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How trauma influences cardiovascular responses to stress: contributions of posttraumatic stress and cognitive appraisals

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Abstract Mechanisms for the association between posttraumatic stress disorder (PTSD) symptoms and cardiovascular diseases remain poorly understood. The present study examined associations among PTSD symptoms, appraisals of a current stressor, baseline cardiovascular indices, and cardiovascular responses to the stressor, including appraisals as a potential mediator of PTSD symptoms and cardiovascular responses. A sample of 125 undergraduates provided information about demographics, physical health, trauma history, and PTSD symptoms. Weight, height, blood pressure (BP), and heart rate (HR) measurements were obtained. During a modified Trier Social Stress Task, appraisals of the stressor were assessed and BP and HR were measured again. Findings suggest that PTSD symptoms are associated with current physical health (resting BP and HR) and more negative appraisals of the stressor; in turn, more negative appraisals were associated with increases in cardiovascular response. In particular, threat appraisal mediated the relationship between PTSD symptoms and increases in systolic BP response.

Keywords Trauma · PTSD · Cognitive appraisal · Blood pressure · Heart rate

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Introduction

Posttraumatic stress disorder (PTSD) symptoms resulting from trauma exposure have been strongly implicated as a risk factor for the development of cardiovascular diseases and related risk factors such as hypertension (Edmondson et al., 2018). Individuals with higher PTSD symptoms have higher prevalence rates of cardiovascular problems and diseases compared to those with lower PTSD symptoms, which has been demonstrated in studies assessing PTSD symptomatology with self-reported screeners (e.g., Jordan et al., 2011; Schnurr et al., 2000) and diagnostic interviews (e.g., Kibler et al., 2009). Evidence for the association between PTSD symptoms and cardiovascular problems and diseases has been found in samples characterized by trauma exposure type such as veterans and sexual assault survivors, as well as community women who have experienced a variety of traumas (Kubzansky et al., 2009). While research has yet to demonstrate that PTSD symptoms in early life increase risk for the development of cardiovascular disease, longitudinal research has found support for relationships between PTSD symptoms in young adulthood and cardiovascular risk factors like higher body mass index (BMI) in later adulthood (Francis et al., 2015).

However, the mechanisms underlying the association between PTSD symptoms and cardiovascular problems and diseases remain poorly identified. Recent research suggests that PTSD symptoms can lead to dysregulated cardiovascular responses to stressors, a risk factor for increasing susceptibility to cardiovascular problems and diseases (Chida & Steptoe, 2010). Individuals with PTSD symptoms demonstrate greater increases in heart rate (HR) and blood pressure (BP) (exaggerated responses) compared to healthy controls in response to stressors (Pole, 2007). One potentially important but understudied factor that may account for this link between PTSD symptoms and exaggerated cardiovascular responses to a stressor is *cognitive stress appraisal*, an individual's understanding of whether and how an encounter is relevant to his or her well-being (Folkman et al., 1986).

Individuals evaluate or appraise multiple aspects of a potentially stressful situation, including its stressfulness, its importance for their identity or well-being (centrality), opportunities for growth and gain (challenge) or harm and loss (threat), and its controllability (by themselves, specified others, or anyone) (Peacock & Wong, 1990). These cognitive stress appraisals are strongly related to effectively coping with and adjusting to many situations (Park, 2006, Riley & Park, 2014), and thus, may be a key way that trauma carries forward to influence cardiovascular responses to subsequent stressors.

Effects of PTSD symptoms on cognitive stress appraisals

To date, most of the research on appraisals in the context of trauma has focused on appraisals of the index trauma rather than appraisals of subsequent stressors. Consistent with the cognitive theory of PTSD (Ehlers & Clark, 2000), which posits that continued negative appraisals of the index trauma maintain PTSD symptoms, studies consistently find that PTSD symptoms are positively associated with appraisals of the index trauma as more threatening (Franz et al., 2013) and central to identity (Berntsen & Rubin, 2006). PTSD symptoms are also associated with negative appraisals of trauma-related stimuli, such that people with higher PTSD symptoms appraise trauma-related cues as more stressful and threatening (Regehr et al., 2007). Associative learning in PTSD may also play a role in the generalization of fear responses to subsequent stressors and stimuli that resemble the original trauma (e.g., Suendermann et al., 2010). A less-examined assumption is that individuals may generalize their stress responses, shaped by past traumatic experiences, to current stressors through their *cognitive stress appraisals* (Brewin et al., 1996; Ehlers & Clark, 2000; Foa et al. 1989). That is, prior trauma may also lead to more negative appraisals of subsequent events following the index trauma. For example, a study of residents affected by Hurricane Hugo found that those with a prior trauma history appraised their current post-disaster situation as more stressful compared to those without a trauma history (Norris & Kaniasty, 1992).

