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Childhood Family Stress and Women's Health: Parasympathetic Activity as a Risk and Resiliency Factor

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Abstract

Childhood family stress (CFS) exacerbates risk for physical health problems across the lifespan. Health risks associated with CFS are particularly relevant for women who tend to endorse more CFS than men. Importantly, some evidence suggests that individuals may vary in their susceptibility to CFS. Parasympathetic activity, which helps to regulate automatic bodily activity (e.g., breathing, digestion), has been proposed to represent a marker of plasticity to environmental exposure. However, no research to date has tested whether parasympathetic activity may modulate the impact of early adversity on health. We examined whether parasympathetic activity would moderate the link between CFS and health complaints in a sample of 68 undergraduate women (*Mean age* = 19.44). Participants self-reported CFS and health complaints. Parasympathetic activity was indexed using high-frequency heart rate variability (HF-HRV) and was evaluated by measuring changes in HF-HRV in response to and following a laboratory-based stress induction. Multiple regression analyses indicated that CFS was significantly associated with more health complaints. Further, HF-HRV in response to stress and during recovery relative to baseline significantly moderated relationship between CFS and health complaints. Specifically, more CFS was significantly associated with more health complaints among women who showed mean or greater decreases in HF-HRV in response to stress. Additionally, lower levels of CFS were associated with fewer health complaints among women who showed mean or greater HF-HRV during recovery relative to baseline. Findings highlight the importance of parasympathetic activity in modulating stress-health links.

Keywords Childhood family stress · High-frequency heart rate variability · Women's health · Biological sensitivity to context · Diathesis stress

A wealth of research has converged on the notion that childhood experiences can lay the foundations for adult health and well-being. Substantial research to date has focused on understanding the role of adverse childhood experiences (ACE) in shaping socioemotional and adjustment outcomes. Individuals who have experienced greater levels of ACE display higher risks of developing mental and physical health problems, such as depression, anxiety, substance use disorder, cardiovascular and metabolic diseases (Monnat & Chandler, 2015; Petrucelli et al., 2019; Webster, 2022). Nevertheless, the focus on ACEs has been criticized because it comprises many different types of adverse exposures (e.g., single parenthood and maltreatment each represent ACEs), which makes it difficult to discern whether specific types of ACEs are particularly poignant for health and well-being (Lacey & Minnis, 2020). As such, extensive research adapted from work on ACEs has focused on characterizing childhood family stress (CFS; e.g., interparental conflict, child psychological and physical abuse, parent–child conflict, chaotic family environment, neglect) as a factor that may create susceptibility of adverse developmental

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outcomes (Repetti et al., 2002; Taylor et al., 2004). Indeed, a growing body of evidence suggests that CFS in particular may confer risk for poorer physical health across lifespan (Bauldry et al., 2012; Hager & Runtz, 2012; Kalmakis & Chandler, 2015; Monnat & Chandler, 2015). Specifically, higher CFS has been associated with greater health concerns and related functional impairments among adults (Bauldry et al., 2012; Hager & Runtz, 2012; Kalmakis & Chandler, 2015; Nelson et al., 2020).

Health risks associated with CFS may be especially relevant for research on contributors to women's health because women experience higher levels of CFS than men regardless of sociodemographic characteristics (e.g., age, ethnicity, education level, and family income; Hager & Runtz, 2012; Liu & Umberson, 2015). Delineating factors that may buffer against or exacerbate the CFS-related health risks may be critical to better understand and improve women's stress-related health outcomes. Some scholars have suggested that intrapersonal factors, such as physiological stress system activity, are associated with CFS (Beauchaine & Zalewski, 2016; Fox et al., 2019). Moreover, physiological stress system activity has been found to modulate individuals' susceptibility to the deleterious health consequences of CFS (Huffman et al.,; 2020; Peng et al., 2021). The current study aimed to investigate associations between CFS and women's health complaints, and whether physiological stress system activity would differentiate individuals' susceptibility to such health risks.

Parasympathetic nervous system (PNS) activity is thought to play a particularly critical role in shaping stress-health relations (Huss et al., 2009; Kolacz & Porges, 2018; Thayer et al., 2010). Studies have observed reduced PNS activity among individuals who suffer from pediatric migraine (Huss et al., 2009), chronic diffuse pain disorders (Kolacz & Porges, 2018), gastrointestinal disorders (Kolacz & Porges, 2018), and exhibit heightened risk for cardiovascular disease (Thayer et al., 2010). The PNS helps to modulate cardiac activity and, accordingly, is often assessed via high-frequency heart rate variability (HF-HRV) which captures variability in heart rates across the respiratory cycle (Beauchaine, 2001). When activated, the PNS helps to promote "rest and digest" functions, including slower heart rate, social engagement, and digestion. Correspondingly, when engaged, the PNS slows bodily functions to conserve energy needed for future stress management (Porges, 2007). Moreover, the PNS has been posited to exert emotion regulatory functions via the vagal nerve in the heart (Beauchaine, 2001; Porges, 2007; Thayer, 2000), and excessive decreases in PNS activity in response to stress have been found to confer emotion dysregulation (Beauchanine, 2001, 2015). Accordingly, HF-HRV is regarded as a transdiagnostic biomarker that may predict health and well-being and a physiological indicator of emotion regulation abilities, such that both resting levels of HF-HRV and changes in HF-HRV in response to stress (i.e., HF-HRV reactivity) have been tied to risk for psychopathology and emotion dysregulation (Beauchaine, 2015). In healthy samples, high levels of resting HF-HRV activation and moderate decreases in HF-HRV in response to stress (i.e., HF-HRV withdrawal) represent the modal response and are believed to confer health (Porges, 2007; Zisner & Beauchaine, 2016). In contrast, low HF-HRV activity at rest and excessive HF-HRV withdrawal in response to stress have been associated with emotion dysregulation, especially among individuals who experienced psychological distress or psychosocial stress (Beauchaine, 2015; Beauchaine & Zalewski, 2016; however, see also Hamilton & Alloy, 2016; Yaroslavsky et al., 2014).

The PNS activity is not a static trait; rather, PNS activity can be dynamically influenced by environmental factors. Research has demonstrated that exposure to psychosocial stressors, such as CFS, corresponds with lower HF-HRV activity, suggesting that stress may affect physiological mechanisms of emotion regulation abilities (Beauchaine & Zalewski, 2016; Fox et al., 2019; Lischke et al., 2019). Notably, individuals display considerable variability in their physiological responses to stress, making some individuals more vulnerable to stress-related health risks than others (Ebner & Singewald, 2017). Therefore, understanding the interactive effects of CFS and PNS activity in accounting for health outcomes may have implications for the intervention and prevention of stress-related health risks. Several studies have found that moderate HF-HRV withdrawal in response to stress is related to better mental health outcomes in the context of low CFS compared to high (Bylsma et al., 2014; Obradovic et al., 2010). This protective effect may be due to such physiological regulatory processes supporting better emotion regulation and social engagement (Beauchaine & Zalewski, 2016; Porges, 2007). Nevertheless, little is known about the role of HF-HRV reactivity in the link between CFS and physical health, which leaves a critical gap in the scientific understanding of biological pathways through which CFS may affect health, particularly in groups who report greater exposure to such stressors (e.g., women; Hager & Runtz, 2012; Liu & Umberson, 2015).

Different theoretical models have been proposed to characterize how PNS activity may alter individuals' susceptibility to the effects of stress on health. The *diathesis-stress* model asserts that certain biological characteristics (e.g., PNS reactivity) may render individuals more vulnerable to the impact of environmental stressors (Monroe & Simons, 1991). In contrast, the *biological sensitivity to context* (BSC) theory proposes that individuals with high stress reactivity may be more susceptible to the impact of adversity but may also reap greater benefits from a positive, enriching environment (Boyce & Ellis, 2005). Conversely, individuals with low stress reactivity may be more resilient to the impact of adversity but instead may benefit less from a positive environment (Boyce & Ellis, 2005). Stated differently, the BSC theory suggests that while individuals with high stress reactivity may exhibit the poorest outcomes in low quality environments (e.g., chronic CFS), these individuals may also display the best outcomes in high quality environments.

