Development and Psychopathology (2024), **36**, 1005–1015
doi:10.1017/S0954579423000251

CAMBRIDGE UNIVERSITY PRESS

Regular Article

An RDoC-based approach to adolescent self-injurious thoughts and behaviors: The interactive role of social affiliation and cardiac arousal

Benjamin W. Nelson, Olivia H. Pollak, Matthew G. Clayton, Eva H. Telzer and Mitchell J. Prinstein
Department of Psychology and Neuroscience, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Abstract

Recent theoretical models have posited that increases in self-injurious thoughts and behaviors (SITBs) during adolescence may be linked to failures in biological stress regulation in contexts of social stress. However, there is a lack of data examining this hypothesis during the transition to adolescence, a sensitive period of development characterized by changes across socioaffective and psychophysiological domains. Building on principles from developmental psychopathology and the RDoC framework, the present study used a longitudinal design in a sample of 147 adolescents to test whether interactions among experiences of social (i.e., parent and peer) conflict and cardiac arousal (i.e., resting heart rate) predicted adolescents' engagement in SITBs (i.e., nonsuicidal self-injury, NSSI; and suicidal ideation; SI) across 1-year follow-up. Prospective analyses revealed that adolescents experiencing a combination of greater peer, but not family, conflict and higher cardiac arousal at baseline showed significant longitudinal increases in NSSI. In contrast, social conflict did not interact with cardiac arousal to predict future SI. Findings indicate that greater peer-related interpersonal stress in adolescents may increase risk for future NSSI among youth with physiological vulnerabilities (i.e., higher resting heart rate) that may be markers of maladaptive stress responses. Future research should examine these processes at finer timescales to elucidate whether these factors are proximal predictors of within-day SITBs.

Keywords: adolescence; cardiac arousal; self-injurious thoughts and behaviors; social stress

(Received 3 February 2022; revised 7 February 2023; accepted 8 February 2023; first published online 8 March 2023)

Introduction

Rates of self-injurious thoughts and behaviors (SITBs) increase dramatically across adolescence (Nock et al., 2008, 2012), with approximately 23% of high school-aged youth endorsing suicidal ideation (i.e., SI; Orri et al., 2020) or nonsuicidal self-injury (i.e., NSSI; Brown & Plener, 2017; CDC, 2019; Peterson et al., 2008). Developmental trajectories of SITBs often include onset of, and transitions among, multiple types of SITBs, including both SI and NSSI. However, studies frequently examine singular SITB outcomes or otherwise consider SITBs as a single construct, making it difficult to identify whether, and which, risk pathways may be specific to particular SITBs. Identifying risk pathways for distinct SITBs in adolescence may aid in understanding the dynamic, potentially transactional developmental progression of SITBs during this period (Oppenheimer et al., 2018).

Interpersonal stress and SITBs in adolescence

Epidemiological data support the relevance of developmental psychopathology approaches for understanding increases in SITBs in adolescence. Consistent with the principle that risk factors may have different effects on functioning based on developmental phase (Cicchetti & Rogosch, 2002), adolescence is characterized by particular changes in socioaffective and biological domains that may increase risk for SITBs during this period. Recent theoretical work posits that adolescent SITBs may occur in the context of failures in stress regulation among adolescents with atypical psychophysiological stress responses, perhaps particularly in response to interpersonally themed stress (Miller & Prinstein, 2019). Indeed, normative social changes in adolescence are associated with increases in interpersonal stress across both familial and peer domains (Collins & Laursen, 2004; Rudolph, 2014), and these experiences, such as peer victimization and poor family cohesion, are associated with both nonsuicidal and suicidal SITB outcomes (King & Merchant, 2008; Massing-Schaffer et al., 2019; Valencia-Agudo et al., 2018).

There is particularly strong evidence for the impact of peer-related stressors on risk for adolescent SITBs. Experiences of peer-related stress such as low peer support, poor quality peer relationships, and peer victimization are associated with both NSSI and SI (Madjar et al., 2017; Tatnell et al., 2014; van Geel et al., 2015; for a review, see Cheek et al., 2020). While more limited, studies examining family stress have also found associations between lower perceived family support or belongingness and NSSI (Tatnell et al., 2014) and SI (Glenn et al., 2022), although family conflict may be more robustly associated with SITBs in younger, preadolescent samples (i.e., 9- and 10-year-olds; DeVille et al., 2020). When examined simultaneously, peer stress (e.g., peer victimization) has been shown to be a stronger predictor of adolescent SITBs than parent or family relational factors (Victor et al., 2019). Indeed, interpersonal stress in these two environments may differentially impact emotional and behavioral functioning in adolescence, as these environments become increasingly separate

Corresponding author: Benjamin W. Nelson, email: bwn@unc.edu

Cite this article: Nelson, B. W., Pollak, O. H., Clayton, M. G., Telzer, E. H., & Prinstein, M. J. (2024). An RDoC-based approach to adolescent self-injurious thoughts and behaviors: The interactive role of social affiliation and cardiac arousal. *Development and Psychopathology* **36**: 1005–1015, https://doi.org/10.1017/S0954579423000251

(Brown, 2013) and the peer environment becomes more salient (Nelson et al., 2016; Somerville, 2013; van den Bos, 2013). Few studies, however, have directly compared experiences of interpersonal stress within peer versus family contexts in relation to distinct SITB outcomes, which may clarify the extent to which interpersonally themed risk for SITBs in adolescence may be particularly elevated when stress is experienced in specific domains (i.e., the peer environment).

Physiological stress reactivity and SITBs

While many adolescents experience significant interpersonal stress and conflict, only a subset go on to experience or engage in SITBs. Adolescence is a period characterized by increased physiological reactivity to stressors compared to childhood and adulthood (Gunnar & Quevedo, 2007; Stroud et al., 2009). Dysregulated physiological arousal and regulatory processes when combined with stressful interpersonal relationships may help explain increases in rates of SITBs during adolescence. Heart rate (HR), measured in beats per minute (bpm), is predominantly influenced by coordination of the sympathetic and parasympathetic branches of the ANS, which activates when an organism faces environmental threat and challenge, including psychosocial stress (Cacioppo et al., 2017). Cardiovascular dysfunction, as reflected by higher cardiac arousal at rest (e.g., high resting HR; see Deutz et al., 2019), has been proposed to be a putative mechanism associated not only with morbidity and mortality (Khan et al., 2015; Qiu et al., 2017; Zhang et al., 2015), but also with a range of psychiatric disorders (Alvares et al., 2015; Clamor et al., 2014; Kandola et al., 2019; Kemp, Brunoni, et al., 2014; Kemp, Quintana, et al., 2014; Latvala et al., 2016; Nelson et al., 2017, 2020, 2022; Paulus et al., 2013) , including SITB (Kaess et al., 2021). Higher resting HR during late adolescence has been shown to be associated with higher risk for adulthood internalizing disorders in a prospective study of over 1 million males (Latvala et al., 2016).

There is also evidence linking cardiovascular functioning, including both HR and heart rate variability (HRV), and SITBs (for a review, see Kang et al., 2020). Among adults, research indicates a direct association between resting HR and completed suicide, independent of depressed mood (Lemogne et al., 2011). Similar cardiovascular patterns (e.g., higher resting HR, lower HRV) are associated with higher suicide risk in large nonclinical and clinical samples with diverse psychiatric presentations (Lee et al., 2021; Chang et al., 2016) and may be associated with SITBs above and beyond covariates such as psychiatric comorbidities (e.g., depression; Chang et al., 2012; Tsypes et al., 2018). While studies in adolescents are fewer, one study found evidence for lower baseline HRV, and greater HRV reactivity during a negative mood induction, among adolescents with histories of self-harm (i.e., including nonsuicidal and/or suicidal self-harm; Crowell et al., 2005). In contrast, similar alterations in cardiac functioning have not been found in other adolescent samples (i.e., youth with NSSI histories; Koenig et al., 2017). Further research is needed to establish whether cardiovascular dysfunction is related to risk for SITBs, including prospectively, and whether these patterns may be specific to certain SITB outcomes (e.g., self-injurious thoughts vs. behaviors, with or without suicidal intent).

Several additional studies in adolescents provide further support for associations between alterations in stress responses, including resting cardiac rate, and risk for psychopathology. Higher resting heart rate was found to be associated with greater internalizing symptoms in a sample of over 5,000 adolescents (Nelson et al., 2022), and related research shows that disrupted hypothalamic–pituitary–adrenal (HPA) axis responses during adolescence are associated with psychopathology, including SITB outcomes (e.g., Eisenlohr-Moul et al., 2018; van Heeringen, 2012; van Heeringen & Mann, 2014). Of note, recent prospective studies show that adolescents' physiological responses to interpersonally themed stress are associated with future SITBs (i.e., 9–18 months later; Giletta et al., 2017; Massing-Schaffer et al., 2019; Miller et al., 2017). In the context of heightened social stress, cardiac regulation (i.e., resting HR) may potentiate risk for SITBs via changes in affect or emotion regulation, as prefrontal and subcortical brain regions that subserve emotional responsivity and regulation also control cardiac responses (Lemogne et al., 2011) and undergo dramatic structural and functional alterations during adolescence (Dahl et al., 2018).

