MITIGATING RISK? SET-SHIFTING ABILITY IN HIGH THREAT SENSITIVE INDIVIDUALS PREDICTS APPROACH BEHAVIOR DURING SIMULATED PEER-REJECTION

KARIN G. COIFMAN, DANIELLE J. HALACHOFF, AND K. MARIA NYLOCKS
Kent State University

In this investigation we explored how two dimensions underlying current models of psychopathology, threat sensitivity and executive cognitive processing, may come together to influence downstream responses to social threat. Specifically, we investigated how set-shifting ability influences responses to simulated peer-rejection in high threat sensitive individuals (n = 66) selected from a larger sample. Our findings suggest the possibility of risk-reducing benefits imparted from higher set-shifting and executive resources. In particular, we saw evidence of greater approach-related behavior, including higher intensity positive emotional expressions and a relative increase in the proportion of parasympathetic activity, with higher set-shifting. Our findings join a small but growing body of research examining how risks elevated by threat sensitivity may be mitigated by executive cognitive processing.

Keywords: threat sensitivity, social threat, executive functioning, approach behavior, set-shifting, positive emotion

Threat sensitivity or the proneness toward hypervigilance and avoidance of threat, anxiety, and related information processing biases and response patterns has been consistently implicated in models of risk for most emotion-related disorders. Indeed, some dimensional models emphasize the key role of threat sensitivity

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Address correspondence to Karin G. Coifman, PhD, Associate Professor, Department of Psychological Sciences, PO Box 5190, Kent State University, Kent, OH 44242; E-mail: kcoifman@kent.edu

(e.g., Beauchaine & Thayer, 2015) often indexed as the sensitivity to the Behavioral Inhibition System, or elevated BIS (Carver & White, 1994; Fowles, 1987; Gray, 1990, 1994). In particular, there are many that argue that individuals scoring high on BIS are at considerably greater risk for the most common disorders, including depression, social anxiety, generalized anxiety disorder, and PTSD. However, not all individuals who report high BIS go on to develop disorders. Indeed, although high threat sensitivity is clearly important in models of risk, what is less understood is how it may be influenced or mitigated by other important factors. In this investigation, we build upon a developing line of inquiry to examine how high BIS may be influenced by executive cognitive processing that is known to be relevant in adaptive emotion regulation and behavioral responses (c.f., Schmeichel & Tang, 2015). Specifically, we examine the influence of set-shifting ability on responses in high threat-sensitive college students experiencing online peer-rejection during a lab-based simulation.

THREAT SENSITIVITY AND THE BEHAVIORAL INHIBITION SYSTEM

There is extensive literature characterizing the role of the Behavioral Inhibition System in the detection of threat, the avoidance of threats (Bishop, Duncan, Brett, & Lawrence, 2004), as well as the role of this system in causing inhibition of movement toward goals (Carver & White, 1994) and elevated anxiety (Gray, 1994). Largely measured by self report (e.g., BIS/BAS Scales; Carver & White, 1994), there is clear evidence that high BIS influences cognitive processing, via selective attention for threats (Ohrmann et al., 2007) as well the regulation of attention (Dennis & Chen, 2007a; Matthews & Mackintosh, 1998). Indeed, patterns of heightened activation and attentional biases may contribute to prolonged and poorly regulated negative emotions in high BIS individuals (Balle, Tortella-Feliu, & Bornas, 2013) as well as, corresponding patterns of behavioral avoidance (Wyer & Calvini, 2011). As such, it is no surprise that elevated threat sensitivity or high BIS is important in dimensional models of psychopathology.

However, although individuals with heightened threat sensitivity have relatively predictable early response and information processing biases to negative and/or ambiguous information, variability in the corresponding emotion and behavioral responses that unfold over time is less well understood. For example, although research has demonstrated that high BIS individuals show reliable attention-orienting biases to threats when threat stimuli presentations are short, considerable variability is evident when stimuli presentations are longer and this has yet to be well-characterized (Shechner et al., 2013). Hence, it may be that individual differences in executive cognitive resources could be responsible for a re-orienting or regulation of attention and emotion in order for some individuals to meet goals (Chevalier, 2015). In particular, the capacity to shift mental set, may facilitate other adaptive responses where exclusive attention to a threat is not as needed.

EXECUTIVE COGNITIVE PROCESSES AND EMOTION REGULATION

Increasingly there is evidence that executive or higher-order cognitive control processes are strongly influential in emotion processing and regulation. Indeed, dominant models of emotion regulation as well as a growing body of evidence have made a compelling case for common underlying circuitry and processes that shape both cognitive control and emotion regulation and related behaviors (c.f., Dennis, 2010; Gray, 2004; Gray, Braver, & Raichle, 2002; Hofmann, Ellard, & Siegle, 2012; Ochsner & Gross, 2005). In particular, a recent review of the literature suggested that any of the following executive processes would be highly relevant to adaptive emotion processing and regulation; these include task or set-shifting, working memory, and response inhibition (c.f., Schmeichel & Tang, 2015). Set-shifting, or the ability to move between tasks, operations or mental sets, may be particularly relevant to adaptive emotion processing (Gross & Thompson, 2007) as it incorporates the neurocognitive domains of attention and inhibitory control (Hofmann, Schmeichel, & Baddeley, 2012) and would facilitate attentional shifts that could dampen or enhance emotional responses in the service of broader goals.

Importantly, there is also a demonstrated association between executive cognitive functions, such as set-shifting, and activity in the parasympathetic nervous system (commonly indexed as high-frequency heart rate variability, HF-HRV) a presumed indicator of broad regulatory resources (Beauchaine, 2015; Berntson et al., 1997; Thayer, Hansen, Saus-Rose, & Johnsen, 2009). In particular, Thayer et al.'s (2009) model of Neurovisceral Integration describes a link between higher vagally-mediated HRV (i.e., HF-HRV) and executive resources. Thayer argues that there is considerable evidence of functional and structural links between pre-frontal brain structures (associated executive cognitive processes) and parasympathetic activity. Indeed, HF-HRV may serve as an index of specific executive cognitive functions (Thayer et al., 2009, p.142) which, as described above, are considered core components of emotion regulation and behavioral adaptation. Indeed, Thayer and colleagues review a broad range of experimental research indicating bi-directional associations between the regulation of autonomic, cognitive, and emotional processes (2009).

More recently, there has also been evidence (and considerable theory c.f., Porges, 2001) that HF-HRV enhancement within task, may predict social-evaluative appraisals and behaviors that are broadly adaptive and suggestive of an approach rather than avoidance, behavioral orientation (e.g., Cundiff, Smith, Baron, & Uchino, 2016; Pieritz, Sussenbach, Rief, & Euteneuer, 2016). For example, HF-HRV enhancement is associated with challenge (versus threat/avoidance) appraisals (Laborde, Lautenbach, and Allen, 2015), as well as improved performance on emotionally laden goal-directed tasks (e.g., face-matching: Gaebler, Daniels, Lamke, Fydrich, & Walter, 2013) and greater use of explicit emotion regulation strategies (Butler, Wilhelm & Gross, 2006).

Recently, there have been several studies suggesting that adults who are high threat sensitive need to recruit greater cognitive control resources to compensate for their increased emotional reactivity (e.g., Derryberry & Reed, 2002). For example, Dennis and Chen (2007a) demonstrated a clear interaction between threat sensitivity and attentional control, such that high threat sensitive individuals with greater attentional control showed improved executive attention performance following fearful faces, by achieving an optimal balance (Dennis & Chen 2007a, 2007b). Indeed, this small body of evidence suggests the possibility that high threat sensitive individuals could exhibit broadly adaptive responses with greater executive cognitive resources.

CURRENT INVESTIGATION

In this investigation, we sought to explore whether high threat sensitive individuals with greater executive resources would demonstrate adaptive downstream emotional responses during a naturalistic lab stressor. The majority of research examining risk-related emotional processing in high threat sensitive individuals has largely depended on lab paradigms targeting early processing biases (see, Mathews & MacLeod, 2005). However, it is possible that key variability in emotion processing may manifest further downstream via compensatory actions that better facilitate movement toward goals. Accordingly, we measured emotion related behaviors during an adapted within-subjects version of the Cyberball paradigm, a well-established elicitor of rejection and/or ostracism related emotion and social threat (Williams, 2007; Williams, Cheung, & Choi, 2000) in a selected sample of high threat sensitive young adults also assessed for executive cognitive functioning. High threat sensitivity is consistently associated with response patterns indicative of avoidance of threat. Given that participants each played multiple games in which peer acceptance/rejection was systematically manipulated, approach-related behaviors would serve participants best over the course of the task.