It is possible that trauma history also negatively impacts appraisals of lower magnitude stressors encountered frequently in everyday life, such as psychosocial stressors; however, few studies have tested relationships between past trauma and appraisals of subsequent psychosocial stressors. A study of World War II male veterans found neither combat exposure nor PTSD status was associated with differences in appraisals of the meaningfulness, controllability, predictability, or stressfulness of a current stressor (e.g., illness of spouse) (Fairbank et al. 1991). In contrast, another study found past trauma was related to negative self-appraisals in response to subsequent psychosocial stressors; women with a history of sexual assault appraised lower coping self-efficacy in response to potential interpersonal threats, hassles, and coercive encounters compared to women without a trauma history (Ozer & Bandura, 1990). Given the limited research, the influence of trauma history on appraisals of subsequent psychosocial stressors remains unclear and may depend on the types of appraisals and populations studied.

Cognitive stress appraisals and cardiovascular responses

Cognitive stress appraisals may, in turn, predict cardiovascular responses to subsequent stressors. Consistent with this idea, studies have demonstrated that subjective appraisals of stressors correspond with cardiovascular responses as measured by systolic blood pressure (SBP), diastolic blood pressure (DBP), and HR. Generally, studies using laboratory-based stressors have found stressfulness, challenge, and threat appraisals to correspond with changes in SBP, DBP, and HR (Blascovich, 2008; Seery et al., 2013). Most studies have found that appraisals of higher threat and higher stressfulness correspond with greater increases in these cardiovascular responses to a stressor (e.g., Feldman et al., 2004; Lepore et al., 1993; Maier et al., 2003), with some exceptions (e.g., O'Connor et al. 2017). However, results have been more mixed regarding the direction of the relationship between challenge appraisals and cardiovascular responses: Some have found challenge appraisals were associated with a *greater* increase in HR in response to a stressor compared to threat appraisals (Tomaka et al., 1993, 1997), while others have found that challenge appraisals were associated with *less of an increase* in HR (Williams et al., 2017). Most of this literature has focused on appraisals of challenge, threat, or stressfulness, while the correspondence between other types of appraisal (e.g., controllability, centrality) and cardiovascular responses has been virtually unstudied.

Appraisals as a link between PTSD symptoms and cardiovascular responses

Cognitive stress appraisals may not only correspond with cardiovascular responses to stressors, but may also partly explain the link between PTSD symptoms and dysregulated cardiovascular responses. Appraisals may be one way by which PTSD symptoms translate into heightened responding to subsequent stressors. One study of combat veterans tested this model and found evidence of a mediating effect of perceived coping ability in the relationship between PTSD symptom severity and slower HR recovery in response to an acoustic startle task (Kibler & Lyons, 2004). Building upon this finding, a more recent study of trauma-exposed civilian women found that higher levels of PTSD symptoms and threat appraisal contributed to less cardiovascular recovery in response to a public speaking task (Kibler, 2018). However, it remains unknown how PTSD symptoms relate to other types of appraisals of the task and how those appraisals in turn correspond with cardiovascular responses.

Additionally, the literature lacks developmental perspectives on the relationships among PTSD symptoms, cognitive stress appraisals, and cardiovascular responses. Studies relating PTSD symptoms to CVD risk factors have primarily used middle-aged and older adult samples. To date, no studies have examined whether relationships between PTSD symptoms, cognitive stress appraisals, and cardiovascular responses are evident as early as young adulthood. Such information would have valuable clinical implications for CVD prevention, suggesting that the association between PTSD symptoms and cardiovascular risk factors can be detected early.

The present study

The present study examined the association between self-reported PTSD symptoms and a baseline cardiovascular health profile, the effects of PTSD symptoms on appraisals of current stressors, the correspondence between appraisals and cardiovascular responses, and the potential mediating role of appraisals in the relationship between PTSD symptoms and cardiovascular responses. Prior studies have focused on the influence of PTSD symptoms on appraisals of trauma-related cues (e.g., trauma recall task) or physiological stressors (e.g., startle task). Given the present study's focus on circumstances that resemble everyday low-grade stressors, the anticipation phase of the Trier Social Stress Task (TSST) (Kirschbaum et al., 1993) was used as the laboratory-based stress induction. To further address gaps in the literature about whether PTSD symptoms pose a detectable risk to cardiovascular health in early adulthood, the present study used a sample of undergraduate students.

The following hypotheses were tested: **H1:** Higher PTSD symptom severity will be associated with greater cardiovascular health risk at baseline (higher resting SBP, DBP, and HR). **H2:** Higher PTSD symptom severity will be associated with more negative appraisals of the stressor (less controllable by others, less controllable by self, more uncontrollable by anyone, more central to identity, more stressful, more threatening, less challenging). **H3:** Appraisals of the stressor as more threatening and more stressful will be related to greater increases in SBP, DBP, and HR in response to the stress induction. **H4 (exploratory):** Due to a lack of literature to inform hypothesis-testing, relationships between the following appraisals and cardiovascular responses will be explored: controllable by others, controllable by self, uncontrollable by anyone, centrality, and challenge. **H5**: Stressfulness and threat appraisals will mediate the relationship between PTSD symptoms and increases in SBP, DBP and HR in response to the stress induction.