Finally, understanding who engages in SITBs likely involves multiple interacting constructs, such that dysfunctions or disruptions across several processes are implicated in emergence of NSSI or SI. Building on developmental psychopathology perspectives, which emphasize transactions between a person and their environment, physiological (i.e., cardiovascular) dysfunction may predict heightened SITB risk only among adolescents experiencing elevated stress in one (e.g., peer or family) or multiple (e.g., peer and family) interpersonal environments. Additionally, in line with the National Institutes of Health Research Domain Criteria (RDoC; NIH, 2016) framework, examination of transdiagnostic processes assessed across multiple units of analysis (e.g., physiology, self-report) is needed to advance understanding of SITB risk (Glenn et al., 2017, 2018). Alterations in socioemotional and physiological stress responses in adolescence overlap with RDoC's 'social processes' and 'arousal/regulatory systems' domains and offer opportunity to test interactions among social and physiological constructs measured across self-report and objective (i.e., physiology) methods.

The current study

The current prospective longitudinal study tested whether adolescents experiencing socially themed or affiliative stress and heightened baseline arousal/regulation (i.e., cardiac) processes are at elevated risk for future SITBs. Given normative increases in socioemotional sensitivity and recalibration of stress–response systems in adolescence, which may increase vulnerability to stressful experiences, we hypothesized that baseline levels of cardiac arousal/regulation would moderate prospective associations between both peer and family affiliative conflict and SITBs (i.e., SI and/or NSSI). Specifically, we hypothesized that neither greater affiliative conflict nor higher resting HR alone would predict SITBs, but that the combination of these interpersonal and physiological factors would predict greater frequency of SI and/or NSSI over 1-year follow-up. We had no a priori hypotheses regarding differential prediction of SI versus NSSI, as prior work examining cardiovascular functioning and SITBs in adolescence is limited and has yielded mixed findings when examining nonsuicidal and suicidal SITB outcomes (Crowell et al., 2005; Koenig et al., 2017).

Method

Participants

The current study included data from a large scale longitudinal research project conducted from 2017 to 2021. Secondary data

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

Table 1. Participant demographics

Variable	*N*	Percentage	Mean (*SD*)
Age	147		Wave 1, Session 1: 12.34 (0.58)
			Wave 1, Session 2: 12.80 (0.53)
			Wave 2, Session 3: 13.70 (0.53)
Sex			
Female	75	51.02%	
Male	72	48.98%	
Race			
White	44	29.93%	
Black	34	23.13%	
Hispanic/Latino	49	33.33%	
Multiracial	14	9.52%	
Other	6	4.08%	

analysis for the current study came from a total of 147 adolescents (72 males, 48.98%) who completed two sessions of data across 1 year (session 1: $M_{age} = 12.34$, $SD = 0.58$; session 2: $M_{age} = 12.8$, $SD = 0.53$) and 116 adolescents completing data at 2 year (session 3: M_{age} = aged 13.7, $SD = 0.53$; due to attrition; see Table 1 for participant demographics).

Recruitment and assessment procedures

Participants were recruited from a small, diverse, and relatively low socioeconomic status (SES) community in rural North Carolina. Participants were recruited from a larger multiwave longitudinal study including over 830 adolescents. Completion of most of the larger study survey in participant schools at session 1 was a prerequisite for participating in the current study. To be eligible, participants had to be in regular education classes, in the 6th or 7th grade at session 1, and at least 11 years and 10 months old at session 2. Participants were excluded if they had ever been diagnosed with a learning disability, such as dyslexia, ever had a seizure, had head trauma, or if participants had braces, a permanent top retainer, or some kind of permanent dental work at the time, as part of the study required a functional magnetic resonance imaging (fMRI) scan. Parent consent and adolescent assent for the study were obtained prior to participation.

Participation took place in three sessions. Session 1 and 3 took place in school, 1 year apart, during which participants completed measures of SITBs. Participants that completed the school assessment at session 1 and met criteria for participation were invited to participate in one lab assessment at session 2 to fill out a survey that asked questions about health, friends, and family, and collected baseline cardiac measurements. The first and last school assessments were separated by an average of 11.28 months ($SD = 0.20$). Sessions 1 and 2 occurred within the same year and are referred to hereafter as Wave 1 (W1). Session 3 is referred to as Wave 2 (W2). Primary reasons for attrition at W2 included students' withdrawal from the study, school transitions (e.g., withdrawal, transfer, graduation), and scheduling conflicts.

Measures

Interpersonal conflict

Peer and family conflict were collected using the Multicultural, multidimensional assessment of parent–adolescent conflict (Ruiz et al., 1998) at W1 (session 2). The measure consists of 8 items that were asked of both close friends and family over the past month including, "You and your friends/family disagreed with each other," "You and your friends/family ignored each other," "You and your friends/family had a serious argument or fight," and "You and your friends/family yelled or raised your voices at each other" and were rated on a Likert scale ranging from 1 (Almost never) to 5 (Almost always). This measure had acceptable reliability for peer ($\alpha = 0.89$) and family ($\alpha = 0.90$) conflict.

SITB

Nonsuicidal self-injury. NSSI frequency was assessed at W1 (session 1) and W2 using a questionnaire adapted from prior research (Prinstein et al., 2008). Items assessed frequency of engagement in five NSSI behaviors without intent to die in the past year (i.e., "Cut or carved my skin on purpose," "Hit myself on purpose," "Inserted objects under my nails or skin on purpose," "Burned my skin on purpose," "Scraped or picked at skin to the point of drawing blood") on a 5-point scale (0 = *Never*, 1 = *1–2 times*, 2 = *3–5 times*, 3 = *6–9 times*, and 4 = *10 or more times*). NSSI frequency was computed as a total score.

Suicidal ideation. Suicidal ideation frequency was assessed using the SQ-N (Heilbron & Prinstein, 2010) at W1 (session 1) and W2. Participants rated the frequency they had experienced eight types of suicidal thoughts in the past year (i.e., "I thought about death," "I thought about how I would kill myself," "I thought that killing myself would solve my problems," "I wished I had the nerve to kill myself," "I thought about telling people I plan to kill myself," "I thought my life was too rotten to continue," "I thought it would be better if I were not alive," and "I wished I were dead") on a 5-point scale (0 = *Never*, 1 = *A few times*, 2 = *Couple times per month*, 3 = *About once per week*, and 4 = *Almost every day*). SI frequency was computed as a total score.

Pubertal development scale

Participants completed the Pubertal Development Scale (PDS) at W1, which is a self-report measure that uses pictures depicting body hair growth, voice change, and facial hair growth for males and body hair growth, breast development, and menarche for females in order to categorize participants on a range from prepubertal to postpubertal and has been shown to have good reliability (Petersen et al., 1988).

Socioeconomic status

Parents completed a 9-item scale at W1 assessing the extent to which they had experienced difficulties meeting their economic needs in the prior 3 months (Conger et al., 2002). Items included questions pertaining to payment of bills (e.g., "How much difficulty did you have paying your bills?") rated on a 5-point scale (0 = *No difficulty at all*, 4 = *A great deal of difficulty*), as well as questions assessing the extent to which statements about basic necessities pertained to them (e.g., "You had enough money to afford the kind of food you needed," "You had enough money to afford the kind of utilities (e.g., electricity, phone, gas, water) you needed") rated on a 5-point scale (0 = *Not true at all*, 4 = *Very true).* These latter items were reverse scored. This questionnaire has been shown to have good reliability (Tsai et al., 2013).

Heart rate

Resting HR was collected at W1 (session 2) and measured in beats per minute and collected using the LifeSource UB-351 Wrist

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

Digital Blood Pressure Monitor that conforms to the European Directive 93/42 EEC for Medical Products and is used for diagnostic purposes (AND, 2021). Prior to single measurement, participants were asked to sit up straight with their legs uncrossed and their feet flat on the floor. The device was placed around participants' left wrist and they were asked to rest their elbow on a table and have their arm up, so that their wrist was at heart level. Heart rate was recorded after participants had been sitting for at least 5 min.

Covariates

We collected PDS, gender, race, and SES as potential covariates. In addition, we controlled for NSSI and SI at W1, in respective models. We only used covariates that were significantly associated with outcome variables to prevent overfitting. Specifically, we controlled for PDS in NSSI models, while we controlled for PDS and gender in SI models.

