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How to Improve Adolescent Stress Responses: Insights From Integrating Implicit Theories of Personality and Biopsychosocial Models

David S. Yeager[1], Hae Yeon Lee[1], and Jeremy P. Jamieson[2]
[1]Department of Psychology, University of Texas at Austin, and [2]Department of Psychology, University of Rochester

Abstract
This research integrated implicit theories of personality and the biopsychosocial model of challenge and threat, hypothesizing that adolescents would be more likely to conclude that they can meet the demands of an evaluative social situation when they were taught that people have the potential to change their socially relevant traits. In Study 1 ($N = 60$), high school students were assigned to an incremental-theory-of-personality or a control condition and then given a social-stress task. Relative to control participants, incremental-theory participants exhibited improved stress appraisals, more adaptive neuroendocrine and cardiovascular responses, and better performance outcomes. In Study 2 ($N = 205$), we used a daily-diary intervention to test high school students' stress reactivity outside the laboratory. Threat appraisals (Days 5–9 after intervention) and neuroendocrine responses (Days 8 and 9 after intervention only) were unrelated to the intensity of daily stressors when adolescents received the incremental-theory intervention. Students who received the intervention also had better grades over freshman year than those who did not. These findings offer new avenues for improving theories of adolescent stress and coping.

Keywords
biopsychosocial model, implicit theories of personality, stress, biological psychology, social-evaluative threat, adolescence, open data, preregistered

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Negative social evaluations are ubiquitous during adolescence (Crosnoe, 2011). Such stressors can contribute to dysregulations in neuroendocrine and autonomic reactivity that can accumulate into mental and physical health problems, impaired cognitive performance, and even academic underachievement (Crosnoe, 2011; Goodyer, 2001; Gunnar, Wewerka, Frenn, Long, & Griggs, 2009; Lopez-Duran, Kovacs, & George, 2009; Marceau, Ruttle, Shirtcliff, Essex, & Susman, 2015).

Here, we integrated two research traditions—each of which has proceeded independently in the literature—to advance theory regarding the causes of and ways to improve adolescents' social-stress responses. These traditions are (a) the *biopsychosocial model of challenge and threat* (Blascovich & Mendes, 2010; Jamieson, Mendes, & Nock, 2013; Seery, 2013), which provides a mechanistic framework for understanding social stress responses, and (b) *implicit theories of personality* (Chiu, Hong, & Dweck, 1997; Dweck, Chiu, & Hong, 1995; Yeager & Dweck, 2012), which are beliefs that shape individuals' interpretations of the meaning of the social stressors they face. Specifically, we examined the effects of an intervention targeting implicit theories of personality on the cognitive, physiological, and behavioral processes well-studied in biopsychosocial models.

Corresponding Author:
David S. Yeager, University of Texas at Austin, Department of Psychology, 108 E. Dean Keeton Stop A8000, Austin, TX 78712
E-mail: dyeager@utexas.edu

Theoretical Background

A fundamental principle of the biopsychosocial model of challenge and threat is that cognitive appraisals of situational demands and coping resources interact to determine stress responses in motivated-performance contexts (Blascovich & Mendes, 2010; Gross, 2015; Jamieson, Mendes, & Nock, 2013; Seery, 2013). When individuals perceive that they possess sufficient resources to cope with the situational demands posed by stressors, they experience *challenge*. However, when situational demands are seen as exceeding resources, individuals experience *threat*.

Physiologically, both challenge and threat states create increased sympathetic nervous system (SNS) activation, but the quality of activation they create differs. Challenge states prepare the body for approach-oriented behaviors. Challenge states increase delivery of oxygenated blood to the brain and peripheral sites by means of increased activation of the sympathetic-adrenal-medullary axis, which produces vasodilation and leads to increased cardiac efficiency (Mendes, Blascovich, Lickel, & Hunter, 2002).

Threat states, by contrast, prepare the body for damage or social defeat, and in contrast to challenge states, also activate the hypothalamic-pituitary-adrenal (HPA) axis, producing reduced cardiac efficiency and increased vascular resistance downstream. Thus, individuals experiencing threat are likely to exhibit increased production of cortisol—a catabolic adrenal hormone that is the end product of HPA-axis activation (Dickerson & Kemeny, 2004; Zijlmans, Beijers, Mack, Pruessner, & de Weerth, 2013). Moreover, threatened individuals, compared with challenged individuals, return to homeostasis more slowly (for instance, they show SNS activation even after stress offset) as stress reactions linger (Dickerson & Kemeny, 2004). Prolonged stress responses can contribute to decreased long-term health and cognitive performance outcomes of chronic threat-type activation (McEwen, 2006).

In the context of the biopsychosocial model of challenge and threat, changing appraisals of resources and demands can change downstream physiology, cognitions, and behavior in stressful situations (e.g., Jamieson, Mendes, Blackstock, & Schmader, 2010; Jamieson, et al., 2013). Surprisingly, experimental research has not fully uncovered why adolescents might appraise everyday stressful social situations as events that they do not have the resources to cope with.

In this vein, we hypothesized that research on implicit theories of personality—which are general belief systems about the malleability of people's socially relevant traits (Chiu et al., 1997; Yeager & Dweck, 2012)—may be informative. Research has shown that some individuals hold more of an *entity theory of personality*, the belief that traits are fixed and cannot change. This belief leads to "fixed" trait attributions of social failures ("I'm not likable") and other people's harmful behaviors ("He's a bad person"; Chiu et al., 1997). Other individuals hold more of an *incremental theory of personality*, the belief that people do have the potential to change.

For individuals with more of an entity theory than an incremental theory, social threats or failures can be viewed as a diagnosis of lasting social reality. From a biopsychosocial perspective, social-evaluative situations might be appraised as highly demanding (because one's fixed status or reputation hangs in the balance) and judged as something that one does not have the resources to cope with (because no amount of resources could overcome a fixed, deficient identity in the face of negative social evaluation). Hence, we hypothesized that for people who hold an entity theory, appraisals of demands should exceed resources—producing the experience of threat described by biopsychosocial models.

As initial support of this possibility, in past studies, an entity theory of personality predicted greater self-reported stress and anxiety following ostracism, as well as greater reports of psychosocial stress (Yeager, Johnson, et al., 2014) and psychopathology (Miu & Yeager, 2015; Schleider, Abel, & Weisz, 2015), compared with an incremental theory of personality. Furthermore, entity theories of personality relate to negative self-conscious emotions, such as shame (Yeager, Trzesniewski, Tirri, Nokelainen, & Dweck, 2011), and these self-conscious emotions co-occur with threat-type physiological reactions to social-evaluative stress (Dickerson & Kemeny, 2004).

