

ORIGINAL ARTICLE

# Respiratory sinus arrhythmia, negative social interactions, and fluctuations in unmet interpersonal needs: A daily diary study

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## Abstract

**Introduction:** This study examined daily fluctuations in the unmet interpersonal needs of thwarted belongingness and perceived burdensomeness in response to daily negative social interactions, as well as the moderating role of respiratory sinus arrhythmia (RSA) across adolescents at lower and higher risk for suicidal ideation.

**Methods:** Fifty five adolescents with major depressive disorder (MDD, i.e., higher-risk group) and without MDD (i.e., lower-risk group) completed measures of resting RSA, and daily measures of negative social interactions, perceived burdensomeness, and loneliness, as a proxy for thwarted belongingness, for 10 consecutive days. Within-person analyses examined the association between daily negative social interactions and unmet interpersonal needs, and the moderating roles of RSA and higher-risk group status. Between-person analyses also examined the association between RSA and unmet interpersonal needs across groups.

**Results:** At the within-person level, participants reported more unmet interpersonal needs on days when they reported more negative social interactions. At the between-person level, higher RSA was associated with decreased loneliness in both groups, and decreased burdensomeness among the higher-risk group.

**Conclusions:** Negative social interactions are associated with daily unmet interpersonal needs. Higher RSA may serve as a protective factor mitigating risk for unmet interpersonal needs, particularly burdensomeness, among adolescents at higher risk for suicidal ideation.

## KEYWORDS

adolescents, daily diary, loneliness, negative social interactions, perceived burdensomeness, respiratory sinus arrhythmia

## INTRODUCTION

Epidemiologically, suicidal ideation emerges during early adolescence and quickly increases in prevalence from 12 to 18 years old (Glowinski et al., 2001; Nock et al., 2013). The prevalence of suicidal ideation in adolescence is estimated between 12% and 33% (Brezo et al., 2007; Nock et al., 2013; Orri et al., 2020), compared to approximately 9% in the general population (Nock et al., 2008). Interpersonal stress is a well-known risk factor for suicidal ideation throughout the lifespan (King & Merchant, 2008; Mueller et al., 2021), but its effects may be particularly relevant to consider in adolescence given that this developmental period is considered critical for the effects of interpersonal stress on mental health outcomes (Blakemore & Mills, 2014; Sisk & Gee, 2022).

The interpersonal-psychological theory of suicide (Joiner, 2005; Van Orden et al., 2010) suggests that unmet interpersonal needs are key risk factors for suicidal ideation. This theory proposes that disruptions in the intrinsic human need to belong and feel connected to others, e.g. perceptions of social disconnectedness, isolation, or loneliness, contribute to a state of *thwarted belongingness* that promotes suicidal ideation. Second, this theory suggests that *perceived burdensomeness*, i.e. the perception that one is not needed and that others may be better off if they were dead, is an interpersonally related cognition contributing to suicidal ideation. Empirical studies report both main and interaction effects of thwarted belongingness and perceived burdensomeness in predicting suicidal ideation cross-sectionally and longitudinally (Chu et al., 2017), including among adolescents (Stewart et al., 2017).

Many interpersonal risk factors have been associated with individual differences in perceptions of unmet interpersonal needs in adolescence, including peer victimization (Brailovskaia et al., 2020), poor perceived social support (Sparks et al., 2023), negative in-person and online interactions (Donker et al., 2014; Moberg & Anestis, 2015), and chronic interpersonal stress (Buitron et al., 2016). However, thwarted belongingness and perceived burdensomeness are also considered dynamic experiences fluctuating in intensity over time, including over hours and days (Kleiman et al., 2017; Van Orden et al., 2010). Within-person fluctuations are considered independent from between-person differences and within-person effects may differ in magnitude or direction from between-person effects (Wang & Maxwell, 2015). Yet, few studies have examined predictors of within-person, short-term fluctuations in unmet interpersonal needs. Two studies using intensive longitudinal designs showed that, among adults with mood and psychotic disorders, being in the physical presence of others was associated with decreased perceptions of thwarted belongingness, but increased

perceived burdensomeness (Hallensleben et al., 2020; Parrish et al., 2021). Another study showed that adolescents at high risk for suicidal ideation reported greater thwarted belongingness the day after negative social interactions with family members (Glenn et al., 2021). This study did not examine changes in perceived burdensomeness. Still, another qualitative study with community adolescents experiencing high burdensomeness showed that relationship conflict is an important source of perceptions of burdensomeness (Hill et al., 2019). Two experimental studies also showed increased perceptions of burdensomeness following negative feedback about one's performance compared to that of teammates (Hartley et al., 2019; Wirth et al., 2021). These findings highlight the importance of better understanding the associations between negative social interactions and daily fluctuations in both thwarted belongingness and burdensomeness among adolescents. Moreover, little work has examined moderators of within-person fluctuations in unmet interpersonal needs.

Respiratory sinus arrhythmia (RSA) is a measure of cardiac vagal tone considered a trans-diagnostic marker of self-regulation and vulnerability to stress (Beauchaine, 2015; Porges, 2003; Thayer & Lane, 2000). RSA represents the variability in beat-to-beat time intervals resulting from vagally mediated parasympathetic output at the sinoatrial node of the heart (Berntson et al., 1997). Meta-analyses indicate that lower resting RSA is associated with greater internalizing psychopathology (Chalmers et al., 2014; Koenig et al., 2016), and lower self-control (Holzman & Bridgett, 2017; Zahn et al., 2016). Conversely, greater RSA is associated with better regulation of emotional and cognitive responses to interpersonal stress. For example, among adults, higher RSA was associated with better social integration in the face of acculturation stress (Doucerain et al., 2016, 2022), greater positive affect in response to positive interactions and social support (Diamond et al., 2011; Hopp et al., 2013), and less hostility during conflicts (Gyurak & Ayduk, 2008). Moreover, children and adolescents with lower resting RSA demonstrated more externalizing (El-Sheikh et al., 2011; Mikolajewski & Scheeringa, 2022; Van der Graaff et al., 2016; Zhang & Gao, 2015) and internalizing symptoms in response to interpersonal stress (Fagundes et al., 2012; Khurshid et al., 2019; McLaughlin et al., 2015; Wetter & El-Sheikh, 2012). Thus, resting RSA may be associated with more flexible and adaptive cognitive, behavioral, and emotional responses to interpersonal stress (Muhtadie et al., 2015).