Statistical analyses

All statistical analyses were conducted with R Studio, version 4.0.2. Statistical significance was defined using 95% confidence intervals and p-values $< .05$. Exploratory analyses including histograms as well as skew and kurtosis statistics were run for each variable to check for normality. SITB measures were winsorized to ± 3 SD to correct for outliers. Peer and family conflict measures were log10 transformed to correct for skew. Peer/Family conflict and resting HR were centered in the interaction model to reduce potential for multicollinearity (Jaccard et al., 1990).

2.8% of data were missing from the final sample, ranging from 0% (age) to 10.88% (SI). To assess whether data were missing completely at random (MCAR) we performed parametric ($p < 0.001$) and nonparametric ($p = 0.638$) tests using the MissMech package (Jamshidian et al., 2014). Despite that data were not MCAR, based on recent recommendations (Matta et al., 2018), in order to account for missing data, we used multiple imputation (100 imputations) using the mice package (van Buuren, 2020) (see Supplemental Material for missing data by variable).

To conduct analyses, we ran a series of models, including nonhierarchical negative binomial models using the MASS package (Ripley et al., 2020) to examine the associations between measures of social conflict, resting HR, and SITB. In addition, we ran zero-inflation Poisson and hurdle models (see Supplementary Material) using the pscl package (Jackman, 2020). In models, we examined peer conflict, parent conflict, resting HR, peer conflict × resting HR, and parent conflict × resting HR as simultaneous predictors of SITB outcomes after controlling for relevant covariates. We ran two separate models based on SITB outcomes, one for NSSI and one for SI. We specifically chose negative binomial models as the main hypotheses required interaction effects. As described in depth by McCabe et al. (2020), nonlinear and count models require special considerations that have to be taken into account when interpreting interaction effects in generalized linear models, and the description of nonlinear probabilities and counts are not equal to the product terms between predictor variables as is the case for linear approaches (McCabe et al., 2020). Therefore, linear models may be inappropriate for evaluating nonlinear and count outcomes and tend to violate assumptions of heteroscedastic and non-normal residual values, as these variables are discrete quantities that are bounded by zero and take on integer values. In order to take the nontraditional approach outlined by McCabe et al. (2020) that allows for the appropriate examination of interaction effects in generalized linear models of nonlinear probabilities and counts, we used the modglm package, which is currently compatible with negative binomial, but not zero-inflation Poisson or hurdle models. This package defines interactions as the change in a marginal effect of one variable as a function of change in another variable with the use of partial derivatives and discrete differences to quantify these effects (McCabe et al., 2020). Furthermore, this package provides a graphical depiction of the interaction point estimates computed observation-wise that are plotted against the model predicted outcome (Hanmer & Ozan Kalkan, 2013; McCabe et al., 2020; Norton et al., 2004). The interaction effect was probed and plotted using marginal effects with the ggeffects package (Lüdecke et al., 2020). All models were adjusted for relevant covariates that were significantly associated with outcome variables to prevent overfitting, which included PDS for NSSI models and PDS and SES for SI models.

Results

Descriptive statistics

Descriptive statistics for primary study variables are presented in Table 2. At W1, 52 participants (35.37%) endorsed NSSI and 60 participants (40.82%) endorsed SI. There was not a significant association at W1 between HR and NSSI ($r = -0.02$, $p = 0.784$) or SI ($r = -0.02$, $p = 0.812$). There was no significant difference in resting HR for participants that endorsed either NSSI or SI compared to participants that did not endorse NSSI or SI ($p < 0.05$). At W2, 40 participants (27.21%) endorsed NSSI and 63 participants (42.86%) endorsed SI. As shown in Figure 1, NSSI ($t(274.93) = 1.77$, $p = 0.077$) and SI ($t(289.30) = -0.66$, $p = 0.508$) trajectories were stable across waves.

NSSI model

In main effect models, peer conflict, family conflict, and resting HR at W1 were not associated with NSSI at W2 (see Table 3). Similarly, there was not a significant interaction between family conflict and resting HR at W1 on NSSI at W2 (see Table 4) after controlling for NSSI at W1 and PDS. In contrast, as shown in Table 4 and Figure 2, there was a significant positive interaction between peer conflict and resting HR at W1 on NSSI at W2, after controlling for NSSI at W1 and PDS, such that the combination of higher peer conflict and higher resting HR was associated with greater NSSI at W2, even after controlling for multiple comparisons ($p = 0.021$). This model explained a substantial amount of the variance in NSSI ($R^2 = 0.48$). The interaction was probed and indicated that the interaction effect was significant at the hypothetical mean of all predictor variables ($\beta = 0.080$, $SE = 0.021$, $t = 3.875$, 95% CI [0.040, 0.120]), indicating that the marginal effect of peer conflict on NSSI was stronger among those with higher resting HR. The average interaction effect across observations also was significant ($\beta = 0.150$, $SE = 0.054$, 95% CI [0.045, 0.256]). The interaction effect ranged from −0.02 to 1.68 across observations. The marginal effect of peer conflict on NSSI was stronger among those with higher HR across the sample and was statistically different from zero 61.90% of the time with 98.00% of the interactions positive and 2.00% of the interactions negative. Figure 3 shows the interaction point estimates computed observation-wise plotted against the model predicted outcome.

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

Table 2. Descriptive statistics

Variable	Wave	Male		Female		White	Black	Hispanic/Latino	Multi-racial	Other
		N (%)	Range	*N* (%)	Range	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
NSSI	W1	17 (11.56%)	0–12	35 (23.81%)	0–20	0.98 (.38)	2.15 (.44)	1.08 (.68)	0.14 (.68)	0.33 (1.04)
	W2	17 (11.56%)	0–4	23 (15.65%)	0–14	0.80 (.35)	1.47 (.39)	0.61 (.33)	0.57 (.61)	0.17 (.94)
SI	W1	24 (16.33%)	0–32	36 (24.49%)	0–32	1.75 (.74)	2.32 (.85)	2.06 (.70)	0.36 (1.32)	3.67 (2.01)
	W2	22 (14.97%)	0–32	41 (27.89%)	0–26	2.02 (.74)	2.91 (.85)	1.71 (.70)	1.29 (1.32)	0.17 (2.01)
		M (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Heart rate	W1	78.00 (12.80)	50–123	84.30 (13.2)**	59–116	79.9 (2.01)	79.9 (2.28)	84.4 (1.90)	77.8 (3.56)	80.7 (5.44)
Peer conflict	W1	1.62 (0.62)	1–3.38	1.63 (0.63)	1–4.25	1.54 (.09)	1.87 (.11)	1.54 (.09)	1.54 (.16)	1.75 (.25)
Family conflict	W1	1.86 (0.86)	1–4.38	1.91 (0.71)	1–4.5	2.00 (.12)	1.84 (.14)	1.90 (.11)	1.53 (.21)	2.04 (.32)

Note. For NSSI and SI variables by gender, counts (N) reflect the number of participants who endorsed NSSI and SI, and percentages (%) reflect percentages of the total sample. Where reported, ranges reflects the range of values for each variable prior to winsorizing and log transformation. NSSI = nonsuicidal self-injury; SI = suicidal ideation; W1 = Wave 1; W2 = Wave 2; **p < .01; ***p < .001.

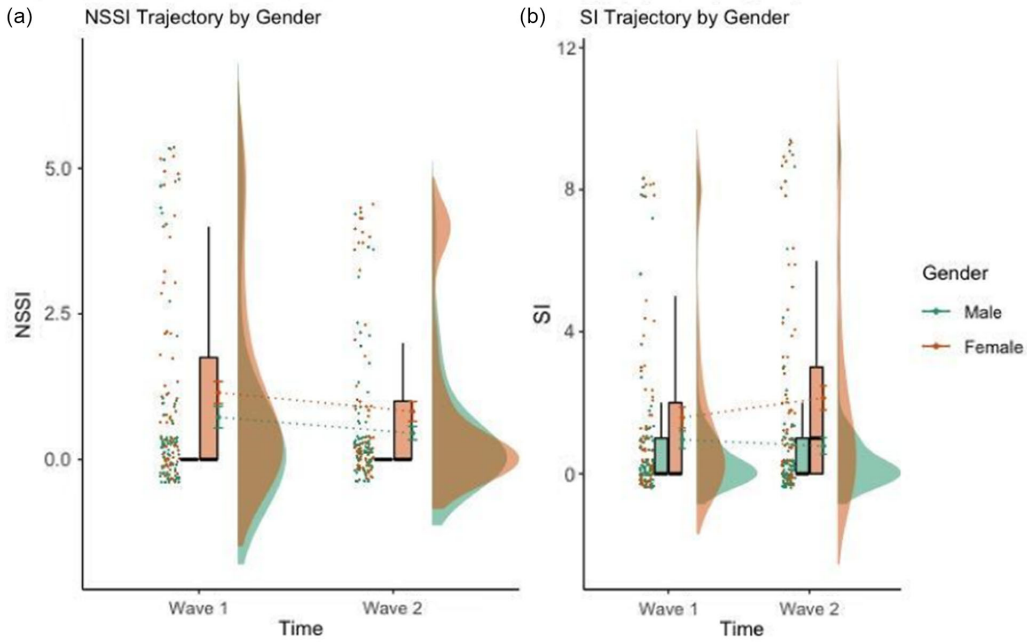

Figure 1. NSSI and SI trajectories by gender. *Note.* Figure shows raw data as individual points, distribution density of observed values, and boxplot. NSSI = non-suicidal self-injury; SI = suicidal ideation; all values are winsorized; green = males; red = females.