Fortunately, adolescents can be taught to adopt an incremental theory of personality. This belief prevents fixed trait attributions so that negative social-evaluative experiences (e.g., peer exclusion or victimization) are not seen as permanent. Because incremental theorists see people—both themselves and others—as malleable, social adversity may be seen as improvable (Erdley & Dweck, 1993; Yeager, Trzesniewski, & Dweck, 2013; Yeager et al., 2011). That is, other people's negative social evaluations of oneself may be viewed as a problem to be solved, rather than a fixed part of one's social reality.

Indeed, prior research has found that an incremental-theory-of-personality intervention reduced self-reported stress and anxiety following ostracism a day later (Yeager, Johnson, et al., 2014). Furthermore, teaching adolescents about the possibility of personality change reduced global self-reported stress (Yeager, Johnson, et al., 2014), behavioral aggression (Yeager et al., 2013), and clinically significant depressive symptoms (Miu & Yeager, 2015; Yeager, Johnson, et al., 2014) at a 9-month follow-up, while also improving academic performance in high school (Yeager, Johnson, et al., 2014; although the latter finding has appeared only in studies with small sample sizes, or in small subgroups, and therefore bears replication). However, no previous research has examined whether implicit theories of personality relate to resource or demand appraisals, or to threat-type cardiovascular or neuroendocrine responses to acute stressors, nor has it shown the mechanisms for effects on performance in the midst of stress.

The Present Research

In the present research, we tested whether implicit theories of personality are global belief systems that create situation-specific appraisals that give rise to challenge or threat responses to acute stressors and therefore provide a key to improving adolescent stress responses. We predicted that teaching adolescents an incremental theory of personality would promote more challenge-type responses to social stress (e.g., perceived resources > perceived demands, increased cardiac efficiency, decreased vascular resistance, and decreased cortisol), which would result in improved cognitive functioning during stress (increased task performance) and more rapid recovery to homeostasis (decreased SNS activation during a recovery epoch), relative to control participants. Two double-blind, randomized controlled studies—a laboratory study and a daily-diary field experiment—were used to investigate these predictions.

Study 1

Method

Participants. We determined that a sample of 60 participants would be needed to achieve an average effect size (d = 0.66), on the basis of similar social-situational-intervention research in laboratory settings using standardized social-stress-induction paradigms. A total of 60 high school students were recruited from the Rochester, New York, area using posted flyers and study information distributed by peers and teachers. Participants (55% female, 45% male; 70% White, 15% Black, 12% Asian or Asian-American, 3% other) were recruited from 9th-, 10th-, and 11th-grade classrooms (mean age = 15.61 years, range = 14–17) and were compensated $50.

Participants were prescreened and excluded for physician-diagnosed hypertension, cardiac abnormalities, the presence of a cardiac pacemaker, taking medications with hemodynamic side effects, and being pregnant or nursing. Time since waking and start date of the previous menstrual cycle (for females) were recorded and included as covariates in hormone analyses. All data exclusions due to malfunctioning equipment, lost data, or noncompliance are listed in the Supplemental Material available online (these varied across measures, and so degrees of freedom varied).

Procedure

Overview. When participants arrived at the laboratory, noninvasive electrocardiography, impedance-cardiography, and blood-pressure sensors were affixed. Participants rested for a 5-min baseline recording and then provided a baseline saliva sample. Each was then randomly assigned to complete an incremental-theory or an active control reading and writing exercise. After the intervention, participants were told they would be asked to complete a social-stress task and given 3 min to prepare for their upcoming self-relevant speeches. They then performed the social-stress task (self-relevant speech followed by mental arithmetic). This was followed by a recovery period (3 min), after which participants provided a reactivity saliva sample (timed to be ~20 min after stress onset; additional details of the stress-task instructions are provided in the Supplemental Material).

Incremental-theory-of-personality intervention. An incremental theory of personality was taught using materials shown to be effective in prior research (Miu & Yeager, 2015; Yeager & Dweck, 2012; Yeager, Johnson, et al., 2014; Yeager et al., 2011). In past research, the manipulation reliably led to changes in self-reported implicit theories (Yeager, Johnson, et al., 2014; Yeager et al., 2011; self-reported theories were not measured here).

The incremental-theory intervention uses insights from research on persuasion and internalization. It consists of a 25-min reading and writing exercise that teaches the idea that (a) if a person is excluded or victimized, it is not because of a fixed, personal deficiency and (b) people who exclude or victimize you are not bad people whose personalities are fixed but instead have complicated motivations subject to change. The exercise presents true scientific evidence showing that people can change, as well as stories from older peers who endorsed this message. At the end of the activity, participants summarize and endorse messages through a “saying is believing” writing exercise, in which they attempt to persuade future students to hold an incremental theory (Aronson, Fried, & Good, 2002; Walton & Cohen, 2011; Wilson & Linville, 1982; quotes from the intervention and sample student responses are presented in the Supplemental Material).

The control condition paralleled the experimental condition, except that it focused on a domain unrelated to social-evaluative threat: adjusting to the physical environment of high school (lockers, hallways, smells). It summarized neuroscience research related to different sensory experiences and included stories from upperclassmen. Hence, it conveyed a positive message and included advice from older peers but was unrelated to beliefs about people’s traits. Note that an entity-theory manipulation was not used because of the ethical concern about teaching a fixed belief; hence, the effect sizes reported here are more conservative than they would have been had we included an entity-theory manipulation as a comparison condition.

Social-stress task. Students performed a controlled social-evaluative-stress task, the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993), which was age-modified for adolescents. This test consisted of a 3-min anticipatory period ("preparation"); a 5-min videotaped speech about the attributes that make teens popular, which participants delivered to two same-race, peer evaluators (one male, one female); and a 5-min mental-arithmetic task: counting backward from 996 in steps of 7. After the TSST, participants rested alone for 3 min to provide a measure of autonomic recovery from stress (the "recovery" period). Throughout the speech and math tasks, evaluators provided neutral and negative nonverbal feedback (crossing arms, frowning, sighing, etc.). Evaluators were very recent high school graduates working in the researchers' lab who were pretested to ensure they appeared to be within the age range of participants (14–17 years). The topic of the speech—a commentary on popular trends among teens—was selected because nonsupportive, nonverbal feedback on one's views about popularity can plausibly be construed as a threat to social status.

Measures

Threat appraisals. A stress-appraisal questionnaire, developed to differentiate between challenge and threat states, was administered immediately before and after the TSST. As is common practice with research using this scale (see Beltzer, Nock, Peters, & Jamieson, 2014), composites of situational demands (e.g., "this situation is demanding") and personal resources (e.g., "I have the abilities to perform well") were computed at each time point (αs > .80; see the Supplemental Material for additional details).

In the context of the biopsychosocial model, threat states stem from a ratio of appraisals of coping resources relative to perceived task demands. We created a threat-appraisal score consistent with this conceptualization by subtracting resources from demands, such that values greater than 0 corresponded to threat appraisals (demands > resources), and values less than 0 corresponded to challenges (perceived resources meet or exceed demands). Threat appraisals were computed and analyzed separately for pre- and post-TSST measures.