Given that resting RSA is associated with differential responses to interpersonal stressors, RSA may be associated with perceptions of unmet interpersonal needs. No research to date has examined the association between RSA and unmet interpersonal needs of thwarted belongingness

or perceived burdensomeness. Emerging research has nonetheless shown that RSA is associated with feelings of loneliness, an important facet of thwarted belongingness (Van Orden et al., 2010). For example, adolescent boys with lower RSA reported greater loneliness over time in the context of hostile and coercive parenting practices (Cai & Tu, 2020). Mothers with lower resting heart rate variability parameters also reported greater loneliness during pregnancy and the post-partum period (Sarhaddi et al., 2022). Furthermore, self-reported resilience to stress was inversely associated with loneliness only among college students with lower resting RSA (Zhao et al., 2022). Thus, more research is needed to examine whether RSA may be directly associated with individual differences in unmet interpersonal needs, and whether RSA moderates the association between within-person negative social interactions and fluctuations in unmet interpersonal needs.

Prior work indicates that the strength of the association between RSA and psychosocial outcomes may differ between clinical and community samples, with larger associations being observed in clinical samples (Graziano & Derefinko, 2013). Furthermore, adolescents with major depressive disorder (MDD) may be considered at higher risk for suicidal ideation, compared to adolescents without MDD. Indeed, there is an increase prevalence of suicidal ideation among adolescents with MDD, compared to their counterparts without MDD (e.g. 85% vs. 12%–33%; Brezo et al., 2007; Cash & Bridge, 2009; Orri et al., 2020). Adolescents with MDD also experience more interpersonal stress (Hammen, 2009), as well as more negative emotional and cognitive reactions to interpersonal stressors (Gunthert et al., 2007; Krackow & Rudolph, 2008). Depressive symptoms are also moderately positively correlated with perceptions of unmet interpersonal needs among adults and adolescents alike (Bell et al., 2018; Elledge et al., 2021; Nalipay & Ku, 2019; Silva et al., 2015; Smith et al., 2018). Thus, these differences in risk for suicidal ideation among adolescents with and without MDD may moderate the association between RSA and psychosocial outcomes, including the associations between RSA and perceptions of thwarted belongingness and perceived burdensomeness.

The first aim of this study was to examine fluctuations in unmet interpersonal needs in response to daily negative social interactions, as well as the moderating role of resting RSA across adolescents at lower and higher risk for suicidal ideation. The second aim of this study was to examine the role of RSA as a predictor of between-person differences in perceptions of unmet interpersonal needs across adolescents at lower and higher risk for suicidal ideation. To capture a range of risk for suicidal ideation, this sample included adolescents with MDD (i.e., higher-risk group) and without MDD (i.e., lower-risk group).

Baseline measures of suicidal ideation and resting RSA were obtained during a laboratory visit. Participants then completed 10 consecutive daily diaries assessing negative social interactions, perceived burdensomeness, and loneliness (used as a proxy for thwarted belongingness in this study) in the last 24h. At the within-person level, it was hypothesized that (1) more daily negative social interactions would be associated with greater daily perceptions of loneliness and burdensomeness, and that this association would be stronger among those with lower RSA (i.e., two-way interaction). It was also expected that the moderating effect of RSA on the association between negative social interactions and unmet interpersonal needs would be stronger among the higher-risk group (i.e. three-way interaction). Similarly, at the between-person level it was hypothesized that those with lower resting RSA would report greater average loneliness and burdensomeness, and that this association would be stronger among the higher-risk group.

## METHOD

### Participants

Participants aged 12–18 years of age, having attained puberty based on self-reported beginning of menstruation for female participants and the development of body hair and voice maturation for male participants, and having daily access to internet during the study period were eligible to participate. Two groups of participants were recruited. The “Higher-Risk” group was comprised of 24 adolescents with a diagnosis of major depressive disorder recruited from a psychiatric outpatient clinic following confirmation of diagnostic status from their clinical case manager. The “Lower-Risk” group comprised 32 adolescents recruited from the community via flyers and social media. During a phone interview to determine eligibility, control participants were required to respond “no” to the following questions to be included in the study: have you felt sad or depressed almost every day, for most of the day, in the last 2 weeks; have you felt less pleasure or interest in your activities most days, for most of the day, in the last 2 weeks; are you currently in psychotherapy or counseling; have you or someone around you thought you needed professional help currently or in the past to deal with your emotions or how you were behaving. Overall, 56 participants were recruited into the study, but one participant from the higher-risk group did not complete the daily diary component of the study. Thus, a total of 55 participants were included in the present study.