SI model

In main effect models, peer conflict, family conflict, and resting HR at W1 were not associated with SI at W2 (see Table 5). Interactions of peer conflict and of family conflict with resting HR at W1 were not significantly associated with SI at W2 (see Table 5).

Discussion

Building on RDoC and developmental psychopathology frameworks, the current study investigated whether interactions among interpersonal and physiological stress-related vulnerabilities in adolescence were associated with nonsuicidal and suicidal SITBs longitudinally. Specifically, we investigated whether adolescents' experiences of interpersonal stress (i.e., affiliative conflict) across peers and family domains, in combination with heightened physiological arousal/regulation (i.e., baseline cardiac arousal), predicted greater frequency of NSSI and SI 1 year later. Results provided partial support for hypotheses.

Consistent with hypotheses, social conflict (i.e., peer or family) and resting HR were not associated with SITBs in main effects analyses, suggesting that neither greater affiliative conflict nor heightened cardiac arousal/regulation processes alone are sufficient to predict adolescents' future engagement in SITBs. Interpersonal difficulties, including conflict with peers or family, are implicated in onset or maintenance of NSSI and SI across theoretical (Joiner, 2005; Nock & Prinstein, 2004; Van Orden et al., 2010) and empirical work (Adrian et al., 2011; Glenn et al., 2022; Oppenheimer et al., 2018; Prinstein et al., 2009; Turner et al., 2016), but relatively few longitudinal studies have examined the temporal sequence of these associations. Regarding NSSI, for example, engagement in NSSI itself may lead to escalations in interpersonal (i.e., family or peer) conflict. One study found that

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

Table 3. Main effect models

A. NSSI	Peer conflict				Family conflict				Resting heart rate			
Predictors	Log-mean	Std. error	CI	*p*-value	Log-mean	Std. error	CI	*p*-value	Log-mean	Std. error	CI	*p*-value
(Intercept)	−2.016	0.672	−3.333 to −0.698	**0.003**	−2.535	0.699	−3.905 to −1.165	**<0.001**	−2.061	1.299	−4.607 to 0.485	0.113
Peer Conflict	−2.141	1.189	−4.472 to 0.190	0.072								
NSSI W1	0.500	0.089	0.326 to 0.674	**<0.001**	0.430	0.086	0.262 to 0.598	**<0.001**	0.442	0.085	0.276 to 0.608	**<0.001**
PDS	0.441	0.256	−0.060 to 0.942	0.085	0.466	0.261	−0.045 to 0.977	0.074	0.445	0.263	−0.070 to 0.960	0.090
Family Conflict					0.678	1.008	−1.298 to 2.654	0.501				
Resting Heart Rate									−0.003	0.013	−0.028 to 0.022	0.799
Observations	147				147				147			
R^2 Nagelkerke	0.396				0.372				0.368			
B. SI	Peer conflict				Family conflict				Resting heart rate			
Predictors	Log-mean	Std. error	Conf. int (95%)	*p*-value	Log-mean	Std. error	Conf. int (95%)	*p*-value	Log-mean	Std. error	Conf. int (95%)	*p*-value
(Intercept)	−1.268	0.667	−2.575 to 0.040	0.057	−1.622	0.570	−2.739 to −0.506	**0.004**	−2.562	1.139	−4.795 to −0.328	**0.025**
Peer Conflict	−0.258	0.242	−0.731 to 0.216	0.286								
SI W1	0.190	0.057	0.077 to 0.302	**0.001**	0.180	0.058	0.067 to 0.293	**0.002**	0.186	0.056	0.076 to 0.297	**0.001**
PDS	0.522	0.234	0.063 to 0.981	**0.026**	0.517	0.236	0.054 to 0.980	**0.029**	0.604	0.240	0.133 to 1.075	**0.012**
Gender	0.555	0.300	−0.033 to 1.144	0.064	0.494	0.301	−0.095 to 1.084	0.100	0.480	0.314	−0.135 to 1.094	0.126
Family Conflict					0.422	0.895	−1.333 to 2.177	0.637				
Resting Heart Rate									0.009	0.011	−0.013 to 0.031	0.429
Observations	147				147				147			
R^2 Nagelkerke	0.299				0.291				0.296			

Table 4. Social conflict, resting heart rate, and NSSI

	Negative binomial		
Predictors	Log-mean	Std. error	*p*-value
(Intercept)	−2.383	0.666	**<0.001**
Peer conflict (centered)	−2.395	1.227	0.051
Resting heart rate (centered)	0.004	0.013	0.781
Family conflict (centered)	0.191	0.203	0.345
NSSI W1	0.515	0.087	**<0.001**
PDS	0.370	0.255	0.147
Peer conflict × resting heart rate	0.232	0.091	**0.010**
Family conflict × resting heart rate	−0.006	0.012	0.607
Observations	147		
R^2 Nagelkerke	0.478		

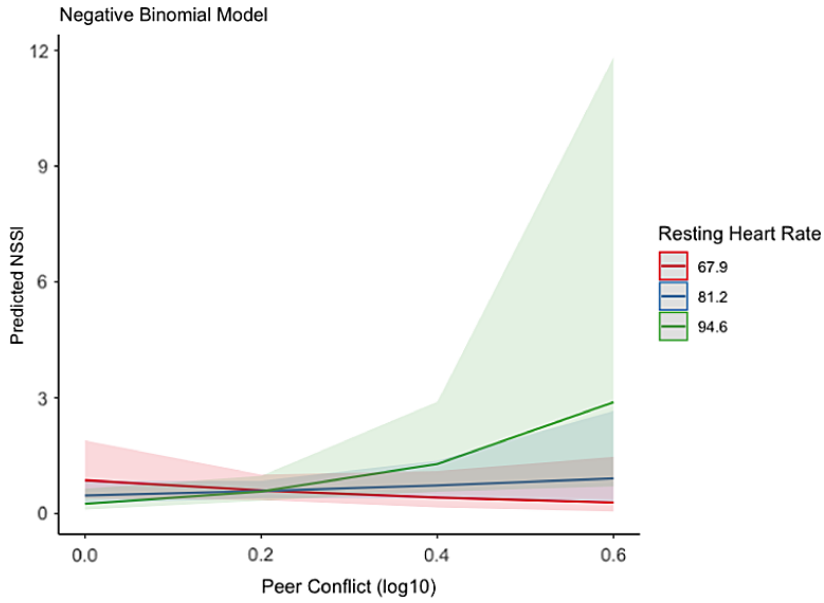

Figure 2. Resting heart rate moderates the effect of peer conflict on NSSI.

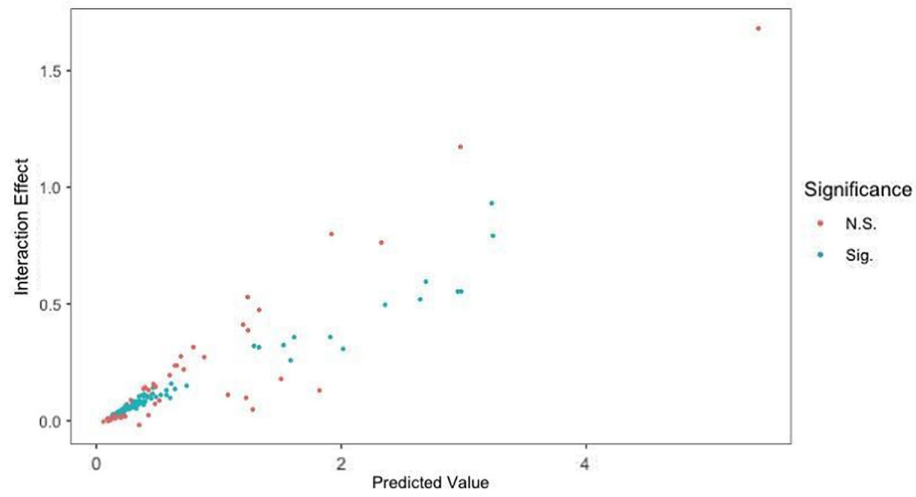

Figure 3. Interaction point estimates computed observation-wise plotted against the model predicted outcome.