In order to detect approach-related responses consistent with the broader social goals of the task, we indexed facial expressions of positive emotion and high-frequency heart rate variability (HF-HRV) in real-time. There is compelling evidence suggesting the role of unconscious positive emotion during social rejection, and specifically in use with the cyberball-paradigm (DeWall et al., 2011) perhaps because of its potential to implicitly regulate negative emotional responses (Quirin, Bode, & Kuhl, 2011) as well as the demonstrated link between positive emotional facial expressions and social connection (Keltner & Haidt, 2001). Indeed, there is a broad theoretical and empirical foundation supporting the critical role of positive emotional expressions in adaptive social functioning and the building of social relationships (Fredrickson, 1998) as well as approach behavior (Burgdorf & Panksepp, 2006; Updegraff, Gable, & Taylor, 2004). In addition, prior research and theory suggests that HF-HRV enhancement during the task could reflect adaptive appraisals (of challenge and not threat) and approach related autonomic activation facilitating adaptive behavioral responses (Porges, 2001). Accordingly, we included both absolute and normalized metrics of HF-HRV so as to be able to examine the influence of executive resources on parasympathetic activity uniquely, as well as in proportion to total autonomic activity.

When developing our hypotheses, we took into consideration several factors relating to emotional responding in social contexts in general and in this specific population. First, we considered that the entire sample had relatively high levels of threat sensitivity a consistent and reliable predictor of negative emotional responses to both ambiguity and explicit threat. Accordingly, we did not anticipate that we would see any meaningful variability in negative emotional responses. Second, we were careful to index other key factors known to govern emotion responses, particularly in social contexts, in order to co-vary possible alternatives for any findings. Specifically, we were concerned with symptoms of depression, given the clear association between depression and dampened emotion responsivity (Byslma, Morris, & Rottenberg, 2008) as well as social avoidance or withdrawal (Hirschfeld et al, 2000). In addition, based on prior research (e.g., Yanagisawa et al., 2011; c.f., Gray, 2004), we anticipated that reward-responsivity would also be relevant in emotion responses during Cyberball, as such we also included scores from reward-responsivity sub-scale of the Behavioral Activation Scale (BAS; Carver & White, 1994). Finally, for the above reasons and the possibility of confounds in emotion self-reports consistent with elevated threat sensitivity (e.g., Aronson, Barrett, & Quigley, 2006; Bolger & Zuckerman, 1995) we elected not to rely solely on self-reported emotional experience. Moreover, we were careful to index executive resources (here set-shifting) in a separate and emotionally neutral task, so as not to risk confounding participant performance on the executive task with reactivity to emotional content (c.f., Yiend, 2009).

Although there is evidence of complex associations between and among the study variables (e.g., Kok et al., 2013; Hansen, Johnsen, & Thayer, 2003; Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004), we focused here on the following two relatively straightforward predictions:

HYPOTHESIS 1

Higher Set-Shifting Ability Will Predict Greater Enhancement of HF-HRV During Simulated Peer Rejection. We anticipated that individuals with greater executive cognitive resources would be less likely to respond with a clear threat response pattern (typically evidenced as HF-HRV suppression; Thayer et al., 2009) and instead evidence an increase or enhancement of HF-HRV in task consistent with a behavioral approach orientation.

HYPOTHESIS 2

Higher Set-Shifting Ability Will Predict Positive Emotion Expressions During Simulated Peer Rejection. We anticipated that individuals with greater executive cognitive resources would exhibit greater positive emotional expressions (e.g., smiles) even during rejection also consistent with an approach orientation

METHOD

PARTICIPANTS AND PROCEDURE

One hundred and thirty-one undergraduate students were recruited for a brief study on "attention and emotion" in exchange for course credit. Individuals scoring in the upper-half of the distribution for the Behavioral Inhibition Scale (BIS), a well-established self-report indicator of threat sensitivity (Carver & White, 1994) were selected for this investigation. The larger sample mean on the BIS was $M = 20.77$, $SD = 3.61$ ($\alpha = .73$). Individuals were selected for this investigation based on scores in the upper 50th percentile of the BIS, and thus the mean was higher,

M = 23.68, SD = 1.91 (consistent with similar, selected high BIS samples, Dennis & Chen, 2007a). The final selected sample (n = 66, Mean age = 20.08, SD = 4.64) was largely female (74%), Caucasian (85%), Non-Hispanic (94%), and in their first (55%) or second (26%) year of undergraduate study.

Following informed consent, all participants completed paper questionnaires described below and then proceeded with the assessment of set-shifting via the Wisconsin Card Sorting Task. After that task was completed, participants commenced the Cyberball task as described below. All participants completed the three Cyberball games in the same sequence. The first, warm-up game constituted the baseline and was followed by a game simulating rejection and then a game simulating acceptance. All behavioral, autonomic and emotion, measures were indexed for all parts of the Cyberball game sequence so that there were scores for each index for each game. All parts of this research were approved by the university Institutional Review Board for research on human subjects. Data from this project is publicly available at http://personal.kent.edu/~kcoifman/resources.htm.[1]

QUESTIONNAIRE MEASURES

Behavioral Inhibition and Behavioral Activation Scales (BIS; BAS). The BIS (Carver & White, 1994) is an established and well-validated, self-report indicator of threat sensitivity. As described above, individuals scoring in the upper half of the distribution of the original sample were selected for this study. The BAS has three sub-scales detailing key components of the behavioral activation system (Carver & White, 1994). In this investigation we focused on scores from the Reward Responsiveness sub-scale as an important covariate, given the social nature of the primary task of interest. Mean scores (final sample) were M = 18.38, SD = 1.67 with acceptable internal consistency (α = .68). We did consider using the summary BAS score as many researchers have done, but there is evidence suggesting that the Reward Responsivity Scale may operate uniquely (Carver and Harmon-Jones,

1. This research was not pre-registered, given its exploratory nature.

2009), and maintaining the subscales is consistent with current research (Black et al., 2014). Moreover, we did rerun all analyses using the summary scale and the effects were largely consistent.

Depression Symptoms. The Center for Epidemiologic Studies Depression Scale (CES-D) is a commonly used and well-validated assessment of depressive symptomatology (Radloff, 1977). The CES-D is comprised of 20 questions, with responses indicated on a three-point Likert scale. Mean CES-D for our final sample was: 13.35 ($SD = 8.50$; $\alpha = .89$).

TASKS

Set-Shifting. The Wisconsin Card Sorting Task (WCST) is a widely used assessment of set-shifting, requiring participants to integrate environmental feedback and adapt in goal-relevant ways to shifting contexts (Heaton, 2003; Grant & Berg, 1948). Administered on a desktop computer, during the WCST, four key-cards are displayed with varying shapes and colors. The objective is to match newly given cards to one of the four key cards according to rules unknown to the participant. The matching rule changes after every ten correct matches without informing the participant of the change. Perseverative errors are the number of mistakes made after each rule change, reflecting the participant's inability to disengage from matching choices consistent with the previous rule. Non-perseverative errors include all other error types (Barcelo & Knight, 2002). The percentage rather than an uncorrected rate of error was used given that the number of rule changes can vary by participant. Mean percentage of perseverative errors in the final sample was: $M = 9.53$, $SD = 4.14$ and percentage of non-perseverative errors was $M = 11.30$, $SD = 9.05$. We tested to see if handedness influenced the responses (i.e., 84% of the sample was right-handed) and it had no impact.