While HF-HRV reactivity has most often been conceptualized as a risk factor or diathesis that can heighten negative effects of CFS on socioemotional adjustment, recent work suggests that it may better reflect a susceptibility factor that can heighten both negative and positive effects of CFS on adjustment. Indeed, consistent with the BSC theory (Boyce & Ellis, 2005), compelling evidence has indicated that individuals with more HF-HRV reactivity (e.g., greater HF-HRV withdrawal in response to stress) may be at heightened risk for poorer socioemotional outcomes in the context of high CFS but may show better socioemotional outcomes in the context of low CFS (Cui et al., 2019; Hagan et al.,; 2020; Huffman et al.,; 2020; Obradovic et al., 2010; Obradovic et al., 2011). No research to date has tested whether HF-HRV reactivity is better characterized as a risk or susceptibility factor with respect to stress-related physical health outcomes. However, Katz and Gottman (1997) have found preliminary support that HF-HRV reactivity may likewise operate as a susceptibility factor for the effects of CFS on physical health. Specifically, drawing data from 56 families of preschool children, Katz and Gottman (1997) found that children with low CFS and more HF-HRV withdrawal in response to stress exhibited fewer parent-reported health issues among children. Nevertheless, these results relied on zero-order correlational analyses. Thus, efforts to replicate when using more vigorous analyses to examine independent and joint effects of CFS and HF-HRV on self-reported health are needed.

The current study aimed to investigate the direct and interactive contributions of CFS and HF-HRV reactivity and recovery to health complaints in a sample of undergraduate women. We hypothesized that a) more CFS and HF-HRV reactivity (i.e., greater HF-HRV withdrawal in response to stress; lower HF-HRV during recovery relative to baseline levels) would each be associated with more self-reported health complaints; and b) that associations between CFS exposure and number of health complaints would be especially pronounced among women exhibiting HF-HRV reactivity in a manner consistent with BSC theory. Specifically, we hypothesized that women with more HF-HRV withdrawal or less HF-HRV recovery would report more health complaints when they also experienced high CFS, but would report fewer health complaints when they experienced low CFS.

Method

Participants

Participants included 68 female undergraduate women ($M = 19.44$, $SD = 2.29$, range = 18–35 years) at a public university in the Northeastern United States. Participants were recruited through the university's undergraduate psychology research pool and received course credits for participation. Eligibility criteria included a minimum age of 18 years, assigned female sex at birth, and not currently pregnant or undergoing cross-hormonal/gender-affirming therapy. The sample was racially, ethnically, and socioeconomically diverse. Demographic characteristics are presented in Table 1.

Procedure

This study drew data from a study that examined the contributions of various life course stressors on health and well-being among women of reproductive age. All procedures were approved by the Institutional Review Board at the University at Albany, State University of New York. Data was collected between March 2019 and March 2020. A trained research assistant obtained written informed consent. Participants were connected to an ambulatory physiological device before completing a social stress task (i.e., the Trier Social Stress Test). Finally, participants completed an interview with a trained research assistant and a self-report survey via Qualtrics about their childhood experiences and current health.

Trier Social Stress Test

The Trier Social Stress Test (TSST; Kirschbaum et al., 1993) involves performing a 5-min speech delivery task and a 5-min verbal arithmetic task in front of a panel of two lab technicians. Lab technicians were instructed not to provide any emotional and verbal feedback, and to pretend to evaluate their performance. The TSST is designed to provoke socially evaluative stress and has been demonstrated to elicit a significant HF-HRV response. At the beginning of the TSST, participants were instructed to sit quietly for 5-min (*baseline*). Then, participants were given 3 min to prepare for a speech to discuss their qualifications for a job of their choice. After the speech preparation period, participants stood and delivered a speech for 5 min (*speech*). Subsequently, participants completed the arithmetic task in which they count backward from 2,023

Table 1 Sample demographics and descriptive statistics

	%
Race/Ethnicity	
Asian	14%
Black	21%
White	30%
Latinx	16%
Biracial/Multiracial	8%
Other[a]	7%
Declined to answer	4%
Annual household income[b]	
19.9 k or less	10%
20–39.9 k	18%
40-60 k	14%
60-80 k	11%
80-100 k	12%
100 k +	19%
Don't know	16%
Medical/ Psychiatry Diagnoses[c]	
Yes	24%
No	76%
	M (SD); min – max
Age	19.4 (2.29); 18–35
BMI	23.7 (4.02); 18.2–36.4
Physical activity level	4.44 (2.21); 1–8
Childhood family stress	26.41(9.63); 11–51
Physical health	4.48(0.94); 2.64–6.43
Baseline HF-HRV (ln[ms^2])	6.38(0.91); 3.88–8.37
HF-HRV during speech task (ln[ms^2])	5.87(0.79); 3.91–7.62
HF-HRV during math task (ln[ms^2])	5.74(0.85); 3.95–7.60
HF-HRV during recovery period (ln[ms^2])	6.49(0.83); 4.54–8.58
HF-HRV Speech reactivity (speech-baseline difference score)	– 0.48(0.80); – 2.04–1.45
HF-HRV Math reactivity (math-baseline difference score)	– 0.66(0.85); – 3.50–1.37
HF-HRV Recovery (recovery-baseline difference score)	0.06(0.54); – 1.35–1.35

[a]Includes Middle Eastern/North African (2%) and "Other" (5%)

[b]Represents participants' caregivers' income since all participants except one reported financial independence; household income for the one participant declaring financial independence was excluded here to aid interpretability

[c]Includes medical and psychiatric conditions, such as asthma, anemia, scoliosis, depression, anxiety, post-traumatic stress disorder, and attention-deficit/ hyperactivity disorder

Higher physical health scores indicate better health (fewer health complaints)

HF-HRV reactivity/ recovery reflect difference scores calculated as task/ recovery HF-HRV—baseline HF-HRV. Negative reactivity scores in response to the speech and math tasks can be interpreted to reflect greater HF-HRV withdrawal in response to stress; positive reactivity scores reflect less HF-HRV withdrawal in response to stress. Positive HF-HRV recovery scores in the context of recovery indicate greater HF-HRV during the recovery period compared to baseline; negative scores values indicate lower HF-HRV during recovery relative to baseline levels

serially by 17 for 5 min (*math*). The TSST ended with a 5-min resting *recovery* period during which participants were instructed to sit quietly.

Measures

Childhood Family Stress (CFS)

The Risky Families Questionnaire (RFQ; Felitti et al., 1998; Taylor et al., 2004) is a 13-item self-report instrument used to assess childhood exposure to family stress and adversity. The RFQ was adapted from the Adverse Childhood Experience (ACE) questionnaire and assesses both traumatic and non-traumatic family psychosocial stressors, including interparental conflict, child psychological and physical abuse, parent–child conflict, chaotic family environment, and neglect. The RFQ has demonstrated good reliability, internal consistency, and validity in adult samples (Felitti et al., 1998; Lehman et al., 2005; Morrill et al., 2019; Taylor et al., 2004). Participants were asked to rate their childhood family environments on a 5-point scale (*1* = not at all and *5* = very often; e.g., "How often did a parent or other adult in the household push, grab, shove, or slap you?"). Three positively worded items were reverse coded (e.g., "Would you say that the household you grew up in was well-organized and well-managed?"). Responses were summed to create a total score, with higher scores indicating greater overall exposure to CFS. The RFQ exhibited good reliability in this sample, $\alpha = 0.88$.

Health Complaints

The Physical Health Questionnaire (PHQ; Schat et al., 2005) is a 14-item self-report measure of health complaints in the past year that has demonstrated good reliability and validity (Schat et al., 2005). Participants were instructed to indicate the frequency of various health complaints using a 7-point scale ranging from infrequent (1) to frequent (7). Sample questions include: "How often have you experienced headaches?" "How many times have you had respiratory infections more severe than minor colds that 'laid you low'?" Responses were reverse coded and averaged to create a mean score, with higher scores indicating better health (i.e., fewer health complaints). The PHQ exhibited good reliability in this sample, $\alpha = 0.84$.

High-Frequency Heart Rate Variability (HF-HRV, ln[ms.^{2}])

HF-HRV was defined as heart rate variability (HRV) occurring in the high-frequency band of the power spectrum (i.e., 0.12 and 0.40 Hz). HRV was assessed using an electrocardiograph (ECG) and respiration frequency information was obtained using BioLab acquisition software (version 3.1.0) and ambulatory MindWare mobile devices sampled at 500 Hz and digitized at 12 bit (MindWare Technologies, Ltd., Gahanna, OH). Electrodes were placed on the participant's torso using a standard 3-lead configuration, and a respiration belt was placed under the participant's chest. Baseline and muscle filter and Notch filter were applied during ECG data acquisition to remove interference from muscle movements and surrounding electrical components.