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

Table 5. Social conflict, resting heart rate, and SI

	Negative binomial		
Predictors	Log-mean	Std. error	*p*-value
(Intercept)	−1.898	0.578	**0.001**
Peer conflict (centered)	−1.579	1.051	0.133
Resting heart rate (centered)	0.009	0.012	0.420
Family conflict (centered)	0.203	0.194	0.294
SI W1	0.194	0.059	**0.001**
PDS	0.623	0.240	**0.010**
Gender	0.457	0.314	0.146
Peer conflict × resting heart rate	−0.006	0.081	0.944
Family conflict × resting heart rate	0.005	0.012	0.661
Observations	147		
R^2 Nagelkerke	0.318		

individuals who disclosed engagement in NSSI, and thus may have experienced interpersonal reinforcement for NSSI, also reported more frequent NSSI (Turner et al., 2016). This suggests a potentially complex or cyclical relationship between interpersonal conflict and NSSI over time that may not emerge in main effects models, and which may require consideration of both aversive (i.e., conflict) and desirable (i.e., support) interpersonal contingencies. It is likely that mechanisms linking interpersonal conflict with development of suicidal outcomes such as SI are similarly complex, such that additional risk or protective factors (e.g., parent history of SI; Oppenheimer et al., 2018;) should be considered when examining risk prospectively. Alternatively, interpersonal conflict may predict subsequent NSSI or SI over short timescales (e.g., minutes, hours, or days; Czyz et al., 2019; Turner et al., 2016) but may be more weakly associated with SITBs over longer time periods (e.g., 1 year), as tested in this investigation.

Our findings shed light on a potentially more complicated picture of the relationship between interpersonal stress and SITB risk by showing that social conflict is associated with increased risk for some types of SITBs only in conjunction with biological vulnerabilities. As hypothesized, the interaction between peer conflict and resting HR at baseline significantly predicted greater frequency of NSSI, but not SI, at follow-up, such that adolescents who experienced greater peer conflict and who exhibited a higher resting HR were at greater risk for NSSI across 1 year of early adolescence. This finding replicated across negative binomial, zero-inflation poisson, and hurdle models and is consistent with a cross-sectional study that found that adolescents with deficiencies in serotonergic functioning, in conjunction with interpersonal dysfunctions (i.e., negative parent–child dyadic interactions), were at heightened risk for self-injurious outcomes (i.e., a composite SITB variable, including NSSI and suicide attempts; Crowell et al., 2008). Our longitudinal finding provides temporal specificity by demonstrating that an interaction of biological vulnerabilities (i.e., cardiac arousal) and interpersonal difficulties (i.e., peer conflict) may precede subsequent engagement in NSSI in adolescence. In contrast, the interaction of peer conflict with cardiac arousal was not associated with SI. The combination of greater peer conflict and higher HR may be specifically associated with NSSI given the potential of NSSI behaviors to provide immediate changes in physiological indices of arousal (Franklin et al., 2010), which may be pertinent for individuals with higher baseline levels of cardiac arousal.

Recent theoretical work posits that adolescents' SITBs may be most likely to occur in the context of failures in acute stress regulation (Miller & Prinstein, 2019), and our finding suggests that similar mechanisms may underlie risk for nonsuicidal (i.e., NSSI) outcomes longitudinally. Findings from developmental affective neuroscience suggest that neural changes during puberty may increase adolescents' sensitivity to their social environment (Casey et al., 2008), which may underlie increased physiological reactivity to stressors (Stroud et al., 2009), prolonged stress response recovery (Gunnar et al., 2009; Stroud et al., 2009), and deficits in cognitive control in response to emotionally evocative stimuli (Cohen et al., 2016; Somerville et al., 2011). The pubertal transition is also associated with significant changes in peer relationships and increases in peer-related stressors (Prinstein & Giletta, 2016), which are often associated with SITBs among adolescents (Juvonen & Graham, 2014; King & Merchant, 2008; Massing-Schaffer et al., 2019). Higher cardiac arousal may be a marker of maladaptive physiological stress responses that, for adolescents experiencing greater stress in the peer environment, increases risk for engagement in NSSI behaviors, which may serve to regulate aversive physiological or affective responses to interpersonal stress (Franklin et al., 2010; Nock & Mendes, 2008).

Although the study had a number of significant strengths, including prospective prediction of both NSSI and SI in a diverse sample of adolescents, results should be interpreted in light of several limitations. First, rather than using gold-standard electrocardiogram, the current study used one single measurement of resting HR with the LifeSource UB-351 Wrist Digital Blood Pressure Monitor. While the device conforms to the European Directive 93/42 EEC for Medical Products and is used for diagnostic purposes, future research should use an electrocardiogram or wearable device to record multiple measures of HR during a resting baseline to ensure accurate values (Nelson & Allen, 2019). Second, our measure of SI captured both passive and active ideation in a community sample (i.e., passive consideration of not being alive, as well as more serious consideration of acting on suicidal thoughts), and prediction of more acute ideation severity may yield different effects. Third, although analyses were adjusted for covariates, we did not correct for other potentially relevant covariates (e.g., medications, BMI, health conditions, sleep, physical activity, depressive symptoms, perceived stress, smoking status) for which data were not collected. Fourth, the sample size was not significantly larger than other studies on adolescent SITB. Future studies should make sure to recruit larger sample sizes. Fifth, we used a limited assessment of SITB by focusing on SI and NSSI and results may not generalize to adolescents along the spectrum of SITBs (especially to those who are engaging in suicidal behaviors). Future research should make sure to examine multiple aspects of SITB. Lastly, results from our large, diverse adolescent sample may improve understanding of SITB risk in the general adolescent population but may not generalize to high-risk or clinically acute samples.

Conclusion

This longitudinal study tested theoretical conceptualizations of SITBs as potential responses to social stress in adolescence, specifically among adolescents exhibiting physiological vulnerabilities (i.e., heightened baseline arousal/regulation) that may be markers

https://doi.org/10.1017/S0954579423000251 Published online by Cambridge University Press

of maladaptive stress responses. Findings indicated that peer-related stressors may increase vulnerability for subsequent engagement in one type of self-injurious behavior (i.e., NSSI) among adolescents with biological vulnerabilities (e.g., heightened cardiac arousal) that may indicate increased physiological sensitivity to stress in the social environment. In contrast, the interaction of family conflict with cardiac arousal was not associated with SITBs, consistent with evidence that developmental changes may render conflict with peers, specifically, a particularly salient and impactful stressor in adolescence (Nelson et al., 2016; Somerville, 2013). Interactions among social (i.e., peer-environmental) and biological (i.e., individual-level) vulnerabilities may be specific to nonsuicidal self-injurious behaviors (vs. suicidal thoughts), as neither peer conflict, cardiac arousal, nor their interaction were associated with SI. Promoting positive peer relationships and increasing social support systems, perhaps especially among adolescents with heightened physiological arousal/regulatory processes, may protect against onset of some types of SITBs in adolescence.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0954579423000251

Funding statement. Preparation of this manuscript was supported by grants from the National Institute of Mental Health to Mitchell J. Prinstein (R01 MH107479) and Eva H. Telzer (R01 DA039923), as well as grants from the NSF to Eva H. Telzer (BCS 1539651) and Matthew G. Clayton (1000255141).

Conflicts of interest. None.

References

AND (2021). *LifeSource UB-351 Wrist Digital Blood Pressure Monitor Manual*. A & D Medical. https://www.aandd.jp/products/manual/medical/ub351_en.pdf

Adrian, M., Zeman, J., Erdley, C., Lisa, L., & Sim, L. (2011). Emotional dysregulation and interpersonal difficulties as risk factors for nonsuicidal self-injury in adolescent girls. *Journal of Abnormal Child Psychology*, *39*(3), 389–400. https://doi.org/10.1007/s10802-010-9465-3

Alvares, G. A., Quintana, D. S., Hickie, I. B., & Guastella, A. J. (2015). Autonomic nervous system dysfunction in psychiatric disorders and the impact of psychotropic medications: A systematic review and meta-analysis. *Journal of Psychiatry & Neuroscience*, *40*(6), 1–16. https://doi.org/10.1503/jpn.140217

Brown, B. B. (2013). Adolescents' relationships with peers. In R. Lerner, & L. Steinberg (Eds.), *Handbook of adolescent psychology* (2nd ed., pp. 363–394). Wiley.

