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Adolescent girls' intrapersonal and interpersonal parasympathetic regulation during peer support is moderated by trait and state co-rumination

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Abstract

Effective emotion regulation (ER) is integral to adolescents' mental well-being and socio-emotional development. During adolescence, peer interactions have an increasingly salient influence on the development of effective ER, but not all supportive peer interactions support adaptive ER. Co-rumination reflects the tendency to seek ER support by engaging with peers in negatively-focused discussion of ongoing problems. We examined associations between co-rumination (state and trait) with measures of individual autonomic (i.e., respiratory sinus arrhythmia, RSA) and affective regulation (self-report) among 30 female close-friend dyads (ages 11–17; 74% White) while engaged in a support-seeking discussion in the laboratory. We found that trait co-rumination corresponded with RSA withdrawal during peer support, suggesting a potential mechanism by which co-rumination contributes to dysregulated ER. We also examined dyadic patterns of physiological regulation via prospective change actor partner interdependence models (APIM). Partner effects were moderated by behaviorally-coded state co-rumination. Dyads with high state co-rumination displayed coupled RSA movement in opposite directions while dyads with low state co-rumination exhibited coupled RSA movement in the same direction. These findings are consistent with similar physiologic linkages in close relationships observed in other developmental periods. Results highlight the importance of multi-modal assessment for characterizing social ER processes across development.

Keywords

co-rumination; respiratory sinus arrhythmia; emotion regulation; parasympathetic; adolescence; peer support

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Adolescence is a critical period for socio-emotional development during which there is an increasing emphasis on developing a social network with same-aged peers outside of the primary parental relationship. These close intimate friendships increasingly become a primary source of support and companionship during adolescent development (Zeman, Cassano, & Adrian, 2013). Thus, peer friendships may have a particularly important influence on emotion regulation (ER) during stress in adolescence, including regulation of affective and physiological responses (Cook, 2020). Further, mounting evidence indicates that *how* adolescents seek support from friends has important implications on their psychosocial wellbeing. Co-ruminating with friends (i.e., the tendency to engage in negatively focused discussion of ongoing problems and reactions to events; Rose, 2002) has adjustment trade-offs of increasing adolescents' friendship quality (Rose, Carlson, & Waller, 2007) while also fostering risk for affective disorders, such as depression and anxiety (Hankin, Stone, & Wright, 2010; Stone, Hankin, Gibb, & Abela, 2011). Clarifying how supportive interpersonal processes within friendship dyads, such as co-rumination, are associated with behavioral and physiological regulation is vital for understanding how to bolster adaptive psychosocial functioning during this sensitive developmental stage.

Co-rumination is thought to confer risk for affective disorders by functioning as an ineffective social ER strategy. There are several possible mechanisms by which this may occur: Co-rumination may (1) increase negative affect during and immediately following co-rumination discussions (i.e., demonstrated in non-friend peers; Zelic et al., 2016), (2) contribute to maintenance of negative affect in daily life (Stone et al., 2019), and/or (3) foster dysphoric rumination (Stone & Gibb, 2015), an established maladaptive ER strategy and transdiagnostic risk factor for depression and anxiety (McLaughlin & Nolen-Hoeksema, 2011). One study demonstrated that whereas non-depressed adolescents tend to co-problem solve with parents when distressed, depressed adolescents report higher reliance on co-ruminating with friends (Waller, Silk, Stone, & Dahl, 2014). While these studies suggest that co-rumination likely influences ER effectiveness in daily life, it is a challenge to objectively measure these processes by relying on self-report. Physiological measures may provide a more objective assessment of the ER processes underlying co-rumination. Yet, the specific physiological mechanisms by which peer co-rumination may alter ER effectiveness remain to be characterized.