Prior to HF-HRV calculation, a trained research assistant reviewed and manually corrected all aberrant R-peaks identified and flagged by MindWare's HRV Analysis software's (version 3.2.3) automatic artifact detection algorithm. Using an interpolation algorithm with a sampling time of 250 ms, a 60-s segment of interbeat intervals (IBIs; the time between heartbeats or ECG R spikes) was created for each minute of the baseline, speech task, arithmetic task, and recovery. The 60-s segments were tapered and linearly detrended using a Hamming window, then processed by fast Fourier transformations with the integration of high-frequency bandwidth 0.12–0.40 Hz; Berntson et al., 2016) to determine HF-HRV values. Respiration data (i.e., respiration peak frequency within 0.12–0.40 Hz which corresponds to respiration rates of 7.20–24.00 bpm) was used to validate HF-HRV by confirming that respiration occurred within the specified range. HF-HRV data were unavailable for 5 participants due to irregular heartbeat ($n = 1$) or technological difficulties and/or experimenter error ($n = 4$).

The mean levels of HF-HRV during each stress task and recovery were computed by averaging HF-HRV across the 60-s segments within each task period. Difference scores (i.e., task HF-HRV—baseline HF-HRV) were computed to capture HF-HRV reactivity to the speech and math tasks and the degree of HF-HRV during recovery relative to baseline. Negative difference scores for the speech and math tasks can be interpreted to reflect HF-HRV withdrawal in response to stress, whereas positive difference scores reflect increases in HF-HRV in response to stress. Positive difference scores for the recovery period can be interpreted to reflect higher levels of HF-HRV during the recovery period than were observed during baseline (greater HF-HRV during recovery relative to baseline), and negative recovery difference scores reflect lower levels of HF-HRV during recovery than were observed during baseline (lower HF-HRV during recovery relative to baseline). The HF-HRV variables were log-transformed (ln[ms^2]) to achieve a more normal distribution.

Covariates

Participants self-reported demographic, lifestyle, and health information as part of the survey. Variables that have been previously linked to poorer health or changes in HF-HRV activity were considered as covariates (i.e., low household income, racial/ethnic minority status, age, body mass index, typical physical activity level, medication, and medical and psychiatric conditions; Beauchaine, 2015; Chen et al., 2006; Masi et al., 2007; Quitana et al., 2016; Treadwell et al., 2011). Participants were asked to self-identify their race and ethnicity. To assess household income, we asked participants to declare if they were financially dependent or independent and to report their income level on an ordinal scale with income levels in 20 k increments. Financially dependent participants reported their caregiver's income level. All participants except one declared financial dependency.

Body mass index (BMI) was derived from participants' self-reported height (ft and inches) and weight (lbs). Participants disclosed any current medical or psychiatric conditions (e.g., asthma, anemia, scoliosis, depression, anxiety, post-traumatic stress disorder, and attention-deficit/ hyperactivity disorder) and any medication use (e.g., birth control, selective serotonin reuptake inhibitor, asthma inhaler, antihistamine, antibiotics).

The physical activity rating scale (Jacoson et al., 1990) was used to assess participant's typical activity levels. We asked participants to choose a description that best matches their activity level for a typical week this year. The description included a range of options from "I avoid walking or exercising" to "I run more than 10 miles per week or spend more than 3 h per week in comparable physical activity."

Sociodemographic and health-related variables were included as covariates for regression models if significantly correlated ($p < 0.05$) with key study variables (e.g., CFS, HF-HRV, health complaints). Among potential covariates, racial/ethnic minority status was significantly correlated with more self-reported health complaints and thus, was included as a covariate in all regression models. No other sociodemographic or health-related variables exhibited significant correlations with key study variables.

Analytic Approach

Key study variables were assessed for univariate and multivariate normality. All variables were standardized prior to analyses. Descriptive and correlational analyses were conducted via SPSS 26. Three multiple regression models were run via Mplus 6.12 (Muthén & Muthén, 2010) using maximum likelihood estimation (Enders, 2008) to examine the direct and interactive contributions of CFS and HF-HRV reactivity. Specifically, women's health complaints were regressed on CFS, HF-HRV difference scores (i.e., in response to the speech, math, and recovery tasks), and their interactions. Simple slope analyses were used to probe significant interaction effects at 1 SD above and below the mean of HF-HRV difference scores. Additionally, to test the presence of BSC effects, regions of significance test with respect to CFS were run to determine the levels of CFS for which HF-HRV responses to the speech, math, and recovery tasks modified susceptibility for health outcomes following recommendations by Roisman et al. (2012). Finally, given our small sample size, several sensitivity analyses were conducted to test the robustness of our findings. We repeated the regression models excluding participants with the physical and mental health conditions known to correlate with HF-HRV (e.g., asthma, depression, anxiety, and post-traumatic stress disorder; Beauchaine, 2016; Franco et al., 2020; Lufti, 2012) and participants who currently takes medications (e.g., birth control, selective serotonin reuptake inhibitor, asthma inhaler, antihistamine, antibiotics). We also investigated the moderating effects of HF-HRV by separately testing the association between CFS and health complaints among those who showed more or less HF-HRV withdrawal to the speech and math tasks (i.e., above or below the median HF-HRV speech and math difference scores), and more and less HF-HRV recovery relative to baseline (i.e., above or below the median HF-HRV recovery difference score). In addition, the field has disagreements on whether it is appropriate to control for baseline levels of HF-HRV when predicting HF-HRV difference scores. Some scholars have suggested that controlling for baseline HF-HRV can help address concerns about the Law of Initial Values (which posits that difference scores are negatively correlated with baseline values; see Bernston, 1994), while others have suggested that since baseline values are already used to calculate difference scores, controlling for baseline levels can result in inflated estimates and errors (Burt & Obradovic, 2013). Given the lack of consensus about which approach is best, we controlled for baseline HF-HRV in all analyses to clarify the influence of phasic physiological changes (i.e. reactivity component) on the link between CFS on health complaints.

Results

Preliminary Analyses

Descriptive statistics and correlations are presented in Tables 1 and 2, respectively. Participants on average reported a moderate number of health complaints (i.e., comparable to participants endorsing 7 of 14 health complaints were "frequent", or that all 14 health complaints occurred "some of the times") and reflected a range of low to high levels of health complaints. The average CFS endorsement in this study was low overall (i.e., comparable to participants endorsing 1 of 13 family risk factors occurring "very often" or 2 family risk factors occurring "sometimes") and was similar to levels that have emerged in healthy adult samples (e.g., Schreier et al., 2019).

As has previously been reported in Lin et al. (2022), a repeated measures ANOVA evaluating the effect of the TSST on HF-HRV indicated that the TSST elicited a significant HF-HRV response, $F(2.29, 128.12) = 24.79$, $p < 0.001$, $\eta^2 = 0.31$. Specifically, we found that participants demonstrated significantly lower levels of HF-HRV during the speech and math tasks compared to baseline levels of HF-HRV. Participants also displayed significantly higher levels of HF-HRV during recovery compared to baseline levels of HF-HRV (see Lin et al., 2022 for more information). HF-HRV speech, math, and recovery difference scores were significantly positively correlated with each other (see

Table 2 Bivariate correlations among key variables (N = 68)

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Racial/Ethnic Minority	–										
2. Low household income	0.17	–									
3. Age	0.12	0.17	–								
4. Body mass index	0.19	−0.34**	−0.03	–							
5. Typical physical activity level	0.02	−0.41**	0.01	−0.04	–						
6. Medical and Psychiatric conditions	−0.10	−0.18	−0.10	0.39**	−0.43**	–					
7. Medication	0.06	−0.12	−0.09	−0.13	−0.18	0.08	–				
8. Childhood Family Stress	−0.12	−0.09	−0.25	−0.04	−0.15	0.13	0.04	–			
9. HF-HRV Speech Reactivity	0.10	−0.02	0.01	0.02	0.18	0.03	0.01	0.19	–		
10. HF-HRV Math Reactivity	−0.04	−0.01	0.18	0.18	0.44	0.04	0.11	0.07	0.74**	–	
11. HF-HRV Recovery	0.21	−0.06	−0.01	0.10	0.08	−0.04	−0.10	0.16	0.28*	0.33*	–
12. Physical Health	0.33*	−0.06	0.03	0.03	0.10	−0.24	−0.26	−0.38**	−0.10	−0.17	0.12

*$p < .05$, **$p < .01$; Racial/ Ethnic Minority is coded White = 0, Other Race = 1; Low-income household is coded less than \$40,000 = 1, more than \$40,000 = 0

Table 2). Specifically, participants who exhibited more HF-HRV withdrawal in response to the speech and math tasks also exhibited less HF-HRV recovery relative to baseline.