Neuroendocrine responses. To measure HPA-axis activation, we assessed cortisol levels using two 1-ml saliva samples. These samples (Time 1) were collected following autonomic measures taken at baseline, when participants arrived at the lab. A posttask sample (Time 2) was taken following the TSST and timed to occur approximately 20 min after the initial description of the speech-math task (i.e., at stress onset). All study sessions were conducted during the afternoon between noon and 6:00 p.m. when cortisol levels are at their waking nadir.

Raw cortisol values demonstrated nonnormality (baseline skew $p < .001$, posttest skew $p = .030$). A ladder-of-powers analysis showed that the joint test of skew and kurtosis was reduced to nonsignificance when a log transformation was carried out. There were no biologically impossible values in this sample. Thus, no outliers were trimmed. For ease of interpretation, the resulting metric was rescaled to have the same mean and standard deviation as the raw data at each time point.

Cardiovascular responses. As is standard in laboratory paradigms examining autonomic responses to stressful social situations, physiological reactivity was computed by subtracting scores taken during baseline from those collected during target tasks (see Jamieson et al., 2013; Llabre, Spitzer, Saab, Ironson, & Schneiderman, 1991; and Mendes et al., 2002, for examples of this approach in social-stress paradigms). Raw baseline scores were also tested to determine whether differences between conditions could interfere with reactivity analyses, and none were found.

Analyses focused on the preejection period—a measure of SNS activation—and two measures that, in conjunction, allowed us to distinguish between approach-motivated challenge and avoidance-motivated threat states: stroke volume and total peripheral resistance.

The preejection-period interval indexes the contractile force of the heart by measuring the time from the initiation of left-ventricle contraction to aortic-valve opening. Greater SNS activation is indicated by shorter preejection-period intervals—that is, the stronger the force of the left-ventricle contraction, the more quickly blood will be ejected from the heart via the aorta. All participants regardless of condition were expected to exhibit SNS activation in anticipation of and during the TSST, because the social-evaluative tasks presented acute demands that had to be addressed. However, we hypothesized that between-conditions differences in preejection periods should manifest after stress offset. Recall that challenge responses to acute stress are associated with a more rapid return to homeostasis relative to threat responses. Thus, if the incremental-theory intervention promoted more challenge-type patterns of responding, individuals should exhibit decreased SNS activation (increased preejection-period intervals) during the recovery epoch after the TSST. We specifically included the recovery epoch in order to examine this arousal after stress offset.

Stroke volume is the amount of blood ejected from the heart during each beat and was calculated using the Kubicek method (Sherwood, Royal, & Hutcheson, 1992). Combined with increased SNS activation, increased stroke volume indicates improved cardiac efficiency and is typically observed in challenge states, whereas a decrease (or little change) in stroke volume is suggestive of threat. Differences in stroke-volume reactivity were predicted at every task epoch.

Note that we assessed cardiac-efficiency stroke volume rather than using the more common metric of cardiac output (stroke volume × heart rate) because we predicted a Condition × Time interaction for preejection-period interval (decreases in preejection-period interval correlate with increases in heart rate). If incremental-theory participants exhibited longer preejection-period intervals (i.e., less SNS activation) at recovery than control participants, this could manifest as reduced heart rate and affect the interpretation of cardiac output in overall analyses. Thus, when differences may exist in heart rate, it is more valid to assess cardiac efficiency with stroke volume. In fact, stroke volume may be considered a more direct indicator of challenge and threat responses than cardiac output because (a) heart rate contributes little to the differentiation of challenges and threats and (b) heart rate is affected by a complex interaction of neural, sympathetic, parasympathetic, and endocrine processes (e.g., Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001).

Total peripheral resistance is a measure of overall resistance in the peripheral vasculature. When a person is threatened, vascular resistance increases, limiting blood flow to the periphery and producing high total peripheral resistance. On the other hand, vasodilation (i.e., reduced total peripheral resistance) accompanies challenge states so as to facilitate delivery of oxygenated blood to the brain and periphery. We calculated total peripheral resistance with the following validated formula: (mean arterial pressure/cardiac output) × 80 (Sherwood et al., 1990). Differences in total peripheral resistance were predicted at every postbaseline epoch (see the Supplemental Material for more detail on all of these cardiovascular measures).

Performance. Two independent coders blind to condition assignment and hypotheses coded video recordings of speech and mental-math tasks using a coding scheme implemented previously in the biopsychosocial literature to index affective responses and speech performance (see Beltzer et al., 2014). Interrater reliability was good (r = .91). Raters provided a joint score when necessary.

Speech performance was quantified as a composite of ratings of participants' confidence, use of nonverbal cues, eye contact, and subjective rating of speech quality (α = .867). Performance on the mental-math tasks was indexed using two measures derived from the video recordings: total number of errors made and lowest correct answer achieved.

Results

Threat appraisals. Students assigned to the incremental-theory manipulation reported lower threat appraisals compared with control participants, both before the TSST (control: M = 1.07, SD = 1.88; intervention: M = −0.19, SD = 1.92), $t(58)$ = 2.57, p = .012, d = 0.63, 95% confidence interval (CI) for the mean difference = [0.14, 1.18], and after the TSST (control: M = 1.47, SD = 1.73; incremental: M = −0.10, SD = 1.64), $t(57)$ = 3.55, p < .001, d = 0.84, 95% CI for the mean difference = [0.38, 1.45]. Figure 1a shows that threat appraisals of control participants were greater than 0 both before and after the task, which indicates that the ratio of perceived demands exceeded perceived resources, $t(29)$s > 2.57, ps < .01. In contrast, incremental-theory participants' threat appraisals were not significantly different from zero, $t(29)$s < 0.51, ps > .59.[1]

We also analyzed the demand and resource subscales separately. The incremental-theory manipulation affected both demand, $t(57)$ = 2.35, p = .022, d = 0.62, 95% CI = [0.09, 1.15], and resources, $t(57)$ = 3.93, p < .001, d = 1.04, 95% CI = [0.48, 1.59]. Although the effects of condition on resources were estimated to be nearly twice as large as the effects of condition on demands, a Wald test from a multivariate regression could not reject the null hypothesis that they were different, $F(1, 58)$ = 2.23, p = .14.

Neuroendocrine responses. There was no significant difference between conditions in salivary cortisol at baseline, t < 1. We then analyzed acute cortisol reactivity (Time 2 – Time 1). This analysis produced the hypothesized condition effect, $t(57)$ = 3.18, p = .002, d = 0.84, 95% CI for the mean difference = [1.96, 8.62]. Incremental-theory participants had lower acute cortisol reactivity (M = −0.48 nmol/L, SD = 4.45) than did control participants (M = 4.81 nmol/L, SD = 7.82; see Fig. 1b).