Simulated Peer Rejection. Cyberball is a commonly used computer paradigm designed and well-validated for the simulation of social rejection (Williams et al., 2000; Williams & Jarvis, 2006). In this adapted, within-subjects version of the paradigm, participants are each told that they will play a series of three-minute, ball-tossing games with three other students logged in at the same time at other locations at the university. Several procedures are included to facilitate this deception (e.g., creation of a player profile with picture that matched those of other student players). In reality, other students or players are simulated and all participants experienced the same rate of rejection throughout the task. Participants were also informed that during some games, their performance (i.e., number of times they are thrown the ball) would be evaluated by the experimenter, who stood behind them keeping a tally of balls received in order to increase the experience of threat. Each participant completed two "games" that were each three minutes in length. The first was deemed a warm-up game with no evaluation. After a brief break, participants commenced a second game, the primary rejection manipulation that included evaluation (tallying the ball tosses to the participant). Participants' experience was pre-programmed so that the rate of rejection was: (1) No rejection—in the warm-up game, participants received the ball 25% of the time (they were one of four total players) and (2) High rejection—in the second rejection game, participants received the ball 7% of the time within the first 30 seconds of the game and no ball tosses for the remaining 2.5 minutes. The within-subjects design in conjunction with a fixed order of presentation, allowed for the isolation of responses to simulated rejection (versus the entire experience). Finally, all participants completed a third game to restore positive mood in which participants all received the ball 50% of the time. Debriefing, at the end of the lab session, confirmed that participants consistently believed the deception.

IN-VIVO ASSESSMENT OF RESPONSES DURING SIMULATED PEER REJECTION

High Frequency Heart Rate Variability (HF-HRV). Heart rate was measured in real-time during all Cyberball games using the Polar Watch RS800CX sd Heart Rate Monitor (HRM; sampling frequency of 1000 Hz), which has been validated as a reliable index of heart rate (Gamelin, Berthoin, & Bosquet, 2006). The HRM data were extracted using Polar Software and exported to a CSV file. Kubios software (Version 2.1, Kuopio, Finland, 2012) was used

TABLE 1. Descriptive Statistics for Behavioral Responses during the Cyberball Task

	Warm-Up Game		Rejection Game	
	M (SD)	Min/Max	*M (SD)*	Min/Max
Positive Facial Emotion	2.77 (1.48)	1.00/6.20	1.99 (1.30)	1.00/6.00
Negative Facial Emotion	1.85 (0.57)	1.00/3.40	1.96 (0.65)	1.00/4.40
HF-HRV Absolute (ms²)	1749.53 (1144.36)	118/4601	1669.60 (1270.09)	216/5664
HF-HRV Normalized (nu)	51.29 (15.99)	0.40/81.40	49.90 (17.22)	1.80/82.10

to quantify HF-HRV (Fast Fourier Transform) in the frequency domains (HF 0.15-0.4Hz and LF 0.04–0.15Hz) from R-R intervals (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalain, 2014) per current recommendations (European Society of Cardiology, 1996). Artifacts were detected and removed using visual methods and the Kubios standard medium level of artifact correction (Mean beats corrected per segment = 1.02 or 0.47%, SD = 1.98 beats or 0.91%). Data was lost for n = 4 participants because of equipment malfunction and n = 2 participants because of experimenter error. Two additional participants were excluded due to levels of HF-HRV between 4–8 standard deviations above the sample mean and numerous artifacts across segments suggesting invalid estimates.

Sample means for HF-HRV for all Cyberball segments in absolute (ms^2) and normalized units (n.u.) for the remaining sample are reported in Table 1. Per current convention and recent recommendations (European Society of Cardiology, 1996; Laborde, Mosley, & Thayer, 2017; Quintana, Alvares & Heathers, 2016), we employed both indices so as to examine effects for HF-HRV uniquely (absolute units) as well as HF-HRV in proportion to total autonomic activity or spectral power (normalized units encompass the influence of both high and low frequency HRV excluding very low frequency—non-autonomic activity; Burr 2007). Overall, HF-HRV estimates were high relative to adult samples and norms (e.g., Nunan, Sanderock, & Brodie, 2010) which may be because of the younger age and potentially active nature of college samples.

Coded Emotion Facial Behavior. Facial behavior was recorded using a high definition video camera. Following data collection, five research assistants, blind to the study details, each rated recordings of participants (without sound) for facial behavior on 7-point Likert scales for degree of negative emotional behavior and degree of positive emotional behavior for each Cyberball game, following procedures previously established (Bonanno, Papa, Lalande, Westphal, & Coifman, 2004). Coders were sufficiently reliable (average ICC = .75; range .60–.88). However, all ratings were averaged across coders, so that each participant received aggregate scores reflecting facial emotion (positive; negative) for each game as rated by all coders, thereby increasing reliability further. Data was lost for $n = 8$ participants because of a mix of experimenter (e.g., failure to focus camera) and technical errors (e.g., participant's face shifted out of view; camera malfunction). Mean coded negative and positive facial emotion for the remaining sample, $n = 58$ is reported in Table 1.

Self-Reported Emotional Experience. Although we did not plan to rely on reported experience, we did assess participants' self-report responses to the task both to confirm the manipulation and to explore similar associations as our hypotheses would suggest. Accordingly, after each game of Cyberball, participants rated the following emotion-words on a 7-point Likert scale: Interest, Fear, Relief, Sadness, Enjoyment, Distress, Guilt, Happiness, Anger, Amusement, and Disgust, selected from contemporary circumplex models of affect (e.g., Rafaeli, Rogers, & Revelle, 2007) and used reliably in prior research (e.g., Coifman & Bonanno, 2010). The emotion-words of Distress, Fear, Guilt, Sadness, and Disgust were aggregated together to derive mean scores for negative affect and Interest, Enjoyment, Happiness, and Amusement for positive affect. Mean levels of reported emotion during the warm-up game were, Negative Affect $M = 1.17$, $SD = .362$ ($\alpha = .54$)[2] and Positive Affect $M = 3.05$, $SD = 1.45$ ($\alpha = .91$). Mean levels of reported emotion during the rejection game were, Negative Affect $M = 1.22$, $SD = .56$ ($\alpha = .86$) and Positive Affect $M = 2.33$, $SD = 1.18$ ($\alpha = .90$).

2. The internal consistency was low for the warm-up game which, although highly consistent with typical lower reliability often found in baseline affect reports, demanded additional examination. It appeared as though the term Disgust was not reported at all by most participants and contributed to the low alpha. However, because disgust was well-integrated in the rejection game assessment, we felt it important to keep it in overall.

RESULTS

MANIPULATION CHECK

To confirm that the Cyberball games were effective in influencing in-vivo emotion responding across the sample, we performed within-subject paired tests. We expected, given the social threat of the rejection trial and the sensitivity of this sample to threat, that there would be changes in emotion consistent with prior use of this paradigm. The results were as expected, indicating a sample-wide decrease in coded positive emotional expressions from the neutral (warm-up) to the rejection games as the social-threat intensified, $t(57) = 4.48$, $p < .001$, 95%CI: 0.43, 1.11, and the same pattern was evident for self-reported positive emotion $t(64) = 8.11$, $p < .001$, 95%CI: 0.54, 0.89. Although, there were no significant differences in negative emotion across the first two games. This was not entirely surprising given the ambiguity of the first game and the explicit threat of the second game. However, there was a significant drop in reported negative affect after the third and final, acceptance as the social threat was no longer present $t(65) = 2.97$, $p = .004$, 95%CI: 0.07, 0.33.

Zero-Order Correlations. We examined associations between all key variables using zero-order correlations (see Table 2). The results suggested some expected associations across emotion response index (i.e., higher negative facial emotion was associated with lower positive facial emotion during rejection, $r = -.31$, $p < .05$). Moreover, consistent with theory, lower perseverative errors (i.e., higher set-shifting) was associated with higher HF-HRVnu during the "warm-up game" $r = -.26$, $p < .05$, and during the rejection "game" $r = -.41$, $p < .01$. However, this same association was not present for HF-HRVms^2.