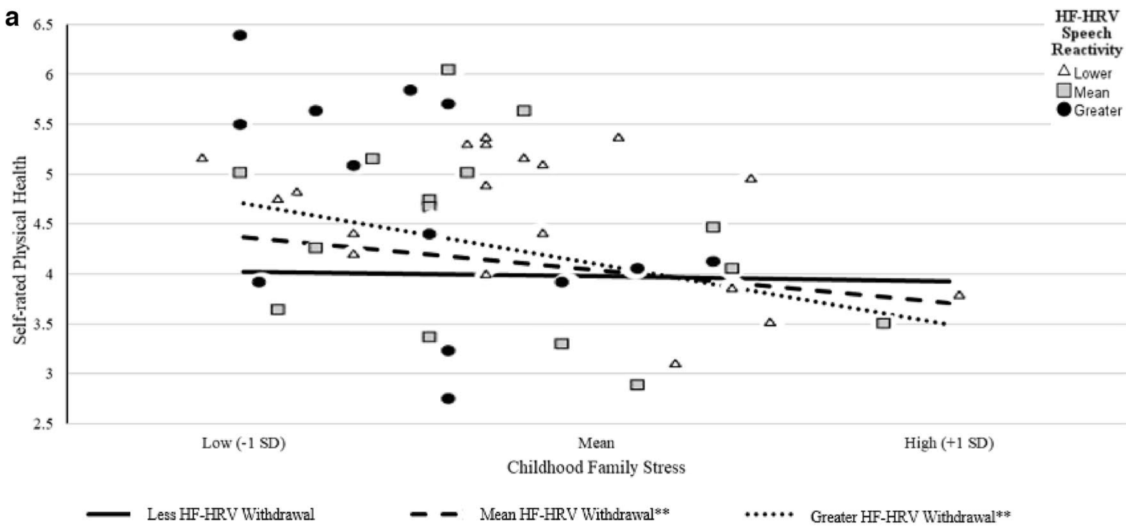
CFS, HF-HRV, and Health

Results of multiple regression models investigating the direct and interactive contributions of CFS and HF-HRV to health complaints are presented in Table 3. In the model examining the role of HF-HRV reactivity to the speech task, higher levels of CFS were significantly associated with more health complaints. HF-HRV reactivity to the speech task was not directly associated with health complaints, but significantly moderated the relation between CFS and health complaints. Simple slope analyses were used to probe the interaction effect of CFS on health complaints. Results indicated that CFS was only significantly associated with more health complaints among women who exhibited mean (($M_{\text{HF-HRV speech reactivity}} = -0.48$), $B = -0.33$, $SE = 0.09$, $p < 0.001$, or greater than mean

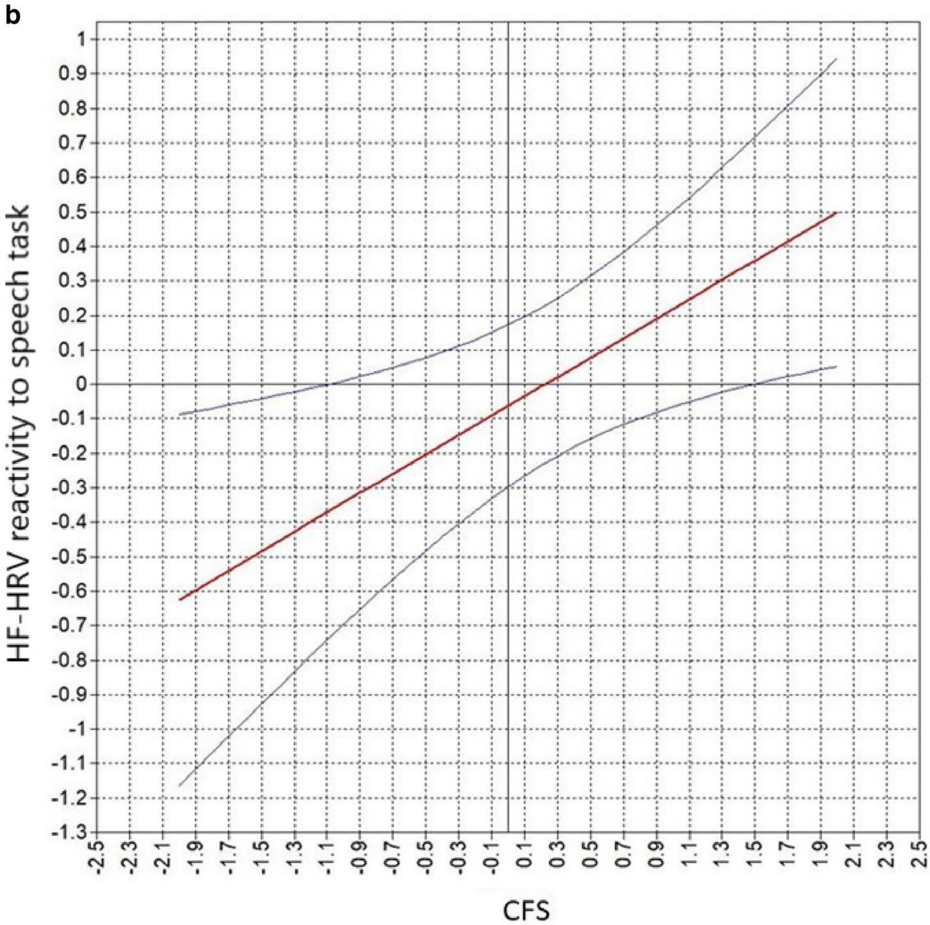
Table 3 Interactive effects of childhood family stress and HF-HRV on health complaints

Variable	*B*	*SE*	*β*	*SE*	*p*
		HF-HRV Speech Reactivity			
Racial/Ethnic Minority	0.54	0.24	0.26	0.12	.022
Childhood Family Stress (CFS)	−0.33	0.08	−0.35	0.10	< .001
HF-HRV Speech Reactivity	−0.06	0.12	−0.07	0.13	.600
CFS x HF-HRV	0.28	0.11	0.25	0.10	.011
R^2	0.28				.012
		HF-HRV Math Reactivity			
Racial/Ethnic Minority	0.60	0.25	0.29	0.12	.013
CFS	−0.35	0.09	−0.37	0.10	< .001
HF-HRV Math Reactivity	−0.16	0.12	−0.17	0.13	.178
CFS x HF-HRV	0.27	0.10	0.24	0.08	.003
R^2	0.29				.004
		HF-HRV Recovery			
Racial/Ethnic Minority	0.58	0.27	0.29	0.13	.026
CFS	−0.28	0.10	−0.30	0.11	.005
HF-HRV Recovery	0.16	0.12	0.17	0.12	.152
CFS x HF-HRV	−0.26	0.09	−0.30	0.10	.004
R^2	0.30				.002

Higher physical health scores = better health (fewer health complaints); Racial/ Ethnic Minority is coded White = 0, Minoritized Racial/Ethnic Background = 1 a



b



($M_{\text{HF-HRV speech reactivity}} = -1.28$) HF-HRV withdrawal in response to the speech task, $B = -0.61$, $SE = 0.16$, $p < 0.001$ (see Fig. 1a). The regions of significance on CFS test indicated that greater HF-HRV withdrawal in response to the speech task was significantly associated with fewer health complaints when CFS was low (i.e., less than -1.1 *SD* from mean levels of CFS), but more health complaints when CFS was high (i.e., greater than 1.5 *SD* from the mean; see

◀**Fig. 1** **a** Moderating Effects of HF-HRV Reactivity in response to the Speech task. *Notes*. Conditional effects of CFS on physical health under conditions of greater, mean, and less HF-HRV withdrawal in response to the speech task. *p < .05, **p < .01. Less HF-HRV withdrawal = 1 standard deviation above the mean of HF-HRV reactivity ($M_{\text{HF-HRV Speech reactivity}} = 0.32$); Greater HF-HRV withdrawal = 1 standard deviation below the mean of HF-HRV reactivity ($M_{\text{HF-HRV Speech reactivity}} = -1.28$). Higher physical health scores = better health (fewer health complaints). **b** Region of Significance Test for HF-HRV in response to Speech Task: CFS as a Moderator. *Notes*. The X-axis depicts a standardized continuous range of CFS, whereas the Y-axis depicts a range of the adjusted effect of HF-HRV reactivity to speech task. The straight plot line demonstrates values of the adjusted effect of HF-HRV speech reactivity corresponding to CFS. The curved lines represent 95% confidence interval around the adjusted effect of HF-HRV speech reactivity on physical complaints. The effect is only considered significant when the 95% confidence bands do not include the adjusted effect of HF-HRV (Y-axis) = 0. In this test, greater HF-HRV withdrawal in response to speech task appeared to be associated with less physical complaints at low levels of CFS, SD < 1.11, and significantly associated with more physical complaints at high levels of CFS, SD > 1.5

Fig. 1b). Taken together, greater HF-HRV withdrawal in response to the speech task appeared to heighten women's susceptibility to the negative *and* positive effects of high and low CFS on health.