On average, participants were 15.55 years old ( $SD = 1.55$ , range: 12–18). Participants in the higher-risk

group were older ( $M = 16.13$ ,  $SD = 1.22$ ) than those in the lower-risk group ( $M = 15.13$ ,  $SD = 1.641$ ;  $t(53) = -2.485$ ,  $p = 0.016$ ). The lower-risk group was 65.6% female, and the higher-risk group was 86.96% female ( $\chi^2 = 3.209$ ,  $p = 0.07$ ). Both groups were predominantly White (lower-risk group: 78.12%; higher-risk group: 69.57%,  $\chi^2 = 0.517$ ,  $p = 0.472$ ). Participants in the higher-risk group were more likely to report smoking at least one cigarette daily (26% of the group) compared to the lower-risk group (3%;  $\chi^2 = 6.352$ ,  $p = 0.012$ ). No participants in the lower-risk group reported taking psychotropic medications, whereas 69.57% of the higher-risk group were prescribed at least one medication for mental health difficulties ( $\chi^2 = 31.39$ ,  $p < 0.001$ ). Participants from both groups had parents with similar levels of education (Bachelor's degree or higher; lower-risk group: 37.5%; higher-risk group: 43.48%,  $\chi^2 = 3.196$ ,  $p = 0.670$ ).

## Measures

### Unmet interpersonal needs

#### *Perceived burdensomeness*

Perceived burdensomeness was measured daily using an item taken from the Interpersonal Needs Questionnaire (INQ; Van Orden et al., 2012). Participants selected the statement that applied best to them in the past 24 h from the following: 0 – I think that people in my life are happier when I'm around; (1) – I do not think that people in my life would be happier if I were gone; (2) – I wonder that people in my life would be happier if I were gone; (3) – I am sure that people in my life would be happier if I were gone. This item has high construct validity, demonstrating the highest item-total correlation among all perceived burdensomeness items on the INQ (Van Orden et al., 2006). Intraclass correlation (ICC) for this item was 0.673, suggesting that 33.7% of the variance in this item is explained by within-person differences and 67.3% is explained by between-person differences (Bonito et al., 2012; Stapleton et al., 2016).

#### *Loneliness*

A single-item measure of loneliness was used as a proxy for daily thwarted belongingness. Loneliness refers to the feeling of distress when one perceives their social needs are not being met (Hawkey & Cacioppo, 2010). Loneliness loaded strongly with the thwarted belongingness subscale of the INQ ( $r = 0.914$ ), but not the perceived burdensomeness subscale ( $r = -0.078$ ) in a sample of young adults, supporting its discriminant validity as a proxy construct for thwarted belongingness (Van Orden et al., 2012). Moreover, evidence suggests that single-item measures of

loneliness are valid and reliable in adolescence (Asher & Paquette, 2003; Mund et al., 2022). Participants rated the extent to which they felt lonely today on a 5-point Likert-type scale ranging from 0 (Not at all) to 4 (Extremely). Approximately half of the variance in loneliness was explained by within-person differences (ICC = 0.525).

### Negative social interactions

Daily negative social interactions were measured using items adapted from Ruehlman and Karoly (1991). Participants selected with whom they had experienced the following four negative social interactions during the last 24 h: (1) [the other person] did not take your problem seriously or belittled you, (2) gave you unhelpful or unsolicited advice, (3) ignored you or withdrew from you, (4) criticized or argued with you. Participants indicated whether they had each interaction with their best friend, other friends, boyfriend or girlfriend, parents, other family members, classmates or coworkers, teachers, or other professionals. Each endorsement was coded as 1. Participants could also select that they had not had this interaction today (i.e. no one), which was coded as 0. Endorsements were added across social groups per interaction, and added again across interactions to obtain an overall score of daily negative social interactions, with higher scores representing more negative social interactions that day. The ICC for this item was 0.794, suggesting that approximately 20% of the variance in this item is explained by within-person differences and approximately 80% is explained by between-person differences.

### Suicidal ideation

Suicidal ideation was measured via the Suicidal Ideation Questionnaire – Junior, Short Form (SIQ-JR; Reynolds, 1987). This measure contains 15-items measuring the spectrum of suicidal ideation ranging from passive thoughts of death (e.g. I thought about death) to active suicidal planning (e.g. I thought about how I would kill myself). Participants rated the extent to which each thought “was on their mind” on a Likert-type scale ranging from 0 (I never had this thought) to 6 (Almost every day) in the last 30 days. Individual items are summed to obtain an overall score of past-month suicidal ideation, with higher scores representing greater suicidal ideation. Internal reliability of this measure within this sample was high (Cronbach's  $\alpha = 0.964$ ). Of note, suicidal ideation was not measured in the daily diary portion of this study, precluding investigation of within-person fluctuations in this outcome.



## Apparatus

Psychophysiological data were collected using the Biopac MP36/35 Four Channel Data Acquisition System (Biopac Systems Inc., California, 2016). Participants wore three chest electrodes in a Lead-II position (right collarbone, left and right bottom ribs) to measure cardiac activity. They were also fitted with a respiratory belt (Biopac SS5LB Respiratory Effort Transducer) that measures respiration via the change in thoracic circumference associated with inspiration and expiration. Continuous electrocardiogram and respiration data were recorded at a sampling rate of 1000 Hz.

### *Respiratory sinus arrhythmia*

RSA was analyzed using the Mindware HRV analysis software, Version 3.1 (Mindware Technologies Ltd). R-peaks from successive QRS complexes in the electrocardiogram recording were identified using the HRV software's automated algorithm. Recordings were also visually screened for recording artifacts and corrected where necessary by two independent raters (ICC=0.99). RSA was calculated using the Fast Fourier transformation that computes the natural log of the 0.15–0.40-Hz frequency band of each 30s-epoch during the resting period. RSA was averaged across all 30s epochs to obtain a measure of vagally mediated parasympathetic influences on the heart while at rest.