Method

Participants

A convenience sample of 136 undergraduates was recruited through the Department of Psychological Sciences participant pool at a large Northeastern university, where approval was acquired and study procedures were followed in accordance with the Institutional Review Board. All undergraduates in the participant pool completed an initial screening survey to determine the studies for which they were eligible; those who self-reported that they had a major medical condition (e.g., cancer), currently smoked, or took medication known to affect BP (e.g., antihypertensives) were ineligible to participate in the present study, as these factors introduce artifacts into BP and HR measurements. To further limit potential artifacts, eligible participants were instructed to refrain from exercise and caffeinated or alcoholic beverages for at least 6 h prior to appointments. Each participant came into the laboratory for a one-time 40-min session during which they completed the Time 1 (baseline) and Time 2 (stressor) procedures.

Procedure

Time 1

Informed consent was obtained from all individual participants who met the study inclusion criteria. Each participant completed the Time 1 survey, which included the demographic form, physical health survey (e.g., list of medications, medical conditions), Trauma History Questionnaire (THQ; Hooper et al., 2011), and PTSD Checklist for Diagnostic and Statistical Manual 5 (PCL-5; Weathers et al., 2013). After 20 min of remaining seated, Time 1 resting BP and HR readings were obtained followed by weight and height measurements.

Time 2

Next, the experimenter used deception by informing participants that they would be randomly assigned to either the control (no task) or experimental (task) condition even though no participants were assigned to the experimental condition. Participants were led to believe that those in the control condition would not perform the task, while those in the experimental condition would take on the role of a job applicant interviewing with a company's managers and present a 5-min speech that would be recorded and watched for nonverbal behavior analysis. These procedures are modified from the TSST. All participants were asked to prepare for the speech before learning to which condition they were assigned. At the beginning of the 10-min preparation period, participants completed the Time 2 measures, which included Time 2 BP and HR response readings followed by the Stress Appraisal Measure (SAM) (Peacock & Wong, 1990). Afterwards, all participants were informed they were assigned to the control condition. Prior research demonstrates that anticipation of the speech task elicits a heightened physiological response comparable to the response produced while performing the task as well as higher threat appraisal when compared to a control condition (Feldman et al., 2004; Fredrickson et al., 2000). At the end of sessions, all participants were debriefed about the purpose of the study and provided with a list of mental health resources (e.g., counseling centers, hotlines).

Measures

Demographics

Participants reported gender, age, racial and ethnic background, and parental education.

Trauma exposure

The THQ assessed the traumas experienced. The THQ consists of 24 forced-choice yes/no questions regarding the occurrence of different traumatic events (e.g., "Have you ever seen someone seriously injured or killed?"). The THQ demonstrates good reliability and validity among clinical and nonclinical samples (Hooper et al., 2011). The THQ was developed using a college sample and has been validated on college-aged samples that experienced trauma (Green et al., 2000, 2005).

PTSD symptoms

The PCL-5 assessed current self-reported PTSD symptoms related to exposure to the "worst event" endorsed on the THQ. The PCL-5 has 20 items (e.g., "Feeling jumpy or easily started") rated on a scale from 0 (not at all) to 4 (extremely), with higher sum scores indicating higher PTSD symptom severity. The PCL has demonstrated adequate internal and test–retest reliability in trauma-exposed college students (Ruggiero et al., 2003). In the present study, Cronbach's alpha was .95.

Body mass index

BMI was calculated after obtaining height (m) and weight (kg) using a professional scale (Health-o-meter 597KL, Pelstar, Bridgeville, IL). Height was measured to the nearest .10 cm and weight was measured to the nearest .10 kg. To account for the effects of BMI on cardiovascular responses, in that BMI is sometimes positively correlated with BP and HR responses (e.g., Steptoe & Wardle, 2005), BMI was entered as a covariate in analyses predicting both resting and changes in BP and HR.

Blood pressure and heart rate

SBP, DBP, and HR were measured at Time 1 and Time 2 using a noninvasive automated BP and HR monitor (Omron HEM-711 automatic deluxe BP monitor, Omron Healthcare, Inc., Bannockburn, IL). The protocol for BP and HR measurement recommended by the American Heart Association (Pickering et al., 2005) was followed. For Time 1, BP was measured twice per arm using the same monitor, with measurements alternating between arms and with 1 min of rest in between measurements. If the two readings for the SBP or DBP of an arm varied by more than 5 mmHg, additional measurements were taken until three readings within 5 mmHg were obtained for both SBP and DBP. The two measurements within the same arm with the smallest difference were averaged to calculate both Time 1 SBP and Time 1 DBP. The two HR measurements that corresponded with the two SBP and DBP measurements were also averaged. For Time 2, SBP, DBP, and HR were measured using the same arm from which Time 1 SBP, DBP, and HR were measured following the same protocol.