Assessment of peripheral indices of emotion processing and stress response can elucidate intra-as well as inter-personal ER processes occurring during social interactions (Murray-Close, 2013a). The autonomic nervous system (ANS) consists of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). SNS assessments capture physiological arousal associated with fight or flight responses to environmental threats or stressors. PNS assessments provide indices of ER processes. Respiratory sinus arrhythmia (RSA; changes in heart rate associated with the respiratory cycle), captures PNS influences on the heart via the vagus nerve, which is also thought to be central to social engagement and reciprocity through its enervation of the facial muscles (Porges, 2003, 2007) (Berntson & Cacioppo, 2007). RSA is thought to be a particularly important index of ER capacity during social interactions (Porges, 2003, 2007). RSA is typically measured by assessing high frequency heart rate variability coinciding with respiration (HF-HRV, see Berntson et al., 1997). Context appropriate reduction in RSA (i.e., RSA withdrawal) in response to

environmental stressors (often associated with corresponding increases in SNS activity) is seen as a flexible ability to regulate biological and affective responses, while a lack of RSA fluctuation in response to the changing environment is associated with reduced ER capacity (e.g., Bylsma, 2021; Hamilton & Alloy, 2016; Porges, 1995).

ANS assessments of co-rumination are currently limited to intrapersonal SNS assessment among samples of undergraduate women. For example, discussing a problem with a friend was associated with increases in salivary alpha-amylase and cortisol (Byrd-Craven, Geary, Rose, & Ponzi, 2008; 2011), indicating an increased stress response. These findings align with prior work supporting co-rumination is a maladaptive ER process that amplifies and maintains negative affect (Stone et al., 2019; Zelic, Ciesla, Dickson, Hruska, & Ciesla, 2016). PNS assessment of co-rumination is important to fully characterize how co-rumination alters ER processes, but unfortunately has not yet been examined in prior research.

Although RSA has not been examined in the context of dyadic co-rumination, lower resting RSA has shown more general associations with trait rumination, (e.g., Borelli, Hilt, West, Weekes, & Gonzalez, 2014; Ottaviani et al., 2016) state rumination, (e.g., da Silva, Witvliet, & Riek, 2016; LeMoult, Yoon, & Joormann, 2016) and perseverative negative thought in daily life, including rumination and worry (Carnevali, Thayer, Brosschot, & Ottaviani, 2018). As an ineffective regulation strategy, we may expect higher trait co-rumination to be associated with lower resting RSA levels, indicating diminished ER capacity. Further, identifying the autonomic concomitants of state co-rumination may inform how this social support strategy contributes to intrapersonal emotion dysregulation. For example, studies of state rumination suggest that co-ruminating with friends may elicit RSA withdrawal within individuals (da Silva et al., 2016; Ottaviani & Shapiro, 2011; Ottaviani, Shapiro, Davydov, & Goldstein, 2008), and repeatedly eliciting RSA withdrawal during supportive, socially reinforced interactions with friends may reflect an ineffective use of physiological resources.

Examining PNS responses in the context of supportive peer interactions is also needed to better understand the social influences on ER during adolescence. Coregulation refers to the synchrony (i.e., temporal concordance) of an individuals' affective and biological responses to the environment with those of their partner during interactions in close relationships (i.e., physiological influences of one partner on another) that may support allostatic balance in both partners (Butler & Randall, 2013; Feldman, 2007). Neurobiological synchrony during parent-infant interactions indicates the infant is developing healthy social affiliations with their caregiver, a critical attachment for psychosocial functioning (Feldman, 2014). PNS synchrony during friendship interactions in adolescence may reflect the successful development of social affiliations outside of the caregiver-offspring relationship.

Initial research on PNS synchrony largely focused on parent-infant/toddler dyads (Palumbo et al., 2017), and more recently, among parent-child/adolescent interactions (e.g., Amole, Cyranowski, Wright, & Swartz, 2017; Han et al., 2019; Li, Sturge-Apple, Liu, & Davies, 2020; McKillop & Connell, 2018; Oshri, Liu, Huffman, & Koss, 2020; Roman-Juan et al., 2020; Suveg et al., 2019; Woody, Feurer, Sosoo, Hastings, & Gibb, 2016). Among adults, PNS synchrony has focused primarily on romantic couples (e.g., Helm, Sbarra, & Ferrer,

2014). In adolescence, extensive literature has documented affective and SNS synchrony during harmful or adversarial peer processes, such as anti-social behavior or deviancy talk, peer victimization, and rejection (for review see Murray-Close, 2013a). However, to our knowledge, only a couple of studies conducted among undergraduates have examined ANS synchrony during supportive *friendship* interactions in which the goal was to self-regulate or resolve conflicts (Cook, 2020; Järvelä, Kivikangas, Kätsyri, & Ravaja, 2014). While there is a relative paucity of ANS synchrony research in adolescent peer friendships, research on parent-child/teen and adult romantic couples may inform what effective versus ineffective ANS synchrony may look like between adolescent friends, given that these represent an increasingly important source of support during adolescence.

