsequent negative affective responses, possibly resulting in downstream influence on interpretation biases (White, Suway, Pine, Bar-Haim & Fox, 2011; Brown, Raio & Neta, 2017). Furthermore, as previously discussed, acute emotional stress might adaptively shift interpretation of ambiguity for the purposes of harm avoidance, abolishing positivity bias until context proves to be safe (Neta et al. 2017; Shackman, Maxwell, McMenamin, Greischar & Davidson, 2011a). Similarly, significant physiological perturbations due to high physical stress, such as heightened arousal, may also serve to shift valence interpretations in the negative direction until homeostatic threat to the system is resolved. This idea is further supported by the relationship between negative affective responses and increased associative thoughts (Ekkekakis, 2003). In contrast, exercise performed at moderate intensity has been shown to modify attention to positive information. Tian and Smith (2011) demonstrated that attentional bias towards pleasant facial expressions increased during cycling at 45% VO^2_{peak} (below VT), compared to unpleasant expressions. Furthermore, attentional bias towards unpleasant stimuli was significantly less during moderate intensity exercise compared to seated rest. Taken together, this work highlights that attentional focus may differ during varying exercise intensities, which may have differing effects on subsequent interpretive biases.

Second, physical stress may impair ability to regulate reflexive affective processing, biasing individuals to view ambiguous faces more negatively.

Consistent with this notion, proposed theories on neural processing during exercise, specifically inverted-*U* and hypo-frontality theories, both propose that when exercise is performed at high intensities (above VT) increases in physiological arousal and/or changes in allocation of neural resources from prefrontal to subcortical regions compromise cognitive and affective processing (Dietrich, 2006; Dietrich & Audiffren, 2011; McMorris et al., 2011; McMorris & Hale, 2012; Lambourne & Tomporowski, 2010). Indeed, empirical work has demonstrated that cognitive control processes are enhanced when performed during moderate intensity conditions (at or below VT) (Chang et al., 2012; Da Silva et al., 2017) and impaired during highly intense exercise (Cantelon et al., 2018; Davranche & McMorris, 2009; McMorris et al., 2009; Schmit et al. 2015). Furthermore, a growing body of work suggests that these top-down regulatory control processes may be critical for interpreting ambiguous social cues positively (Brown, Raio, Neta, 2017; Kim et al., 2013; Petro et al., 2018). In support of this notion, when participants are asked to take their time to consider alternative interpretations of surprise, instead of relying on their gut reaction when making valence judgements, ratings were more positive (Neta & Tong, 2016). Thus, engaging in additional regulatory processing, or reappraisal, of automatic responses to ambiguity can lead to shifts in appraisals from negative to positive. Therefore, a differing pattern of results might be predicted at differing exercise intensities. At moderate intensities, when cognitive control processes are intact, participants may be able to regulate initial negative responses, whereas at high intensities ability to override initial negativity bias in response to surprise will be diminished. However, previous work has not examined valence bias during physical stress, leading to our first research question: *How does physical stress influence valence bias of ambiguous social cues?*

Valence resolution in context

Examining responses to facial ambiguity in isolation allows for measurement of interpretive biases, however, in the real-world scenario's faces are rarely experienced out of context. During social interactions, the context surrounding a face can take many forms, including visual scenes, verbal cues, body language or facial expressions of others (Barrett, Mesquita & Gendron, 2011). These surrounding visual scenes (environment) provide both information about the face, but also provide important information about the situational context in which the facial expression occurs, offering cues to guide our own behavior (Carroll & Russell, 1996). Furthermore, the transient and dynamic nature of facial expressions emphasizes the importance of context in their interpretation (Blanchette, Richard, Cross, 2007). In particular, the dual valence representation of surprise makes interpretation of this expression highly dependent upon the context in which it is encountered (Neta, Davis & Whalen, 2011; Weiser & Brosch, 2012). Accordingly, to resolve this ambiguity we must use cues from the environment to determine if the target individual is reacting to the presence of a negative event (signaling threat) or positive event (signaling reward).

Previous work has demonstrated the influence of contextual manipulations on the valence resolution of surprise. *Explicit* verbal contexts that define the valence of the facial expression, specifically by offering explanation for what triggered it, shift valence ratings in a negative and positive direction, respectively (Kim et al., 2004). In contrast, *implicit* contexts that do not offer a specific explanation, but rather only imply whether the environment is positive or negative can also be used to modulate valence ratings (Neta, Davis & Whalen, 2011). For instance, unpredictable environments are highly aversive and can elicit anxiety-like behavior and hypervigilance to threat (Grillon, Baas, Lissek & Milstein, 2004). Unpredictable presentations of surprised expressions biases neural systems critical for threat detection (Davis et al., 2016). Additionally, a temporal context of clearly valanced faces is sufficient to modulate valence ratings. Findings demonstrate that surprised faces are rated more positively when presented interleaved with unambiguously happy faces and more negatively with angry expressions (Neta, Davis, Whalen, 2011). Taken together, since surprised expressions carry a dual-valence representation that must be resolved (Neta, Norris & Whalen, 2009), resolution of the predictive meaning of these expressions tends to be congruent with the context in which it is presented. However, only when the context is clearly valanced (positive or negative) will it have a facilitatory effect on interpretation of the target expression (surprise). When the context (such as neutral) does not provide clear cues to disambiguate the valence, reliance will be placed on initial interpretive biases, which may potentially be influenced by the current state of the perceiver (Brown, Raio & Neta 2017; Neta et al., 2018).

Physical stress and valence resolution

Response to and resolution of emotional ambiguity has not yet been addressed within the domain of physical stress. However, previous theoretical and empirical work can guide predictions concerning the influence of physical stress on ability to use contextual cues during valence resolution. According to Easterbrook's cue utilization theory (1959), increased emotional arousal leads to a restriction in attentional processing capacity. As such, increases in physiological arousal due to high physical stress might result in a narrowed range of attention, restricting processing to salient cues in one's central focus of attention, such as facial expressions (Keil, Moratti, Sabatinelli, Bradley, & Lang, 2005; Lang & Bradley, 2010) In line with this notion, recent work probing memory for threatening vs. nonthreatening scene details demonstrated a significant narrowing of attention due to high intensity exercise. Specifically, results demonstrated that high physical restricted processing and memory to emotionally salient central details (weapons) over peripheral details of the broader visual scene (Brunyé & Mahoney, 2018). Thus, high physical stress appeared to exaggerate the attentional narrowing that occurs when viewing emotional stimuli. Therefore, we might predict that under moderate intensity conditions, when physiological arousal is lower, more global focus of attention will lead to ability to use contextual cues to guide valence resolution. In contrast, during high intensity, increased physiological arousal will result in more local focus of attention (on salient stimuli, i.e. surprised faces) hindering this resolution process (Chang et al., 2009; Hutterman & Memmert, 2012). However, resolution of ambiguity during exercise has not been examined, leading to our second research question: *How does* *physical stress influence ability to use contextual cues to guide valence resolution of ambiguous social cues?*

The present study

Facial expressions shed light on the emotions and intentions of others. Therefore, fluent recognition and interpretation of these signals is of vital importance during social interactions. Previous work has demonstrated that shifts in valence bias of ambiguous facial expressions (surprise) can occur during acute emotional stress states (Brown, Raio & Neta, 2017; Neta et al., 2018), yet response to and resolution of ambiguity during physical stress remains unknown. Physical stress influences both attentional deployment, as well as effortful cognitive control processes, that may contribute to significant shifts in interpretation of ambiguous information (Brunyé & Mahoney, 2018; Cantelon et al., 2018). Importantly, even slight shifts in interpretive biases may determine differences in perceiving information as safe vs. threatening, which could have significant behavioral consequences for law enforcement and military personnel operating high stakes environments. Thus, the present study was aimed at understanding interpretation of ambiguous emotional information during high levels of physiological exertion similar to those experienced by individuals high stress jobs.