Cardiovascular responses. There were no differences between incremental-theory and control participants in raw baseline cardiovascular measures, Fs < 1. Reactivity scores were then analyzed in 4 (time: anticipation vs. speech vs. mental math vs. recovery) × 2 (condition: incremental theory vs. control) mixed analyses of variance.

Analysis of the preejection-period interval yielded the expected main effect of time, $F(1, 49)$ = 57.03, p < .001, d = 2.16, and the predicted Time × Condition interaction, $F(1, 49)$ = 6.62, p = .013, d = .74 (see Fig. 2a). Simple contrasts were used to decompose the interaction based on a priori predictions. Incremental-theory participants exhibited less SNS activation (higher preejection-period intervals) at recovery, after stress offset, than did control participants, $F(1, 49)$ = 10.41, p = .002, d = 0.92, 95% CI for the mean difference = [−7.37, −0.93]. For participants in the incremental-theory condition,

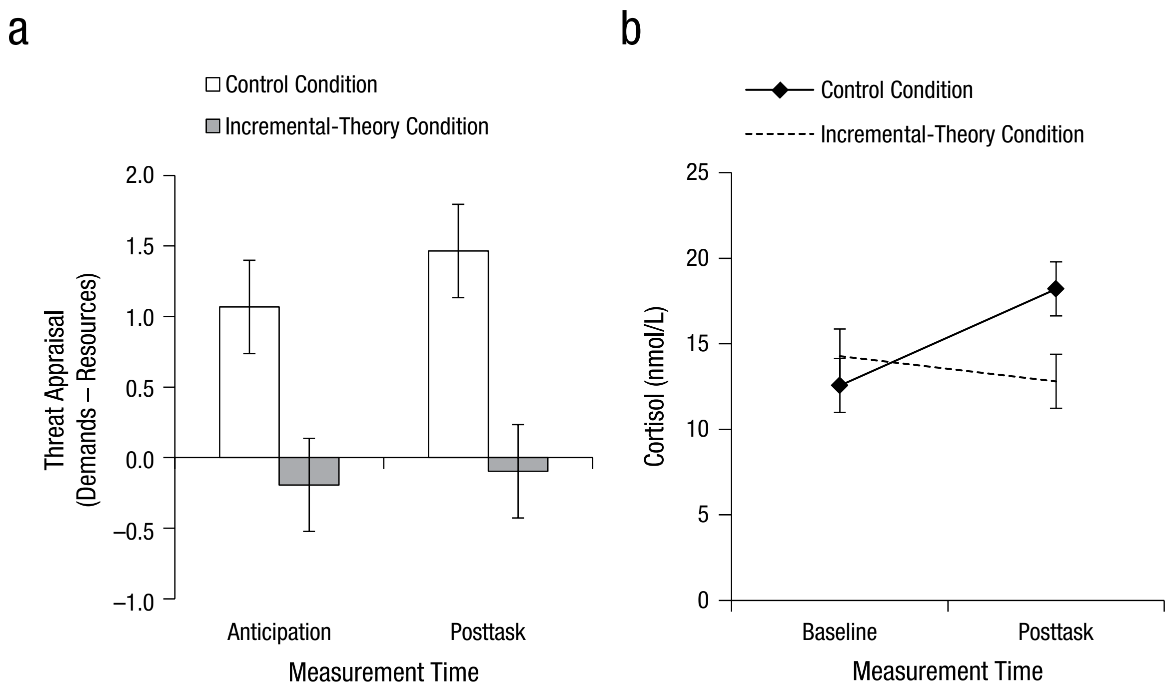

Fig. 1. Mean (a) self-reported threat-appraisal score and (b) salivary-cortisol level in Study 1 as a function of measurement time (before and after the stress test) and condition. Threat-appraisal scores were calculated by subtracting the resources participants had to confront a threat from their perceived demands of that threat. Error bars show ±1 *SEM*.

pretask and recovery preejection-period levels did not differ, $F(1, 49) = 0.10$, $p > .75$, which indicates that these participants had a more rapid return to homeostasis than did control participants. Figure 2a furthermore shows that it was not the case that participants in the incremental-theory condition were disengaged during the stressful task: No between-conditions differences in SNS activation were observed in anticipation of and during the stress task.

Next, analysis of stroke-volume reactivity produced the predicted main effect of condition, $F(1, 48) = 11.17$, $p = .002$, $d = 0.95$, 95% CI for the mean difference = [−11.09, −2.76]. As shown in Figure 2b, across all reactivity epochs, incremental-theory participants ejected more blood per beat compared with control participants. Finally, for total peripheral resistance, the hypothesized main effect emerged: Incremental-theory participants exhibited less vascular resistance (lower total-peripheral-resistance) across all times than did control participants, $F(1, 46) = 12.65$, $p = .001$, $d = 1.02$, 95% CI for the mean difference = [72.65, 262.04] (see Fig. 2c).

Performance. Speech performance and lowest number achieved in the mental-math task were significantly correlated ($r = -.360$, $p = .008$), as were mental-math errors and lowest number achieved ($r = .638$, $p < .001$). To account for family-wise error, we analyzed effects of condition on performance variables in a multivariate analysis of variance (no covariates were included). As hypothesized, this analysis yielded a multivariate main effect of condition, Wilks's $\lambda = .828$, $F(3, 49) = 3.39$, $p = .025$, $\eta_p^2 = .172$; overall, incremental-theory participants performed better than did control participants. In separate exploratory analyses, the effect of condition on the three performance metrics varied in significance but not direction: speech task, $p = .061$, mental-math errors, $p = .019$, lowest number in mental math, $p = .44$ (see the Supplemental Material for more detail).

To conduct exploratory mediation analyses for effects on performance, we computed a composite for pretask appraisals (demands – resources) and two cardiovascular-reactivity composites (total-peripheral-resistance reactivity during the speech and math epochs, and stroke-volume reactivity during the speech and math epochs), as well as a composite of the three performance metrics (see Table S4 in the Supplemental Material for all zero-order correlations).