### *Respiration rate*

Respiration rate was extracted using the BSL Pro Software, version 4.1 (Biopac Systems Inc., California, 2016), given that respiration can alter the association between RSA and cardiac vagal modulation (Quintana et al., 2016). Linear interpolation was used to down-sample respiration data to 62.50 samples per second. A band pass finite impulse response filter was applied with a low pass threshold fixed at 0.05 Hz and a high pass threshold fixed at 1 Hz. Respiration recordings were smoothed using the mean value across 45 samples. Respiration peaks (inhalations) were identified by the software's automated algorithm and visually screened and corrected as necessary. Resting respiration rate (in breaths per minute) was extracted from the mean of the width in time between successive breaths during the resting period.<sup>1</sup>

## Procedure

Participants attended a two-hour laboratory session during which they provided demographic information and completed self-reported measures. Respiration and RSA were collected during a 5-min “vanilla” resting period

during which participants viewed a video of scenic landscapes without sound. Participants were asked to stay seated, minimize movement, avoid falling asleep, and breathe normally during this period. Other tasks were also completed during this laboratory visit as part of the larger study. Afterwards, participants were given instructions about the daily diary portion of the study. Starting that same evening, participants were asked to complete a daily diary questionnaire every evening for the next 10 days, in which they rated their daily negative interactions, perceived burdensomeness, and loneliness in the last 24-h. To encourage adherence, participants who missed an entry were emailed the following morning with a reminder to complete their next diary that evening. A total of 492 entries were completed, with on average 8.94 daily diary entries per participant ( $SD = 2.31$ ; range = 1–14 entries). Participants received \$15CAD for the laboratory visit and \$15CAD for the daily diary portion of the study. This study was approved by the institutional ethics review boards of Concordia University (#30006535) and of the Douglas Mental Health University Institute (IUSMD#16–10). Participants and their legal guardian provided informed assent and consent, respectively.

## Statistical analyses

Assumptions for linear regression were checked in the data. The assumption of normality of residuals was met in models predicting perceived burdensomeness, but not in models predicting suicidal ideation nor loneliness. Data transformations did not correct for violation of this assumption, thus the non-transformed, raw data were used for all subsequent analyses. These results must therefore be interpreted with caution. Preliminary descriptive analyses explored group differences in RSA, loneliness, burdensomeness, and suicidal ideation. Non-parametric Spearman's rho correlations were used to describe the associations among study variables across groups.

Multilevel modeling was used to explore the effect of within- and between-person association between negative social interactions on daily loneliness and perceived burdensomeness, as well as the moderating effects of resting RSA and higher-risk group (versus lower-risk group). Centering strategies were used to differentiate the between-person (level-2) and within-person (level-1) deviations in negative social interactions. Daily negative social interaction scores were averaged across the 10 diary days to obtain person-means. Person-means were centered around the sample mean to obtain between-person deviations, with higher scores representing more negative social interactions during the entire daily diary period relative to the entire sample. Next, individual

TABLE 1 Descriptive statistics and Spearman Rho correlations among study variables.

	M (SD): Lower-risk group	M (SD): Higher-risk group	1	2	3	4	5	6
1. Past-month suicidal ideation	3.09 (3.35)	31.65 (19.12) <sup>a</sup>		0.76***	0.56**	0.30	-0.41*	0.11
2. Average burdensomeness	0.17 (0.27)	1.33 (0.72) <sup>a</sup>	0.53**		0.61**	0.43*	-0.51*	0.43*
3. Average loneliness	0.33 (0.39)	1.77 (0.88) <sup>a</sup>	0.35*	0.38*		0.50*	-0.27	0.33
4. Average negative social interactions	0.41 (0.48)	1.02 (1.54) <sup>a</sup>	0.06	0.35*	0.29		-0.26	0.32
5. Resting RSA	6.95 (1.06)	6.40 (1.32) <sup>b</sup>	0.15	<0.01	-0.08	-0.18		-0.48*
6. Respiration rate	15.45 (3.79)	15.42 (2.87)	0.04	0.18	0.01	-0.15	-0.27	

Note: Correlations above the diagonal represent associations within the clinical group ( $n = 23$ ) and correlations below the diagonal represent associations within the control group ( $n = 32$ ).

Abbreviation: RSA, Respiratory Sinus Arrhythmia.

<sup>a</sup>Significant group difference at  $p < 0.001$ .

<sup>b</sup>Trending group difference at  $p < 0.09$ .

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

daily negative social interaction scores were centered around the person-mean to obtain within-person deviations on this measure, with higher scores representing greater daily negative social interactions than usual for a given participant. These within- and between-person differences in negative social interactions are considered independent using this disaggregation method (Curran & Bauer, 2011). Participants were required to have at least 3 entries to compute personal averages and obtain within-person fluctuations for each variable. Two participants (one higher-risk and one lower-risk participant) were removed for these within-person analyses as they had less than 3 daily diary entries. Results were identical when these two participants were included in the analyses.

Models 1 examined the main effects of level-2 predictor between-person negative interactions and level-1 predictor, within-person fluctuations in negative interactions on same-day loneliness and burdensomeness. Models 2 examined the additional main effects of resting RSA and higher-risk group. Models 3 added the two-way interaction effects between negative social interactions with moderators resting RSA and higher-risk group on same-day unmet interpersonal needs. Models 4 included the three-way interaction among between-person negative interactions, resting RSA, and higher-risk group, as well as within-person interactions, resting RSA, and higher-risk group on daily loneliness and burdensomeness. Age was included as a covariate in the main models. The simple slopes of significant interaction terms were calculated to depict the interaction. An unstructured covariance structure was specified for all models, and degrees of freedom were estimated using

the between-within method for fixed effects. Statistical analyses were conducted using SAS PROC MIXED, version 9.4 (Cary, North Carolina, USA).

Between-person associations between resting RSA and loneliness and perceived burdensomeness across the daily diary period were also examined. Loneliness and perceived burdensomeness scores were averaged across the 10 daily diaries to obtain individual participant means. The moderation models tested the association of resting RSA on average perceived burdensomeness and loneliness, and the moderating effect of higher-risk group (versus lower-risk group). The simple slopes of significant interaction terms were calculated to depict significant interactions. Age was included as a covariate to account for group differences on this variable. All continuous covariates and predictors were sample mean-centered. These analyses were conducted using the PROCESS macro version 4.0 for SPSS (Hayes, 2021).