Cognitive stress appraisals

The seven subscales of the SAM assessed cognitive appraisals of the laboratory stressor. The SAM is intentionally designed to assess appraisals of an anticipatory stressor. Each subscale has four items rated on a 5-point scale from 1 (not at all) to 5 (extremely): Threat (e.g., "Is this going to have a negative impact on me?"), Challenge (e.g., "How eager am I to tackle this problem?"), Centrality (e.g., “Does this situation have important consequences for me?”), Controllable By Self (e.g., “Do I have the ability to do well in this situation?”), Controllable By Others (e.g., “Is there help available to me for dealing with this problem?”), Uncontrollable By Anyone (e.g., “Is the problem unresolvable by anyone?”), and Stressfulness (e.g., “Does this situation create tension in me?”). Subscale scores are the sum of item responses, with a higher subscale score indicating higher appraisal on that dimension. Cronbach’s alphas in the present study were similar to those reported in the original validation study of the SAM (Peacock & Wong, 1990): .80 for Threat, .74 for Challenge, .87 for Centrality, .90 for Controllable By Self, .89 for Controllable By Others, .69 for Uncontrollable By Anyone, and .76 for Stressfulness. The SAM demonstrates satisfactory internal consistency and convergent validity among undergraduates (Peacock & Wong, 1990).

Data analytic plan

A priori power analysis was performed using G*Power 3.1 to estimate sample size. Assuming an alpha value of .05, an effect size of .10 (to detect between a small and medium effect size; see Cohen, 1988), and power set at .80, the originally projected sample size needed for mediation analyses was 134. Given that PTSD symptoms are one of the variables of interest in the present study, only participants who endorsed experiencing at least one traumatic event in their lifetime were included in all analyses (n = 125). Visual inspection of Q–Q plots showed multivariate normality with no outliers for stress appraisals and cardiovascular responses. Shapiro–Wilk tests were not significant, demonstrating multivariate normality. Gender and BMI were tested as potential covariates for predicting the dependent variables (cognitive stress appraisals; resting and changes in SBP, DBP, and HR) using t-tests and bivariate correlations, and included in the models for testing H1–H5. To test H1–H4, hierarchical multiple regressions were conducted. To test H5, mediation analyses with 95% confidence intervals and 5000 bootstrap samples were conducted using the PROCESS macro for SPSS (Hayes, 2012). For testing H3–H5, resting BP or HR was also entered as a covariate due to the differential impact of resting BP and HR on the amount of stress-induced BP and HR change (Nestel, 1969); furthermore, controlling for baseline levels when predicting difference scores is recommended (e.g., Allison, 1990). Compared to Sobel’s test, bootstrapped confidence intervals are less biased for examining the significance of indirect paths (Preacher & Hayes, 2008). Appraisals of stressfulness and threat were considered significant mediators if the 95% confidence intervals for the indirect effect did not include zero.

Results

Sample characteristics

On average, participants were 19.16 years old (SD = 1.25) with a BMI of 23.71 (SD = 4.25). The racial and ethnic breakdown was 49.6% White, 24.8% Asian, 12.0% Hispanic/Latino, 5.6% Black/African-American, 7.2% bi-racial or multi-racial, .8% other, 0% American Indian/Alaskan Native, and 0% Native Hawaiian/Pacific Islander. Over half of participants (56.0%) had at least one parent with a bachelor’s degree or beyond. Descriptive statistics and bivariate correlations of key study variables are presented in Table 1. The average participant reported experiencing between three and four traumatic events (M = 3.77, SD = 3.46; range = 1–22). Table 2 presents the prevalence rates of different trauma types. The most common traumas experienced by the sample were injury, illness, or death of someone close, accidents, and witnessing death or injury. Of the sample, 18.4% would be recommended for further assessment of a possible PTSD diagnosis using the recommended cut-score of 33 on the PCL-5 (Bovin et al. 2015). There were no differences in PTSD symptoms based on gender.

The sample appraised the modified TSST as, on average, slightly threatening, central to identity, and uncontrollable by anyone; between slightly and moderately stressful, challenging, and controllable by others; and between moderately and considerably controllable by self. On average, men appraised the stressor as more of a challenge (M = 2.66, SD = .85) than did women (M = 2.34, SD = .84), $t(123) = 2.09$, $p < .05$. Women appraised the stressor as more of a threat (M = 1.87, SD = .78) than did men (M = 1.60, SD = .65), $t(123) = -2.03$, $p < .05$. Higher BMI was associated with appraisals of the stressor as more controllable by self, less stressful, less threatening, and less uncontrollable by anyone. Further analyses revealed that the associations between higher BMI and more adaptive appraisals remained after controlling for gender.