Anticipatory threat appraisals were correlated with subsequent total peripheral resistance, $r = .34$, $p = .014$, and stroke volume, $r = .38$, $p = .004$, during the speech and math epochs. Next, total peripheral resistance strongly predicted performance, $r = -.37$, $p = .009$, but stroke volume did not, $r = .11$, $p = .440$. A mediational analysis computed via the method devised by Imai, Keele, and Tingley (2010) found a significant indirect effect of condition on speech and math performance via total peripheral

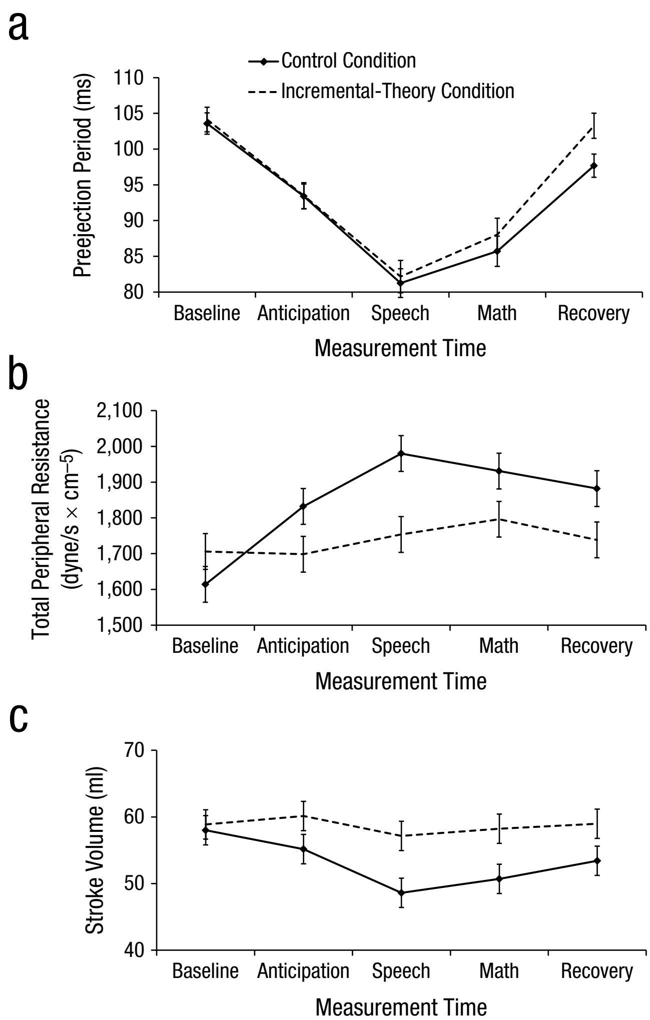

Fig. 2. Mean (a) preejection-period interval, (b) total peripheral resistance, and (c) stroke volume in Study 1 as a function of measurement time and condition. Each factor was measured at baseline, prior to the speech and math tests (anticipation period), during each test, and at recovery. Error bars show ±1 *SEM*.

resistance during the speech and math epochs, $b = -0.13$, 95% CI = [−0.32, −0.02], $p = .02$, but not via stroke volume, $b = -0.01$, 95% CI = [−0.18, 0.15], $p = .79$ (also see Table S3 and Fig. S1 in the Supplemental Material). Hence, this mediation analysis was consistent with the hypothesis that the incremental theory of personality promoted more adaptive appraisals for an upcoming evaluative task, which reduced threat-type stress reactivity (total peripheral resistance) and thereby allowed individuals to demonstrate improved cognitive performance.

However, we emphasize caution when interpreting these exploratory mediation results. Cardiovascular measures have rarely proven useful for definitive mediational tests of effects of social stress on performance and behavior (see Mendes & Jamieson, 2011). Critically, the temporal activation of stress responses differs between approach-motivated challenge states and avoidance-motivated threat states. Thus, using the cardiovascular signals from the same temporal epoch in a regression analysis for both intervention and control participants can be misleading. Moreover, the relationship between physiological response and behavioral outcomes is not typically monotonic as is assumed in most mediation analyses. Furthermore, a key assumption of causal mediation analysis—temporal precedence—is violated here because physiology and behavior are measured concurrently. Finally, power calculations for this study were conducted for main effects, not indirect effects. Nevertheless, these exploratory analyses provide initial evidence in line with our theoretical expectations and warrant examination in future confirmatory research.

In sum, Study 1 found support for our hypotheses: The incremental-theory-of-personality manipulation improved cognitive, cardiovascular, neuroendocrine, and behavioral reactions to social stress delineated by the biopsychosocial model of challenge and threat. Despite this encouraging evidence, we did not examine longer-term stress processes (appraisals or physiological responses) or accumulated behavioral outcomes (e.g., academic achievement) in Study 1. Nor did we explore processes in a naturalistic setting; hence, conclusions were limited to a controlled laboratory environment and to a single acute stressor.

Study 2

In Study 2, we implemented an incremental-theory-of-personality manipulation in ninth-grade classrooms and collected saliva samples and daily diary reports of social-evaluative stressors. The focal and preregistered hypothesis was that we would find a Daily Stress × Condition interaction, such that the incremental theory would sever the effect of daily social stressors on threat appraisals and neuroendocrine responses (similar to the hypothesized findings reported by Sherman, Bunyan, Creswell, & Jaremka, 2009; Stephens, Townsend, Hamedani, Destin, & Manzo, 2015; Walton & Cohen, 2011). While a naturalistic daily-diary study sacrifices clarity about the nature or timing of the stressors and makes it more difficult to measure task-specific appraisals, the diary affords a real-world assessment of a variety of daily social stressors that can undermine health (Almeida, 2005). As a secondary matter, in Study 2, we sought to replicate the effect of the incremental theory of personality on grades observed in previous research (Yeager, Johnson, et al., 2014).

Method

Participants. Study 2 was conducted with ninth-grade Algebra 1 students (55.2% female, 44.8% male; 56.7%

White, 39.7% Hispanic, 3.1% African American) in the first semester of high school, when threats to social status and academic rank are known to be substantial, pervasive, and unpredictable (Crosnoe, 2011). Sample size was determined by the maximum number of participants who were willing to provide consent. There were two analytic samples because of independent consent processes: one for the intervention and self-reports and a second for salivary hormone analysis.

A total of 303 participants consented to complete the intervention and self-report questions and have their school records analyzed; a subsample of these (n = 205) also consented to provide saliva samples. An attrition analysis found that the characteristics of participants in the intervention and control groups who did not consent to have saliva samples taken were not significantly different (see the Supplemental Material).

Procedure. Each participant was randomly assigned—at the individual level (i.e., within classrooms)—to complete the incremental-theory intervention or control materials in his or her Algebra 1 class (see Study 1 for the manipulation). Materials were contained in individualized envelopes, a procedure analogous to that used in affirmation studies (Cohen, Garcia, Purdie-Vaughns, Apfel, & Brzustoski, 2009). After completing the materials, students placed them back in the envelopes and handed them to the experimenters. Materials took 20 to 30 min to complete. Teachers and research assistants were unaware of hypotheses or intervention content (and were thus blind to condition), and the messages were never discussed with students after this experience.[2]

Saliva samples were collected at baseline (1 or 2 days before intervention) and each of Days 5 through 9 after intervention. All saliva samples were collected at the same time of day (e.g., students in second-period Algebra 1 always provided samples in second period) to control for diurnal rhythm within individuals. Samples were frozen and shipped off-site to be assayed for adrenal hormones: cortisol and dehydroepiandrosterone sulfate (DHEA-S; see the Supplemental Material).