Brown, R. C., & Plener, P. L. (2017). Non-suicidal self-injury in adolescence. *Current Psychiatry Reports*, *19*(3), 20. https://doi.org/10.1007/s11920-017-0767-9

Cacioppo, J. T., Tassinary, L. G., & Berntson, G. G. (Eds.) (2017). *Handbook of psychophysiology* (4th ed.). Cambridge University Press. https://doi.org/10.1017/9781107415782

Casey, B. J., Jones, R. M., & Hare, T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences*, *1124*(1), 111–126. https://doi.org/10.1196/annals.1440.010

CDC (2019). *Youth Risk Behavior Surveillance System (YRBSS)*. CDC. https://www.cdc.gov/healthyyouth/data/yrbs/index.htm

Chang, H. A., Chang, C. C., Chen, C. L., Kuo, T. B., Lu, R. B., & Huang, S. Y. (2012). Major depression is associated with cardiac autonomic dysregulation. *Acta Neuropsychiatrica*, *24*(6), 318–327. https://doi.org/https://doi.org10.1111/j.1601-5215.2011.00647.x

Chang, S. S., Bjørngaard, J. H., Tsai, M. K., Bjerkeset, O., Wen, C. P., Yip, P. S., & Gunnell, D. (2016). Heart rate and suicide: Findings from two cohorts of 533 000 Taiwanese and 75 000 Norwegian adults. *Acta Psychiatrica Scandinavica*, *133*(4), 277–288. https://doi.org/10.1111/acps.12513

Cheek, S. M., Reiter-Lavery, T., & Goldston, D. B. (2020). Social rejection, popularity, peer victimization, and self-injurious thoughts and behaviors among adolescents: A systematic review and meta-analysis. *Clinical Psychology Review*, *82*, 101936. https://doi.org/10.1016/j.cpr.2020.101936

Cicchetti, D., & Rogosch, F. A. (2002). A developmental psychopathology perspective on adolescence. *Journal of Consulting and Clinical Psychology*, *70*(1), 6–20. https://doi.org/https://doi.org

Clamor, A., Hartmann, M. M., Köther, U., Otte, C., Moritz, S., & Lincoln, T. M. (2014). Altered autonomic arousal in psychosis: An analysis of vulnerability and specificity. *Schizophrenia Research*, *154*(1-3), 73–78. https://doi.org/10.1016/j.schres.2014.02.006

Cohen, A. O., Dellarco, D. V., Breiner, K., Helion, C., Heller, A. S., Rahdar, A., Pedersen, G., Chein, J., Dyke, J. P., Galvan, A., & Casey, B. (2016). The impact of emotional states on cognitive control circuitry and function. *Journal of Cognitive Neuroscience*, *28*(3), 446–459. https://doi.org/10.1162/jocn_a_00906

Collins, W. A., & Laursen, B. (2004). Parent-adolescent relationships and influences. In: *Handbook of adolescent psychology* (2nd ed., pp. 331–361). John Wiley & Sons, Inc. https://doi.org/10.1002/9780471726746

Conger, R. D., Wallace, L. E., Sun, Y., Simons, R. L., McLoyd, V. C., & Brody, G. H. (2002). Economic pressure in African American families: A replication and extension of the family stress model. *Developmental Psychology*, *38*(2), 179–193. https://doi.org/10.1037/0012-1649.38.2.179

Crowell, S. E., Beauchaine, T. P., McCauley, E., Smith, C. J., Stevens, A. L., & Sylvers, P. (2005). Psychological, autonomic, and serotonergic correlates of parasuicide among adolescent girls. *Development and Psychopathology*, *17*(4), 1105–1127. https://doi.org/10.1017/S0954579405050522

Crowell, S. E., Beauchaine, T. P., McCauley, E., Smith, C. J., Vasilev, C. A., & Stevens, A. L. (2008). Parent-child interactions, peripheral serotonin, and self-inflicted injury in adolescents. *Journal of Consulting and Clinical Psychology*, *76*(1), 15–21. https://doi.org/10.1037/0022-006X.76.1.15

Czyz, E. K., Horwitz, A. G., Arango, A., & King, C. A. (2019). Short-term change and prediction of suicidal ideation among adolescents: A daily diary study following psychiatric hospitalization. *Journal of Child Psychology and Psychiatry*, *60*(7), 732–741. https://doi.org/10.1111/jcpp.12974

Dahl, R. E., Allen, N. B., Wilbrecht, L., & Suleiman, A. B. (2018). Importance of investing in adolescence from a developmental science perspective. *Nature*, *554*(7693), 441–450. https://doi.org/10.1038/nature25770

Deutz, M. H. F., Woltering, S., Vossen, H. G. M., Deković, M., van Baar, A. L., & Prinzie, P. (2019). Underlying psychophysiology of dysregulation: Resting heart rate and heart rate reactivity in relation to childhood dysregulation. *Journal of the American Academy of Child & Adolescent Psychiatry*, *58*(6), 589–599. https://doi.org/10.1016/j.jaac.2018.09.434

DeVille, D. C., Whalen, D., Breslin, F. J., Morris, A. S., Khalsa, S. S., Paulus, M. P., & Barch, D. M. (2020). Prevalence and family-related factors associated with suicidal ideation, suicide attempts, and self-injury in children aged 9 to 10 years. *JAMA Network Open*, *3*(2), e1920956. https://doi.org/10.1001/jamanetworkopen.2019.20956

Eisenlohr-Moul, T. A., Miller, A. B., Giletta, M., Hastings, P. D., Rudolph, K. D., Nock, M. K., & Prinstein, M. J. (2018). HPA axis response and psychosocial stress as interactive predictors of suicidal ideation and behavior in adolescent females: A multilevel diathesis-stress framework. *Neuropsychopharmacology*, *43*(13), 2564–2571. https://doi.org/10.1038/s41386-018-0206-6

Franklin, J. C., Hessel, E. T., Aaron, R. V., Arthur, M. S., Heilbron, N., & Prinstein, M. J. (2010). The functions of nonsuicidal self-injury: Support for cognitive-affective regulation and opponent processes from a novel psychophysiological paradigm. *Journal of Abnormal Psychology*, *119*(4), 850–862.

Giletta, M., Hastings, P. D., Rudolph, K. D., Bauer, D. J., Nock, M. K., & Prinstein, M. J. (2017). Suicide ideation among high-risk adolescent females: Examining the interplay between parasympathetic regulation and friendship support. *Development and Psychopathology*, *29*(4), 1–15. https://doi.org/10.1017/S0954579416001218

Glenn, C. R., Cha, C. B., Kleiman, E. M., & Nock, M. K. (2017). Understanding suicide risk within the Research Domain Criteria (RdoC) framework: Insights, challenges, and future research considerations.

Clinical Psychological Science, *5*(3), 568–592. https://doi.org/10.1177/2167702616686854

Glenn, C. R., Kleiman, E. M., Cha, C. B., Deming, C. A., Franklin, J. C., & Nock, M. K. (2018). Understanding suicide risk within the Research Domain Criteria (RdoC) framework: A meta-analytic review. *Depression and Anxiety*, *35*(1), 65–88. https://doi.org/10.1002/da.22686

Glenn, C. R., Kleiman, E. M., Kandlur, R., Esposito, E. C., & Liu, R. T. (2022). Thwarted belongingness mediates interpersonal stress and suicidal thoughts: An intensive longitudinal study with high-risk adolescents. *Journal of Clinical Child and Adolescent Psychology*, *51*(3), 295–311. https://doi.org/10.1080/15374416.2021.1969654

Gunnar, M., & Quevedo, K. (2007). The neurobiology of stress and development. *Annual Review of Psychology*, *58*(1), 145–173. https://doi.org/10.1146/annurev.psych.58.110405.085605

Gunnar, M. R., Wewerka, S., Frenn, K., Long, J. D., & Griggs, C. (2009). Developmental changes in hypothalamus-pituitary–adrenal activity over the transition to adolescence: Normative changes and associations with puberty. *Development and Psychopathology*, *21*(1), 69–85. https://doi.org/10.1017/S0954579409000054

Hanmer, M. J., & Ozan Kalkan, K. (2013). Behind the curve: Clarifying the best approach to calculating predicted probabilities and marginal effects from limited dependent variable models. *American Journal of Political Science*, *57*(1), 263–277. https://doi.org/10.1111/j.1540-5907.2012.00602.x

Heilbron, N., & Prinstein, M. (2010). Adolescent peer victimization, peer status, suicidal ideation, and nonsuicidal self-injury: Examining concurrent and longitudinal associations. *Merrill-Palmer Quarterly*, *56*(3), 388–419. https://doi.org/10.1353/mpq.0.0049

Jaccard, J., Wan, C. K., & Turrisi, R. (1990). The detection and interpretation of interaction effects between continuous variables in multiple regression. *Multivariate Behavioral Research*, *25*(4), 467–478. https://doi.org/10.1207/s15327906mbr2504_4

Jackman, S. (2020). *Pscl* (1.5.5) [Computer software]. https://cran.r-project.org/web/packages/pscl/index.html

Jamshidian, M., Jalal, S., & Jansen, C. (2014). MissMech: An R package for testing homoscedasticity, multivariate normality, and missing completely at random (MCAR). *Journal of Statistical Software*, *56*(6). https://doi.org/10.18637/jss.v056.i06

Joiner, T. E. (2005). *Why people die by suicide*. Harvard University Press.