PRIMARY ANALYSIS

Data Analytic Strategy. We first examined all key variables regarding conventions and assumptions in linear analysis. There was no evidence of any violations including, violations of the assumption of normality. In all analyses, we were guided by the statistical convention of $p < .05$ for significance in all analyses. To

TABLE 2. Zero-order Correlation Analysis of Study Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Warm-up Game Positive Emotional Experience	—												
2. Rejection Game Positive Emotional Experience	**.88****	—											
3. Warm-up Game Negative Emotional Experience	.24	.15	—										
4. Rejection Game Negative Emotional Experience	**.33****	.16	**.44****	—									
5. Warm-up Game Positive Facial Emotion	**.41****	.25	.18	.01	—								
6. Rejection Game Positive Facial Emotion	.22	.17	.03	−.07	**.56****	—							
7. Warm-up Game Negative Facial Emotion	−.18	−.10	−.09	−.14	−.24	−.21	—						
8. Rejection Game Negative Facial Emotion	−.12	−.10	−.10	−.12	−.16	**−.31***	**.61****	—					
9. Warm-up Game HF-HRVnu	.16	.10	−.25	.09	−.02	.08	.13	−.04	—				
10. Rejection Game HF-HRVnu	.19	.12	−.07	.22	.00	−.06	.18	.13	**.71****	—			
11. Warm-up Game HF-HRV ms²	−.17	−.14	−.23	.06	−.01	.04	-.00	.14	**.43****	**.29***	—		
12. Rejection Game HF-HRV ms²	−.15	−.12	−.21	.16	−.09	.02	.13	.09	**.54****	**.48****	**.81****	—	
13. Perseverative Errors	−.07	−.08	−.02	−.05	−.10	−.19	−.18	−.04	**−.26***	**−.41****	−.15	−.19	—
14. Nonperseverative Errors	.02	-.04	−.15	−.11	.09	.07	−.15	−.05	−.17	−.23	−.13	−.14	**.61****

Note. **$p < .01$; *$p < .05$.

test our two hypotheses we employed step-wise ordinary least squares (OLS) regression. In each analyses, one emotion processing/response variable (e.g., HF-HRVnu or ms^2 or positive coded emotion facial behavior) indexed during the rejection game was the dependent variable and the matching emotion processing/response indexed in the warm-up game was entered as a control in order to isolate only those particular responses elicited during the rejection game. The primary independent variable was percentage of perseverative errors in the WCST as the index of set-shifting (percentage rather than an uncorrected score was used given that the number of rule changes can vary by participant). We also included percentage of non-perseverative errors, to control for general error-making, and controlled for other variables known to influence real-time assessment of emotion, including age (Charles & Carstensen, 2010) and gender (Kring & Gordan, 1998). Moreover, given the potential for depression symptoms to influence not only negative but also positive emotional responsivity, we co-varied reported depression symptoms. Finally, given the social context of the task and the link between BAS reward responsivity and emotion in social contexts (e.g., Yanagisawa et al., 2011) we also included the BAS reward responsivity subscale.

HYPOTHESIS TESTING

HYPOTHESIS 1

Higher Set-Shifting Ability Will Predict Greater Enhancement of HF-HRV During Simulated Peer Rejection. In this analysis, HF-HRVnu or ms^2 during the rejection game was the dependent variable and we included HF-HRV nu or ms^2 in the "warm-up game" as a predictor and all covariates described above. For the examination of HF-HRVnu, which estimates the proportion of HF-HRV relative to all cardiac autonomic modulation, the final model was significant, $F(7,49) = 10.41$, $p < .001$, $R^2 = .60$, and as predicted, lower perseverative errors predicted higher HF-HRVnu during rejection, $\beta = -.38$, $p = .01$, $sr^2 = .06$, above and beyond warm-up levels of HF-HRVnu. We examined the data further to confirm that the results of this association were indicative of enhanced HF-HRVnu, rather than an absence of suppression. An examination of mean levels, by employing a median split of set-shifting perseverative errors, suggested that HF-HRVnu was enhanced for individuals with higher set-shifting ability from the warm-up game $M = 54.61$, $SD = 16.35$ to the Rejection game $M = 56.07$, $SD = 17.00$, as compared to $M = 49.86$, $SD = 14.41$, to $M = 45.80$, $SD = 17.97$ for individuals with lower set-shifting ability. For the examination of HF-HRV ms^2, which is an estimate of the absolute levels of HF-HRV, the final model was also significant, F(7,50) = 14.60, $p < .001$, $R^2 = .67$. However, perseverative errors did not reach significance when predicting HF-HRV ms^2 during rejection, $\beta = -.15$, $p = n.s.$ (for a complete summary, see Table 3).

HYPOTHESIS 2

Higher Set-Shifting Ability Will Predict Positive Emotion Expressions During Simulated Peer Rejection. Here, coded positive facial emotion during the rejection game was the dependent variable and we included coded positive facial emotion in the warm-up game as a predictor and all covariates described above. Again the final model was significant, $F(7,50) = 7.14$, $p < .001$, $R^2 = .50$, and as predicted, lower perseverative errors predicted higher coded positive facial emotion during rejection, $\beta = -.37$, $p = .01$, $sr^2 = .07$, above and beyond warm-up levels of coded positive facial emotion (for a complete summary see Table 4). Interestingly, both age and gender remained significant predictors in the final step, suggesting that being male, $\beta = -.35$, $p < .01$, $sr^2 = .11$, and of older age, $\beta = .23$, $p = .04$, $sr^2 = .05$, were also associated with higher positive facial behavior. We probed these relationships carefully given the relatively small proportion of males in the sample and confirmed that there were no outliers that were driving the overall relationships. Moreover, there were only weak differences by gender ($p < .08$) in positive facial emotion (higher for males) and negative facial emotion (lower for males) and no differences in perseverative or non-perseverative error rates. Finally, we examined the data further while employing a median split of set-shifting perseverative errors. We found that positive emotional expressions were better maintained (rather than enhanced) for individuals with higher set-shifting ability (e.g., lower perseverative errors) from the warm-up game $M = 3.19$, $SD = 1.50$ to the Rejection game $M = 2.42$, $SD = 1.65$ as compared to $M = 2.77$, $SD = 1.51$, to $M = 1.87$, $SD = 1.17$ for individuals with lower set-shifting ability.

Although these were the primary analyses, we did explore whether reported positive affect demonstrated a similar association as coded behavior (see supplemental tables for a full summary). We ran the same analysis inserting reported positive emotional experiences (to the rejection game as the dependent variable, controlling for warm-up game levels), although the complete model was significant, $F(7,57) = 33.13$, $p < .001$, $R^2 = .80$, perseverative errors had no significant association with reported positive emotional experiences during the rejection game (see Table S1). Next we examined negative emotional responses and as expected, we did not find a significant influence of perseverative errors on negative emotional responses. In the first regression coded negative facial emotion during the rejection game was the dependent variable and we controlled for coded negative facial emotion in the warm-up game and included all covariates described above. Again the final model was significant, $F(7,50) = 4.63$, $p < .001$, $R^2 = .39$, however, perseverative errors was not associated with coded negative facial emotion during rejection (see Table S2). When we ran the same analysis inserting reported negative emotional experiences (to the rejection game as the dependent variable, controlling for warm-up game levels), the complete model was significant, $F(7,57) = 3.40$, $p < .01$, $R^2 = .29$, perseverative errors had no significant association with reported negative emotional experiences during the rejection game although both higher depression symptoms, $\beta = .25$, $p < .05$, $sr^2 = .05$, and higher BAS Reward responsiveness, $\beta = .29$, $p < .05$, $sr^2 = .07$, did predict higher reported negative emotion during rejection (see Table S3).

DISCUSSION

In this investigation, we sought to examine how executive resources may influence emotion responses in high threat sensitive individuals during a naturalistic social threat paradigm in-

TABLE 3. OLS Regression Analysis Examining the Association between Higher Set-Shifting Ability and High Frequency Heart Rate Variability, Normalized (nu), and Absolute Values (ms^2) During Simulated Peer-Rejection, in High Threat-Sensitivity Individuals

Dependent Variable	HF-HRVnu During Peer Rejection				
*$p < .05$, **$p < .01$	β	*t*	sr^2	R^2	ΔR^2
Step 1 Age	−.16	−1.12	.02	.05	—
Sex	.16	1.14	.02		
Depression	.08	0.53	.01		
Reward Responsiveness	.02	0.15	.00		
$F(4,52) = .72$, $p = .58$					
Step 2 Age	−.06	−0.59	.00	.53	.48**
Sex	−.02	−0.21	.00		
Depression	.13	1.27	.02		
Reward Responsiveness	−.05	−0.46	.00		
Warm-up Game HF-HRVnu	.73**	7.26	.48		
$F(5,51) = 11.68$, $p < .001$					
Step 3 Age	−.04	−0.37	.00	.60	.06*
Sex	−.08	−0.83	.01		
Depression	.15	1.52	.02		
Reward Responsiveness	−.03	−0.30	.00		
Warm-up Game HF-HRVnu	0.67**	6.89	.40		
Percent Perseverative Errors	−.38*	−2.66	.06		
Percent Non-Perseverative Errors	.19	1.37	.02		
$F(7,49) = 10.41$, $p < .001$					