Past research with adults has linked DHEA-S to more adaptive social-stress outcomes (Epel, McEwen, & Ickovics, 2010). However, adolescence is a developmental period marked by somewhat different hormonal function than adulthood (Gunnar et al., 2009; Marceau et al., 2015). In adolescent samples, cortisol and DHEA-S are positively correlated in response to real-world social stressors, as opposed to laboratory stressors, for which they may be negatively correlated (Marceau et al., 2015). Thus, to more fully capture neuroendocrine effects of the intervention, we assayed both cortisol and DHEA-S and expected the same patterns for both. Each day after participants provided a saliva sample, they typed a description of any negative events that happened to them that day and completed survey questions assessing daily stressors and appraisals.

Measures

Grades. Students' grades in core subjects (math, English, science, and social studies) in the fall and spring semesters of ninth grade, and their prestudy grades and test scores in the same subjects, were collected from the school registrar. Ninth-grade achievement was a composite of postmanipulation performance in the core subjects and ranged from 0 to 4, and prior achievement was a composite of the z-scored values for prior grades and test scores.

Daily stressors. Immediately after participants provided saliva samples, participants freely wrote about one to three negative, stressful events in response to an open-ended prompt; they then rated the overall intensity of the negative events (1 = *not at all negative*, 4 = *extremely negative*). Two independent coders blind to hypotheses and condition categorized events. To mirror the TSST—a socially and intellectually evaluative task—from Study 1, we analyzed participants' social- and academic-evaluative stressors. Ratings across the three potential stressors were averaged into a composite for each day.

Threat appraisals. Immediately after listing daily stressors, participants were asked a single secondary-threat-appraisal item: "Overall, how confident are you that you can handle the stresses you experienced today in school so far?" (1 = *I can handle the stress really well*, 10 = *I can't handle the stress at all*). Higher values indicated that they did not have the resources to meet environmental demands.

Neuroendocrine measures. Cortisol and DHEA-S levels showed highly nonnormal distributions (joint tests of skew and kurtosis, $p < .001$) and biologically implausible high and low values. Values were trimmed (top and bottom 1.5% of the distribution). Therefore, our inferences are limited to the 97% of adolescents in the normal range. A ladder-of-powers analysis showed that the optimal method of transforming the trimmed data was a square-root transformation (see histograms in the Supplemental Material for untransformed and transformed data). To facilitate interpretation, we linearly transformed the resulting values to have the same mean and standard deviation as the raw data. The same procedure was followed for both cortisol and DHEA-S. As expected, cortisol and DHEA-S were positively correlated, $r = .395$, $p < .001$ (this correlation was half as strong before trimming and transforming, which testifies to the validity of the method), and so were analyzed both individually and in combination as a single adrenal-hormone variable.

Results

Test of baseline differences. Incremental-theory and control participants did not differ across a number of demographic self-report variables, including gender, ethnicity, prior achievement, global stress, and depressive symptoms (see Table S5 in the Supplemental Material). Furthermore, at baseline, as expected, there was no Daily Stress × Condition interaction predicting threat appraisals, cortisol, or DHEA-S (*p*s > .20; see Fig. 3). Moreover, no between-conditions differences in daily diary reports of social-evaluative stressors were observed at baseline (p = .29) or after intervention (p = .89). Thus, there were no differences in exposure to social stressors, which allowed for a test of differences in reactivity (see Almeida, 2005).

Replication of intervention effect on grades. Replicating the findings of Yeager, Johnson, et al. (2014), the present results showed that participants assigned to the incremental-theory intervention had higher core-course grade point averages (GPAs) in the fall semester of ninth grade (raw M = 2.70, SD = 0.61) than did control participants (raw M = 2.62, SD = 0.61), $t(298)$ = 2.41, p = .016, d = 0.279, 95% CI = [0.05, 0.49]. The same effect of intervention on GPA emerged in the spring semester (control: M = 2.66, SD = 0.63, intervention: M = 2.76, SD = 0.61), $t(299)$ = 2.33, p = .020, d = 0.269, 95% CI = [0.04, 0.48]. Analyses of GPA included prior achievement, advanced-placement course enrollment (which can affect grading scales), and gender (a highly significant predictor of grades) as covariates. Statistical significance was no different when we controlled only for prior achievement. Interestingly, the effect size of this social intervention was analogous to that of growth-mind-set-of-intelligence and sense-of-purpose interventions on grades (Paunesku et al., 2015; Yeager, Henderson, et al., 2014), which explicitly focused on academic motivation, unlike the present intervention.

Threat appraisals. Threat appraisals were analyzed using multigroup structural equation modeling, in which a latent daily-stress variable—indicated by the five post-manipulation daily-stressor reports—predicted a latent threat-appraisal variable—indicated by the five daily-appraisal reports, analyzed across the intervention and control groups. We used Mplus (Version 7.11; Muthén & Muthén, 2012) software to conduct this analysis.

As expected, in the control condition, there was a significant effect of daily social-evaluative stressors on threat appraisals, β = 0.329, p = .003, 95% CI = [0.11, 0.55]. Yet, as predicted, there was no such relation in the intervention condition, β = −0.034, p = .738, 95% CI = [−0.24, 0.17]. A test of nested models showed a significant reduction in model fit with these paths constrained to be equal across the intervention and control conditions; this test showed a significant Daily Stress × Condition interaction, $\Delta\chi^2(1, N = 319)$ = 6.577, p = .010 (Table 1). These analyses confirmed our first preregistered hypothesis.

There was no main effect of condition on threat appraisals (see Table S5), although none was predicted. In a simple-effects analysis in a mixed-effects regression model, the predicted reduction in threat appraisals on high-stress days (1 SD above the mean) did not reach significance, b = −0.275, $t(463)$ = −1.30, p = .194, d = 0.12, 95% CI = [−0.02, 0.30].[3]

Neuroendocrine responses. Using the same structural-equation-modeling approach, we found that, in the control condition, there was no relation between reports of daily social-evaluative stressors and levels of either cortisol or DHEA-S from Days 5 to 9 after intervention (see Table 1; for the full model, see Fig. S2 in the Supplemental Material). This finding represented a failure to find the pattern in the control condition, which we had expected the incremental-theory intervention to reduce. This precluded the possibility of carrying out our preregistered analysis exactly as planned.

Therefore, we examined the days on which this theoretically expected relation *was* present in the control condition and on which we could conduct our preregistered analysis. Figure 3 shows that over the final 2 days—Days 8 and 9 after intervention—there was a relation in the control condition between reports of daily social-evaluative stressors and both cortisol, β = 0.59, 95% CI = [0.06, 1.12], p = .028, and DHEA-S, β = 0.58, 95% CI = [0.04, 1.13], p = .036. In a latent-variable model that combined cortisol and DHEA-S into a single measure of adrenal hormones, we found an even stronger relation, β = 0.68, p = .003, 95% CI = [0.22, 1.13]. Therefore, we were able to carry out our preregistered analysis on data from Days 8 and 9 after intervention.

