Title: An RDoC-Based Approach to Adolescent Self-Injurious Thoughts and Behaviors: The Interactive Role of Social Affiliation and Cardiac Arousal

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Abstract

Self-injurious thoughts and behaviors (SITB) increase dramatically across adolescence. Despite the prevalence and severity of these outcomes, remarkably little research has elucidated why adolescence represents a particularly high-risk period for the emergence of SITB. Recent theoretical models have posited that SITB may result from failures in biological stress regulation in the context of social stress. However, there is a lack of data examining these associations during the transition to adolescence, a sensitive period of development that is characterized by changes across socio-affective and psychophysiological domains that may interact to heighten risk for SITB. The present study used a prospective longitudinal design among 147 adolescents. We built on advantages offered by the RDoC framework to test the interaction of experiences of social conflict (i.e., parent and peer conflict) with cardiac arousal (i.e., resting heart rate) to predict adolescent non-suicidal self-injury (NSSI) and suicidal ideation (SI) across one year. Longitudinal analyses revealed that while neither greater peer conflict nor higher cardiac arousal at baseline were associated with SITB outcomes at follow-up, adolescents experiencing the combination of greater peer conflict and higher cardiac arousal at baseline showed significant longitudinal increases in NSSI at follow-up. In addition, there were null effects for family conflict and SI outcomes. Findings indicate that youth with greater peer conflict and heightened arousal during the transition to adolescence may be at increased risk for NSSI. Future research should examine these processes at finer timescales in order to elucidate whether these factors are proximal predictors of within-day SITB.

Keywords: Adolescence, Self-Injurious Thoughts and Behaviors, Social Stress, Cardiac Arousal

General Scientific Summaries

This prospective longitudinal study examined SITB as a potential response to socially-themed or affiliative stress among adolescents, specifically when adolescents exhibited heightened resting cardiac arousal. Findings indicated that adolescents experiencing the combination of greater peer conflict and heightened cardiac arousal showed significantly greater NSSI behaviors compared to their peers with lower peer conflict or cardiac arousal.

Introduction

Adolescence is a developmental period partly characterized by increased socioemotional sensitivity and recalibration of stress-response systems during which changes across socio-affective and psychophysiological domains may increase vulnerability to stressful experiences and heighten risk for psychopathology, including self-injurious thoughts and behaviors (SITB; Dahl et al., 2018; Gunnar & Quevedo, 2007; Nelson et al., 2017; Stroud et al., 2009). Rates of SITB, including suicidal ideation (SI) and non-suicidal self-injury (NSSI), increase dramatically across adolescence (Nock et al., 2012; Nock et al., 2008), with approximately 23% of high-school aged teens endorsing SI (Orri et al., 2020) and/or NSSI (Brown & Plener, 2017; CDC, 2019; Peterson et al., 2008). Despite the prevalence and severity of these outcomes, research over the past 50 years has largely examined the same set of risk factors, most of which show weak predictive validity for SITB (Franklin et al., 2017; Nock, 2009; Zalsman et al., 2016). Further, remarkably little research has elucidated why adolescence represents a particularly high-risk period for the emergence of SITB, as reflected by an absence of adolescent-specific suicide theories and a relative lack of empirical work in adolescent, compared to adult, samples (Franklin et al., 2017; Miller & Prinstein, 2019).

Recent theoretical work suggests that adolescent SITB may occur in the context of failures in stress regulation, perhaps especially in reaction to interpersonally-themed stress. These models adopt a developmental approach to explain adolescent SITB within the context of unique changes in social and physiological processes during this period, positing that SITB may occur following acute social stressors, especially among adolescents with atypical psychophysiological responses to stress (Miller & Prinstein, 2019).