Objectives and Hypotheses.

The first objective was to replicate previous findings that emotional state and physiological responses differ due to varying levels of physical stress. Based on extant literature, exercise performed at or below VT (moderate condition) should result in positive affective responses, whereas exercise above VT (high condition) should result in negative affective responses (Ekkekakis, Petruzzello & Parfitt, 2011; Ekkekakis, Hargreaves & Parfitt, 2013). Additionally, felt arousal should increase with exercise intensity, thus, we predicted that arousal would be higher during the high compared to moderate condition (Ekkekakis, Hall & Petruzzello, 2002). Finally, if our exercise manipulation had its intended effects, both perceived exertion and heart rate should be higher during high vs. moderate exercise condition.

The second objective was to assess whether physical stress influences valence bias of ambiguous social cues. Previous work has suggested that both attention and cognitive control processes can influence positive shifts in valence bias of surprised expressions, whereas acute emotional stress leads to negative interpretations (Brown, Raio & Neta, 2017; Neta & Tong, 2016; White, Suway, Pine, Bar-Haim & Fox, 2011). Given that exercise below VT (moderate Condition) and above VT (high condition) differentially influence attention and regulatory control processes (Brunyé & Mahoney, 2018; Cantelon et al., 2018), we predicted that valence bias would be more negative under the high vs. moderate condition.

The third objective was to assess whether physical stress influences ability to use contextual cues to guide valence resolution of ambiguous social cues. Previous work has demonstrated that the physiological arousal induced by high intensity physical exercise narrows attentional focus, restricting processing and memory to emotionally salient central details over peripheral details of the broader visual scene (Brunyé & Mahoney, 2018). Thus, we might predict that when ambiguous facial expressions are presented within context, the moderate intensity condition will lead to more global (focus on context) processing, whereas high intensity will lead to more local (focus on face) processing. This could result in differences in ability to use contextual cues to resolve valence, where under the moderate intensity condition, surprised faces will be rated more positively when presented in positive contexts and more negatively in negative contexts. However, under the high intensity condition participants will rely on default interpretations of surprise, likely leading to more negative interpretations. Thus, when surprise is presented in neutral context conditions, valence bias should mirror results presented above (objective 2).

The fourth objective was to explore whether individual differences in emotion regulation (cognitive reappraisal) influence differences in valence bias between varying levels of physical stress. Previous work has demonstrated a relationship between emotion regulation and valence bias. Specifically, those who report greater difficulty regulating their emotions interpret surprise more negatively following acute emotional stress (Brown, Raio & Neta, 2017). Additionally, preliminary works suggests that those who report greater use of cognitive reappraisal in daily life have a more positive valence bias and are less susceptible to negative shifts in valence bias due to stress exposure (Neta, Tong, Brown & Davis, under review). Therefore, we predicted that individuals endorsing greater habitual use of cognitive reappraisal (as measured by the

Emotion Regulation Questionnaire (ERQ; Gross & John, 2003)), would demonstrate smaller negative shifts in bias during the high intensity condition.

Methods

Participants

Forty-eight individuals (29 female, age mean ± SD 20.67 ± 2.96, mean BMI 23.37 ± 2.70) participated for monetary compensation of $100 (see Table 2 for sample characteristics). All participants were regular exercisers, who reported engaging in at least 30 minutes of moderate intensity aerobic exercise 5 days per week, or 20 minutes of vigorous intensity exercise 3 days per week. Participants were recruited via Tufts paid SONA postings and were either Tufts University students or community members. Written informed consent was obtained, and both the Tufts University Institutional Review Board and the Army Human Research Protections Office approved all procedures.

Research Design

This study used a repeated measures design, with exercise Intensity 2(moderate, high), Context (positive, negative, neutral) and Time (min 30, min 35) as the within-subjects' factors. Sample size estimation was based on effect sizes from two previous studies. First, Neta & Tong (2016), who found that surprised expressions were rated more positively when considering alternative explanations vs. rating based on gut reaction ($\eta^2 = .43$). Using GPower, the total sample size was estimated to be 57 with an alpha level of $p = 0.05$ and a power of 0.80, using repeated measure ANOVA with two degrees of freedom. Second, Tian & Smith (2011) who found that attentional bias to pleasant stimuli increased during moderate intensity exercise ($\eta^2 = .22$). Using GPower, the total sample size was estimated to be 45 with an alpha level of $p = 0.05$ and a power of 0.80, using repeated measure ANOVA with two degrees of freedom.

Stimuli and Paradigm

Pilot study (stimuli norming).

Online pilot study. To create stimuli sets of ambiguous facial expressions for use in the *Valence Ratings Task* and *Visual Context Task*, we first conducted a pilot study in order to obtain normative ratings of valence and arousal. Normative ratings were first collected using Amazon mechanical Turk (mTurk) crowdsourcing website. We recruited 200 participants (18 years or older), who were invited to partake in a study involving rating images, words and videos in exchange for $1.50. To ensure participants were attentive and motivated, we restricted participation to workers who had an approval rate of at least 90% on previous human intelligence tasks (HITS) and who had completed at least 50 HITS on mTurk. Furthermore, as intercultural differences in terms of valence and arousal judgments or response styles may differ between countries, we restricted participation to workers from the United States. Upon providing consent, participants were presented with a series of faces and asked to rate the valence and arousal of each face. After providing ratings, participants were asked to complete a standard demographic questionnaire including items on gender, age, ethnicity, race, current occupation and highest level of education.

Stimuli included surprised facial expressions, of which 70 identities (35 males) were drawn from the Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Ohman, 1998), 45 (26 males) from the NimStim Face Stimulus Set (Tottenham et al., 2009), 60 (30 males) from the Umeå University Database of Facial Expressions (Samuelsson et al., 2012) and 49 (18 males) from the IASLab Face Set (www.affective-science.org), for a total of 224 faces (109 males). Faces were presented on a white background, aligned vertically along the middle of the pupils and horizontally along the center of the nose. Additionally, each image was matched for brightness and contrast and standardized to 700x400 pixels, while maintaining aspect ratio. Participants were presented with each face and asked to rate the valence as either positive or negative, as well as rate the intensity of the emotion being displayed in the face using a visual analog scale ranging from 1 (not at all aroused/intense) to 100 (very aroused/intense). From these ratings, we planned to select a subset of images that were deemed the “most ambiguous”, with approximately 50% of the sample rating the faces as positive and 50% as negative. These ambiguous facial expressions were then to be used for stimuli in our main study.

Our online pilot yielded a set of 30 ambiguous faces, out of 224 total faces. Given that the tasks in our main study would require four subsets of ambiguous facial expressions, we determined that a stimulus set of 30 would not provide adequate number of trials to yield statistical power necessary to measure desired effects. Previous studies in our lab obtaining similar ratings with a smaller total set of these surprised expression stimuli yielded a higher end count of these "most ambiguous" faces (n=36). Therefore, we determined results may be unreliable. Currently, there is debate in the literature as to whether mTurk provides truthful and reliable data (see Peer, Brandimarte, Samat & Acquisti, 2016; Hauser, Paolacci, & Chandler 2018; Kaan & Drummey, 2018; Kees, Berry, Burton, Sheehan, 2017).