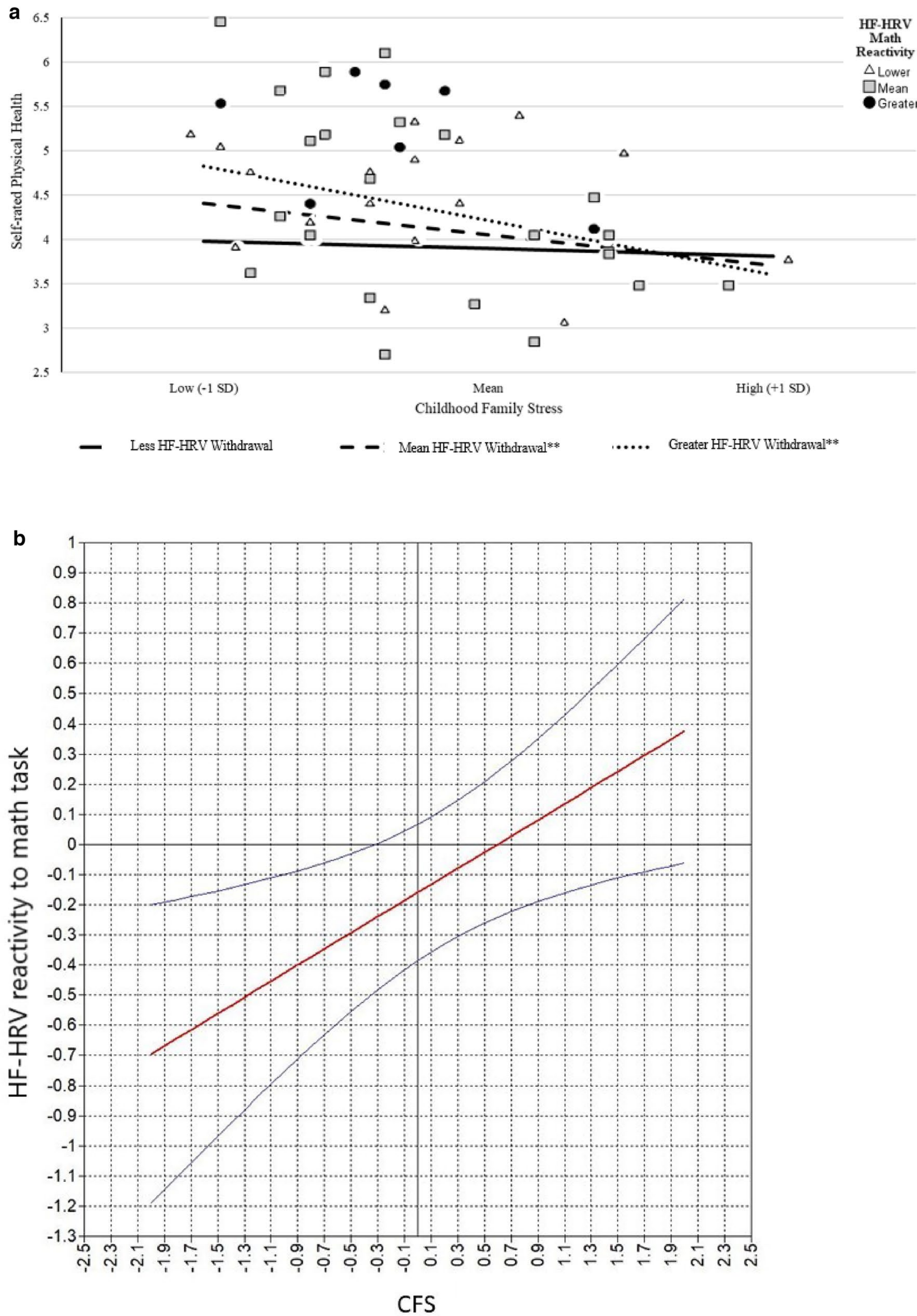
In the model examining the role of HF-HRV reactivity to the math task, CFS was again significantly associated with more health complaints. HF-HRV reactivity to the math task was not directly associated with health complaints, but significantly moderated associations between CFS and health complaints. Simple slope analyses indicated that lower CFS was only significantly associated with fewer health complaints among women who displayed mean ($M_{\text{HF-HRV math reactivity}} = -0.65$), $B = -0.35$, $SE = 0.09$, $p < 0.001$, or greater than mean ($M_{\text{HF-HRV math reactivity}} = -1.51$) HF-HRV withdrawal in response to the math task, $B = B = -0.62$, $SE = 0.15$, $p < 0.001$ (see Fig. 2a). The regions of significance test on CFS indicated that greater HF-HRV withdrawal in response to the math task was only significantly associated with fewer health complaints at mean or lower levels of CFS (i.e., less than 0.30 *SD* from the mean of CFS; see Fig. 2b). Taken together, greater HF-HRV withdrawal in response to the math task appeared to heighten women's susceptibility only to the promotive effects of low or mean CFS on health.

Lastly, in the model examining the role of HF-HRV during recovery, CFS was again significantly associated with more health complaints. HF-HRV recovery difference scores were not directly associated with health complaints, but significantly moderated associations between CFS and health complaints. Simple slope analysis indicated that lower CFS was only significantly associated with fewer health complaints among women who exhibited mean (i.e., approximately comparable levels of HF-HRV following TSST relative to baseline, $M_{\text{HF-HRV recovery}} = -0.06$) or greater than mean (i.e., increased HF-HRV following TSST relative to baseline, $M_{\text{HF-HRV recovery}} = 0.48$) HF-HRV recovery difference scores, $B = -0.28$, $SE = 0.11$, $p = 0.007$ and $B = -0.54$, $SE = 0.11$, $p < 0.001$, respectively (see Fig. 3a). A regions of significance test on CFS indicated that greater HF-HRV during recovery relative to baseline was associated with fewer health complaints at low levels of CFS (i.e., less than −0.30 *SD* from the mean of CFS; see Fig. 3b). Taken together, greater HF-HRV during the recovery period compared to baseline appeared to heighten women's susceptibility to the benefits of low CFS for health.

Sensitivity Analyses

Results of the regressions excluding participants with health conditions (n = 50) that have been found to influence HF-HRV (i.e., asthma, depression, anxiety, and post-traumatic stress disorder; Beauchaine, 2016; Franco et al., 2020; Lufti, 2012) yielded results that were consistent with primary analyses. In this subsample, HF-HRV reactivity to the speech and math tasks and recovery difference scores each significantly moderated the relation between CFS and health complaints in a manner consistent with the primary analysis, $B = 0.26$, $SE = 0.12$, $p = 0.029$; $B = 0.24$, $SE = 0.10$, $p = 0.018$; and $B = -0.30$, $SE = 0.13$, $p = 0.013$, respectively (see Supplemental Table 1 for full results). Simple slope analyses probing the significant interactions indicated that results were comparable to primary analyses. Specifically, CFS was only significantly associated with more health complaints among women who exhibited mean, B = −0.36, SE = 0.12, p = 0.002, or greater than mean HF-HRV withdrawal in response to the speech task, B = -0.63, SE = 0.20, p = 0.002. Moreover, lower CFS was only significantly associated with fewer health complaints among women who displayed mean, B = −0.39, SE = 0.12, p = 0.001, or greater than mean HF-HRV withdrawal in response to the math task, B = −0.65, SE = 0.20, p = 0.001. Lastly, lower CFS was only significantly associated with fewer health complaints among women who exhibited mean, B = −0.36, SE = 0.12, p = 0.003, or greater than mean HF-HRV recovery relative to baseline, B = −0.66, SE = 0.16, p < 0.001.