As expected, the relation of daily stressors with all neuroendocrine measures was nonsignificant among intervention participants—cortisol: β = −0.42, 95% CI = [−1.00, 0.17], p = .165; DHEA-S: β = −0.20, 95% CI = [−0.68, 0.28], p = .243; and latent variable for the HPA axis: β = −0.33, 95% CI = [−0.80, 0.15], p = .243. A multigroup analysis showed that the relation of daily social-evaluative stressors with cortisol, DHEA-S, and HPA-axis activation on Days 8 and 9 significantly differed between conditions—cortisol: $\Delta\chi^2(1, N = 192)$ = 6.542, p = .011; DHEA-S: $\Delta\chi^2(1, N = 192)$ = 4.390, p = .036; and HPA-axis activation: $\Delta\chi^2(1, N = 192)$ = 8.688, p = .003 (Table 1; also see Fig. S3 in the Supplemental Material). In a mixed-effects regression model, there was also a simple effect of both cortisol, b = −5.53 nmol/L, $t(233)$ = −2.802, p = .006, d = 0.31, 95% CI = [0.09, 0.52], and DHEA-S, b = −156.85 pg/ml, $t(249)$ = −3.275, p = .001,

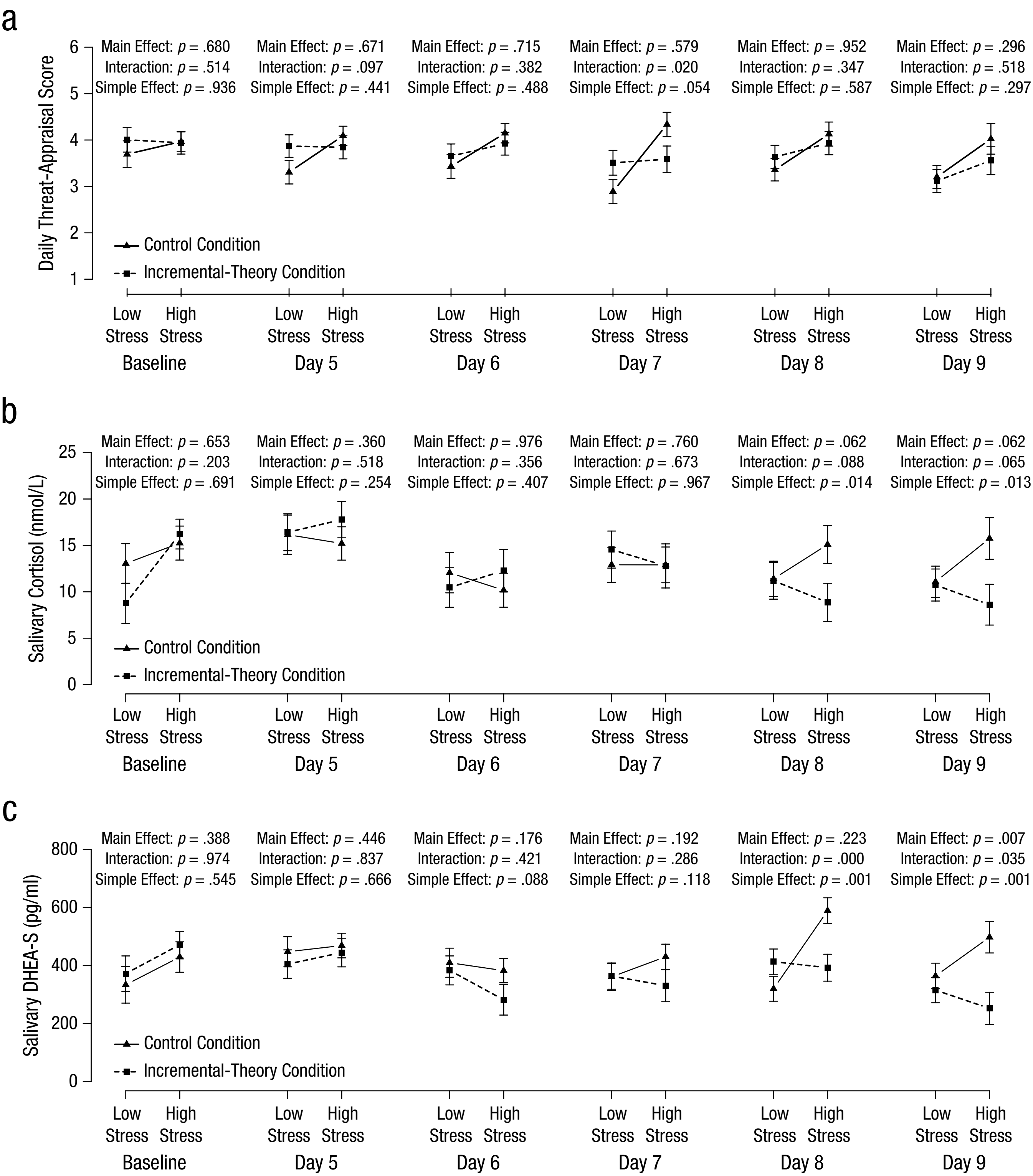

Fig. 3. Mean (a) daily threat-appraisal score, (b) salivary-cortisol level, and (c) salivary-dehydroepiandrosterone-sulfate (DHEA-S) level in Study 2 for participants in the control and incremental-theory conditions. Results are shown separately across all measurement occasions, for days on which participants reported low stress (1 *SD* below the mean) and high stress (1 *SD* above the mean) in a daily diary. Significance (*p*) values are shown for the main effect of condition, the Daily Stress × Condition interaction, and the simple effect of condition estimated at 1 standard deviation above the mean. Error bars show ±1 *SEM*.

Table 1. Results of the Models Predicting the Effect of Daily Stressors in Study 2

		Control condition			Intervention condition			Model-fit difference test		
Dependent variable	*n*	β	*SE*	*p*	β	*SE*	*p*	$\Delta\chi^2$	Δdf	*p*
Threat appraisal (Days 5–9)	319	0.329	0.110	.003	−0.034	0.103	.738	6.577	1	.010
Cortisol (Days 5–9)	192	−0.078	0.198	.694	−0.274	0.204	.178	0.390	1	.532
DHEA-S (Days 5–9)	192	0.104	0.229	.649	−0.124	0.190	.514	0.591	1	.442
HPA axis (Days 5–9)	192	0.093	0.201	.643	−0.190	0.189	.313	1.038	1	.308
Threat appraisal (Days 8 and 9)	319	0.394	0.135	.003	−0.271	−0.141	.054	11.941	1	.0005
Cortisol (Days 8 and 9)	181	0.591	0.269	.028	−0.415	0.298	.165	6.542	1	.011
DHEA-S (Days 8 and 9)	184	0.584	0.279	.036	−0.199	0.243	.412	4.390	1	.036
HPA axis (Days 8 and 9)	184	0.675	0.231	.003	−0.326	0.243	.180	8.688	1	.003

Note: Covariates in this model included gender, baseline daily stressor, prior academic performance, baseline hormone levels, day of the week, and time of day. DHEA-S = dehydroepiandrosterone sulfate, HPA = hypothalamus-adrenal-pituitary.

d = 0.36, 95% CI = [0.14, 0.58], on high-stress days (1 *SD* above the mean) in Days 8 and 9. Therefore, this analysis supported the hypothesized Daily Stress × Condition interaction on the final 2 of the 5 postmanipulation days—the 2 on which the expected associations of daily stress and HPA-axis activation were present in the control condition.