In-lab pilot study. In order to yield a larger set of ambiguous facial expression stimuli, we re-ran our pilot study in the laboratory with a sample of 51 participants (34 female, mean age ± SD 20.57 ± 2.86). Participants were recruited via Tufts paid SONA postings and were either Tufts University students or community members and compensated $10 for participation. Written informed consent was obtained, and both the Tufts University Institutional Review Board and the Army Human Research Protections Office approved all procedures.

Procedure and stimuli were identical to that described above (*Online pilot-study*). Results yielded a stimulus count of 64 ambiguous faces, out of the total set of 224. Final stimuli set consisted of surprised facial expressions, of which 25 identities (11 males) were drawn from the Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Ohman, 1998), 14 (10 males) from the NimStim Face Stimulus Set (Tottenham et al., 2009), 12 (4 males) from the Umeå University Database of Facial Expressions (Samuelsson et al., 2012) and 13 (4 males) from the IASLab Face Set (www.affective-science.org).

Main Study

Valence Ratings Task.

Stimuli included a set of 32 surprised facial expressions, randomly drawn from a total set of 64 faces (29 male). For each participant, stimuli were randomly divided into two sets of 16 faces, with one set presented in the Moderate intensity condition and the other in the High condition.

During the task, participants were told that they would view a series of faces and would be asked to rate the valence of each face as either positive or negative, as quickly as possible based on their gut reaction. Participants used a response keypad to make ratings, using the index finger of their dominant hand. Response buttons for positive/negative were counterbalanced across participants. There was no time limit for responses. During the task, each face was randomly presented three times, for a total of 48 trials. Stimuli were presented electronically using the PsychoPy software (Peirce, 2007) and displayed on a 15" screen, approximately 60 cm from the participants. During each trial, participants were first presented with a black fixation cross displayed on a white background for 500 ms, then each surprised face for 500 ms, followed by an interstimulus interval (ISI) of 1,500 ms. ISI was consistent across trials, as previous work has demonstrated that unpredictability enhances negative interpretations (Davis et al., 2016). Participants were able to make a response starting at stimulus onset and throughout the ISI period (total available response time = 2,000 ms). In total, the *Valence Rating Task* lasted approximately 5 minutes.

Visual Context Task.

Stimuli included a set of 32 surprised facial expressions, randomly drawn from the total set of 64 faces. Additionally, 96 emotional content images obtained from the Open Affective Science Image Set (OASIS; Kurdi, Lazano, Banaji, 2017) were used for visual contextual stimuli. This included 32 Positive (mean±SD, 6.11±.22), 32 Negative (1.97±.27) and 32 Neutral images (4.06±.10) according to the normative ratings (both valence and arousal levels were rated on 7-point Likert scale with 1 = very negative/very low and 9 = very positive/very high; data from Kurdi, Lazano, Banaji, 2017). The context images were then divided into two sets of 48 images, with valence and arousal matched across sets (see Table 1 for comparisons). For each participant, surprised face stimuli were randomly divided into two sets of 16 faces, with one face set and one visual context set presented in each exercise condition. The orders of these sets counterbalanced across participants.

Similar to the *Valence Ratings Task*, participants were told to rate the valence of each face based on their gut reaction. Participants were not given specific instructions about context images, so as to avoid prompting participants towards either using or not using these cues when rating the faces. Participants used a response keypad to make ratings using the index finger of their dominant hand. Response buttons for positive/negative were counterbalanced across participants. There was no time limit for responses. Stimuli were presented electronically using the PsychoPy software (Peirce, 2007) and displayed on a 15” screen, at approximately 60 cm from the participants. During each trial, first a fixation cross was displayed to orient participants’ attention to the center of the screen (500 ms). Next, a context image, conveying either a Positive, Negative, or Neutral scene was presented for 1000 ms. Duration of these images was set according to time required for the processing of valence (100-250 ms) and arousal (200-1,000 ms) of similar types of emotional content images (Codispoti et al., 2007; Olofsson and Polich, 2007). Finally, a surprised facial expression was presented for 500 ms, followed by an ISI of 1,500 ms. Participants were able to make a response starting at stimulus onset, and throughout the ISI period (total available response time = 2,000 ms). Ordering of these face/context pairs was pseudorandomized so that the same face identity was not presented during subsequent trials. In total, the task lasted approximately 5 minutes.

Cycling task.

Participants visited the laboratory for two sessions and completed a 40-minute bout of continuous cycling at either moderate or high intensity on a Monark cycle ergometer (Monark LC6), followed by a 5-minute cool down. Moderate and high exercise intensities were chosen based on guidelines from the American College of Sports Medicine (Garber et al., 2011) corresponding to 65% and 85% of Heart Rate Reserve (HRR) determined using the Karvonen Formula, calculated as: Target HR = % of target intensity (age adjusted $HR_{max} – HR_{rest}$) + HR_{rest}. These intensities were chosen to reflect exercise performance below and above VT (Green, Crews, Bosak & Peveler, 2003; Stojiljković et al., 2004). Furthermore, in order to measure interpretation and resolution of ambiguity during both moderate and high physical stress states, we used an exercise protocol previously employed in our lab combining moderate/high intensity with a prolonged duration. Under high intensity conditions this protocol has been shown to elicit ratings of exertion indicative of performance at RCP, with increased negative affective responses (Cantelon et al., 2018). During the cycling task, participants were instructed to gradually increase the resistance of the ergometer within the first 7-8 minutes until the target HR was achieved. HR was monitored using Polar telemetry and participants were asked to adjust ergometer resistance as necessary to maintain the target HR (± 7-8%) throughout the 40-minute bout of cycling. Participants were allowed to choose their cycling cadence throughout the task. Self-selected cadence allowed for reduced resource allocation required for monitoring physical movements inherent to cycling and minimized dual task effects as compared with a fixed rate (Davranche, Hall & McMorris, 2009). After 40 minutes, participants completed a 5-minute cool-down. Test sessions were separated by at least 72 hours.

Water was freely available throughout the session. To reduce the influence of hydration status on cognitive and physical performance, participants were asked to consume half a liter of water the night before and half a liter of water the morning of a test session. Participants were also required to consume at least one meal prior to a morning test session (i.e., breakfast), and at least two meals prior to an afternoon test session (i.e., breakfast, lunch); with no limit in time of day for testing. Lastly, they were asked to refrain from alcohol consumption within 24 hours prior and to consume their normal amount of caffeine on the day of each test session.

Self-report Questionnaires.

*Godin Leisure Time Questionnaire***.** The Godin Leisure Time Exercise Questionnaire was used to quantify subjects' activity level by measuring the number of times they engage in strenuous, moderate, and light exercise for at least 15 minutes over an average week (Godin & Shephard, 1985). Individuals who score at least 24 are considered active and those who score less than 14 are considered inactive (Godin, 2011). Therefore, only individuals scoring above 24 were eligible to participate.

Rated Perceived Exertion (RPE). Ratings of perceived exertion were given using the Borg RPE scale, ranging from 6 (no exertion at all) to 20 (maximal exertion) (Borg, 1982).

Feeling Scale (FS). The FS is a one-item inventory measuring the extent to which pleasant or unpleasant feelings are experienced, ranging from +5 (very good) to -5 (very bad) (Hardy & Rejeski, 1989).

Felt Arousal Scale (FAS). The FAS is a one-item inventory measuring feelings of arousal from 1 (low arousal) to 6 (high arousal) (Svebak & Murgatroyd, 1985).

Emotion Regulation Questionnaire (ERQ). The ERQ was used to measure use of cognitive reappraisal and expressive suppression emotion regulation strategies (Gross & John, 2003). Participants rated 10 items on a scale ranging from 1 (strongly disagree) to 7 (strongly agree), that assess emotional experience and emotional expression of both positive and negative emotions.