Sensitivity analyses were conducted testing the above-described models with the following covariates to determine the robustness of main analyses: ethnicity (coded White = 0 vs. non-White = 1), sex (coded male = 0 vs. female = 1), smoker (coded no = 0 vs. yes = 1), taking psychotropic medication (coded no = 0 vs. yes = 1), and resting respiration rate. These latter three covariates were included due to their potential impact on reducing RSA (Guo et al., 2022; Henje Blom et al., 2010), and to account for the covariation between RSA and respiration rate (Quintana et al., 2016). For all analyses, statistical significance was set at  $\alpha < 0.05$ . Given the small sample size limiting the statistical power to explore interaction effects, data trends were also explored when  $\alpha < 0.10$ .

## RESULTS

**Table 1** provides the descriptive statistics and Spearman rho correlations between RSA, suicidal ideation, average unmet interpersonal needs, and average negative social interactions across groups. The higher-risk group reported a significantly worse psychosocial profile than the control group. There was a trend towards group differences in resting RSA, with the lower-risk group having higher resting RSA than the higher-risk group ( $t(53) = -1.737$ ,  $p = 0.088$ ). In contrast, there were no group differences in resting respiration rate ( $t(53) = -0.26$ ,  $p = 0.979$ ). In both groups, there were moderate to large positive associations between loneliness, burdensomeness, and suicidal ideation. Negative social interactions were moderately and positively associated with unmet interpersonal needs in both groups, and moderately associated with suicidal ideation in the higher-risk group. Of note, there were significant associations of RSA with suicidal ideation and burdensomeness in the higher-risk group, such that lower RSA was associated with greater suicidal ideation and burdensomeness in this group; these associations were not significant in the lower-risk group (see supplemental information for a depiction of these associations).

Results from multilevel analyses examining the between- and within-person effects of negative social experiences on daily unmet interpersonal needs, and the moderating effects of higher-risk group and RSA are presented in **Table 2**. For burdensomeness, there were independent between-person and within-person main effects of negative social interactions. Participants reported more burdensomeness on days when they experienced more negative social interactions. Also, participants who experienced more negative social interactions on average across the daily diary period also reported stronger daily perceptions of burdensomeness. In model 2, higher-risk group and within-person effects of negative social interactions were independent predictors of daily burdensomeness, but the between-person effect of negative social interactions was no longer significant. In model 3, a significant interaction between higher-risk group and within-person negative interactions emerged. As depicted in **Figure 1**, Panel A, participants in the higher-risk group reported greater burdensomeness on days when they reported more negative social interactions than usual for them, while this association was not significant in the lower-risk group. The between-person interaction between RSA and higher-risk group (see **Figure 2**) was a significant predictor of daily burdensomeness. In Model 4, a trending interaction between within-person negative interactions, resting RSA, and higher-risk group was found. As depicted in **Figure 1**, Panel B, participants in the higher-risk group reported greater burdensomeness on days when

they reported more negative interactions than usual, but this within-person effect was attenuated among those in the higher-risk group with higher RSA. There was no association between RSA and within-person negative interactions in the lower-risk group. No two-way nor three-way interactions emerged between RSA, higher-risk group, and between-person negative social interactions.

In the loneliness models, between- and within-person negative interactions as well as higher-risk group were significant independent predictors of daily loneliness. Participants reported more loneliness on days when they experienced more negative social interactions. Also, participants who experienced more negative social interactions on average across the daily diary period also reported greater daily loneliness. Participants in the higher-risk group also reported more loneliness than the lower-risk group, regardless of the amount of negative social interactions. When examining potential interactions with higher-risk group and RSA, model fit decreased in models including the two-way and three-way interactions. Therefore, models with interaction effects were not further interpreted.

Results from analyses examining the effect of resting RSA on between-person differences in unmet interpersonal needs, and the moderating effect of higher-risk group, are presented in **Table 3**. RSA and higher-risk group were independent predictors of burdensomeness, and a significant interaction emerged, depicted in **Figure 2**. Participants in the higher-risk group with higher RSA had lower burdensomeness than their counterparts with lower RSA. No association between RSA and burdensomeness was observed in the lower-risk group. RSA and higher-risk group were also significant independent predictors of loneliness. Higher RSA was associated with lower loneliness across both groups (no interaction effect).

For both sets of models, sensitivity analyses were conducted. In the multilevel models, although the main effects were somewhat weakened, the pattern of results remained the same. In the between-person models, although the covariates were not independently associated with burdensomeness ( $\Delta R^2 = 0.01$ ,  $p = 0.932$ ), the RSA by higher-risk group interaction was weakened ( $p = 0.062$ ), likely due to loss of power in the fully adjusted model. Similarly, although covariates were not significantly associated with loneliness ( $\Delta R^2 = 0.039$ ,  $p = 0.413$ ), the association between RSA and loneliness was weaker ( $p = 0.085$ ) in the fully adjusted model.