On average, participants had baseline cardiovascular indices and BMI within normal range. Average resting SBP (M = 109.53, SD = 10.67), DBP (M = 64.71, SD = 6.74) and HR (M = 73.77, SD = 13.20) were within normal range according to guidelines of the American College of Cardiology and American Heart Association (Whelton et al., 2017). Average BMI (M = 23.71, SD = 4.25) was also considered within normal range according to the National Institutes of Health (National Heart, Lung, and Blood Institute, 1998). Differences in baseline cardiovascular indices emerged based on gender and BMI. Higher BMI was associated with higher resting SBP, but lower resting HR. Men had higher resting SBP (M = 117.04,

Table 1 Key variable descriptive statistics

Variable	Range	*M (SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13
1. PTSD symptoms	0–76	17.59 (17.41)	1												
2. Time 1 SBP	87.5–143	109.53 (10.67)	.09	1											
3. Time 1 DBP	50.5–87.5	64.71 (6.74)	.30**	.52**	1										
4. Time 1 HR	50.5–127	73.77 (13.20)	.27**	.04	.43**	1									
5. Threat appraisal	1–4.5	1.76 (.74)	.18*	− .23**	− .05	− .01	1								
6. Challenge appraisal	1–5	2.47 (.86)	.08	.19*	.14	.10	− .04	1							
7. Centrality appraisal	1–4.5	1.58 (.81)	.11	.00	.08	.05	.47**	.43**	1						
8. Controllable by self appraisal	1.5–5	3.84 (.87)	− .17	.13	.02	− .12	− .43**	.41**	− .06	1					
9. Controllable by others appraisal	1–5	2.73 (1.11)	− .28**	− .07	− .05	.02	− .03	.21*	.12	.30**	1				
10. Uncontrollable by anyone appraisal	1–4	1.65 (.71)	.24**	− .07	.01	.05	.48**	− .04	.15	− .34**	− .12	1			
11. Stressfulness appraisal	1–4.5	2.29 (.78)	.22*	− .07	.04	− .06	.80**	− .04	.33**	− .38**	− .07	.50**	1		
12. SBP Change	− 20.5 to 30.5	4.95 (9.07)	− .11	− .04	− .01	− .11	.20*	.14	.17	− .08	− .04	.11	.20*	1	
13. DBP change	− 12.5 to 15.5	2.27 (5.30)	− .12	− .06	− .21*	− .14	.04	.02	.06	− .11	− .03	.11	.08	.33**	1
14. HR change	− 21 to 22	1.22 (5.41)	− .10	.001	− .02	− .25**	.11	− .05	.06	.04	.01	.10	.16	.07	.35**

PTSD posttraumatic stress disorder, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *HR* heart rate

$^{*}p < .05$; $^{**}p < .01$

SD = 10.40) than did women (*M* = 104.63, *SD* = 7.57), $t(80.73) = 7.20$, $p < .001$. Paired *t*-tests revealed significant differences between Time 1 SBP and Time 2 SBP (difference: *M* = 4.95, *SD* = 9.07), $t(123) = -6.08$, $p < .001$; between Time 1 DBP and Time 2 DBP (difference: *M* = 2.27, *SD* = 5.30), $t(123) = -4.77$, $p < .001$; and between Time 1 HR and Time 2 HR (difference: *M* = 1.22, *SD* = 5.41), $t(123) = -2.51$, $p < .05$. There were no differences in cardiovascular responses based on gender or BMI. Resting DBP significantly correlated with DBP Change ($r = -.21$, $p < .05$), and resting HR significantly correlated with HR Change ($r = -.25$, $p < .01$).

Trauma and baseline cardiovascular indices (H1)

H1 was supported in that higher PTSD symptom severity was associated with higher resting DBP and higher resting HR. Controlling for gender and BMI, individuals with higher PTSD symptom severity had higher resting DBP ($B = .12$, $SE = .03$, $p < .001$; $R^2 = .09$, $F(3, 118) = 4.07$, $p < .01$) and higher resting HR ($B = .20$, $SE = .07$, $p < .01$; $R^2 = .12$, $F(3, 118) = 5.46$, $p < .01$). Additional analyses were conducted to further examine the magnitude of difference in resting BP and HR between individuals with lower (PCL score < 33) and higher (PCL score ≥ 33) PTSD symptom severity. *T*-tests indicated that individuals with higher PTSD symptoms had higher resting DBP by an average of 4.07 mmHg (*M* = 68.02, *SD* = 8.07 vs. *M* = 63.95, *SD* = 6.20), $t(122) = -2.68$, $p < .01$, and

Table 2 Prevalence of trauma types

Type	Prevalence (%)
1. Injury, illness, death (someone else)	66.9
2. Serious accident	33.6
3. Witnessed death or injury	32.8
4. Seen or handled dead bodies	26.4
5. Natural disaster	21.0
6. Other (e.g., childhood physical abuse)	18.2
7. Beaten, spanked, pushed	17.6
8. Robbed	16.8
9. Serious injury	15.3
10. Threat of death or injury	15.2
11. Mugged	14.4
12. Sexually touched against will	14.4
13. Serious illness (self)	12.0
14. Close friend or family killed	11.2
15. Home broken into (not there)	10.4
16. Home broken into (while there)	10.4
17. Other unwanted sexual contact	10.4
18. Sex against will	10.4
19. Man-made disaster	9.7
20. Attacked without weapon	7.2
21. Dangerous chemical exposure	7.2
22. Attacked with weapon	5.6
23. Combat	3.2
24. Spouse, partner, or child died	.8