Procedure

Interested participants were given up to 60 minutes to complete the consent and screening materials. Screening materials included the Godin Leisure

Time Questionnaire to determine whether participants engaged in habitual physical activity (at least 30 minutes of moderate intensity aerobic exercise 5 days per week). If deemed eligible to participate, they completed a demographic questionnaire and the ERQ. Next, participants donned a HR monitor and began the cycling task, in which they were asked to cycle continuously for 40 minutes, followed by a 5-minute cool down. During the cycling task, participants completed the RPE, FS and FAS prior to beginning exercise, at minute 30 prior to completing the *Valence Ratings Task*, at minute 35 prior to the *Visual Context Task* and following cool-down. Test sessions 1 and 2 were identical with the exception of the exercise intensity. Following completion of the study, participants were debriefed and compensated for their participation. See Figure 1 for schematic representation of the study schedule.

Example test session schedule:

-05 min – Don HR monitor
00 min – RPE_0, FS_0, FAS_0
00 min – Begin Exercise
30 min – RPE_1, FS_1, FAS_1, Valence Ratings Task
35 min – RPE_2, FS_2, FAS_2, Visual Context Task
40 min – Cool Down
45 min – RPE_4, FS_4, FAS_4

Statistical Methods

First, valence bias scores were calculated for ratings made during the *Valence Ratings Task* and *Visual Context Task*. The dependent measure used to represent valence bias was percentage of negative ratings (% negative), calculated as the percent of trials in which a participant rated a surprised facial expression negatively, of the total number of trials (excluding omissions).

To determine whether physical stress led to changes in physiological response and if participants adhered to prescribed target heart rates for high and moderate exercise conditions, we examined average heart rate (bpm) throughout the *Cycling Task* using a paired samples *t*-test. To assess differences in emotional state between exercise conditions we conducted separate 2(Intensity: high, moderate) x 2 (Time: min 30, min 35) repeated measures ANOVA's with ratings of perceived exertion, affect and arousal.

To assess differences in valence bias due to level of physical stress, we conducted a paired samples *t*-test, comparing % negative ratings between high and moderate conditions. To assess the influence of visual contextual cues on valence resolution during physical stress, we conducted an omnibus 2(Intensity: moderate, high) x 3(Context: positive, negative, neutral) repeated measures ANOVA.

Additionally, we assessed differences in response time between high and moderate conditions. In line with the notion that negative interpretations of ambiguity may be more automatic and positive interpretations require additional regulation, previous work has demonstrated that response times tend to be slower when surprised faces are rated as positive and faster when faces rated are rated as negative (Neta & Tong, 2016, Neta et al., 2009). Thus, to assess differences in response times when interpreting ambiguity in the *Valence Ratings Task*, we conducted a 2(Intensity: high, moderate) x 2(Rating: positive, negative) repeated measures ANOVA. To assess differences in responses times when resolving ambiguity in the *Visual Context Task,* we conducted a 2(Intensity: high, moderate) x 2(Rating: positive, negative) x 3(Context: positive, negative, neutral) repeated measures ANOVA.

Finally, to assess whether differences in habitual use of cognitive reappraisal influenced shifts in valence bias due to levels of physical stress, we conducted a 2(Intensity: high, moderate) repeated measures ANCOVA on % negative ratings in the *Valence Ratings Task,* with scores from the cognitive reappraisal subscale of the ERQ entered as a covariate.

All statistical analyses were performed using SPSS v.18.0 (IBM Corp., Armonk, NY, USA). Data was assessed for normality using Shapiro-Wilk tests. When sphericity was violated, Greenhouse-Geisser corrections were used. When an ANOVA yielded a significant main effect or interaction ($p < .05$), post-hoc tests using the Bonferroni corrections were conducted. Effect sizes were provided for all analyses, using η_p^2 for ANOVAs, and Cohen's *d* for *t*-tests. Data reported are mean ± standard error, unless otherwise stated.

Results

Emotional State and Physiological Response

Heart Rate.

Throughout the *Cycling Task,* average heart rate (bpm) was confirmed to be significantly different between conditions $t(47) = 16.9$, $p < .001$, $d = 2.44$, (95% CI, 20.0 to 25.4). Average heart rate was higher during high (164 ± 0.99 bpm) compared to moderate intensity condition (141 ± 0.87 bpm).

Perceived Exertion.

Analysis of Rated Perceived Exertion (RPE) revealed a significant main effect of Intensity *F*(1, 47) = 286.31, $p < .001$, $\eta_p^2 = .86$ such that reported exertion levels were higher in the high compared to moderate condition (see Table 3). No significant main effect of Time, or Intensity by Time interaction were found (*p*s > .137).

Feeling Scale (FS).

Analysis of Feeling Scale (FS) ratings revealed a significant main effect of Intensity *F*(1, 47) = 16.99, $p < .001$, $\eta_p^2 = .27$ such that emotional valence was more negative in the high compared to moderate condition (see table 4). No significant main effect of Time, or Intensity by Time interaction were found (*p*s>.132).

Felt Arousal Scale (FAS).

Analysis of a Felt Arousal Scale (FAS) ratings revealed a significant main effect of Intensity *F*(1, 47) = 24.51, $p < .001$, $\eta_p^2 = .36$, such that emotional arousal was higher in the high compared to moderate condition (see Table 5). No significant main effect of Time, or Intensity by Time interaction were found (*p* s> .613).

Physical Stress and Valence Bias

Valence bias.

Analysis of percentage of negative ratings in the *Valence Ratings Task* revealed that valence bias of ambiguous social cues did not significantly differ between the exercise Intensity conditions $t(47) = .494$, $p = .624$, (95% CI, -.0542 to .0329) (see Figure 2).

Response Time.

Analysis of response times revealed a significant main effect of Rating, such that response times were faster when faces were rated as negative compared to positive $F(1, 47) = 5.83$, $p = .020$, $\eta_p^2 = .035$ (see Figure 3). No significant main effect of Intensity or Intensity by Rating interaction were found (ps > .195).

Physical Stress and Valence Resolution

Valence resolution.

Analysis of percentage of negative ratings in the *Visual Context Task* revealed a significant main effect of Context, $F(2,9\ 4) = 32.20$, $p < .001$, $\eta_p^2 = .41$. Post-hoc tests revealed that percentage of negative ratings were higher following negative > neutral > positive context images (ps < .001) (see Figure 4). No significant main effect of Intensity ($p > .297$) or Intensity by Context interaction were found ($p > .375$).

Response Time.

There were 6 participants who always rated surprise as negative (% negative = 100) and therefore were not included in this analysis. Analysis of response times revealed a significant main effect of Rating $F(1, 38) = 4.30$, $p = .045$, $\eta_p^2 = .102$, such that participants response times were faster when faces were rated as negative compare to positive (see Figure 5). No other significant main effects or interactions were found (ps < .067).

Exploratory analyses

Cognitive Reappraisal and Valence Bias.

Analyses revealed a significant between-subjects' effects, such that cognitive reappraisal scores differed significantly between participants ($F(1, 46) = 5.42$, $p < .024$, $\eta_p^2 = .105$) (see Table 2 for sample characteristics). After controlling for cognitive reappraisal scores (as measured by ERQ), analysis of percentage of negative ratings revealed no significant within-subjects' effects. Specifically, no main effect of Intensity ($p < .0554$), or interaction between Intensity by ERQ were found ($p > .484$).

Discussion

In the present study, we evaluated whether physical stress influenced interpretation and resolution of emotional ambiguity. Participants cycled for 40 minutes at moderate and high intensities, while completing measures of perceived exertion, affect, arousal. In addition, participants rated surprised facial expressions as either positive or negative, when presented alone, or following positive, negative or neutral context images.