## DISCUSSION

This study explored the within-person fluctuations in unmet interpersonal needs in response to negative social

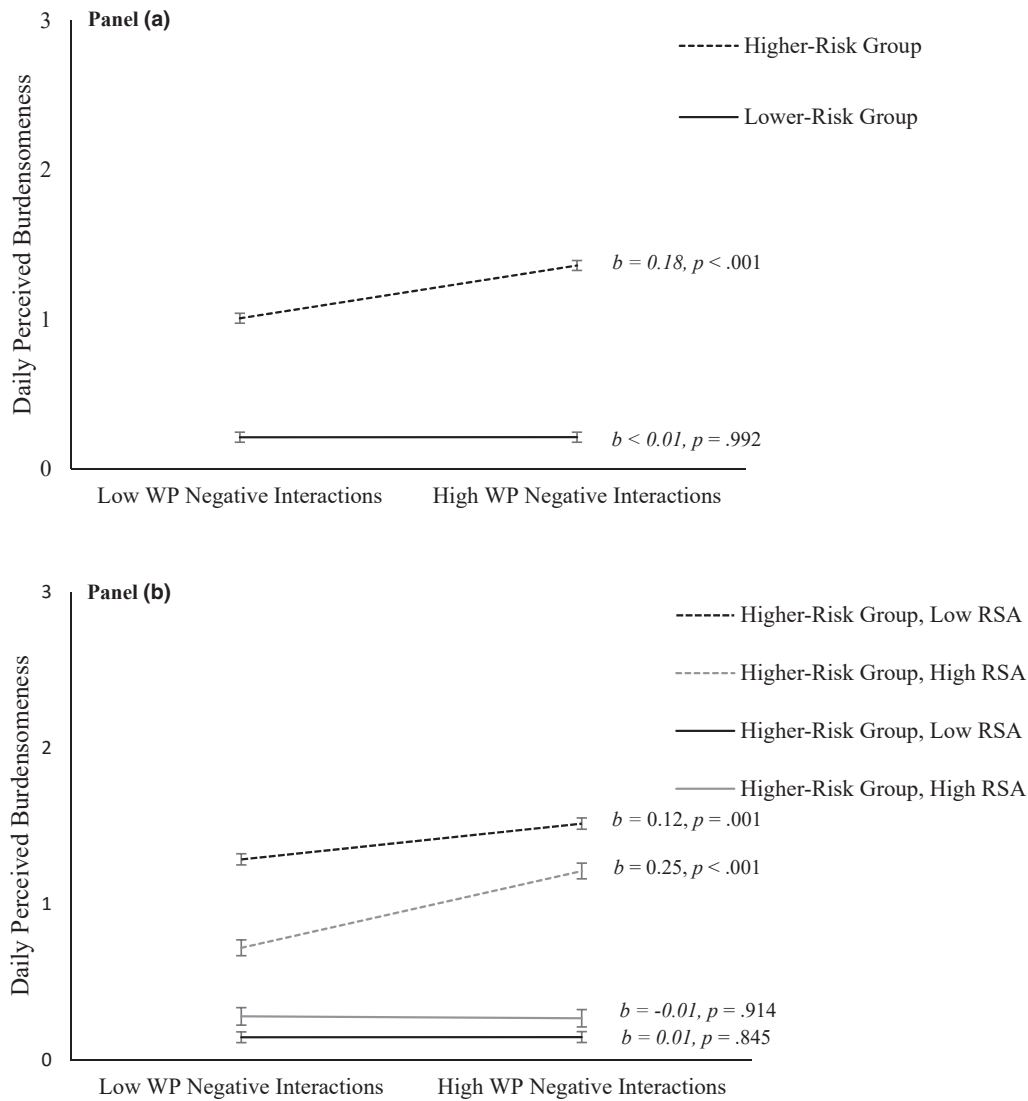
TABLE 2 Multilevel regression models predicting daily unmet interpersonal needs ( $n = 489$ ).

	Perceived burdensomeness				Loneliness			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Fixed effects								
Intercept	0.63 (0.09)*** 0.10 (0.06) <sup>t</sup>	0.71 (0.06)*** -0.03 (0.04)	0.69 (0.07)* -0.03 (0.04)	0.70 (0.06)*** -0.02 (0.04)	0.90 (0.10)*** 0.08 (0.06)	0.98 (0.06)*** -0.05 (0.04)	0.98 (0.07)*** -0.06 (0.04)	0.98 (0.07)*** -0.06 (0.04)
Age		0.11 (0.06) <sup>t</sup>						
BP negative interactions	0.25 (0.08)**	0.08 (0.02)***	0.11 (0.08)	0.11 (0.08)	0.43 (0.09)***	0.26 (0.06)***	0.24 (0.09)*	0.24 (0.09)*
WP negative interactions	0.08 (0.02)***	0.08 (0.02)***	0.09 (0.02)***	0.09 (0.02)***	0.13 (0.04)***	0.13 (0.04)***	0.15 (0.04)***	0.15 (0.04)***
H-R group		0.50 (0.07)***	0.51 (0.06)***	0.49 (0.06)***		0.59 (0.07)***	0.60 (0.07)***	0.59 (0.07)***
RSA		-0.08 (0.05)	-0.08 (0.05)	-0.06 (0.05)		-0.07 (0.06)	-0.09 (0.06)	-0.07 (0.06)
RSA × WP negative interactions			0.03 (0.02)	0.03 (0.02)			0.05 (0.03) <sup>t</sup>	0.05 (0.03) <sup>t</sup>
H-R Group × WP negative interactions			0.08 (0.02)***	0.09 (0.02)***			-0.02 (0.04)	-0.02 (0.04)
RSA × BP negative interactions			0.02 (0.05)	0.09 (0.07)			0.05 (0.06)	0.08 (0.08)
H-R group × BP negative interactions			-0.01 (0.08)	-0.01 (0.08)			0.03 (0.10)	0.02 (0.09)
H-R group × RSA			-0.12 (0.05)*	-0.12 (0.05)*			-0.07 (0.06)	-0.07 (0.06)
H-R Group × RSA × WP negative interactions				0.03 (0.02) <sup>t</sup>				0.01 (0.03)
H-R group X RSA X BP negative interactions				-0.10 (0.07)				-0.04 (0.08)
Random effects								
Intercept	0.37 (0.08)***	0.15 (0.03)***	0.14 (0.03)***	0.13 (0.03)***	0.43 (0.10)***	0.14 (0.04)***	0.14 (0.04)***	0.13 (0.04)***
Residuals	0.24 (0.02)***	0.24 (0.02)***	0.23 (0.02)***	0.23 (0.02)***	0.62 (0.04)***	0.62 (0.04)***	0.61 (0.04)***	0.61 (0.04)***
Model fit statistics								
AIC	843.0	804.6	794.8	793.9	1270.0	1227.6	1232.3	1236.0
BIC	854.9	820.3	820.4	823.5	1281.8	1243.3	1257.9	1265.5

Abbreviations: BP, Between-Person; H-R Group, Higher-Risk Group; RSA, Respiratory Sinus Arrhythmia; WP, Within-Person.