Table 3 Threat appraisal predicting systolic blood pressure change

Predictors	Systolic Blood Pressure Change				
	B (*SE*)	β	*t*	*p*	Adj. R^2
Step 1					.005
Intercept	20.70 (11.24)†		1.84	.07	
Time 1 SBP	− .11 (.10)	− .13	− 1.08	.28	
Gender	− 3.88 (2.06)†	− .21	− 1.88	.06	
BMI	− .07 (.22)	− .03	− .31	.75	
Step 2					.04
Intercept	12.14 (11.64)		1.04	.30	
Time 1 SBP	− .09 (.10)	− .10	− .89	.37	
Gender	− 4.11 (2.03)*	− .22	− 2.03	.04	
BMI	.01 (.22)	.01	.06	.95	
Threat appraisal	2.61 (1.13)*	.21	2.31	.02	

Step 1: $F(3, 118) = 1.20$

Step 2: $F(4, 117) = 2.27^{\dagger}$

BMI body mass index, *SBP* systolic blood pressure

†$p < .10$; *$p < .05$

higher resting HR by an average of 8.95 beats per minute ($M = 81.07$, $SD = 15.23$ vs. $M = 72.11$, $SD = 12.17$), $t(122) = -3.03$, $p < .01$. To account for the effects of gender and BMI, general linear models were also computed with PTSD symptom severity as a dichotomous variable predicting resting DBP and resting HR. For resting DBP, there was a significant difference between individuals with high and low PTSD symptoms, $F(1, 118) = 6.98$, $p < .01$; gender and BMI were not significant covariates. For resting HR, there was a significant difference between individuals with high and low PTSD symptoms, $F(1, 118) = 10.36$, $p < .01$; BMI was also a significant covariate, $F(1, 118) = 4.11$, $p < .05$.

Trauma and cognitive stress appraisals (H2)

H2 was mostly supported in that higher PTSD symptoms were associated with more negative appraisals, with the exception of centrality, challenge, and controllable by self. Individuals with higher PTSD symptoms appraised the stressor as less controllable by others ($B = -.02$, $SE = .01$, $p < .01$; $R^2 = .09$, $F(3, 117) = 3.80$, $p < .05$), more stressful ($B = .01$, $SE = .004$, $p < .05$; $R^2 = .08$, $F(3, 117) = 3.73$, $p < .05$), and more uncontrollable by anyone ($B = .01$, $SE = .003$, $p < .01$; $R^2 = .18$, $F(3, 119) = 8.78$, $p < .001$). The association between PTSD symptoms and threat appraisal was also marginally significant ($B = .01$, $SE = .004$, $p = .06$; $R^2 = .10$, $F(3, 119) = 4.37$, $p < .01$). BMI was a significant covariate in predicting appraisals of stressfulness ($B = -.04$, $SE = .02$, $p < .05$), uncontrollable by anyone ($B = -.06$, $SE = .01$, $p < .001$), and threat ($B = -.04$, $SE = .02$, $p < .05$). Gender was not a significant covariate.

Cognitive stress appraisals and cardiovascular responses (H3, H4)

Hierarchical regression models of stressfulness appraisal predicting cardiovascular responses and threat appraisal predicting cardiovascular responses were conducted. As presented in Table 3, individuals who appraised the stressor as more threatening demonstrated a greater increase in SBP response. However, threat appraisal did not predict DBP or HR responses. Additionally, stressfulness appraisal did not predict SBP, DBP, or HR responses. Therefore, H3 was partially supported. Contrary to exploratory H4, no evidence of relationships between other types of appraisals and cardiovascular responses was found.

Closer examination of the BP and HR responses to the stressor revealed that some individuals had an increase, while others had a decrease (see range of SBP Change, DBP Change, and HR Change in Table 1). *T*-tests and Chi square tests revealed no significant differences between individuals who had positive and negative scores for SBP Change, DBP Change, and HR Change based on demographic variables or BMI. However, individuals who had positive and negative scores for SBP Change and DBP Change differed on appraisals. For SBP Change, individuals with negative scores, compared to individuals with positive scores, rated the stressor as less central ($M = 1.33$, $SD = .61$ vs. $M = 1.65$, $SD = .85$; $t(57.03) = -2.13$, $p < .05$), more controllable by others ($M = 3.22$, $SD = 1.26$ vs. $M = 2.67$, $SD = 1.06$; $t(108) = 2.18$, $p < .05$), less stressful (M = 1.94, SD = .65 vs. M = 2.38, SD = .74; $t(108) = -2.67$, $p < .01$), and less threatening (M = 1.50, SD = .50 vs. M = 1.82, SD = .78; $t(110) = -1.99$, $p < .05$). For DBP Change, individuals with negative scores, compared to individuals with positive scores, rated the stressor as more controllable by self (M = 4.21, SD = .68 vs. M = 3.67, SD = .88; $t(106) = 3.23$, $p < .01$) and less uncontrollable by anyone (M = 1.40, SD = .47 vs. M = 1.71, SD = .78; $t(100.91) = -2.56$, $p < .05$).