Physical stress effects on emotional state and physiological response

Moderate and high levels of physical stress differentially influenced participants physiological response and emotional state. Consistent with extant literature, high exercise intensity increased heart rate and level of perceived exertion, decreased affective valence and increased emotional arousal, in comparison to moderate intensity (Ekkekakis, Hall & Petruzzello, 2004; 2008). However, we found greater variability in ratings of emotional valence during high compared to moderate intensities at minutes 30 and 35 of cycling. Examination of deviations in mean ratings indicated that participants feelings during high physical stress ranged from -1 (fairly bad) to +3 (good). This is in contrast with previous work demonstrating that at intensities proximal to respiratory compensation point (RCP; characterized by RPE of 15-17), emotional valence is uniformly negative (Ekkekakis, Hall & Petruzzello, 2004; 2008). Such negative affective responses are often associated with an internal (associative) focus of attention (on thoughts of breathing rate, fatigue, and perspiration) (Brick, MacIntyre & Campbell, 2014; Ekkekakis, 2003). However, given that responses varied, it is unclear whether all participants reached a level of physiological demand wherein such shifts in attentional deployment may have occurred, or alternatively, whether participants utilized strategies to regulate their emotional experience while exercising.

Indeed, previous work has demonstrated that use of emotion regulation strategies improves emotional state during physical stress. For instance, use of cognitive reappraisal during endurance exercise at 75-85% maximum heart rate reduces negative emotional experience, specifically emotional arousal and perceived exertion (Giles et al., 2018). Thus, it is possible that participants in our study may have varied in their tendency to adopt such strategies to regulate affective experience during exercise. As such, this may have influenced their appraisal of the physical stressor during the high intensity condition. Affective or emotional states may act as informational cues, both biasing attention and guiding behavior (Easterbrook, 1959; Bowler et al., 2017; Clore & Palmer, 2009; Schwarz & Clore, 1983).Thus, future research could disentangle factors that might influence differences in appraisal of physical stress, as this might influence one's tendency to use affect as information and subsequently impact downstream effects on interpretive biases (White, Suway, Pine, Bar-Haim & Fox, 2011).

Physical stress effects on valence bias

In line with a growing body of work proposing an 'initial-negativity hypothesis' (Neta, Davis, Whalen, 2011; Neta, Norris & Whalen, 2009; Neta & Tong, 2016; Neta & Whalen, 2010), automatic interpretations of surprise were more negative. This was demonstrated by quicker response times when participants rated surprise as negative vs. positive. Thus, negative interpretations were potentially first and fast, whereas positive interpretations may have required a slower process via recruitment of regulatory control (Neta & Tong, 2016). However, although we found differences in time to respond, ultimate determination of surprise as positive or negative did not differ as a function of physical stress. Specifically, percentage of surprised facial expressions rated as negative did not significantly differ between high and moderate exercise conditions.

Although contrary to predictions, results from Brown and colleagues (2017) revealed no significant differences in valence bias as a function of acute stress exposure. This study utilized a between-participants design wherein participants rated surprise following cold-pressor exposure or control condition. Findings indicated that exposure to a stressor was not sufficient to alter valence interpretations, but rather, individuals with greater neuroendocrine response (as measured by salivary cortisol) had higher negativity bias following acute stress (Brown, Raio & Neta, 2017). The measurement of valence bias between participants limits direct comparison with our results. However, it is worth noting that circulating cortisol levels may increase in response to exercise performed within the moderate intensity range (above 65% HRR) (Hill et al., 2008; Pfitzinger, & Douglas, 1999). Though elevated glucocorticoid release is more common at higher exercise intensities, individuals with lower cardiorespiratory fitness tend to demonstrate increases at lower levels of physical exertion. In contrast, exercise training leads to positive adaptations in HPA axis response, including higher threshold of activation and blunted cortisol response when exercise in performed at the same absolute intensity (Kjaer, 1992; Luger et al., 1987). We recruited individuals who endorsed engaging in regular exercise to reduce confounding effects of fitness level, however, there was a wide range in reported levels of habitual physical activity (see Table 2). We did not measure HPA axis reactivity in the present study, but a growing body of work suggests that it may alter interpretation of ambiguous social cues (Brown, Raio & Neta, 2017; Ito et al., 2017; Park et al., 2016). Future work could examine whether differences in physiological stress reactivity between individuals alters valence bias as a function of exercise intensity.

Furthermore, a lack of overall difference between experimental conditions has been demonstrated in previous work utilizing within-participants designs. Recent work in our lab also revealed a lack of overall change in bias between stress and no stress conditions (Neta et al., 2017). Yet, individuals with a more positive valence bias under safe (control) conditions, interpreted surprise more negatively when under threat of unpredictable shock. This shift was associated with increased emotional arousal. This suggests that individual differences in both stress reactivity and hypervigilance to threat may drive some individuals, but not others, to shift their interpretation of ambiguity while under acute stress states. Although we found significant differences between levels of emotional arousal between moderate and high conditions, this did not lead to differences in valence bias. However, as we recruited a sample of regular exercisers, they were likely attuned to the general increases in physiological arousal that occur during cardiovascular exercise (Acevedo & Ekkekakis, 2006; Ekkekakis, Hall & Petruzzello, 2002). Interestingly, reappraisal of physiological signals that occur in response to stress states can help shift appraisals of stress from negative to more positive, and reduce negative affect (Jamieson, Berry Mendes & Nock. 2013). Having experienced heightened levels of arousal during past bouts of exercise may have led participants to determine that they had the resources necessary to meet situational demands of the physical stressor(s) (Blascovich & Mendes, 2010). In contrast, negative appraisal of arousal as threat can have feed forward effects, leading to increased vigilance for threat cues and negative interpretations of ambiguity (Jamieson, Berry Mendes & Nock. 2012; Neta et al., 2017; Giles et al., under review). Future work should examine if and how appraisal of arousal systematically differs between physical and emotional stressors, as this may shed light on influences on downstream behavior.

Taken together, a growing body of work highlights the importance of individual difference factors in driving interpretations of emotional ambiguity. Although individuals vary in their tendency to interpret surprise either positively or negatively, it has been suggested that individuals with a more positive bias may be qualitatively different from those who interpret ambiguity negatively. As such, experimental manipulations of valence ratings of surprise have been more successful in those with a more positive bias (as measured under baseline, no stress conditions) (Neta et al., 2017; Neta & Whalen, 2010; Giles et al. under review). One potential explanation is that those who arrive at positive appraisals of surprise may employ a regulatory strategy to override initial negative interpretation (Neta & Whalen, 2010). Indeed, positive interpretations of surprise are associated with greater activity in the medial prefrontal cortex (mPFC), suggesting that regulatory influence is needed to override the initial negativity (Kim et al., 2003). Thus, disruption of this regulatory mechanism during acute stress may preferentially affect those individuals exhibiting positive appraisals. Empirical work has demonstrated that cognitive control processes are enhanced when performed during moderate intensity conditions (at or below VT) (Chang et al., 2012; Da Silva et al., 2017) and impaired during highly intense exercise

(Cantelon et al., 2018; Davranche & McMorris, 2009; McMorris et al., 2009; Schmit et al. 2015). Interestingly, although mean percentage of negative ratings was 65% across both conditions in our study, there is greater variability in the range of percent negativity in the high (29% to 98% negative) compared to moderate condition (39% to 92%). It is possible that shifts in appraisal from positive to negative, or vise verse, may be occurring from baseline to moderate and/or high intensities. However, without a no stress condition we are unable to disentangle these patterns. Thus, future work should explore whether the lack of effect of physical stress on valence bias observed here may be attributed to mediating factors, such as baseline valence bias.