Likewise, results of the regression models excluding participants who reported taking medications (n = 61) that has been linked to HF-HRV (i.e., selective serotonin reuptake inhibitor, antihistamine; Penttilä et al., 2005; van Zyl et al., 2008) were also consistent with primary analyses. In this subsample, more CFS was again associated with poorer health, and HF-HRV reactivity to the speech and math tasks and recovery difference scores each significantly moderated the relation between CFS and health complaints in the manner consistent with the primary analyses, $B = 0.30$, $SE = 0.11$, $p = 0.007$; $B = 0.28$, $SE = 0.11$, $p = 0.002$; and $B = -0.26$,


a
Self-rated Physical Health
6.5
6
5.5
5
4.5
4
3.5
3
2.5
HF-HRV Math Reactivity
Lower
Mean
Greater
Low (-1 SD)
Mean
High (+1 SD)
Childhood Family Stress
Less HF-HRV Withdrawal
Mean HF-HRV Withdrawal**
Greater HF-HRV Withdrawal**
b
HF-HRV reactivity to math task
CFS

◂**Fig. 2** **a** Moderating Effects of HF-HRV reactivity in response to the Math task. *Notes*. Conditional effects of CFS on physical health at greater, mean, and less HF-HRV withdrawal in response to math task. $^{*}p<.05$, $^{**}p<.01$. Less HF-HRV withdrawal = 1 standard deviation above the mean of HF-HRV reactivity ($M_{\text{HF-HRV Math reactivity}} = 0.21$); Greater HF-HRV withdrawal = 1 standard deviation below the mean of HF-HRV reactivity ($M_{\text{HF-HRV Math reactivity}} = -1.51$). Higher physical health scores = better health (fewer health complaints). **b** Region of Significance Test for HF-HRV in response to Math task: CFS as a Moderator. *Notes*. The X-axis depicts a standardized continuous range of CFS, whereas the Y-axis depicts a range of the adjusted effect of HF-HRV reactivity to math task. The straight plot line demonstrates values of the adjusted effect of HF-HRV math reactivity corresponding to CFS. The curved lines represent 95% confidence interval around the adjusted effect of HF-HRV math reactivity on physical complaints. The effect is only considered significant when the 95% confidence bands do not include the adjusted effect of HF-HRV (Y-axis) = 0. In this test, greater HF-HRV withdrawal in response to math task only appeared to be associated with less physical complaints at low levels of CFS, SD < 0.3

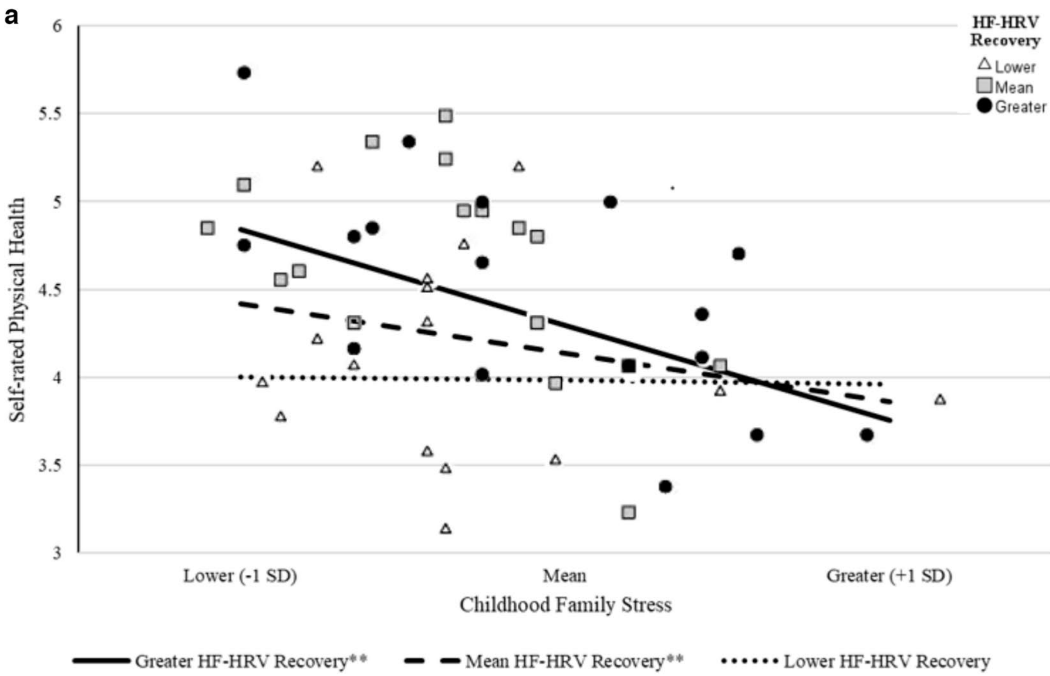
$SE = 0.09$, $p = 0.005$, respectively (see Supplemental Table 2 for full results). Simple slope analyses probing the significant interactions indicated that results were comparable to primary analyses. Specifically, CFS was only significantly associated with more health complaints among women who exhibited mean, B = -0.33, SE = 0.09, p < 0.001, or greater than mean HF-HRV withdrawal in response to the speech task, B = −0.63, SE = 0.17, p < 0.001. Moreover, lower CFS was only significantly associated with fewer health complaints among women who displayed mean, B = −0.36, SE = 0.10, p < 0.001, or greater than mean HF-HRV withdrawal in response to the math task, B = −0.65, SE = 0.16, p < 0.001. Lastly, lower CFS was only significantly associated with fewer health complaints among women who exhibited mean, B = −0.29, SE = 0.11, p = 0.008, or greater than mean HF-HRV recovery relative to baseline, B = −0.55, SE = 0.12, p < 0.001.

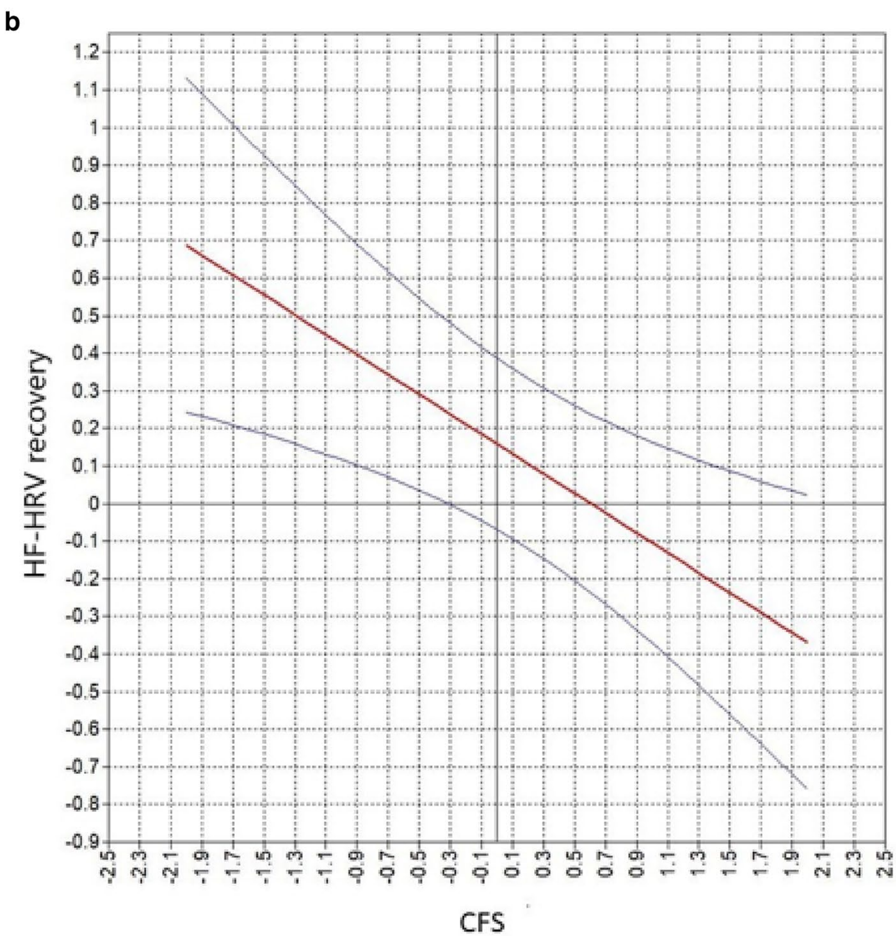
When we tested associations between CFS and health complaints among the subgroups of individuals who exhibited more and less HF-HRV withdrawal in response to the speech and math tasks, and individuals who exhibited more and less HF-HRV during the recovery period compared to baseline, results were again largely consistent with the results of primary analyses. CFS was associated with more health complaints in both subgroups of women who exhibited more, $B = -0.24$, $SE = 0.12$, $p = 0.044$, and less HF-HRV withdrawal in response to the speech task, $B = -0.39$, $SE = 0.12$, $p = 0.013$. Also consistent with the results of primary analyses, lower CFS was significantly related to fewer health complaints among the subgroup of women who exhibited more HF-HRV withdrawal in response to the math task, $B = -0.65$, $SE = 0.11$, $p < 0.001$, but not in those who exhibited less HF-HRV withdrawal in response to math task, $B = -0.05$, $SE = 0.12$, $p = 0.66$. Lastly, and again consistent with the results of primary analyses, low CFS was only significantly associated with fewer health complaints among participants who exhibited greater HF-HRV during the recovery period, $B = -0.66$, $SE = 0.13$, $p < 0.001$, but not those who exhibited less HF-HRV during the recovery period, $B = -0.09$, $SE = 0.12$, $p = 0.44$.