Cognitive stress appraisals as mediators (H5)

Based on the relationships found between PTSD symptoms and appraisals, and between appraisals and cardiovascular responses, one mediation model was tested using PTSD symptoms as the independent variable, threat appraisal as the mediator, and SBP Change as the dependent variable. The model is depicted in Fig. 1. PTSD symptoms were positively associated with threat appraisal (B = .01, SE = .004, 95% CI = .001, .02, $p < .05$; $F(4, 117) = 3.69$, $R^2 = .11$, $p < .05$), and threat appraisal was positively associated with SBP Change when controlling for PTSD symptoms (B = 2.95, SE = 1.14, 95% CI = .68, 5.21, $p < .05$; $F(5, 116) = 1.77$, $R^2 = .09$, $p < .05$). There was no direct effect, but a significant indirect effect (B = .02, SE = .02, 95% CI = .002, .07), demonstrating a mediating effect of threat appraisal. The total effect was nonsignificant, consistent with indirect-only mediation (e.g., MacKinnon et al., 2007; Zhao et al., 2010). Given that a significant mediating effect was detected, H5 was partially supported.

Discussion

The present study contributes to the literature on the effects of PTSD symptomatology on developmental trajectories of cardiovascular problems and diseases by examining the relationships among PTSD symptoms, different types of cognitive stress appraisals, and cardiovascular responses in young adults. Of note, this is the first study to test these relationships using a standardized, non-trauma-related laboratory stressor that resembles common stressors

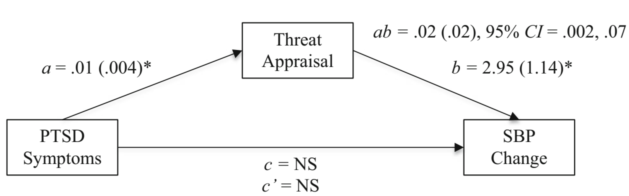

Fig. 1 Threat appraisal mediating associations between PTSD symptoms and SBP change. *Note PTSD* posttraumatic stress disorder, *SBP* systolic blood pressure, *NS* not significant. *$p < .05$

experienced by a college student population. One of the study's main findings is that individuals with higher PTSD symptoms had higher resting DBP and higher resting heart rate compared to individuals with lower PTSD symptoms. Individuals with higher PTSD symptoms had higher resting DBP by an average difference of 4.07 mmHg, a clinically meaningful difference in terms of increased cardiovascular disease incidence; an increase in resting DBP by 4.07 mmHg corresponds with a 10–20% increase in the incidence of coronary heart disease events (Law et al., 2009). Individuals with higher PTSD symptoms also had higher resting HR by an average of 8.95 beats per minute; this finding is suggestive of another clinically significant difference between individuals with higher and lower PTSD symptoms, considering that each 11-beats per minute increase in resting heart rate is associated with a 15% increase in risk of cardiovascular disease incidence (Ho et al., 2014). The findings from the present study about the positive associations that PTSD symptoms share with resting DBP and resting heart rate are consistent with extant literature regarding the association between PTSD symptomatology and cardiovascular risk (e.g., Sumner et al., 2016). Our findings extend the current literature base, which has mostly focused on adult samples of veterans and sexual assault survivors, by demonstrating that the link between PTSD and cardiovascular health risk is evident even among relatively healthy young adults.

Findings from this study provide preliminary evidence that the enduring effects of trauma may influence appraisals of subsequent stressors. Individuals with higher PTSD symptoms formed more negative appraisals of the laboratory stressor, suggesting that PTSD symptoms may be related to the ways in which individuals interpret subsequent non-trauma-related stressors. While prior studies have found that individuals with higher PTSD symptoms tend to perceive trauma-related laboratory stressors as more threatening (Regehr et al., 2007), it is interesting to note that these findings generalize to non-trauma-related psychosocial stressors. The present study's findings are also consistent with prior research demonstrating gender differences in appraisals (Rasmusson & Friedman, 2002), such that women appraised the laboratory stressor as more threatening. Further research should examine the extent to which gender socialization and biological differences explain women's heightened threat sensitivity to stressors in laboratory conditions. Positive associations were also found between BMI and adaptive appraisals of the stressor that were not explained by gender differences. One interpretation of this secondary finding is that individuals who are overweight might compensate for the negative consequences of weight stigma by increasing self-confidence and effort to achieve other goals (Puhl & Brownell, 2003).

Results from the present study regarding correspondence between appraisals and cardiovascular responses are consistent with previous research, which has found that appraisals of laboratory stressors as more threatening are related to greater BP increases (Feldman et al., 2004; Maier et al., 2003; Tomaka et al., 1993, 1997). Specifically, higher threat appraisal was associated with a greater increase in SBP response. These findings add to the mixed literature about which cardiovascular indices correspond with appraisals; however, one point of consistency between extant research and present findings is that threat appraisal, in particular, corresponds with cardiovascular responses.