Dependent Variable	HF-HRVms² During Peer Rejection				
Step 1 Age	−.06	−0.40	.00	.01	.01
Sex	−.03	−0.24	.00		
Depression	.01	0.08	.00		
Reward Responsiveness	.03	0.17	.00		
$F(4,53) = .908$, $p = .99$					
Step 2 Age	.03	0.35	.00	.66	.65**
Sex	.05	0.57	.00		
Depression	.07	0.83	.01		
Reward Responsiveness	−.01	−0.12	.00		
Warm-up Game HF-HRVms²	.82**	10.05	.65		
$F(5,52) = 20.40$, $p < .001$					
Step 3 Age	.04	0.42	.00	.67	.01
Sex	.02	0.28	.00		
Depression	.08	0.94	.01		
Reward Responsiveness	−.02	−0.17	.00		
Warm-up Game HF-HRVms²	.82**	9.75	.62		
Percent Perseverative Errors	−.15	−1.16	.01		
Percent Non-Perseverative Errors	.13	1.02	.01		
$F(7,50) = 14.60$, $p < .001$					

TABLE 4. OLS Regression Analysis Examining the Association between Higher Set-Shifting Ability and Positive Facial Emotion During Simulated Peer-Rejection, in High Threat-Sensitivity Individuals

Dependent Variable	Positive Facial Emotion During Peer Rejection				
$^*p < .05$, $^{**}p < .01$	β	t	sr^2	R^2	ΔR^2
Step 1 Age	.14	1.07	.02	.15	—
Sex	–.35**	–2.70	.12		
Depression	–.16	–1.16	.02		
Reward Responsiveness	–.09	–0.63	.01		
$F(4,53) = 2.38$, $p = .06$					
Step 2 Age	.15	1.36	.02	.42	.27**
Sex	–.30**	–2.78	.09		
Depression	–.07	–0.61	.00		
Reward Responsiveness	–.07	–0.57	.00		
Warm-up Game Positive Facial Emotion	.53**	4.94	.27		
$F(5,52) = 7.64$, $p < .001$					
Step 3 Age	.23*	2.14	.05	.50	.08*
Sex	–.35**	–3.34	.11		
Depression	–.05	–0.42	.00		
Reward Responsiveness	–.02	–0.15	.00		
Warm-up Game Positive Facial Emotion	.48**	4.62	.21		
Percent Perseverative Errors	–.37*	–2.69	.07		
Percent Non-Perseverative Errors	.16	1.17	.01		
$F(7,50) = 7.14$, $p < .001$					

volving the simulation of peer-rejection. Specifically, in a sample with elevated scores on the BIS, we examined how set-shifting performance during a neutral, unrelated task predicted real-time behavioral responses elicited during an adapted within-subjects version of the Cyberball paradigm (Williams et al., 2000). The results suggested emotion-related benefits associated with higher set-shifting (i.e., lower perseverative errors) during the rejection game of Cyberball. Specifically, higher set shifting was associated with greater approach-related behavior operationalized as greater coded facial expressions of positive emotion and suggested an enhanced proportion of HF-HRV (relative to all cardiac autonomic modulation) during the rejection game. As we anticipated, given the nature of the sample, we did not find evidence of meaningful variability in negative facial emotion that was related to set-shifting. Overall these findings are consistent with a growing literature demonstrating overlap between executive cognitive resources, broader regulatory resources, as well as adaptive emotion regulatory responses. Notably, these findings are also the first to demonstrate how downstream behaviors are impacted by both elevated threat sensitivity and elevated executive resources, and they join the growing literature examining the complex balance between these processes (e.g., Dennis & Chen, 2007a; Derryberry & Reed, 2002).

The main finding that higher set shifting ability predicted greater positive facial emotion is a powerful indicator that executive resources may mitigate risks associated with elevated threat sensitivity. There has been consistent evidence linking positive emotion with physical and psychological health for decades (e.g., Pressman & Cohen, 2005). Indeed, recent work has demonstrated that low positive emotionality is a key predictor of the onset of affective disorders up to 10 years in the future (Kendall et al., 2015). Moreover, the adaptive function of positive emotional expressions in social contexts is well-established (Fredrickson, 1998; Keltner & Haidt, 2001). Given the socially-threatening nature of the Cyberball task used here, including in particular the within-subjects design that included multiple games, the demand on participants to continue to engage with others was clear. Hence, the ability to maintain social approach responses (i.e., positive emotional facial expressions) suggests an important pathway by which high BIS individuals could remain psychology healthy.

Although we did not find clear evidence of absolute HF-HRV enhancement, the association between set-shifting and an increase in the proportion of HF-HRV (nu), relative to total cardiac autonomic modulation, should not be dismissed. There is a vast literature focused on the role of balance in the autonomic nervous system in physical health. Our data suggest that higher set-shifting was associated with an increase in the proportion of total cardiac autonomic modulation that was para-sympathetically driven, consistent with a model of approach-related responding and adaptive appraisal. However, it is notable that the relative increase HF-HRVnu from the neutral to the rejection game could also be due, in part, to a decrease in sympathetic activity. Normalized indices of HF-HRV represent the proportion of HF to all cardiac autonomic activity. This includes low frequency (LF) modulation which is influenced by both parasympathetic and sympathetic activity. Accordingly, although we believe these findings important, they demand explicit replication involving the additional assessment of sympathetic activity. However, that there was such a discrepancy in our HF-HRV results, suggests caution and a clear need for future research.

It is notable that when positive emotions are examined on more objective indicators (e.g., facial behavior; unconscious appraisals), the results may be even more compelling than when reliance is exclusively on self-report, as was the case here (e.g., Papa & Bonanno, 2008). This may be due to the vulnerability of self-reports to numerous, complex influences that have been well-documented (e.g., demand characteristics, dispositional differences, environment, memory) as compared to more objective indices (e.g., behavior; autonomic activity), as well as the likelihood that much of in-the-moment emotion responding is outside of awareness (Bargh & Williams, 2007). Participants in our study reported consistently that they believed they were actually playing with peers at other locations in the university. As such, there was a possibility of reward from increased positive emotional expressions (i.e., more ball tosses from other players). Prior research using this paradigm has demonstrated convincingly that non-conscious positive emotion is present and highly relevant to adaptive responses (DeWall et al., 2011). Our finding of increased positive emotional expressions, but not positive emotion reports, relating to set-shifting could indicate that participants were benefitting yet presumably unaware of these processes.

We did not expect and did not find evidence of meaningful variability in negative emotional responses (both facial and reported) in high threat-sensitive individuals in relation to set-shifting ability during rejection. We believe this was likely the case because the entire sample was selected for their high scores on the BIS. However, there may also be more subtle reasons. Unlike positive emotions, which are consistently and uniformly associated with approach-related behavior, only some negative emotions are clearly tied to avoidance (i.e., fear, disgust) whereas, other negative emotions have more mixed associations. For example, sadness is generally associated with withdrawal, evidence for guilt is mixed, and anger is convincingly associated with approach, rather than withdrawal (Carver & Harmon-Jones, 2009). Accordingly, neither of our negative emotion indicators were parsed in such a way as to test this effectively, and therefore the null findings here could also indicate a lack of sensitivity to the relevant constructs as they manifest in negative emotional responses.

Finally, a strength of this investigation was that we were also able to consider two plausible alternative explanations to our findings. In particular, we evaluated the role of depression symptoms and reward responsivity (i.e., BAS) in emotional processing and responses to simulated peer-rejection. Overall, we found that neither construct influenced the main study findings. However, both were important in other ways. Indeed, both higher scores on the BAS reward responsiveness and higher depression symptoms were associated with higher reported negative emotion during rejection, even when controlling for warm-up game levels of reported negative emotion. These results are certainly consistent with interpersonal models of depression (Coyne, 1976; Gotlib & Hammen, 1992) as well as models of the behavioral approach system (Carver & White, 1994) and evidence linking the two (Beevers & Meyer, 2002).