Results of the regressions controlling for baseline HF-HRV yielded results that were largely consistent with primary analyses Specifically, and consistent with primary analyses, HF-HRV reactivity to the speech and math tasks each significantly moderated the relation between CFS and health complaints, B = 0.34, SE = 0.12, p = 0.004; and B = 0.42, SE = 0.14, p < 0.01 respectively (see Supplemental Table 3 for full results). Furthermore, simple slope analyses likewise yielded results that were comparable to primary analyses. When considering HF-HRV reactivity to the speech task, CFS was only significantly associated with more health complaints among women who exhibited mean, B = −0.31, SE = 0.11, p = 0.006, and greater than mean HF-HRV withdrawal, B = −0.63, SE = 0.19, p = 0.001. When considering HF-HRV reactivity to the math tasks, lower CFS was only significantly associated with fewer health complaints among women who displayed mean, B = −0.41, SE = 0.13, p = 0.002, and greater than mean HF-HRV withdrawal, B = −0.75, SE = 0.20, p < 0.001. Our findings along with others (Llabre et al., 1991; Rogosa, 1995; Roisman, 2007) suggested that baseline values correction may have negligible impact on phasic changes (i.e., during reactivity). However, analyses considering HF-HRV recovery indicated that the interaction term was non-significant when controlling for baseline HF-HRV, B = −0.22, SE = 0.15, p = 0.13 (see Supplemental Table 3).

Discussion

This study aimed to investigate the role of PNS activity in modulating the link between CFS and women's health complaints. Consistent with prior research (Bauldry et al., 2012; Hager & Runtz, 2012; Kalmakis & Chandler, 2015; Monnat & Chandler, 2015), higher CFS endorsement was associated with more health complaints in this sample of young women. McEwen and Stellar's (1993) allostatic load theory proposes that exposure to repeated or chronic environmental challenges may accelerate wear and tear on physiological stress systems in ways that undermine health. The significant CFS-health association adds to the growing body of evidence suggesting that early life exposures may have long-term implications for health years after stress exposures. Therefore, it constitutes a critical next step to delineate ways to effectively offset the health consequences of early adverse experiences such as CFS. In addition, since women tend to experience higher levels of CFS (Hager & Runtz, 2012; Liu & Umberson, 2015) and report more health issues than men


a
HF-HRV Recovery
Lower
Mean
Greater
Self-rated Physical Health
Lower (-1 SD)
Mean
Greater (+1 SD)
Childhood Family Stress
Greater HF-HRV Recovery**
Mean HF-HRV Recovery**
Lower HF-HRV Recovery


b
HF-HRV recovery
CFS

◂**Fig. 3** **a** Moderating Effects of HF-HRV during the Recovery Period relative to Baseline. *Notes*. Conditional effects of CFS on physical health at high, average, and low levels of HF-HRV recovery. *$p<.05$, **$p<.01$. Lower HF-HRV recovery = 1 standard deviation below the mean of HF-HRV recovery ($M_{\text{HF-HRV Recovery}}=-0.60$); Greater HF-HRV recovery = 1 standard deviation above the mean of HF-HRV recovery ($M_{\text{HF-HRV Recovery}}=0.48$). Higher physical health scores = better health (fewer health complaints). **b** Region of Significance Test for HF-HRV during recovery relative to baseline: CFS as a Moderator. *Notes*. The X-axis depicts a standardized continuous range of CFS, whereas the Y-axis depicts a range of the adjusted effect of HF-HRV during recovery relative to baseline. The straight plot line demonstrates values of the adjusted effect of HF-HRV during recovery relative to baseline corresponding to CFS. The curved lines represent 95% confidence interval around the adjusted effect of HF-HRV during recovery relative to baseline on physical complaints. The effect is only considered significant when the 95% confidence bands do not include the adjusted effect of HF-HRV (Y-axis) = 0. In this test, greater HF-HRV during recovery relative to baseline only appeared to be associated with more physical health complaints at low levels of CFS, SD > −0.3

(Boerma et al., 2016), exposure to CFS may represent a vital link for understanding women's health outcomes.

On the other hand, and contrary to our hypothesis, neither HF-HRV stress reactivity nor HF-HRV task recovery was significantly directly associated with health complaints among young women. The absence of these relations was surprising given the extensive literature documenting links between PNS activity and health conditions (e.g., migraine, pain disorders, and cardiovascular diseases; Huss et al., 2009; Kolacz & Porges, 2018; Thayer et al., 2010). The non-significant associations may be attributable to the characteristics of our sample which consisted of young and relatively healthy women. In fact, only 25% of our sample reported that any one health complaint occurred frequently. This is distinctive from most of the existing studies that have used adult clinical samples with more chronic health conditions (Kolacz & Porges, 2018; Thayer et al., 2010). Most research that showed association between more ACEs and worse health outcomes were conducted in older adult populations, who may have presented with ACEs over their lifespan and age-related health issues (Lacey & Minnis, 2020). Hence, it is possible that associations between HF-HRV activity and health may be more muted in younger samples with fewer health problems. It is also conceivable that the lack of significant associations may have been related to how the PHQ was constructed. Specifically, the PHQ conflates frequency of various health problems and does not measure the severity and how disabling the health problems are to the participants. For example, a participant with more extreme frequent scores may obtain similar scores as a participant with less frequency scores across large number of health symptoms. Given that previous studies have found greater HF-HRV reactivity among samples with chronic health problems (Kolacz & Porges, 2018; Thayer et al., 2010), changes in HF-HRV may be associated with the chronicity of physical health complaints but not frequency of physical health complaints.

HF-HRV Reactivity, CFS, and Health

As hypothesized, the association between CFS and health complaints was moderated by levels of HF-HRV stress reactivity. Consistent with prior findings that children with less HF-HRV withdrawal in response to stress and low levels of CFS exhibited better physical health (per parent reports; Katz & Gottman, 1997), Specifically, our results suggest that HF-HRV stress reactivity may differentiate the degree to which CFS may contribute to health outcomes. Our study expands upon Katz and Gottman's findings in children and demonstrates for the first time that the interactive contributions of CFS and HF-HRV to self-reported physical health outcomes may extend to adulthood. Our results provide preliminary evidence that HF-HRV stress reactivity may serve as a marker of responsiveness or a mechanism of change in interventions to alleviate CFS-related negative health outcomes in young women.

Of interest, the manner in which HF-HRV stress reactivity moderated CFS-health associations differed across the speech and math tasks. On the one hand, and consistent with the BSC theory (Boyce & Ellis, 2005), greater HF-HRV withdrawal in response to the speech task appeared to confer susceptibility both to the negative *and* positive health consequences related to high and low CFS, respectively. In particular, greater HF-HRV withdrawal in response to the speech task was associated with fewer health complaints when CFS was low, but more health complaints when CFS was high. Heightened levels of stress reactivity may confer hypervigilance to threat cues in the context of high stress environments (e.g., high CFS), but greater receptivity to environmental supports and emotion regulation in the context of low stress environments (e.g., low CFS). Thus, greater HF-HRV stress reactivity may have served to exacerbate the negative consequences of CFS on health under conditions of high CFS, and also to promote health under conditions of low CFS. Indeed, HF-HRV reactivity has been found to serve as a marker for individual differences in emotion regulation. For example, greater HF-HRV withdrawal was associated with difficulties in emotion regulation (e.g., non-acceptance of emotional responses, impulse control difficulties, lack of emotional clarity, Zhang et al., 2015). Thus, HF-HRV reactivity may reflect the underlying physiological and psychological coping in response to environmental demands.

On the other hand, greater HF-HRV withdrawal in response to math task appeared to only amplify the promotive effects of low CFS on fewer health complaints. These findings contradict diathesis-stress theory and show *partial* consistency with the BSC theory; individuals with greater HF-HRV withdrawal to the math task appeared to benefit even more from low CFS than their less reactive counterparts. Taken together, results from the current study suggest that HF-HRV stress reactivity may indeed influence associations between CFS and health, and further that the promotive effects of HF-HRV reactivity on health may be more robust than its risky effects. Consistent with this suggestion, examination of the regions of significance test on CFS revealed that when risky effects of CFS on health emerged with respect to HF-HRV reactivity to the stress task, they only emerged at very high levels of CFS (> 1.5 SD above the mean). Therefore, HF-HRV stress reactivity may generally function to promote health at low to moderately low levels of CFS low but heighten health risks when CFS is very high.