Juvonen, J., & Graham, S. (2014). Bullying in schools: The power of bullies and the plight of victims. *Annual Review of Psychology*, *65*(1), 159–185. https://doi.org/10.1146/annurev-psych-010213-115030

Kaess, M., Hooley, J. M., Klimes-Dougan, B., Koenig, J., Plener, P. L., Reichl, C., & Cullen, K. R. (2021). Advancing a temporal framework for understanding the biology of nonsuicidal self-injury: An expert review. *Neuroscience & Biobehavioral Reviews*, *130*, 228–239. https://doi.org/10.1016/j.neubiorev.2021.08.022

Kandola, A., Ashdown-Franks, G., Stubbs, B., Osborn, D. P. J., & Hayes, J. F. (2019). The association between cardiorespiratory fitness and the incidence of common mental health disorders: A systematic review and meta-analysis. *Journal of Affective Disorders*, *257*, 748–757. https://doi.org/10.1016/j.jad.2019.07.088

Kang, G. E., Patriquin, M. A., Nguyen, H., Oh, H., Rufino, K. A., Storch, E. A., & Najafi, B. (2020). Objective measurement of sleep, heart rate, heart rate variability, and physical activity in suicidality: A systematic review. *Journal of Affective Disorders*, *273*, 318–327. https://doi.org/10.1016/j.jad.2020.03.096

Kemp, A. H., Brunoni, A. R., Santos, I. S., Nunes, M. A., Dantas, E. M., De Figueiredo, R. C., Pereira, A. C., Ribeiro, A. L. P., Mill, J. G., Andreão, R. V., Thayer, J. F., Benseñor, I. M., & Lotufo, P. A. (2014). Effects of depression, anxiety, comorbidity, and antidepressants on resting-state heart rate and its variability: An ELSA-Brasil cohort baseline study. *American Journal of Psychiatry*, *171*(12), 1328–1334. https://doi.org/10.1176/appi.ajp.2014.13121605

Kemp, A. H., Quintana, D. S., Quinn, C. R., Hopkinson, P., & Harris, A. W. F. (2014). Major depressive disorder with melancholia displays robust alterations in resting state heart rate and its variability: Implications for future morbidity and mortality. *Frontiers in Psychology*, *5*, 1–9. https://doi.org/10.3389/fpsyg.2014.01387

Khan, H., Kunutsor, S., Kalogeropoulos, A. P., Georgiopoulou, V. V., Newman, A. B., Harris, T. B., Bibbins-Domingo, K., Kauhanen, J., Gheorghiade, M., Fonarow, G. C., Kritchevsky, S. B., Laukkanen, J. A., & Butler, J. (2015). Resting heart rate and risk of incident heart failure: Three prospective cohort studies and a systematic meta-analysis. *Journal of the American Heart Association*, *4*(1), e001364. https://doi.org/10.1161/JAHA.114.001364

King, C. A., & Merchant, C. R. (2008). Social and interpersonal factors relating to adolescent suicidality: A review of the literature. *Archives of Suicide Research*, *12*(3), 181–196. https://doi.org/10.1080/13811110802101203

Koenig, J., Rinnewitz, L., Parzer, P., Resch, F., Thayer, J. F., & Kaess, M. (2017). Resting cardiac function in adolescent non-suicidal self-injury: The impact of borderline personality disorder symptoms and psychosocial functioning. *Psychiatry Research*, *248*, 117–120. https://doi.org/10.1016/j.psychres.2016.12.024

Latvala, A., Kuja-Halkola, R., Rück, C., D'Onofrio, B. M., Jernberg, T., Almqvist, C., Mataix-Cols, D., Larsson, H., & Lichtenstein, P. (2016). Association of resting heart rate and blood pressure in late adolescence with subsequent mental disorders: A longitudinal population study of more than 1 million men in Sweden. *JAMA Psychiatry*, *73*(12), 1268. https://doi.org/10.1001/jamapsychiatry.2016.2717

Lee, D., Baek, J. H., Cho, Y. J., & Hong, K. S. (2021). Association of resting heart rate and heart rate variability with proximal suicidal risk in patients with diverse psychiatric diagnoses. *Frontiers in Psychiatry*, *12*, 652340. https://doi.org/10.3389/fpsyt.2021.652340

Lemogne, C., Thomas, F., Consoli, S. M., Pannier, B., Jégo, B., & Danchin, N. (2011). Heart rate and completed suicide: Evidence from the IPC cohort study. *Psychosomatic Medicine*, *73*(9), 731–736. https://doi.org/10.1097/PSY.0b013e3182365dc7

Lüdecke, D., Aust, F., Crawley, S., & Ben-Shachar, M. (2020). *Ggeffects: Create Tidy Data Frames of Marginal Effects* (1.0.1) [Computer software]. https://cran.r-project.org/web/packages/ggeffects/index.html

Madjar, N., Ben Shabat, S., Elia, R., Fellner, N., Rehavi, M., Rubin, S. E., Segal, N., & Shoval, G. (2017). Non-suicidal self-injury within the school context: Multilevel analysis of teachers' support and peer climate. *European Psychiatry*, *41*(1), 95–101. https://doi.org/10.1016/j.eurpsy.2016.11.003

Massing-Schaffer, M., Helms, S. W., Rudolph, K. D., Slavich, G. M., Hastings, P. D., Giletta, M., Nock, M. K., & Prinstein, M. J. (2019). Preliminary associations among relational victimization, targeted rejection, and suicidality in adolescents: A prospective study. *Journal of Clinical Child & Adolescent Psychology*, *48*(2), 288–295. https://doi.org/10.1080/15374416.2018.1469093

Matta, T. H., Flournoy, J. C., & Byrne, M. L. (2018). Making an unknown unknown a known unknown: Missing data in longitudinal neuroimaging studies. *Developmental Cognitive Neuroscience*, *33*, 83–98. https://doi.org/10.1016/j.dcn.2017.10.001

McCabe, C., Halvorson, M. A., King, K. M., Cao, X., & Kim, D. S. (2020). Interpreting interaction effects in generalized linear models of nonlinear probabilities and counts [Preprint]. *PsyArXiv*. https://doi.org/10.31234/osf.io/th94c

Miller, A. B., Eisenlohr-Moul, T., Giletta, M., Hastings, P. D., Rudolph, K. D., Nock, M. K., & Prinstein, M. J. (2017). A within-person approach to risk for suicidal ideation and suicidal behavior: Examining the roles of depression, stress, and abuse exposure. *Journal of Consulting and Clinical Psychology*, *85*(7), 712–722. https://doi.org/10.1037/ccp0000210

Miller, A. B., & Prinstein, M. J. (2019). Adolescent suicide as a failure of acute stress-response systems. *Annual Review of Clinical Psychology*, *15*(1), 425–450. https://doi.org/10.1146/annurev-clinpsy-050718-095625

Nelson, B. W., & Allen, N. B. (2019). Accuracy of consumer wearable heart rate measurement during an ecologically valid 24-hour period: Intraindividual validation study. *JMIR Mhealth and Uhealth*, *7*(3), e10828. https://doi.org/10.2196/10828

Nelson, B. W., Byrne, M. L., Sheeber, L., & Allen, N. B. (2017). Does context matter? A multi-method assessment of affect in adolescent depression across multiple affective interaction contexts. *Clinical Psychological Science*, *5*(2), 239–258. https://doi.org/10.1177/2167702616680061

Nelson, B. W., Flannery, J. E., Flournoy, J., Duell, N., Prinstein, M. J., & Telzer, E. (2022). Concurrent and prospective associations between fitbit wearable-derived RdoC arousal and regulatory constructs and adolescent internalizing symptoms. *Journal of Child Psychology and Psychiatry*, *63*(3), 282–295. https://doi.org/10.1111/jcpp.13471

Nelson, B. W., Sheeber, L., Pfeifer, J., & Allen, N. B. (2020). Psychobiological markers of allostatic load in depressed and nondepressed mothers and their adolescent offspring. *Journal of Child Psychology and Psychiatry*, *62*(2), 199–211. https://doi.org/10.1111/jcpp.13264

Nelson, E. E., Jarcho, J. M., & Guyer, A. E. (2016). Social re-orientation and brain development: An expanded and updated view. *Developmental Cognitive Neuroscience*, *17*, 118–127. https://doi.org/10.1016/j.dcn.2015.12.008

NIH (2016). *Mechanisms underlying suicide risk: Integrating RdoC to inform novel and personalized intervention research*. https://www.nimh.nih.gov/news/events/2016/mechanisms-underlying-suicide-risk/index.shtml

Nock, M., Borges, G., & Ono, Y. (2012). *Suicide: Global perspectives from the WHO World Mental Health Surveys*. Cambridge University Press.