LIMITATIONS

There were some limitations to this investigation. First, this was an exploration of phenomenon in a college sample pre-selected to have a particular behavioral orientation and level of risk. We would argue that this was essential in order to be able to explore how executive cognitive processes could result in more adaptive responses and potentially mitigate risk. Moreover, we believe our lab-simulation was an important first step as it employed a paradigm that has been well-tested and proven to elicit salient emotional responses in a pre-selected sample well-established to have greater risk for disease and greater difficulty processing emotional content. In addition, we were able to index objectively, real-time emotion processing and responses that have been previously tied to long-term psychological health. Yet it is clear that future work must further examine the interaction of these processes as they unfold over time. Moreover, these findings must be replicated in a larger more diverse sample in order to know the extent to which they are at play in psychological health.

In addition, our assessment of set-shifting was only in a neutral context and some evidence has indicated that disentangling the contributions of specific executive processes may require careful assessment of these processes in emotional contexts (see, Yiend, 2009). Moreover, we only indexed one type of executive cognitive processing and there are others known to be relevant to emotion regulatory processes (i.e., working memory, inhibition). Despite this limitation, we did find clear evidence of meaningful benefits to higher set-shifting ability which supports our future work examining these processes across the spectrum of executive cognitive processing. Finally, we were unable to index respiration rate directly due to our use of Polar Heart Rate Monitors. Although we could have employed paced respiration methods, it would have detracted from the emotion elicitation and interfered with task demands. Recently, there has been a call to consider the role of respiration in estimates of HF-HRV and this will be important in future research.

CLINICAL IMPLICATIONS

Increasingly, there is a research emphasis on identifying core dimensions underlying models of psychopathology and psychiatric risk. Here we examined how two such dimensions, threat sensitivity and executive cognitive processing, may come together to influence downstream emotional responses and processes. Our findings suggest the possibility of risk-reducing benefits imparted from higher set-shifting in at-risk, high threat sensitive participants. In particular, we saw greater positive facial emotion with higher set-shifting and some evidence of HF-HRV enhancement, both presumed indicators of psychological health and resilience. Indeed, our findings join a small but growing body of research examining how risks elevated by threat sensitivity may be mitigated by executive cognitive processing. Accordingly, these data provide an interesting frame for the development of new interventions. Although there has been a surge of treatments attempting to mitigate early attentional biases that are known to be both predicted by high BIS (e.g., Hakamata et al., 2010), our findings may suggest that attention to shifting later-stage or downstream processing could also be beneficial.

CONCLUSION

This research is the first to suggest the adaptive influence of the balance of higher executive cognitive resources with high BIS on down-stream emotion during a naturalistic lab-based provocation. Indeed, this research suggests a path by which high BIS individuals may maintain psychological health. Indeed, increasingly there is evidence and theory arguing for models of disease that consider the potential imbalance of top down resources with bottom-up activation (see Ochsner & Gross, 2005). We believe that these data contribute to the development of more complex models of psychiatric risk and health, as well as provide a foundation for future studies examining the complex relationships between these processes over time.

REFERENCES

Aronson, K. R., Barrett, L. F., & Quigley, K. (2006). Emotional reactivity and the over report of somatic symptoms: Somatic sensitivity or negative reporting style? *Journal of Psychosomatic Research, 60,* 521–530. https://doi.org/10.1016/j.jpsychores.2005.09.001

Balle, M., Tortella-Feliu, M., & Bornas, X. (2013). Distinguishing youths at risk for anxiety disorders from self-reported BIS sensitivity and its psychophysiological concomitants. *International Journal of Psychology, 48,* 964–977. https://doi.org/10.1080/00207594.2012.723804

Barcelo, F., & Knight, R. T. (2002). Both random and perseverative errors underlie WCST deficits in prefrontal patients. *Neuropsychologia, 40,* 349–356. https://doi.org/10.1016/S0028-3932(01)00110-5.

Bargh, J. A., & Williams, L. E., (2007). The nonconscious regulation of emotion. In J. Gross (Ed.) *Handbook of Emotion Regulation.* (pp. 429–445). New York: Guilord Press.

Beauchaine, T. P. (2015). Respiratory sinus arrhythmia: A transdiagnostic biomarker of emotion dysregulation and psychopathology. *Current Opinion in Psychology, 3,* 43–47. https://doi.org/10.1016/j.copsyc.2015.01.017

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal Of Psychophysiology, 98,* 338–350. https://doi.org/10.1016/j.ijpsycho.2015.08.004

Beevers, C. G., & Meyer, B. (2002). Lack of positive experiences and positive expectancies mediate the relationship between BAS responsiveness and depression. *Cognition and Emotion, 16*, 549–564. https://doi.org/10.1080/02699930143000365

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., . . . Van Der Molen, M. W. (1997). Heart rate variability: Origins, methods and interpretive caveats. *Psychophysiology, 34*, 623–648. https://doi.org/10.1111/j.1469-8986.1997.tb02140.x

Bishop, S., Duncan, J., Brett, M., & Lawrence, A. D. (2004). Prefrontal cortical function and anxiety: Controlling attention to threat-related stimuli. *Nature Neuroscience, 7*, 184–188. https://doi.org/10.1038/nn1173

Black, C. L., Goldstein, K. E., LaBelle, D. R., Brown, C. W., Harmon-Jones, E., Abramson, L. Y., & Alloy, L. B. (2014). Behavioral approach system sensitivity and risk taking interact to predict left-frontal EEG asymmetry. *Behavior Therapy, 45*(5), 640–650. https://doi.org/10.1016/j.beth.2014.01.006

Bolger, N., & Zuckerman, A. (1995). A framework for studying personality in the stress process. *Journal of Personality And Social Psychology, 69*, 890–902. https://doi.org/10.1037/0022-3514.69.5.890

Bonanno, G. A., Papa, A., Lalande, K., Westphal, M., & Coifman, K. (2004). The importance of being flexible: The ability to enhance and suppress emotional expression as a predictor of long-term adjustment. *Psychological Science, 15*, 482–487. https://doi.org/10.1111/j.0956-7976.2004.00705.x

Burgdorf, J., & Panksepp, J. (2006). The neurobiology of positive emotions. *Neuroscience and Biobehavioral Reviews, 30*, 173–187. https://doi.org/10.1016/j.neubiorev.2005.06.001

Burr, R. L. (2007). Interpretation of normalized spectral heart rate variability indices in sleep research: A critical review. *Sleep, 30*, 913–919.

Butler, E. A., Wilhelm, F. H., & Gross, J. J. (2006). Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction. *Psychophysiology, 43*, 612–622. https://doi.org/10.1111/j.1469-8986.2006.00467.x

Bylsma, L. M., Morris, B. H., & Rottenberg, J. (2008). A meta-analysis of emotional reactivity in major depressive disorder. *Clinical Psychological Review, 28*, 676–691. https://doi.org/10.1016/j.cpr.2007.10.001

Carver, C. S., & Harmon-Jones, E. (2009). Anger is an approach-related affect: Evidence and implications. *Psychological Bulletin, 135*, 183–204. https://doi.org/10.1037/a0013965

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology, 67*, 319–333. https://doi.org/10.1037/0022-3514.67.2.319

Charles, S. T., & Carstensen, L. L. (2010). Social and emotional aging. *Annual Review of Psychology, 61*, 383–409. https://doi.org/10.1146/annurev.psych.093008.100448

Chevalier, N. (2015). Executive function development: Making sense of the environment to behave adaptively. *Current Directions in Psychological Science, 24*, 363–368. https://doi.org/10.1177/0963721415593724

Coifman, K. G., & Bonanno, G. A. (2010). When distress does not become depression: Emotion context sensitivity and adjustment to bereavement. *Journal of Abnormal Psychology, 119*, 479–490. https://doi.org/10.1037/a0020113

Coyne, J. C. (1976). Depression and the response of others. *Journal of Abnormal Psychology, 85*, 186–193. https://doi.org/10.1037/0021-843X.85.2.186

Cundiff, J. M., Smith, T. W., Baron, C. E., & Uchino, B. N. (2016). Hierarchy and health: Physiological effects of interpersonal experiences associated with socioeconomic position. *Health Psychology, 35*, 356–365. https://doi.org/10.1037/hea0000227

Dennis, T. A. (2010). Neurophysiological markers for child emotion regulation from the perspective of emotion-cognition integration: Current directions and future challenges. *Developmental Neuropsychology, 35*, 212–230. https://doi.org/10.1080/87565640903526579

Dennis, T. A., & Chen, C. (2007a). Neurophysiological mechanisms in the emotional modulation of attention: The interplay between threat sensitivity and attentional control. *Biological Psychology, 76*, 1–10. https://doi.org/10.1016/j.biopsycho.2007.05.001

Dennis, T. A., & Chen, C. (2007b). Emotional face processing and attention performance in three domains: Neurophysiological mechanisms and moderating effects of trait anxiety. *International Journal of Psychophysiology, 65*, 10–19. https://doi.org/10.1016/j.ijpsycho.2007.02.006

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology, 111*, 225–236. https://doi.org/10.1037/0021-843X.111.2.225

DeWall, C. N., Twenge, J. M., Koole, S. L., Baumeister, R. F., Marquez, A., & Reid, M. W. (2011). Automatic emotion regulation after social exclusion: Tuning to positivity. *Emotion, 11*, 623–636. https://doi.org/10.1037/a0023534

European Society of Cardiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation and clinic use. *European Heart Journal, 17*, 354–381.