During adolescence there is a social reorientation from parents to peers (Nelson et al., 2016; van den Bos, 2013) as socioemotional information from peer relationships becomes more salient (Somerville, 2013). This reorientation may result in interpersonally themed stress across both familial and peer domains, with particularly salient implications for SITB, as these behaviors often follow experiences of socially-themed stress (King & Merchant, 2008; Massing-Schaffer et al., 2019). For example, peer stressors have been consistently associated with NSSI. Greater peer victimization (Valencia-Agudo et al., 2018; van Geel et al., 2015), lower perceived peer support (Tatnell et al., 2014), and lower quality peer relationships (Madjar et al., 2017) are associated with higher levels of NSSI. In contrast to research on peer risk factors, studies examining family stress and NSSI are limited (Victor et al., 2019), though some research suggests lower perceived family support may be associated with onset and maintenance of NSSI over time (Tatnell et al., 2014). When peer and family predictors have been examined simultaneously, research has shown that while both peer and parent relational factors predicted new NSSI onset, only peer stress (e.g., peer victimization) predicted new NSSI onset when included in the same model (Victor et al., 2019). Taken together, this research indicates that peer stress may be a particularly potent social stressor that increases risk for SITB, but few studies have directly compared experiences of interpersonal stress within peer versus family contexts as risk factors for adolescent SITB (Tatnell et al., 2014; Victor et al., 2019). In light of calls from suicide researchers for new formal suicide theories and greater precision of theoretical components (Millner et al., 2020), examining specific *sources* of social stress in adolescence may improve granularity of “social processes” associated with SITB risk.

While many adolescents experience significant interpersonal stress and conflict, only a subset go on to engage in SITB. Physiological processes, including arousal and regulatory

processes, represent an intriguing target of study as normative processes whose disruption or interaction with changes in other domains (e.g., interpersonal stressors) may help explain why some adolescents are at heightened risk for SITB as adolescence is associated with increased physiological reactivity to stressors when compared to childhood and adulthood (Stroud et al., 2009). Heart rate (HR), measured in beats per minute (bpm), is predominantly influenced by the coordination of the sympathetic and parasympathetic branches of the ANS, which activates when an organism faces environmental threat and challenge as well as 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; B. W. Nelson et al., 2017, 2020; Paulus et al., 2013). Indeed, disrupted patterns of physiological response are implicated in psychopathology and SITB outcomes (e.g., Eisenlohr-Moul et al., 2018; van Heeringen, 2012; van Heeringen & Mann, 2014). Emerging research suggests that adolescents' physiological responses to socially-themed stress are prospectively associated with adolescent girls' SITB 9 to 18 months later (Giletta et al., 2017; Massing-Schaffer et al., 2019; Miller et al., 2017). Among adults, research indicates a direct association between resting HR and completed suicide, independent of depressed mood (Lemogne et al., 2011); other studies have shown associations between reduced heart rate variability (HRV), which can be reflected as increased resting HR, and adult female suicide attempts, even after controlling for psychiatric status history and current symptoms (Tsypes et al., 2018). In the context of heightened social stress, baseline cardiac regulation (i.e., resting HR) may potentiate risk for SITB via changes in

affect or emotion regulation. However, relatively little research has examined whether or how disruptions in physiological regulatory systems may increase SITB risk in adolescence (Glenn et al., 2017).

Finally, understanding who engages in SITB likely involves multiple interacting constructs, such that dysfunctions or disruptions across several processes are implicated in the onset of SI or NSSI. These socioemotional and stress-response changes that partly characterize the transition to adolescence overlap with the National Institutes of Health Research Domain Criteria (RDoC) domains of Social Processes and Arousal/Regulatory Systems, and prior work provides robust support for associations of these domains with SITB, including in adolescent samples (Glenn et al., 2017, 2018; NIH, 2016). Therefore, we build on the RDoC framework as an organizing structure for examining how the interaction of multiple transdiagnostic units of analysis may increase risk for adolescent SITB.

Current Study

The current prospective longitudinal study examined SITB as a potential response to socially-themed or affiliative stress among adolescents exhibiting heightened baseline arousal/regulation (i.e., cardiac) processes. 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 will moderate the prospective associations between both peer and family affiliative conflict and SITB (i.e., SI and/or NSSI) across time. Specifically, we hypothesized that neither greater affiliative conflict nor higher resting HR alone would predict SITB, but instead that the combination of greater affiliative conflict combined with higher resting HR would be associated with greater incidence of SI and/or NSSI. We had no a priori hypotheses

regarding differential prediction of SI versus NSSI outcomes, as the extent to which these outcomes share a common etiology or risk factors requires further empirical study (Nock, 2010; Whitlock et al., 2013).

Materials and Methods

Participants.

The current study included data from a large-scale longitudinal research project conducted from 2017 to 2021. Secondary data analysis for the current study came from a total of 147 adolescents (72 males, 48.98%) who completed 2 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.