Finally, emotion regulation ability is another factor that may contribute to positive appraisals of ambiguity. Specifically, previous work has demonstrated that those who report greater difficulty regulating their emotions, or report lower habitual use of cognitive reappraisal strategy, interpret surprise more negatively and are more susceptible to negative shifts in valence bias due to emotional stress exposure (Brown, Raio & Neta, 2017; Neta, Tong, Brown & Davis, under review). Neuroimaging work has supported this notion, revealing significant shared activation between those regions involved cognitive reappraisal and those involved when positive valence biases emerge (Petro, Tong, Henley & Neta, 2018). Furthermore, individuals who arrive at positive appraisals of surprise have been shown to exhibit greater emotion regulation success, as well as greater activity in the left middle frontal gyrus, a brain region implicated in emotion regulation (Petro, Tong, Henley, & Neta, 2018). Though this previous research suggests that regulatory influence may be needed to override initial negative appraisals of ambiguity, after controlling for individual differences in reappraisal tendency we still found no effect of physical stress on valence bias. However, habitual exercise has been associated with cognitive reappraisal success more generally (Giles et al. 2017). Thus, we might predict that the population from which we recruited regular exercisers) may exhibit more positive valence biases at baseline and could potentially continue to interpret ambiguous social cues positively under stress. This might be another factor contributing to the lack of difference in negativity bias between moderate and high physical stress conditions, yet, with our lack of control condition this remains speculative.

Physical stress effects on valence resolution

Here we provide evidence that ability to use contextual cues to guide valence resolution remains intact during both moderate and high levels of physical stress. Specifically, we found a significant effect of context in the *Visual Context Task*, such that surprise was rated most negatively in negative, most positively in positive and varied in neutral contexts. Results mirror previous work demonstrating that even *implicit* contexts that do not offer a specific explanation, but rather only imply whether the environment is positive or negative, can promote resolution of ambiguity (Neta, Davis & Whalen, 2011). Additionally, we found further support for the ‘initial negativity hypothesis’, as again response times were faster when faces were rated as negative vs. positive, regardless of context or exercise intensity (Neta, Davis, Whalen, 2011; Neta, Norris & Whalen, 2009; Neta & Tong, 2016; Neta & Whalen, 2010). However, we did not find evidence that shifts in attentional deployment, or reliance on internal emotional state, may have influenced valence interpretations when no clear contextual cues were provided to disambiguate whether faces were positive or negative. Specifically, when surprised faces were presented following a neutral context image, we found no difference in percentage of negative ratings between exercise intensities. Importantly, when analyzing ratings of exertion, affect and arousal there were no significant changes over time. Thus, emotional state did not significantly differ when interpreting facial emotional ambiguity in isolation (*Valence Ratings Task)* or in context (*Valence Ratings Task)*. Therefore, it is unlikely that exercise duration influenced the present results.

A growing body of work suggests both attentional deployment and/or top-down regulatory control may be processes critical to interpretation of ambiguous social cues. However, we did not find differences in valence resolution as a function of physical stress, which is proposed to be driven by mechanisms of attentional bias to threat (White, Suway, Pine, Bar-Haim & Fox, 2011). Previous work examining similar effects of arousal biasing attention during exercise, did so by comparing low vs. high exercise intensities. Findings demonstrated that high level of physical stress exaggerated attentional narrowing and restricted processing to emotionally salient central details over peripheral details of the broader environment (Brunyé & Mahoney, 2018). In the present study, we sought to examine whether this proposed attentional narrowing also occurs between levels of moderate and high physical stress and if this influences participants ability to use contextual cues to resolve valence ambiguity. We did not find support for this notion. However, as Brunyé and Mahoney (2018) did not obtain a measurement of felt arousal during exercise, it is difficult to delineate how both physiological level and appraisal of arousal might bias attention under varying levels of physical stress, as previously discussed. It is possible that attentional processing did not significantly differ between levels of moderate and high physical stress, as manipulated here, which could have led to the lack of differences in valence ratings in neutral contexts. However, response to and resolution of emotional ambiguity has not been widely addressed within the domain of physical stress. Therefore, future work should continue to explore how physical stress may similarly or dissimilarly alter attention and subsequent interpretive biases demonstrated during emotional stress.

Limitations and future directions

In the present study, we did not observe differences in interpretation, or resolution, of emotional ambiguity during varying levels of physical stress. To further understand the relationships between physical stress and valence bias, future research could expand upon these findings in three primary ways. First, future work including both physical stress and non-stress conditions, using a complete factorial design, would enable a more complete understanding of the independent and interactive effects of physical stress on interpretation of ambiguity. Additionally, this type of design might allow us to better understand how individual differences, (such as baseline valence bias, or emotion regulation during exercise) might influence both tendencies to interpret ambiguity either positively or negatively, as well as shifts that may occur due to physical stress.

Second, both subjective *and* objective measures of physiological exertion change during the course of physical stress. Our exercise manipulation used age-adjusted heart rate estimates (HRR) to determine and control exercise intensities at around 65% and 85% of a participant's maximum heart rate. However, in contrast to previous work, participants did not report negative affective responses under high intensity. Using more precise methods to determine and tailor intensity to specific physiological events that occur during the exercise bout (such as reaching ventilatory or respiratory compensation thresholds) might allow us to more precisely characterize how such physiological changes influence emotional state and subsequent behavior. Additionally, further differentiating the parameters of our intensity manipulations, such as employing a maximum heart of 65% HRR and minimum of 85% HRR, might allow us to more accurately assess effects due to higher and lower levels of physical stress.

A third limitation could potentially lie in the sample size of 48 participants. Although our sample size exceeded previous work finding shifts in attentional bias during exercise (mean between-subjects effect $\eta^2 = .22$) (Tian & Smith, 2011), it was smaller than Neta and Tong (2016), who found that surprised expressions were rated more positively when considering alternative explanations vs. rating based on gut reaction ($\eta^2 = .43$). A priori power analysis using these two effects sizes yielded sample size estimates of 45 and 57. Although our sample (n = 48) was within the estimated range, previous work in our lab obtaining valence ratings using a similar set of ambiguous facial stimuli has used larger samples (n = 64) (Neta et al., 2017; Giles et al., under review). Thus, increasing sample size could increase statistical power to detect differences between physical stress conditions and enable greater ability to systematically assess individual differences.

Conclusions

Previous work has examined the influence of acute emotional stress on valence bias of ambiguous social cues, yet the influence of physical stress remains unexplored. The objective of the present study was to determine whether physical stress influences interpretation and resolution of emotional ambiguity. Results suggest that despite differences in participant's emotional state between moderate and high levels of physical stress, valence interpretation of ambiguous social cues remains unaffected. Furthermore, ability to use contextual cues to resolve facial emotional ambiguity remains intact during both moderate and high exercise intensities. Importantly, a growing body of work has highlighted the complex relationship between individual differences and appraisals of ambiguity, including stress appraisal and reactivity. Future research should continue to explore how these factors might impact the effects of physical stress and interpretive biases. Understanding factors that influence interpretation of ambiguity is important, as even slight shifts might alter if information perceived as safe vs. threatening. This could have significant behavioral consequences for individuals operating high-stakes environments.