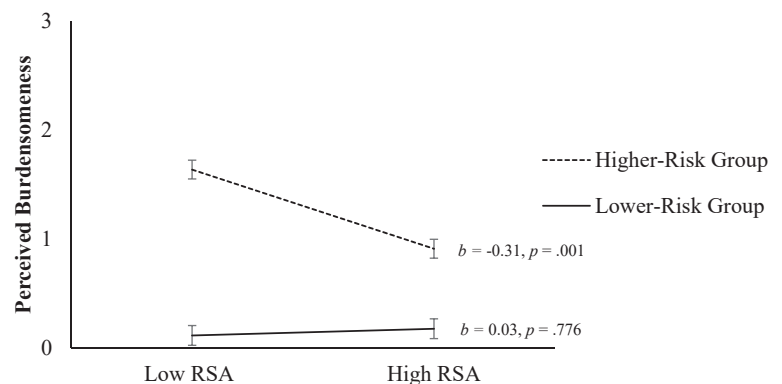
†  $t > |1.96|$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ .





**FIGURE 1** Panel (a) illustrates the two-way, cross-level interactions of within-person (WP) negative interactions and group predicting daily perceived burdensomeness. Panel (b) illustrates the three-way interaction between higher-risk group, RSA, and within-person negative interactions predicting daily perceived burdensomeness.

**FIGURE 2** Resting RSA and higher-risk group interaction predicting average perceived burdensomeness.



interactions, and the moderating effect of resting RSA across adolescents who are at higher- and lower-risk for suicidal ideation. Within-person fluctuations in negative

social interactions were independent predictors of same-day loneliness in both groups and of perceived burdensomeness in the higher-risk group. Furthermore, although

	Perceived burdensomeness	Loneliness	Suicidal ideation
	Effects (SE)	Effects (SE)	Effects (SE)
Intercept	0.71 (0.07)***	1.02 (0.06)***	16.23 (1.60)***
Age	-0.04 (0.04)	-0.08 (0.06)	-0.93 (1.06)
Resting RSA	-0.12 (0.06)*	-0.14 (0.07)*	-2.98 (1.33)*
H-R group	1.57 (0.07)***	0.72 (0.09)***	39.84 (9.14)***
H-R group × Resting RSA	-0.14 (0.06)*	-0.10 (0.07)	-3.88 (1.34)**
Fit statistics			
$R^2$	0.653	0.623	0.663

Note: This table presents only conditional main effects and interaction effects. The pattern of results for covariate and main effect models were identical.

Abbreviations: H-R Group, Higher-Risk Group; RSA, Respiratory Sinus Arrhythmia; SE, Standard Error.  $t < 0.09$ ; \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

not significant according to typical statistical significance threshold, there was a trending 3-way interaction at  $p < 0.081$ , suggesting that resting RSA may moderate the association of within-person negative social interactions with perceived burdensomeness in the higher-risk group. Among adolescents at higher risk for suicidal ideation, those with higher resting RSA tended to report less daily perceived burdensomeness, especially on days when they reported fewer negative social interactions than usual for them. When examining between-person differences, resting RSA was inversely associated with loneliness in both groups, and between-person differences in perceived burdensomeness in the higher-risk group. These results provide support for negative social interactions as important predictors of daily fluctuations in unmet interpersonal needs, and identify resting RSA as a moderator of loneliness and burdensomeness in response to interpersonal stress among adolescents.

The current study replicates findings of Glenn et al. (2021), showing that within-person differences in negative social interactions were associated with daily fluctuations in loneliness in both the lower- and higher-risk groups, but also extends these findings by showing that negative social interactions were associated with daily fluctuations in perceived burdensomeness among adolescents with MDD who are at higher-risk for suicidal ideation. Perceptions of loneliness are very common in adolescence, with up to 70% of adolescents and young adults reporting feeling lonely “sometimes” or “often” (Qualter et al., 2015). In contrast, no data are available about the prevalence of perceptions of burdensomeness in adolescence, nor their developmental trajectory (Hill & Pettit, 2014). Perceived burdensomeness is a consistently stronger independent predictor of suicidal ideation across studies with adolescents, compared to thwarted belongingness (Calear et al., 2021; Hill & Pettit, 2014; Horton

et al., 2016; Podlogar et al., 2017; Rogers & Joiner, 2019). In this context, loneliness may be a more normative experience of unmet interpersonal needs that fluctuates based on daily social experiences, whereas perceived burdensomeness may be a more extreme unmet interpersonal need, thereby remaining quite low in adolescents without MDD.

Adolescents with MDD may exhibit cognitive distortions influencing their interpretation of social interactions, often resulting in the activation of core beliefs that they are not needed by, or make things worse for, others (Van Orden et al., 2010). Indeed, greater difficulty reappraising negative social interpretations in light of disconfirming evidence predicted greater perceived burdensomeness over 1 week (Everaert et al., 2021). Moreover, adolescents with MDD may be more likely to appraise neutral or ambiguous social interactions as more negative and/or interpret positive interactions as less positive (Everaert, 2021). Such distorted interpretations may lead to adolescents with MDD perceiving more frequent negative social interactions, as observed in this study, and subsequently experiencing more frequent perceptions of burdensomeness. Thus, distorted interpretations of negative social interactions may contribute to enhanced perceived burdensomeness among adolescents with MDD who are at higher risk for suicidal ideation.