All participants were recruited from a small, relatively low socioeconomic status (SES), diverse, rural community in 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 (metal), 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 3 sessions. Session 1 and 3 took place in school, one year apart,

during which participants completed measures of SITB. 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 ($SD = 0.20$). As session 1 and 2 both occurred within the same year, for the remainder of the study they will be referred to as Wave 1 (W1), while session 3 will be referred to as Wave 2 (W2).

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 friend/family ignored each other,” “You and your friend/family had a serious argument or fight,” and “You and your friend/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 and was based on past research (Prinstein et al., 2008) with 5 questions, including “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,” and “Scraped or picked at skin to the point of drawing blood” with each item specifying “without intending to die.” Participants selected from 5 response

options including, 0 (never), 1 (1-2 times), 2 (3-5 times), 3 (6-9 times), and 4 (10 or more times). A total score was computed for the NSSI measure.

Suicidal Ideation. Participants completed the SQ-N (Heilbron & Prinstein, 2010) to assess SI at W1 (session 1) and W2, which included 8 item including, “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.” Participants selected from a 5 response options including, 0 (never), 1 (a few times), 2 (couple times per month), 3 (about once per week), and 4 (almost every day). A total score was computed for the SI measure.

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 to assess the extent to which they had experienced any difficulties meeting their economic needs over the last 3 months (Conger et al., 2002). Parents completed responded to questions such as “How much difficulty did you have paying your bills” (0 = *no difficulty at all*, 4 = *a great deal of difficulty*), “You had enough money to afford the kind of food you needed” and “You had enough money to afford the kind of utilities (e.g., electricity, phone, gas, water) you needed” (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 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 minutes.

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 non-hierarchical 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 x resting HR, and parent conflict x 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), count models require special considerations that have to be taken into account when interpreting interaction effects in generalized linear models as the description of 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 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. Therefore, in order to take the non-traditional 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 had to use 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). Interaction effects are presented relative to the hypothetical mean value across variables as is the prevailing approach as well as an average interaction effect that describes the interaction for the whole sample, which can be used to infer about the population of interest as has been recommended by recent research. 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 (Lüdtke 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.

As shown in Figure 1, there was significant variability in both NSSI and SI trajectories from W1 to W2. Specifically, there was a slight insignificant decrease in NSSI ($t(274.93) = 1.77$, $p = 0.077$) and SI ($t(289.30) = -0.66$, $p = 0.508$) across waves. See Table 2 for differences by gender and race among all study variables.

NSSI Model.

In main effect models, there was not a significant association between peer conflict, parent conflict or resting HR at W1 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 count 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 count 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.

SI Model.

In main effect models, there were no significant associations between peer conflict, family conflict, or resting HR at W1 with SI at W2 (see Table 5). The interaction between peer conflict and resting HR and family conflict and resting HR at W1 were not significantly associated with SI at W2 (see Table 5).

Discussion

The current study investigated the interaction of two RDoC domains (i.e., social and arousal/regulatory processes) in predicting SITB among adolescents. Specifically, we investigated whether adolescents' experiences of socially-themed or affiliative conflict with

peers and family, in combination with heightened baseline arousal/regulation (i.e., cardiac arousal), predicted SI and NSSI longitudinally. Results provided partial support for hypotheses.

Consistent with hypotheses, there were no significant main effect associations between social conflict (peer or family) or resting HR with either NSSI or SI, suggesting that neither greater affiliative conflict nor heightened cardiac arousal/regulation processes alone are sufficient to explain adolescents' engagement in SITB. While initially perplexing, given interpersonal theories of NSSI, specifically, which suggest that interpersonal difficulties may contribute to onset or maintenance of NSSI (Nock & Prinstein, 2004; Prinstein et al., 2009), as well as prior empirical findings showing associations between both family and peer interpersonal conflict and NSSI in adolescents (e.g., Adrian et al., 2011; Turner et al., 2016), a majority of prior work has been cross-sectional, leaving uncertain how or why interpersonal conflict may be related to NSSI engagement. It may be that engagement in NSSI leads to escalation in interpersonal (i.e., family or peer) conflict, which might explain our insignificant findings. Indeed, few studies have examined whether interpersonal or social conflict temporally precedes occurrence of NSSI in adolescence, and our findings suggest that social conflict in itself may not be a robust risk factor for NSSI, at least over longer timescales. Alternatively, while prospective studies are rare, a few recent investigations have shown associations between interpersonal conflict and subsequent NSSI over short timescales (Turner et al., 2016), suggesting that interpersonal conflict may be a proximal predictor of NSSI but may be weakly associated with NSSI over longer time periods, as tested in this investigation. Further, recent work using daily diary methodology has shown associations between adolescents' NSSI behaviors and proximal increases in social support. Interestingly, Turner and colleagues (2016) found that individuals who disclosed engagement in NSSI, and thus experienced potential interpersonal reinforcement