One unexpected finding is that BP and HR decreased in response to the stressor for approximately 25% of participants. Typically, SBP, DBP, and HR increase following exposure to the TSST protocol (Kudielka et al., 2007). While research has demonstrated that individuals with childhood trauma may respond differently during the TSST (e.g., blunted reactivity; Gooding et al. 2016) than do healthy controls, no other studies of trauma-exposed individuals have reported *decreased* BP or HR in response to a stressor. Exploratory analyses in the present study indicated that individuals with decreased BP made more adaptive appraisals of the stressor compared to individuals with increased BP, anticipating the stressor to be more controllable, less stressful, and less threatening. These results suggest that the heterogeneity of cardiovascular responses to the stressor may be related to differences in appraisals. However, whether a decrease in BP in response to a stressor differs from blunted and exaggerated reactivity as a prognostic marker for cardiovascular diseases remains unknown. These findings highlight the importance of studying the heterogeneity of cardiovascular responses to a stressor.

Finally, the present study demonstrated support for threat appraisal as a mediator between PTSD symptoms and cardiovascular responses to subsequent low-grade stressors. The presence of an indirect effect of higher PTSD symptoms on greater cardiovascular responsivity that is mediated by higher threat appraisal suggests that PTSD symptoms influence appraisals of subsequent low-grade stressors, and that these appraisals correspond with greater responsivity. This is the first study to demonstrate this mediating relationship in a sample of young adults with diverse trauma histories. The size of the indirect effect suggests that threat appraisal plays a small role in explaining how PTSD symptoms affect stress-induced SBP Change. Therefore, other potential psychological and physiological mechanisms of action should be further examined. Moreover, the lack of direct effects of PTSD symptoms on *cardiovascular* responses to the stressor may be due to the overall normal physical health of the sample as well as the types of traumas experienced by the sample, many of which were indirect traumas (e.g., injury, illness, or death of someone else). It is possible that better physical health may protect against the effects of PTSD symptoms on cardiovascular responses and indirect traumas may have less of an effect on cardiovascular responses to a stressor.

Strengths and limitations

The present study has limitations to be addressed in subsequent research. For one, the sample comprised relatively physically healthy college students, thereby limiting the generalizability of findings to populations that are older and have significant health problems. It is also possible that a sample with more severe trauma history would have resulted in different findings, such as direct effects of PTSD symptom severity on cardiovascular responses, which have been found in studies with samples of combat veterans and sexual assault survivors (Beckman et al., 2002; Griffin, 2008). The use of self-reported PTSD symptoms is another limitation of our study. Additionally, data on the time since the index trauma was not collected, which likely affects PTSD symptom severity. Further, the use of the anticipation phase of the TSST, rather than the full protocol, may have limited the ability to detect larger effects with respect to appraisals and cardiovascular responses. Indeed, participants did not strongly endorse any of the appraisals, with the average participant rating the stressor as between slightly and moderately stressful. Given the nature of our stressor, some of the appraisal dimensions of the SAM may have been less relevant. For example, the modified TSST is a stressor that is not highly controllable by others. While our study did not include a measure of reported distress, controlling for baseline levels of distress in future studies would allow for interpretations of the independent role of appraisals that are not confounded by the contributions of negative affectivity.

Despite these limitations, the present study makes several contributions to the extant literature. The study expands upon the current knowledge base by examining different types of appraisals that have historically been ignored in the literature on appraisals and cardiovascular responses, such as centrality appraisals. Further, the study builds upon previous work regarding the effect of trauma on appraisals of trauma-related cues (e.g., reading scripts of the traumatic event) by exploring the ways in which PTSD symptoms are associated with appraisals of non-trauma-related stressors. Although limited for the aforementioned reasons, the use of the anticipation phase of the TSST as a stress induction has several advantages. The use of the same stressor across all participants allows for inferences about the influence of PTSD symptoms on the stress response that are not attributable to differences in stressors. Also, given that public speaking and social evaluation are common stressors for college students, the use of the modified TSST allows for ecologically valid inferences about how college students' trauma histories likely influence their appraisals of everyday stressors and how these appraisals correspond with cardiovascular responses. Finally, the anticipation phase of the TSST presents the methodological advantage over the full TSST protocol by eliminating vocalization as a potential artifact that contributes to increases in cardiovascular responses (Tomaka et al., 1994).

Future directions

The present study provides support for continuing this line of scientific inquiry into the ways in which past traumatic experiences carry forward to affect current physical health as well as appraisals of subsequent stressors. Future studies should prospectively examine whether psychological and physiological responses to subsequent stressors following trauma exposure mediate the relationship between trauma and risk for cardiovascular disease development. Such studies can utilize ecological momentary assessments to capture in-the-moment appraisals as well as BP and HR responses to stressors that are personally significant for an individual. A better understanding of how trauma can alter the stress response and how these responses compound over time to jeopardize long-term cardiovascular health may identify alterable mechanisms for disrupting the linkage between trauma and cardiovascular diseases.

Compliance with ethical standards

Conflict of interest All authors declare no conflict of interest.

Human and animal rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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