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Tables

Table 1

Context image set means (SD) for Valence and Arousal

		Valence		Arousal	
Image Type	Set	Average	SD	Average	SD
Positive	Set A	6.11	.22	4.17	.54
	Set B	6.11	.23	4.16	.50
Negative	Set A	1.97	.29	4.19	.62
	Set B	1.96	.15	4.20	.14
Neutral	Set A	4.06	.06	2.22	.41
	Set B	4.06	.10	2.22	.40

Table 2

Sample Characteristics (N=48; 29 females)

		Average	SD	Min	Max
Age		20.67	2.96	18	28
BMI		23.37	2.70	19.37	29.65
Godin Leisure Time		72.54	17.99	30	119
ERQ	Cognitive Reappraisal	5.16	1.05	2	7
	Expressive Suppression	3.41	.990	1	5.75

Table 3

Perceived Exertion Scale (RPE) means (SEM) for exercise Intensity and Time (N=48)

	High	Moderate
Minute 30	15.50 (.23)	12.44 (.23)
Minute 35	15.85 (.22)	12.63 (.20)

Rated perceived exertion was significantly higher under the high compared to moderate condition ($p < .001$) but did not significantly differ by Time between minutes 30 and 35 of cycling ($p = .137$). No Intensity by Time interaction was found ($p = .595$).

Table 4

Feeling Scale (FS) means (SEM) for exercise Intensity and Time (N=48)

	High	Moderate
Minute 30	+1.42 (.34)	+2.29 (.21)
Minute 35	+1.08 (.31)	+2.13 (.23)

Rated emotional valence was significantly higher under the high compared to moderate condition ($p < .001$) but did not significantly differ by Time between minutes 30 and 35 of cycling ($p = .132$). No Intensity by Time interaction was found ($p = .598$).

Table 5

Felt Arousal Scale (FAS) means (SEM) for exercise Intensity and Time (N=48)

	High	Moderate
Minute 30	4.04 (.19)	3.29 (.17)
Minute 35	4.06 (.21)	3.23 (.19)

Rated arousal was significantly higher under high compared to moderate condition ($p < .001$) but did not significantly differ between minutes 30 and 35 of cycling ($p = .700$). No Intensity by Time interaction was found ($p = .613$).

Figures

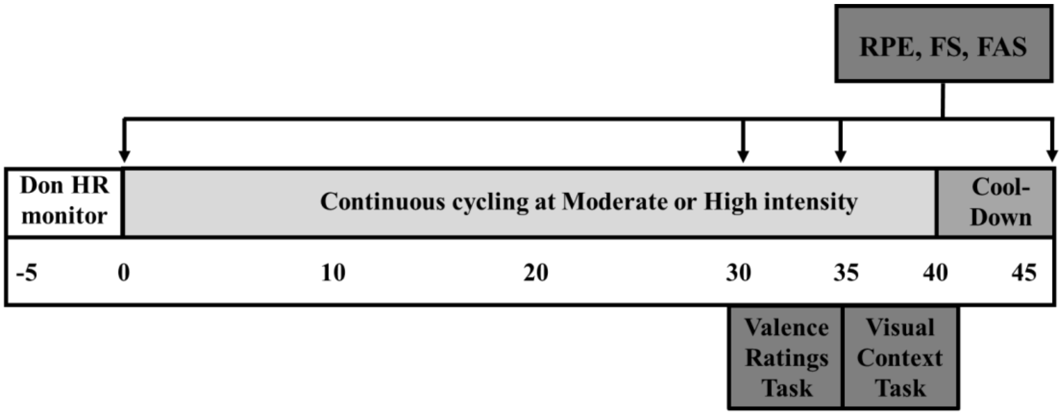

*Figure 1***.** Schematic representation of study schedule. During the study sessions, participants first donned the heart rate monitor. They began the cycling task, at one of two exercise Intensities (moderate, high). During the 40-minute cycling task, participants completed the Borg Scale of Perceived Exertion (RPE), the Feeling Scale (FS) and the Felt Arousal Scale (FAS) prior to beginning, at minute 30, minute 35 and following cooldown. At minute 30, participants completed the Valence Ratings Task, and at minute 35, they completed the Visual Context Task.

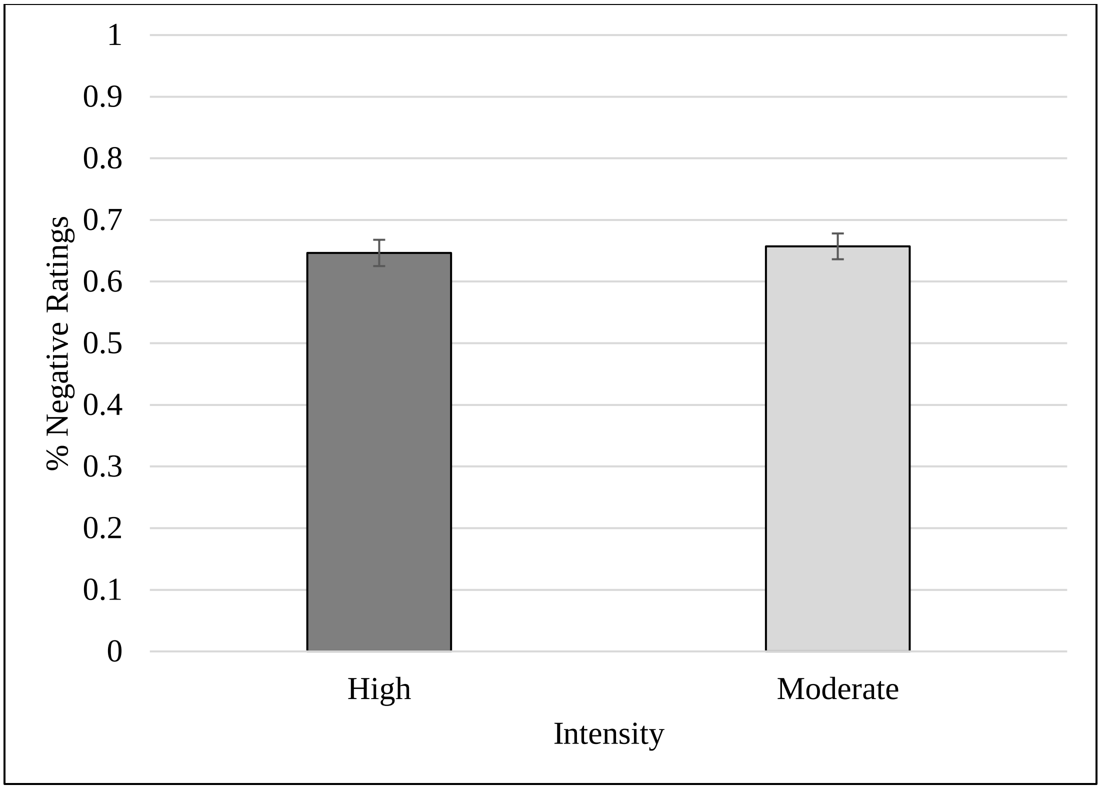

*Figure 2***.** Percent negative means (SEM) by exercise Intensity. Percentage of negative ratings were not significantly different between high and moderate Intensity conditions (*p* = .624).