for NSSI, also reported more frequent NSSI over the study period, pointing to a potentially complex and multifaceted, or perhaps even cyclical, relationship between interpersonal conflict, interpersonal support, and NSSI over time. The relationship between interpersonal factors and NSSI engagement may be more complex than main effects models testing only interpersonal conflict and understanding these associations may instead involve examining both aversive (i.e., conflict) and desirable (i.e., support) interpersonal contingencies.

Indeed, our findings shed light on a potentially more complicated picture of associations between interpersonal difficulties and NSSI risk by suggesting that social conflict may be significantly associated with increased risk for later NSSI only in conjunction with biological vulnerabilities. As hypothesized, the interaction between peer conflict and resting HR at baseline significantly predicted increased NSSI, but not SI, at follow-up, such that greater peer conflict combined with higher resting HR was prospectively associated with greater NSSI across one year of early adolescence. This result replicated across negative binomial, zero-inflation poisson, and hurdle models. This finding is aligned with another investigation that found evidence for an interaction between biological vulnerabilities and interpersonal conflict in predicting NSSI in adolescents. Crowell and colleagues (2008) found that adolescents exhibiting deficiencies in serotonergic functioning, in conjunction with interpersonal dysfunctions (i.e., specifically, negative parent-child dyadic interactions), were at heightened risk for self-injurious outcomes (i.e., a composite outcome variable, including both NSSI and suicide attempts). While this study was cross-sectional, leaving open the possibility that NSSI may influence negative familial interaction patterns and serotonergic levels over time, our longitudinal findings provide additional specificity in elucidating a temporal relationship between the interaction of biological vulnerabilities (i.e., cardiac arousal) and interpersonal difficulties (i.e., peer conflict) in elevating

risk for *future* NSSI in adolescence. While this particular interaction of biological and social factors did not predict SI, this finding nevertheless provides further support for an interactive role of physiological and social processes in predicting some SITB outcomes, as well as RDoC as a helpful framework for identifying mechanisms across domains that may be jointly implicated in SITB.

The significant interaction between peer stress and physiological arousal in predicting NSSI is also aligned, though indirectly, with recent theoretical work suggesting that *suicidal* self-injurious thoughts and behaviors may be most likely to occur in the context of failures in acute stress regulation (Miller & Prinstein, 2019). This work draws on findings from clinical and developmental psychology, as well as affective neuroscience, to posit that the adolescent transition is marked by person-environment interactions that heighten risk for SITB. For example, recent advances in developmental affective neuroscience suggest that adolescents experience neural changes during puberty that increase sensitivity to their social environment (Casey et al., 2008). These neural changes may make adolescents more vulnerable to social perturbations and may underlie findings showing increased physiological responses to stressors (Stroud et al., 2009) and deficits in cognitive control in response to emotionally evocative stimuli among adolescents (Cohen et al., 2016; Somerville et al., 2011). Meanwhile, the pubertal transition is also associated with significant changes in peer relationships, including increases in number and frequency of peer interactions, as well as parent-child conflict (Prinstein & Giletta, 2016). Normative changes in peer relations in adolescence, including new forms of peer status and opportunities for emotionally intimate dyadic peer experiences (e.g., friendships, romantic relationships), often represent significant sources of stress; notably, peer-related stressors

represent some of the most frequently cited precipitants of suicidal behaviors among adolescents (Juvonen & Graham, 2014; King & Merchant, 2008; Massing-Schaffer et al., 2019).