Resting RSA was associated with unmet interpersonal needs. Higher resting RSA was associated with decreased average loneliness in both groups, and with decreased average burdensomeness among adolescents at higher risk for suicidal ideation. A similar pattern of results emerged at the within-person level, such that resting RSA emerged as a potential moderator of the within-person association between daily negative social interactions and perceived burdensomeness among the higher-risk group. Although these within-person results were not

TABLE 3 Moderation models predicting between-person unmet interpersonal needs and suicidal ideation ( $N = 55$ ).

statistically significant ( $p < 0.081$ ), likely due to the small sample size limiting statistical power for the detection of interaction effects, this similar pattern of results at the between- and within-person level provide preliminary insight into potential mechanisms via which resting RSA may modulate risk for unmet interpersonal needs, and subsequently suicidal ideation (Van Orden et al., 2010). Prior work suggests that higher resting RSA is associated with more adaptive cognitive and emotional responses to interpersonal stress (e.g., Fagundes et al., 2012; Khurshid et al., 2019; McLaughlin et al., 2015; Muhtadie et al., 2015). Adolescents with lower RSA may have greater difficulties down-regulating negative affective states and reappraising cognitive distortions in general and in response to negative social interactions specifically, enhancing perceptions of loneliness and burdensomeness. Those with higher resting RSA may be better able to self-regulate, protecting them against more intense perceptions of burdensomeness, and potentially reducing risk for more severe suicidal ideation over time.

Of note, resting RSA was inversely correlated with past-month severity of suicidal ideation only among adolescents in the higher risk group (see Figure S1 for a depiction of this interaction effect). These results are consistent with past meta-analytic evidence suggesting that the association between RSA and socio-emotional outcomes is stronger in clinical than in community samples (Graziano & Derefinko, 2013). Although higher resting RSA has been associated with better social and emotional outcomes (Beauchaine, 2015; Graziano & Derefinko, 2013; Koenig et al., 2016), past research examining the association between resting RSA and suicidal ideation has been mixed. Among adults, various parameters of resting heart rate variability, including RSA, were reduced among individuals with past or current suicidal ideation, compared to non-clinical control participants (Adolph et al., 2018; Chang et al., 2012, 2013, 2017; Khandoker et al., 2017; Tsytses et al., 2018; Wilson et al., 2016). Moreover, resting RSA was inversely correlated with suicidal ideation within both clinical and non-clinical samples (Forkmann et al., 2016; Rottenberg et al., 2002). However, others studies reported a small positive association (Lin et al., 2015) or no association (Gutierrez et al., 2016) between RSA and suicidal ideation. Among clinical and non-clinical samples of children and adolescents, most studies to date found no association between resting RSA and suicidality (Giletta et al., 2017; James et al., 2017; Wielgus et al., 2016), although one study found decreasing RSA among adolescents with increasing suicidal ideation over a one-week period (Sheridan et al., 2021). The present findings suggest that differences across studies on the association between RSA and suicidal risk may be related to differences in unmet interpersonal needs. Thus, more

research is needed to examine the association of resting RSA with between-person and within-person differences in unmet interpersonal needs and suicidal ideation across clinical and community samples.

Although the inclusion of two groups is a strength of this study in order to capture a wider range of unmet interpersonal needs and risk for suicidal ideation, the complex statistical modeling including three-way interactions in this study requires large sample sizes to achieve adequate power. Moreover, the higher-risk group tended to be older and have a greater proportion of female participants than the lower-risk group. Although this sex and age distribution accurately reflects the greater propensity of older female adolescents to both suffer from depressed mood and seek help compared to younger and male adolescents (Sen, 2004), further research is needed among larger, more generalizable samples. Also, the statistical assumption of normality of residuals were not satisfied in all analyses. These results must therefore be interpreted with caution and reinforce the importance of replication in larger samples. This study also used single-item daily measurements of loneliness and burdensomeness that may not capture the multi-dimensional aspects of thwarted belongingness (e.g., social isolation, absence of reciprocal care) and perceived burdensomeness (e.g., self-hate, shame, perceptions of burdensomeness on family; Van Orden et al., 2010). Indeed, while loneliness is highly prevalent in adolescence, multi-dimensional, cumulative experiences of thwarted belongingness may not be. Therefore, future research could include more comprehensive assessments of these constructs using the validated Interpersonal Needs Questionnaire (Van Orden et al., 2012). Future research should also include daily assessments of suicidal ideation to better understand how RSA is associated with prospective between- and within-person differences in this outcome, in addition to unmet interpersonal needs.

Despite these limitations, this study provides evidence that negative social interaction are associated with increased perceived burdensomeness, especially among higher-risk adolescents with MDD. Furthermore, these findings provide preliminary evidence for the utility of resting RSA as a risk factor for between-person differences in unmet interpersonal needs in adolescence. This study also shed light on a potential mechanism via which resting RSA modulates responses to negative social interactions, impacting daily burdensomeness. This pathway may inform interventions targeting unmet interpersonal needs that have demonstrated mixed efficacy in reducing perceived burdensomeness (Hill & Pettit, 2019; Webb et al., 2022; Zullo et al., 2021). More work is needed to identify how to modify emotional reactions and cognitive distortions in response to daily negative social interactions, and to examine whether

and how RSA predicts longitudinal changes in unmet interpersonal needs and suicidal ideation among lower and higher risk adolescents.

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## CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, [SM], upon reasonable request.

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## ENDNOTE

<sup>1</sup> Resting respiration rate could not be obtained for one participant due to poor recording quality. This missing value was replaced with the sample mean to avoid listwise deletion during analyses. Results were the same with this participant excluded from analyses.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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