Fowles, D. C. (1987). Application of a behavioral theory of motivation to the concepts of anxiety and impulsivity. *Journal of Research in Personality, 21*, 417–435. https://doi.org/10.1016/0092-6566(87)90030-4

Fredrickson, B. L. (1998). What good are positive emotions? *Review of General Psychology, 2*, 300–319. https://doi.org/10.1037/1089-2680.2.3.300

Gaebler, M., Daniels, J. K., Lamke, J., Fydrich, T., & Walter, H. (2013). Heart rate variability and its neural correlates during emotional face processing in social anxiety disorder. *Biological Psychology, 94*, 319–330. https://doi.org/10.1016/j.biopsycho.2013.06.009

Gamelin, F. X., Berthoin, S., & Bosquet, L. (2006). Validity of the polar S810 heart rate monitor to measure R-R intervals at rest. *Medicine and Science in Sports, 38*, 887–893. https://doi.org/101249/01.mss.00002181135.79476.9c

Gotlib, I. H., & Hammen, C. L. (1992). *Psychological aspects of depression: Toward a cognitive-interpersonal integration*. Oxford, England: John Wiley & Sons.

Grant, D. A., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology, 38*, 404–411. https://doi.org/10.1037/h0059831

Gray, J. R. (1990). Brain systems that mediate both emotion and cognition. *Cognition & Emotion, 4*, 26–288. https://doi.org/10.1080/02699939008410799

Gray, J. R. (1994). Personality dimensions and emotion systems. In P. Ekman & R. J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 329–331). New York: Oxford University Press.

Gray, J. R. (2004). Integration of emotion and cognitive control. *Current Directions In Psychological Science, 13,* 46–48. https://doi.org/10.1111/j.0963-7214.2004.00272.x

Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceeding of the National Academy of Sciences, 99,* 4115–4160. https://doi.org/10.1073/pnas.062381899

Gross, J. J., & Thompson, R. A. (2007). Emotion regulation: Conceptual foundations. In J. J. Gross (Ed.), *Handbook of emotion regulation* (pp. 3–24). New York: Guilford Press.

Hakamata, Y., Lissek, S., Bar-Haim, Y., Britton, J. C., Fox, N. A., Leibenluft, E., Ernst, M., & Pine, D. S. (2010). Attention bias modification treatment: A meta-analysis toward the establishment of novel treatment for anxiety. *Biological Psychiatry, 68,* 982–990. https://doi.org/10.1016/j.biopsych.2010.07.021

Hansen, A. L., Johnsen, B. H., Sollers, J. J., Stenvik, K., & Thayer, J. F. (2004). Heart rate variability and its relation to prefrontal cognitive function: The effects of training and detraining. *European Journal of Applied Physiology, 93,* 263–272. https://doi.org/10.1007/s00421-004-1208-0

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology, 48,* 263–274. https://doi.org/10.1016/S0167-8760(03)00073-4

Heaton, R. K. (2003). Wisconsin card sorting test [: computer version 4 [WCST: CV4]. *Psychological Assessment Resources.*

Hirschfeld, R.M.A., Montgomery, S. A., Keller, M. B., Kasper, S., Schatzberg, A. F., Möller, H-J., . . . Bourgeois, M. (2000). Social functioning in depression: A review. *Journal of Clinical Psychiatry, 61,* 268–275. https://doi.org/10.4088/JCP.v61n0405

Hofmann, S. G., Ellard, K. K., & Siegle, G. J. (2012). Neurobiological correlates of cognitions in fear and anxiety: A cognitive-neurobiological information processing model. *Cognition & Emotion, 26*(2), 282–299. https://doi.org/10.1080/02699931.2011.579414

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends In Cognitive Sciences, 16,* 174–180. https://doi.org/10.1016/j.tics.2012.01.006

Keltner, D., & Haidt, J. (2001). Social functions of emotions. In T. J. Mayne, G. A. Bonanno, T. J. Mayne, & G. A. Bonanno (Eds.), *Emotions: Current issues and future directions* (pp. 192–213). New York: Guilford Press.

Kendall, A. D., Zinbarg, R. E., Mineka, S., Bobova, L., Prenoveau, J. M., Revelle, W., & Craske, M. G. (2015). Prospective associations of low positive emotionality with first onsets of depressive and anxiety disorders: Results from a 10-wave latent trait-state modeling study. *Journal of Abnormal Psychology, 124,* 933–942. https://doi.org/10.1037/abn0000105

Kok, B. E., Coffey, K. A., Cohn, M. A., Catalino, L. I., Vacharkulksemsuk, T., Algoe, S. B., Brantley, M., & Fredrickson, B. L. (2013). How positive emotions build physical health: Perceived positive social connections account for the upward spiral between positive emotions and vagal tone. *Psychological Science, 24,* 1123–1132. https://doi.org/10.1177/0956797612470827

Kring, A. M., & Gordon, A. H. (1998). Sex differences in emotion:expression, experience and physiology. *Journal of Personality and Social Psychology, 74,* 686–703. https://doi.org/10.1037/0022-3514.74.3.686

Laborde, S., Lautenbach, F., & Allen, M. S. (2015). The contribution of coping-related variables and heart rate variability to visual search performance under pressure. *Physiology & Behavior, 139,* 532–540. https://doi.org/10.1016/j.physbeh.2014.12.003

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research —recommendations for experiment planning, data analysis, and data reporting. *Frontiers in Psychology, 20,* https://doi.org/ 10.3389/fpsyg.2017.00213.

Matthews, A., & Mackintosh, B. (1998). A cognitive model of selective processing in anxiety. *Cognitive Therapy and Research, 22,* 539–560. https://doi.org/10.1023/A:1018738019346

Mathews, A., & MacLeod, C. (2005). Cognitive vulnerability to emotional disorders. *Annual Review of Clinical Psychology, 1,* 167–195. https://doi.org/10.1146/annurev.clinpsy.1.102803.143916

Nunan, D., Sandercock, G.R.H., & Brodie, D. A. (2010). A quantitative systemic review of normal values for short-term heart rate variability in healthy adults. *PACE, 33,* 1407–1417. https://doi.org/ 10.111/j.1540-8159.2010.02841.x

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends In Cognitive Sciences, 9,* 242–249. https://doi.org/10.1016/j.tics.2005.03.010

Ohrmann, P., Rauch, A. V., Bauer, J., Kugel, H., Arolt, V., Heindel, W., & Suslow, T. (2007). Threat sensitivity as assessed by automatic amygdala response to fearful faces predicts speed of visual search for facial expression. *Experimental Brain Research, 183,* 51–59. https://doi.org/10.1007/s00221-007-1022-0

Papa, A., & Bonanno, G. A. (2008). Smiling in the face of adversity: The interpersonal and intrapersonal functions of smiling. *Emotion, 8,* 1–12. https://doi.org/10.1037/1528-3542.8.1.1

Pieritz, K., Sussenbach, P., Fief, W., & Euteneuer, F. (2016). Subjective social status and cardiovascular reactivity: An experimental examination. *Frontiers in Psychology, 7,* 1091. https://doi.org/10.3389/fpsyg.2016.01091.