While discussed in the context of suicidal outcomes, similar processes may be at play when considering our findings, whereby interactions between biological vulnerabilities and changes in peer relations in adolescence may increase sensitivity to social stressors and likelihood of engagement in self-injurious behaviors. Indeed, we found evidence for the combination of peer-related stress (e.g., peer conflict) and biological vulnerabilities (e.g., cardiac arousal) as predictors of NSSI. A growing body of work suggests adolescents are both more physiologically reactive to stressors and exhibit prolonged stress response recovery (Gunnar et al., 2009; Stroud et al., 2009). Our finding builds on this, suggesting that adolescents experiencing peer conflict may be most likely to engage in NSSI behaviors if they also exhibit higher baseline levels of cardiac arousal. While cardiac arousal was operationalized as resting heart rate rather than in direct response to stress, this physiological index nevertheless points to associations between heightened basal levels of physiological arousal and SITB. In contrast to hypotheses, the interaction of peer conflict and cardiac arousal was not associated with SI. Associations of these constructs with NSSI, but not SI, might suggest that these processes are specific to, or more robustly predictive of, self-injurious *behaviors*, rather than self-injurious *thoughts*, or to non-suicidal, rather than suicidal, outcomes.

Limitations and Future Directions

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, thus collapsing across ideation severity to include both adolescents who passively considered not being alive, as well as adolescents who seriously considered acting on suicidal thoughts. This may have resulted in lack of specificity in capturing a more acutely suicidal outcome measure of suicidal ideation, although recent work has suggested that passive and active ideation may be surprisingly similar in terms of psychological and other characteristics often associated with suicide risk (Liu et al., 2020).

Conclusion

This prospective longitudinal study examined SITB as a potential response to social stress among adolescents, specifically among adolescents exhibiting heightened baseline arousal/regulation (i.e., cardiac arousal) processes. Findings indicated that adolescents experiencing the combination of greater peer conflict and heightened baseline levels of cardiac arousal showed significantly greater NSSI behaviors over one year follow-up, compared to peers with lower peer conflict or cardiac arousal. This result was replicated across negative binomial, zero-inflation poisson, and hurdle models. In contrast, neither peer conflict, cardiac arousal, nor their interaction were associated with SI, suggesting that these processes may be specific to self-injurious behaviors, rather than self-injurious thoughts, or to self-injurious outcomes engaged in without suicidal intent. Lastly, the interaction of cardiac arousal with family conflict did not significantly predict SITB, indicating that normative social processes, including reorientation from parents to peers, that characterize the adolescent developmental period may make conflict

with peers, specifically, a particularly salient and impactful stressor. Peer-related stressors may increase vulnerability for subsequent engagement in self-injurious behaviors such as NSSI, particularly among adolescents with particular biological vulnerabilities (e.g., heightened cardiac arousal).

Taken together, our findings provide longitudinal support for an interaction of biological vulnerabilities with socially-themed stress in predicting at least some types of SITB in adolescents. Examining the interaction of physiological and social factors represents a relatively novel contribution toward understanding how biological and environmental factors interact to predict adolescent SITB. Importantly, our longitudinal analyses mark an important contribution to the limited literature examining risk factors for SITB, which has insufficiently addressed developmental considerations to better understand emergence of SITB among adolescents, specifically. Clinically, findings suggest that promoting positive peer relationships and increasing social support systems, perhaps especially among adolescents with heightened physiological arousal/regulatory processes, may buffer against onset of harmful, self-injurious behaviors that most frequently emerge in the transition to adolescence.

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%	

Table 2. Descriptive Statistics

Variable	Wave	M (SD)						
		Gender		Race				
		Male	Female	White	Black	Hispanic/Latino	Multi-Racial	Other
NSSI	W1	0.73 (1.57)	1.15 (1.64)	0.98 (.38)	2.15 (.44)	1.08 (.68)	0.14 (.68)	0.33 (1.04)
	W2	0.45 (0.99)	0.82 (1.46)	0.80 (.35)	1.47 (.39)	0.61 (.33)	0.57 (.61)	0.17 (.94)
SI	W1	0.94 (2.11)	1.58 (2.53)	1.75 (.74)	2.32 (.85)	2.06 (.70)	0.36 (1.32)	3.67 (2.01)
	W2	0.75 (1.97)	2.14 (2.93)***	2.02 (.74)	2.91 (.85)	1.71 (.70)	1.29 (1.32)	0.17 (2.01)
Heart Rate	W1	78.00 (12.80)	84.30 (13.2)**	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)	1.63 (0.63)	1.54 (.09)	1.87 (.11)	1.54 (.09)	1.54 (.16)	1.75 (.25)
Family Conflict	W1	1.86 (0.86)	1.91 (0.71)	2.00 (.12)	1.84 (.14)	1.90 (.11)	1.53 (.21)	2.04 (.32)

Note. NSSI = Nonsuicidal Self-Injury; SI = Suicidal Ideation; W1 = Wave 1; W2 = Wave 2; ** = $p < .01$; *** = $p < .001$.