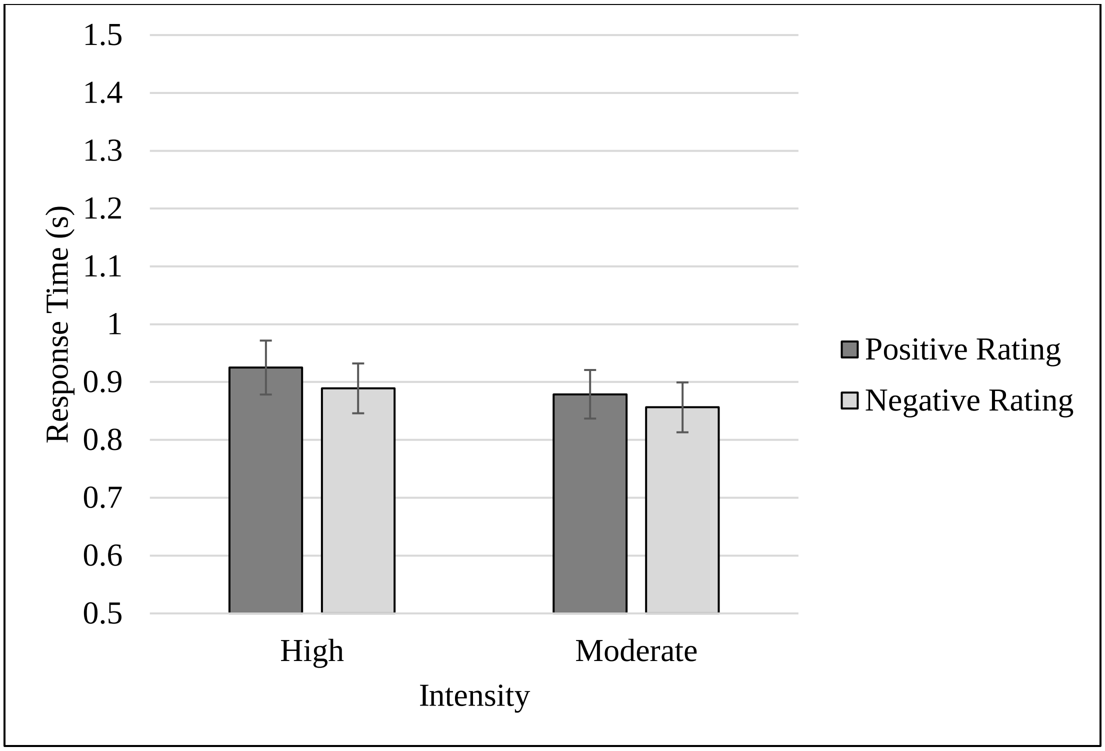

Figure 2. Response time means (SEM) by exercise Intensity and Rating. Response times were significantly faster when surprise was rated as negative vs. positive (*p* = .020). Response times did not significantly differ between high and moderate Intensity conditions (*p* = .195). No Intensity by Rating interaction was found (*p* = .565)

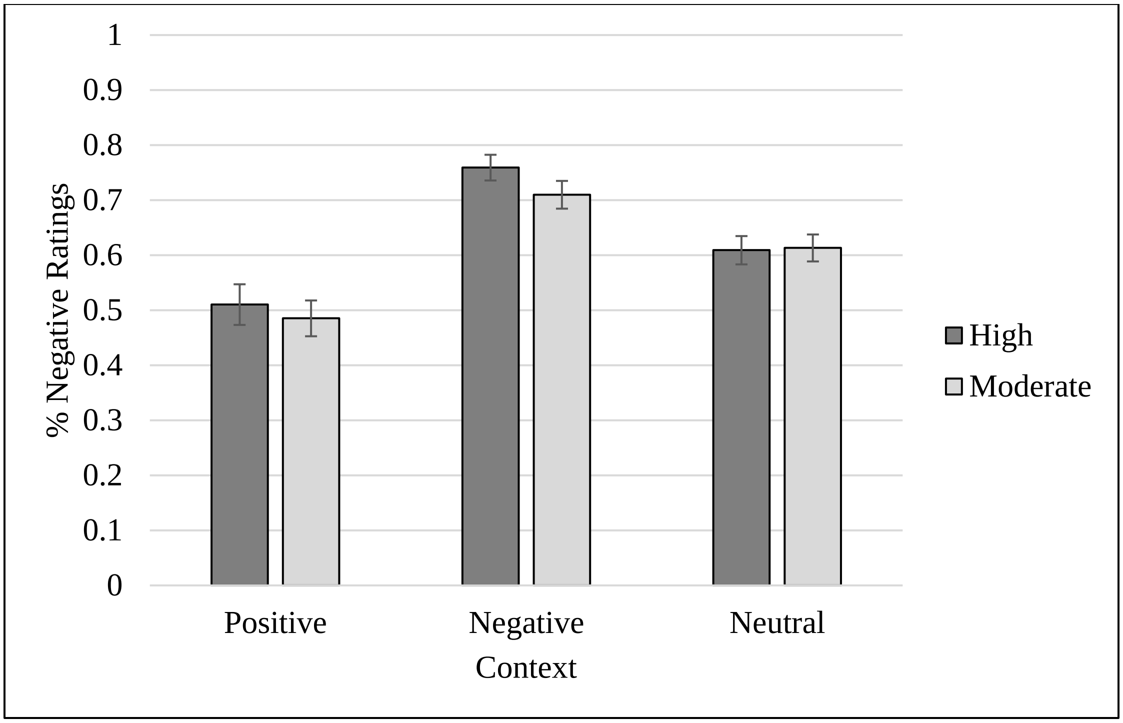

Figure 4. Percent negative means (SEM) by exercise Intensity and Context. Percentage of negative ratings were significantly higher in negative > neutral > positive contexts (*p*s < .001). Ratings were not significantly different between high and moderate Intensity conditions (*p* = .297). No Intensity by Context interaction was found (*p* = .364).

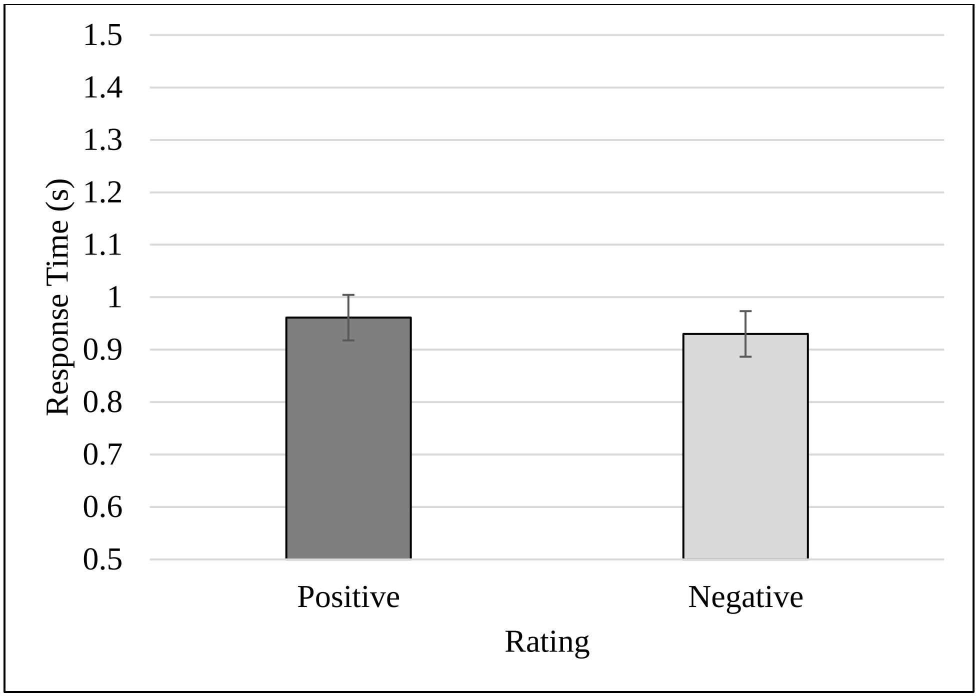

Figure 5. Response time means (SEM) by Rating, collapsed across Intensity and Context conditions. Response times were significantly faster when surprise was rated as negative vs. positive (*p* = .045).