Porges, S. W. (2001). The polyvagal theory: phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology, 42,* 123–146. https://doi.org/10.1016/S0167-8760(01)00162-3

Pressman, S. D., & Cohen, S. (2005). Does positive affect influence health? *Psychological Bulletin, 131,* 1106–1111. https://doi.org/10.1037/0033-2909.131.6.925.

Quintana, D. S., Alvares, G. A., & Heathers, J.A.J. (2016). Guidelines for reporting articles on psychiatry and heart rate variability (GRAPH): Recommendations to advance research communication. *Translational Psychiatry, 6,* 1–10. https://doi.org/ 10.1038/tp.2016.73.

Quirin, M., Bode, R. C., & Kuhl, J. (2011). Recovering from negative events by boosting implicit positive affect. *Cognition and Emotion, 25,* 559–570. https://doi.org/10.1080/02699931.2010.536418.

Radloff, L. S. (1977). The CES-D scale a self-report depression scale for research in the general population. *Applied Psychological Measurement, 1*, 385–401. https://doi.org/10.1177/014662167700100306

Rafaeli, E., Rogers, G. M., & Revelle, W. (2007). Affective synchrony: Individual differences in mixed emotions. *Personality and Social Psychology Bulletin, 33*, 915–932. https://doi.org/10.1177/0146167207301009

Shechner, T., Jarcho, J. M., Britton, J. C., Leibenluft, E., Pine, D. S., & Nelson, E. E. (2013). Attention bias of anxious youth during extended exposure of emotional face pairs: An eye-tracking study. *Depression and Anxiety, 30*(1), 14–21. https://doi.org/10.1002/da.21986

Schmeichel, B. J., & Tang, D. (2015). Individual differences in executive functioning and their relationship to emotional processes and responses. *Current Directions In Psychological Science, 24*, 93–98. https://doi.org/10.1177/0963721414555178

Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalain, P. A. (2014). Kubios HRV—Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine, 113*, 210–220. https://doi.org/10.1016/j.cmpb.2013.07.024

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine, 37*, 141–153. https://doi.org/10.1007/s12160-009-9101-z

Updegraff, J. A., Gable, S. L., & Taylor, S. E. (2004). What makes experiences satisfying? The interaction of approach-avoidance motivation and emotions in well-being. *Journal of Personality and Social Psychology, 86*, 496–504. https://doi.org/10.1037/0022-3514.86.3.496

Williams, K. D. (2007). Ostracism: The kiss of social death. *Social and Personality Psychology Compass, 1*, 236–247. https://doi.org/10.1111/j.1751-9004.2007.00004.x

Williams, K. D., Cheung, C., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the internet. *Journal of Personality and Social Psychology, 79*, 748–762. https://doi.org/10.1037/0022-3514/79.5.748

Williams, K. D., & Jarvis, B. (2006). Cyberball: A program for use in research on interpersonal ostracism and acceptance. *Behavior Research Methods, 38*, 174–180. https://doi.org/10.3758/BF03192765

Wyer, N. A., & Calvini, G. (2011). Don't sit so close to me: Unconsciously elicited affect automatically provokes social avoidance. *Emotion, 11*, 1230–1234. https://doi.org/10.1037/a0023981

Yanagisawa, K., Masui, K., Onoda, K., Furutani, K., Nomura, M., Yoshida, H., & Ura, M. (2011). The effects of the behavioral inhibition and activation systems on social inclusion and exclusion. *Journal of Experimental Social Psychology, 47*, 502–505. https://doi.org/10.1016/j.jesp.2010.11.014

Yiend, J. (2009). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition & Emotion, 24*, 3–47. https://doi.org/10.1080/02699930903205698

SUPPLEMENTAL MATERIALS

TABLE S1. OLS Regression Analysis Examining the Association between Higher Set-Shifting Ability and REPORTED Positive Emotional Experiences During Simulated Peer-Rejection, in High Threat-Sensitivity Individuals

Dependent Variable	Positive Emotional Experiences During Peer Rejection					
	B	*SE*	β	sr^2	R^2	ΔR^2
Step 1 Age	.00	.03	−.00	.00	.02	.01
Sex	−.06	.28	−.03	.00		
Depression	−.01	.02	−.11	.01		
Reward Responsiveness	−.07	.08	−.11	.01		
$F(4,60) = .27$, $p = .90$						
Step 2 Age	.00	.01	.02	.00	.80	.78**
Sex	.21	.13	.10	.01		
Depression	−.01	.01	−.08	.01		
Reward Responsiveness	−.03	.04	−.05	.00		
Positive Emotional Experiences During Warm-up Game	.70**	.05	.89	.78		
$F(5,59) = 46$, $p < .001$						
Step 3 Age	.00	.01	.01	.00	.80	.01
Sex	.19	.14	.09	.01		
Depression	−.01	.01	−.10	.01		
Reward Responsiveness	−.04	.04	−.07	.00		
Positive Emotional Experiences During Warm-up Game	.71**	.05	.90	.78		
Percent Perseverative Errors	.02	.02	.70	.00		
Percent Non-Perseverative Errors	−.01	.01	−.11	.01		
$F(7,57) = 33.13$, $p < .001$						

Notes. Data is freely available online at http://personal.kent.edu/~kcoifman/resources.htm
**$p < .001$.

TABLE S2. OLS Regression Analysis Examining the Association between Higher Set-Shifting Ability and CODED Negative Facial Emotion During Simulated Peer-Rejection, in High Threat-Sensitivity Individuals

Dependent Variable	Negative Facial Emotion During Peer Rejection					
	B	*SE*	β	sr^2	R^2	ΔR^2
Step 1 Age	−.03	.02	−.20	.04	.08	.002
Sex	.27	.20	.19	.03		
Depression	.00	.01	.04	.00		
Reward Responsiveness	.03	.06	.07	.00		
$F(4,53) = 1.07$, $p = .38$						
Step 2 Age	−.01	.02	−.07	.00	.39	.31**
Sex	.05	.17	.04	.00		
Depression	.01	.01	.10	.01		
Reward Responsiveness	.02	.05	.05	.00		
Negative Facial Emotion During Warm-up Game	.67**	.13	.60	.31		
$F(5,52) = 6.52$, $p < .001$						
Step 3 Age	−.01	.02	-.08	.01	.39	.008
Sex	.09	.17	.06	.00		
Depression	.01	.01	.10	.01		
Reward Responsiveness	.01	.05	.04	.00		
Negative Facial Emotion During Warm-up Game	.69**	.13	.60	.32		
Percent Perseverative Errors	.01	.02	.08	.00		
Percent Non-Perseverative Errors	.00	.01	.02	.00		
$F(7,50) = 4.63$, $p < .001$						

Notes. Data is freely available online at http://personal.kent.edu/~kcoifman/resources.htm
*$p < .05$; **$p < .001$

TABLE S3. OLS Regression Analysis Examining the Association between Higher Set-Shifting Ability and REPORTED Negative Emotion Experience During Simulated Peer-Rejection, in High Threat-Sensitivity Individuals

Dependent Variable	Negative Emotion Experience During Peer Rejection					
	B	*SE*	β	sr^2	R^2	ΔR^2
Step 1 Age	−.00	.02	−.01	.00	.09	.07*
Sex	.07	.17	.05	.00		
Depression	.02*	.01	.27	.07		
Reward Responsiveness	.08	.05	.21	.04		
$F(4,60) = 1.40$, $p = .24$						
Step 2 Age	−.00	.01	−.03	.00	.29	.21**
Sex	.12	.15	.10	.01		
Depression	.02*	.01	.24	.05		
Reward Responsiveness	.10*	.04	.27	.06		
Negative Emotion Experience During Warm-up Game	.86**	.21	.46	.21		
$F(5,59) = 4.86$, $p < .01$						
Step 3 Age	−.00	.02	−.01	.00	.29	.00
Sex	.12	.16	.09	.01		
Depression	.02*	.01	.25	.05		
Reward Responsiveness	.10*	.04	.29	.07		
Negative Emotion Experience During Warm-up Game	.88**	.22	.47	.21		
Percent Perseverative Errors	−.01	.02	-.07	.00		
Percent Non-Perseverative Errors	.00	.01	.06	.00		
$F(7,57) = 3.40$, $p < .01$						

Notes. Data is freely available online at http://personal.kent.edu/~kcoifman/resources.htm
$^*p < .05$; $^{**}p < .001$