Nock, M. K., Borges, G., Bromet, E. J., Cha, C. B., Kessler, R. C., & Lee, S. (2008). Suicide and suicidal behavior. *Epidemiologic Reviews*, *30*(1), 133–154. https://doi.org/10.1093/epirev/mxn002

Nock, M. K., & Mendes, W. B. (2008). Physiological arousal, distress tolerance, and social problem-solving deficits among adolescent self-injurers. *Journal of Consulting and Clinical Psychology*, *76*(1), 28–38.

Nock, M. K., & Prinstein, M. J. (2004). A functional approach to the assessment of self-mutilative behavior. *Journal of Consulting and Clinical Psychology*, *72*(5), 885–890. https://doi.org/10.1037/0022-006X.72.5.885

Norton, E. C., Wang, H., & Ai, C. (2004). Computing interaction effects and standard errors in logit and probit models. *The Stata Journal: Promoting Communications on Statistics and Stata*, *4*(2), 154–167. https://doi.org/10.1177/1536867X0400400206

Oppenheimer, C. W., Stone, L. B., & Hankin, B. L. (2018). The influence of family factors on time to suicidal ideation onsets during the adolescent developmental period. *Journal of Psychiatric Research*, *104*, 72–77. https://doi.org/https://doi.org

Orri, M., Scardera, S., Perret, L. C., Bolanis, D., Temcheff, C., Séguin, J. R., Boivin, M., Turecki, G., Tremblay, R. E., Côté, S. M., & Geoffroy, M.-C. (2020). Mental health problems and risk of suicidal ideation and attempts in adolescents. *Pediatrics*, *146*(1), e20193823. https://doi.org/10.1542/peds.2019-3823

Paulus, E. J., Argo, T. R., & Egge, J. A. (2013). The impact of posttraumatic stress disorder on blood pressure and heart rate in a veteran population. *Journal of Traumatic Stress*, *26*(1), 169–172. https://doi.org/10.1002/jts.21785

Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, *17*(2), 117–133. https://doi.org/10.1007/BF01537962

Peterson, J., Freedenthal, S., Sheldon, C., & Andersen, R. (2008). Nonsuicidal self injury in adolescents. *Psychiatry (Edgmont (Pa.: Township))*, *5*(11), 20–26.

Prinstein, M., & Giletta, M. (2016). Peer relations and developmental psychopathology. In D. Cicchetti (Ed.), *Developmental psychopathology* (pp. 527–579). Wiley.

Prinstein, M. J., Guerry, J. D., Browne, C. B., & Rancourt, D. (2009). Interpersonal models of nonsuicidal self-injury. In M. K. Nock (Ed.), *Understanding nonsuicidal self-injury: Origins, assessment, and treatment* (pp. 79–98). American Psychological Association. https://doi.org/10.1037/11875-005

Prinstein, M. J., Nock, M. K., Simon, V., Aikins, J. W., Cheah, C. S. L., & Spirito, A. (2008). Longitudinal trajectories and predictors of adolescent suicidal ideation and attempts following inpatient hospitalization. *Journal of Consulting and Clinical Psychology*, *76*(1), 92–103. https://doi.org/10.1037/0022-006X.76.1.92

Qiu, S., Cai, X., Sun, Z., Li, L., Zuegel, M., Steinacker, J. M., & Schumann, U. (2017). Heart rate recovery and risk of cardiovascular events and all-cause mortality: A meta-analysis of prospective cohort studies. *Journal of the American Heart Association*, *6*(5). https://doi.org/10.1161/JAHA.117.005505

Ripley, B., Venables, B., Bates, D., Hornik, K., Gebhardt, A., & Firth, D. (2020). *MASS* (7.3-53) [Computer software]. https://cran.r-project.org/web/packages/MASS/index.html

Rudolph, K. D. (2014). Puberty as a developmental context of risk for psychopathology. In Lewis Eds., & K. D. Rudolph (Eds.), *Handbook of developmental psychopathology* (pp. 331–354). Springer.

Ruiz, S., Gonzales, N., & Formoso, D. (1998). *Multicultural, multidimensional assessment of parent-adolescent conflict*. Society for Research on Adolescence.

Somerville, L. H. (2013). The teenage brain: Sensitivity to social evaluation. *Current Directions in Psychological Science*, *22*(2), 121–127. https://doi.org/10.1177/0963721413476512

Somerville, L. H., Hare, T., & Casey, B. J. (2011). Frontostriatal maturation predicts cognitive control failure to appetitive cues in adolescents. *Journal of Cognitive Neuroscience*, *23*(9), 2123–2134. https://doi.org/10.1162/jocn.2010.21572

Stroud, L. R., Foster, E., Papandonatos, G. D., Handwerger, K., Granger, D. A., Kivlighan, K. T., & Niaura, R. (2009). Stress response and the adolescent transition: Performance versus peer rejection stressors. *Development and Psychopathology*, *21*(1), 47–68. https://doi.org/10.1017/S0954579409000042

Tatnell, R., Kelada, L., Hasking, P., & Martin, G. (2014). Longitudinal analysis of adolescent NSSI: The role of intrapersonal and interpersonal factors. *Journal of Abnormal Child Psychology*, *42*(6), 885–896. https://doi.org/10.1007/s10802-013-9837-6

Tsai, K. M., Telzer, E. H., Gonzales, N. A., & Fuligni, A. J. (2013). Adolescents' daily assistance to the family in response to maternal need: Daily assistance to the family. *Journal of Marriage and Family*, *75*(4), 964–980. https://doi.org/10.1111/jomf.12035

Tsypes, A., James, K. M., Woody, M. L., Feurer, C., Kudinova, A. Y., & Gibb, B. E. (2018). Resting respiratory sinus arrhythmia in suicide attempters. *Psychophysiology*, *55*(2), e12978. https://doi.org/10.1111/psyp.12978

Turner, B. J., Cobb, R. J., Gratz, K. L., & Chapman, A. L. (2016). The role of interpersonal conflict and perceived social support in nonsuicidal self-injury in daily life. *Journal of Abnormal Psychology*, *125*(4), 588–598. https://doi.org/10.1037/abn0000141

Valencia-Agudo, F., Burcher, G. C., Ezpeleta, L., & Kramer, T. (2018). Nonsuicidal self-injury in community adolescents: A systematic review of prospective predictors, mediators and moderators. *Journal of Adolescence*, *65*(1), 25–38. https://doi.org/10.1016/j.adolescence.2018.02.012

van Buuren, S. (2020). *mice: Multivariate Imputation by Chained Equations* (3.12.0) [Computer software]. https://cran.r-project.org/web/packages/mice/index.html

van den Bos, W. (2013). Neural mechanisms of social reorientation across adolescence. *Journal of Neuroscience*, *33*(34), 13581–13582. https://doi.org/10.1523/JNEUROSCI.2667-13.2013

van Geel, M., Goemans, A., & Vedder, P. (2015). A meta-analysis on the relation between peer victimization and adolescent non-suicidal self-injury. *Psychiatry Research*, *230*(2), 364–368. https://doi.org/10.1016/j.psychres.2015.09.017

van Heeringen, K. (2012). Stress-diathesis model of suicidal behavior. In Y. Dwivedi (Ed.), *The neurobiological basis of suicide*. CRC Press/Taylor & Francis. https://www.ncbi.nlm.nih.gov/books/NBK107203/

van Heeringen, K., & Mann, J. J. (2014). The neurobiology of suicide. *The Lancet Psychiatry*, *1*(1), 63–72. https://doi.org/10.1016/S2215-0366(14)70220-2

Van Orden, K. A., Witte, T. K., Cukrowicz, K. C., Braithwaite, S. R., Selby, E. A., & Joiner, T. E., Jr (2010). The interpersonal theory of suicide. *Psychological Review*, *117*(2), 575–600. https://doi.org/10.1037/a0018697

Victor, S. E., Hipwell, A. E., Stepp, S. D., & Scott, L. N. (2019). Parent and peer relationships as longitudinal predictors of adolescent non-suicidal self-injury onset. *Child and Adolescent Psychiatry and Mental Health*, *13*(1), 1. https://doi.org/10.1186/s13034-018-0261-0

Zhang, D., Shen, X., & Qi, X. (2015). Resting heart rate and all-cause and cardiovascular mortality in the general population: A meta-analysis. *CMAJ*, *188*(3), 1–11. https://doi.org/10.1503/cmaj.150535/-/DC1