Table 3. Main Effect Models.

A. NSSI												
<i>Predictors</i>	Peer Conflict				Family Conflict				Resting Heart Rate			
	<i>Log-Mean</i>	<i>std. Error</i>	<i>CI</i>	<i>P-Value</i>	<i>Log-Mean</i>	<i>std. Error</i>	<i>CI</i>	<i>P-Value</i>	<i>Log-Mean</i>	<i>std. Error</i>	<i>CI</i>	<i>P-Value</i>
(Intercept)	-2.016	0.672	-3.333 – -0.698	0.003	-2.535	0.699	-3.905 – -1.165	<0.001	-2.061	1.299	-4.607 – 0.485	0.113
Peer Conflict	-2.141	1.189	-4.472 – 0.190	0.072								
NSSI W1	0.500	0.089	0.326 – 0.674	<0.001	0.430	0.086	0.262 – 0.598	<0.001	0.442	0.085	0.276 – 0.608	<0.001
PDS	0.441	0.256	-0.060 – 0.942	0.085	0.466	0.261	-0.045 – 0.977	0.074	0.445	0.263	-0.070 – 0.960	0.090
Family Conflict					0.678	1.008	-1.298 – 2.654	0.501				
Resting Heart Rate									-0.003	0.013	-0.028 – 0.022	0.799
Observations	147				147				147			
R ² Nagelkerke	0.396				0.372				0.368			

B. SI												
<i>Predictors</i>	Peer Conflict				Family Conflict				Resting Heart Rate			
	<i>Log-Mean</i>	<i>std. Error</i>	<i>Conf. Int (95%)</i>	<i>P-Value</i>	<i>Log-Mean</i>	<i>std. Error</i>	<i>Conf. Int (95%)</i>	<i>P-Value</i>	<i>Log-Mean</i>	<i>std. Error</i>	<i>Conf. Int (95%)</i>	<i>P-Value</i>
(Intercept)	-1.268	0.667	-2.575 – 0.040	0.057	-1.622	0.570	-2.739 – -0.506	0.004	-2.562	1.139	-4.795 – -0.328	0.025
Peer Conflict	-0.258	0.242	-0.731 – 0.216	0.286								
NSSI W1	0.190	0.057	0.077 – 0.302	0.001	0.180	0.058	0.067 – 0.293	0.002	0.186	0.056	0.076 – 0.297	0.001
PDS	0.522	0.234	0.063 – 0.981	0.026	0.517	0.236	0.054 – 0.980	0.029	0.604	0.240	0.133 – 1.075	0.012
Gender	0.555	0.300	-0.033 – 1.144	0.064	0.494	0.301	-0.095 – 1.084	0.100	0.480	0.314	-0.135 – 1.094	0.126
Family Conflict					0.422	0.895	-1.333 – 2.177	0.637				
Resting Heart Rate									0.009	0.011	-0.013 – 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

<i>Predictors</i>	Negative Binomial		
	<i>Log-Mean</i>	<i>Std. Error</i>	<i>P-Value</i>
(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 x Resting Heart Rate	0.232	0.091	0.010
Family Conflict x Resting Heart Rate	-0.006	0.012	0.607
Observations	147		
R ² Nagelkerke	0.478		

Table 5. Social Conflict, Resting Heart Rate, and SI

<i>Predictors</i>	Negative Binomial		
	<i>Log-Mean</i>	<i>Std. Error</i>	<i>P-Value</i>
(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 x Resting Heart Rate	-0.006	0.081	0.944
Family Conflict x Resting Heart Rate	0.005	0.012	0.661
Observations	147		
R ² Nagelkerke	0.318

Figure 1. NSSI and SI Trajectories by Gender. Note: NSSI = non-suicidal self-injury; SI = suicidal ideation; all values are winsorized.

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.

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