The finding that there were differences in the roles of HF-HRV reactivity to the speech and math tasks in CFS-health associations (i.e., differential consistency with BSC theory) was unexpected. Different stimulus conditions (e.g., social threat, cognitive challenge, emotion evocation) are known to induce distinctive physiological responses that are associated with emotional responsivity (e.g., responsivity to social threat; emotion dysregulation; Zisner & Beauchaine, 2016). Accordingly, scholars have underscored the importance of assessing physiological activity in stimulus conditions relevant to key questions of interest (i.e., assessing HF-HRV reactivity to social threat for questions related to the effects of social stress on health). However, the speech and math tasks utilized in the current study were delivered in a similar manner (e.g., in front of a panel of lab technicians) as both comprised components of the TSST, which is conceptualized to elicit social evaluative threat. In fact, because the TSST speech and math tasks are generally considered comparable, HF-HRV reactivity to the TSST is often assessed by averaging HF-HRV activity across the speech and math tasks (e.g., Frisch et al., 2015). Concordantly, inspection of zero-order correlations between HF-HRV reactivity to the speech and math tasks in the current sample indicated a strong positive correlation ($r = 0.75$), suggesting that the tasks elicited similar forms of HF-HRV reactivity.

Nevertheless, modest differences between tasks may have elicited subtle yet meaningful differences in stress reactivity. For instance, these tasks involve different academic skills (e.g., oral language vs. arithmetic skills). While both tasks are cognitively challenging, performance on the speech task may require more interpersonal skills (e.g., initiating conversations) and offer a better representation of one's social functioning than the math task. Hence, the speech task may capture a broader range of sensitivity to social environmental factors, such as CFS, than the math task. Additionally, participants were given a 3-min "preparation" period for the speech task, whereas they did not have time to prepare for the math task. Thus, it is conceivable that the tasks may have elicited different perceptions of controllability and social evaluation threat, contributing to distinctive stress reactivity (Frisch et al., 2015). Given these potential differences, it may be helpful if future research continues to clarify the degree to which the speech and math components should be treated as comparable or distinctive conditions.

HF-HRV during Recovery, CFS, and Health

The present study was the first to examine how CFS and HF-HRV during recovery period may interact to contribute to physical health. We found that women who exhibited greater HF-HRV during the recovery period than they did during baseline appeared to benefit more from the positive effects of low CFS on health. While this finding was in contrast to our hypothesis that HF-HRV during the recovery period would operate as a susceptibility factor in a manner consistent with BSC theory, it nonetheless aligns with prior suggestions that greater HF-HRV during the recovery period may reflect the greater adaptability of the PNS to environmental changes and better emotion regulation and may be protective to health risks (Friedman, 2007; Mezzacappa et al., 2001; Movius & Allen, 2005; Santucci et al., 2008; Page-Gound et al., 2010; Weissman & Mendes, 2021). Nevertheless, because this finding was not replicated when controlling for baseline HF-HRV, results should be interpreted with caution. Importantly, scholars disagree about whether it is appropriate to control for baseline levels of HF-HRV when predicting HF-HRV difference scores. Some scholars have suggested that its inclusion is important for addressing the Law of Initial Values, whereas others have suggesting that because it's already incorporated into the calculation of HF-HRV difference scores, that further controlling for it may inflate coefficient estimates (Burt & Obradovic, 2013). Few studies to date have reported estimates with and without controlling for baseline values, yet those that have reported estimates from analyses with and without baseline controls have tended to yield comparable results when considering HF-HRV reactivity (Llabre et al., 1991; Rogosa, 1995; Roisman, 2007). No studies have yet compared the effect of controlling for baseline levels when considering HF-HRV recovery. Thus, it may be important for scholars to investigate and clarify whether HF-HRV baseline values should be controlled when considering HF-HRV recovery. Moreover, as previously discussed, the significance of HF-HRV recovery following stress exposure is understudied, and no prior research has examined the degree to which HF-HRV recovery may influence stress-health associations. Replication with larger samples would be essential to derive any conclusive knowledge.

Limitations and Future Directions

The present study had several limitations. First, the small sample size may have limited statistical power to detect significant associations. While psychophysiological research often relies on smaller samples due to more time-consuming protocols (Laborde et al., 2017), replications with larger samples are needed to verify generalizability of current findings. Second, CFS and health complaints are based on self-report, which may be subject to recall inaccuracy. Although we used well-validated, widely used measures to assess these constructs, findings should ideally be replicated using a multi-informant approach (e.g., self, spouse, parent, medical provider).

Third, the cross-sectional design of this study limits our ability to deduce the directionality of hypothesized associations. A longitudinal study design may help elucidate long-term independent and joint effects of CFS and PNS activity on women's health outcomes across development. Fourth, our research focused exclusively on women. Research has identified notable sex differences in PNS activity, including HF-HRV (Koenig et al., 2016). Sex has also been shown to interact with PNS activity in accounting for socioemotional outcomes (e.g., internalizing and externalizing problems; Hinnant & El-Sheikh, 2013; Morales et al., 2015; Vidal-Ribas et al., 2017) and psychological processes (e.g., emotion regulation abilities; Lischke et al., 2019; Zhang et al., 2015). For example, Lischke et al. (2019) have found that higher HF-HRV is associated with cognitive reappraisal (i.e., an emotion regulation strategy) only among male but not female participants. Thus, future research should replicate findings in samples of men, as well as investigate potential sex differences in the effects of CFS and HF-HRV on health.

In addition, our results relied on a sample with relatively good health and low levels of CFS. Thus, findings from this sample may have better reflected the promotive effects of low CFS on health. Although these findings are meaningful, it is possible that they may not generalize to samples with more health problems or higher levels of CFS. It is also important to note that despite the non-clinical nature of the current sample, several participants reported preexisting health conditions and use of medications that have been associated with HF-HRV and perceived health problems in prior research (e.g., asthma, depression, anxiety, posttraumatic stress disorder, use of selective serotonin reuptake inhibitor; antihistamine; Beauchaine, 2016; Franco et al., 2020; Lufti, 2012; Penttilä et al., 2005; van Zyl et al., 2008). Sensitivity analyses excluding these participants resulted in consistent findings as those of primary analyses. In other words, in this sample of young women, preexisting health conditions and medication use appeared to play limited role in the relations between HF-HRV, CFS, and health problems. Future research should replicate current findings in larger, more diverse samples with greater variability in CFS and/or health concerns. Relatedly, we did not ask participants to restrict their caffeine and nicotine intake before attending the lab study and did not assess participants' typical caffeine and nicotine intake. Given caffeine and nicotine have been each been found to influence HRV activity (Quintana et al., 2016), it may be important to replicate results from the current study when controlling for caffeine and nicotine intake.

Lastly, while we tested the effects of BSC in this study, we did not technically test the BSC effects in a range of low to high quality childhood environments. While low CFS may denote more stability and fewer conflicts in the family environment, this may not necessarily encompass characteristics of a high-quality family environment (e.g., high family cohesion, positive parenting). Future research should investigate the role of heightened stress response systems in both stressful, health-compromising, and supportive, health-enhancing conditions, consistent with BSC theory. Notably, our study only measured one index of the frequency domain of HRV (i.e., HF-HRV). Other HRV indices, such as the low frequency HRV, should also be examined to replicate the current findings and better understand the role of autonomic functioning in the association between CFS and health. Lastly, given that PNS and sympathetic nervous system are both major components of autonomic nervous system and works together to regulate bodily functioning, SNS may also play a role in shaping the link between CFS and health. Future studies focused on understanding the CFS-health links should concurrently examine both PNS and sympathetic functioning to form a more comprehensive conclusion.

Conclusion

Current findings highlight the potential role of parasympathetic activity in modulating the associations between CFS and physical health complaints among young women. The results overall suggest that HF-HRV stress reactivity and recovery may represent important intrapersonal markers of susceptibility to poor health outcomes associated with childhood stress (Fagundes et al., 2014; Price & Crowell, 2016). Continued research on how parasympathetic activity and childhood stress exposures may interact to affect physical health may contribute to efforts to identify individuals with greater burden for poor health outcomes and in need of prevention services. Lastly, our findings provide preliminary evidence that supports BSC theory in the context of HF-HRV stress reactivity and diathesis-stress hypothesis in the context of HF-HRV recovery. Results are consistent with the notion that HF-HRV stress reactivity may confer susceptibility to negative and positive influences of CFS on health in a manner consistent with BSC theory, whereas greater

HF-HRV during recovery relative to baseline may amplify the positive effects of low CFS on health. Future research investigating PNS activity indexed during different states (e.g., reactivity and during recovery period) may help to build a more comprehensive understanding of how intrapersonal regulatory attributes interact with environmental stressors to contribute to health outcomes.

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Author Contribution All authors contributed to the study's conception and design. Conceptualization is proposed by LSC. Material preparation and data collection were performed by BL and AJY. Formal data analysis was conducted by AJY. The first draft of the manuscript was written by LSC. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability Due to the sensitive nature of the questions asked in this study, participants were assured raw data would remain confidential and would not be shared.

Declarations

Conflict of interest The authors declare no competing interests.

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