Finally, on Days 8 and 9, there was a main effect of the incremental-theory intervention on cortisol and DHEA-S; cortisol was lower for intervention participants (*M* = 9.22, *SD* = 5.02) than for control participants (*M* = 10.21, *SD* = 5.38), $t(233) = -2.10$, $p = .037$, $d = 0.19$, 95% CI = [0.01, 0.41], and this same pattern was found for DHEA-S (control: *M* = 381.65, *SD* = 287.12; intervention: *M* = 348.78, *SD* = 289.44), $t(249) = -2.17$, $p = .032$, $d = 0.11$, 95% CI = [0.02, 0.42]. However, there was no main effect for all postmanipulation days (5–9), *t*s < 1 (see the Supplemental Material and Fig. 3).

Discussion

The present research integrated the biopsychosocial model of challenge and threat with implicit theories of personality to show how beliefs can affect situation-specific appraisals and regulate responses to social stressors. Participants who were taught an incremental theory of personality—the belief that people have the potential to change—exhibited improved cognitive, physiological (neuroendocrine and cardiovascular), and behavioral (task performance) responses to acute social stress compared with control participants (Study 1). In Study 2, we extended these findings by demonstrating that an incremental-theory-of-personality intervention, delivered once in ninth-grade classrooms, reduced HPA-axis activation (measured using cortisol and DHEA-S) a week later, especially on high-stress days, while improving grades 7 months later. Now that these two formal models have been empirically integrated, they provide a basis for novel predictions and a more holistic picture of adolescent stress processes.

The present research also helped disambiguate why the socially oriented implicit-theory-of-personality intervention—in which motivation to learn in school was never mentioned—could affect academic performance many months later. Previous research tested for, but did not consistently find, mediation of implicit-theory-of-personality effects on grades via self-reported responses to Cyberball ostracism (Yeager, Johnson, et al., 2014). Yet we found that being exposed to an incremental theory of personality reduced threat-type reactions known to compromise cognitive performance, both in the short term (Study 1) and chronically (Study 2), and these reductions mediated effects on performance (Study 1). In the real-world context of high school, adolescents may struggle with making friends, feel excluded or left out by peers, encounter direct victimization, or face myriad other normal evaluative experiences. Yet when adolescents come to view social difficulties as events that can be overcome, they may appraise them as challenges. Such appraisals could cause them to exhibit more adaptive coping and perhaps even come to develop closer relationships—thus setting in motion a positive recursive process that gains strength through its repetition (Aronson et al., 2002; Wilson & Linville, 1982; Walton & Cohen, 2011; Yeager & Dweck, 2012).

A potential limitation of this research involves the unexpected finding that in the control condition in Study 2, daily stressors did not predict adrenal-hormone responses until Days 8 and 9 after intervention. However, the data observed in Study 2—combined with the strong evidence in Study 1—suggest that HPA-axis effects were not spurious. First, intervention effects for self-reported appraisals were found for all postmanipulation days. Second, the incremental-theory manipulation improved grades up to 7 months after intervention. Third, the two different adrenal hormones showed highly parallel findings on Days 8 and 9.

What accounted for this unexpected finding? Negative affect exhibits lagged effects on consequences of threat-typed stress responses, such as academic achievement (Flook & Fuligni, 2008), or pain and gastrointestinal symptoms (Charles & Almeida, 2006). Repeated failures to return to homeostasis from prior threat reactions may accumulate to more maladaptive responses to subsequent stressors (e.g., McEwen, 2006). Indeed, in our study, the first postmanipulation day on which there was an independently significant intervention effect on threat appraisals was Day 7 (see Fig. 3). Neuroendocrine effects on Days 8 and 9 may well be indicative of control participants' failure to return to homeostasis.

Finally, the present studies may have public health implications and contribute to improving adolescents' stress responses with efficiency at scale, because the incremental-theory intervention can be delivered directly to students with no specialized staff training. At the same time, it will be important to avoid platitudes such as simply telling adolescents that "people can change" (Yeager & Dweck, 2012). A high priority is to develop more comprehensive methods to help instantiate an incremental theory. A related priority is to reduce the prevalence of negative evaluative experiences (such as bullying) so that adolescents have fewer stressors to contend with in the first place.

Action Editor

Gretchen Chapman served as action editor for this manuscript.

Author Contributions

D. S. Yeager and J. P. Jamieson conceived the research and designed the experimental materials and procedures. H. Y. Lee collected data and modified study procedures. All authors analyzed the data. H. Y. Lee created all figures and the table and ran all supplementary analyses. D. S. Yeager drafted and finalized the manuscript, and H. Y. Lee and J. P. Jamieson provided critical edits and authored original text.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at http://pss.sagepub.com/content/by/supplemental-data

Open Practices

All data have been made publicly available via the Open Science Framework and can be accessed at https://osf.io/sgwv6/. The hypotheses and data-analysis plan for Study 2 were preregistered at Open Science Framework (https://osf.io/ufamv/). The complete Open Practices Disclosure for this article can be found at http://pss.sagepub.com/content/by/supplemental-data. This article has received the badges for Open Data and Preregistration. More information about the Open Practices badges can be found at https://osf.io/tvyxz/wiki/1.%20View%20the%20Badges/ and http://pss.sagepub.com/content/25/1/3.full.

Notes

1. In this article, all reported means and standard deviations are from the raw data, all statistical tests are from covariate-adjusted models, and all effect sizes were calculated from those statistical tests. Grade level and gender did not interact with these or any other results and so are not considered further.

2. At the request of our funder, brief expressive-writing and control manipulations, fully crossed with the incremental-theory intervention, was delivered 2 days after the experimental manipulation. This was not expected to have effects on the outcomes investigated here and was included only for exploratory purposes; this expectation of a null effect was preregistered before we collected any data (https://osf.io/6axwy/). Indeed, none of the findings reported here interacted with this second manipulation nor were they affected by inclusion of that variable in statistical models.

3. In Study 2, degrees of freedom for mixed-effects models were estimated using the lmerTest package in R (Kuznetsova, Brockhoff, & Christensen, 2015).

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