Among parent-child/adolescent dyads, greater affective and PNS synchrony in certain contexts have been associated with mental health and well-being. Healthy mother-adolescent dyads without maternal or child symptoms or history of depression display positive RSA synchrony (coupled movement in the same direction over time) during positive and conflict discussions, whereas dyads with depression history or symptoms present display a lack of synchrony (Amole et al., 2017; McKillop & Connell, 2018; Woody et al., 2016) or negative synchrony (coupled movement in opposite directions) (Suveg et al., 2019). Similarly, among father-adolescent dyads, non-verbal affective behavioral synchrony was present among dyads with adolescents at low risk of anxiety, but not among dyads where adolescents are at high risk for anxiety (Roman-Juan, et al., 2020). Further, positive RSA synchrony among parent-adolescent dyads during challenging tasks and conflict discussions has been linked with adaptive traits such as more effective maternal emotional expression (Han et al., 2019) and adolescents' lower emotional insecurity (Li et al., 2020). Among adult romantic couples positive RSA synchrony has consistently been associated with higher relationship quality (Helm et al., 2014). Overall, findings suggest that positive RSA synchrony between adolescents and their mothers (who continue to be a primary source of support and intimacy) is beneficial for socio-emotional development and interpersonal ER (e.g., Butler & Randall, 2013). If this pattern extends to adolescent friendships, physiological synchrony during supportive peer interactions may be associated with greater psychosocial adjustment in adolescence.

However, positive synchrony is not always adaptive. For example, positive physiological synchrony has been shown in mother-child dyads with mothers who overstimulate their child, a situation which contributes to the child's emotion dysregulation (e.g., Field, 2007; Papoušek, 2007). Similarly, couples during conflict tasks also show positive physiological synchrony (Butler & Randall, 2013; Coutinho et al., 2020). Along these lines, Butler and Randall (2013) suggest that physiological synchrony in dyadic interactions may be beneficial when partners help stabilize each other around an optimal set point (i.e., morphostatic synchrony), but synchrony can also interrupt regulatory processes when it results in leading each other away from an optimal setpoint (i.e., morphogenic synchrony; also see Helm et al., 2014). Indeed, a few parent/adolescent studies have found that PNS synchrony (Oshri et al., 2020) and SNS synchrony (McKone, Woody, Ladouceur, & Silk, 2020) during conflict tasks were associated with the amplification of negative affect and associated expressions. To date, no studies have examined changes in PNS activity during interactions between adolescent friends. Examining PNS synchrony during support-seeking

peer interactions may clarify how friendships can influence adolescents' ER during this important developmental stage.

PNS synchrony between friendship dyads may differ according to their tendency to co-ruminate. However, the social vs affective adjustment tradeoffs of co-rumination raise multiple possibilities regarding the effect on how PNS synchrony may be altered. Given evidence suggesting that positive synchrony between parent-adolescent dyads is adaptive and evidence that co-rumination is a maladaptive ER strategy (Stone et al., 2019; Waller et al., 2014) associated with depression, one possibility is that co-ruminators (with poorer ER and potentially more dysphoric) may display a *lack* of PNS synchrony or negative PNS synchrony while attempting to regulate with peers. Although, given that co-rumination has been found to exert depression contagion effects (Schwartz-Mette & Rose, 2012), it is also possible that co-ruminators dysregulate together, showing positive (specifically, morphogenic) synchrony. Conversely, the social benefits of co-rumination for increasing intimacy and validation (Rose et al., 2007) could align with the research supporting positive PNS synchrony among adults romantic couples. Interpreting the effects of co-rumination on PNS synchrony within adolescent friendships requires considering cooccurring changes in both affect as well as friendship closeness.

The current study sought to examine the influence of co-ruminating with friends on intra- and interpersonal regulation/dysregulation of emotion, as measured by changes in self-reported affect, behaviorally-coded state rumination, friendship closeness, and assessment of PNS activity. Specifically, we aimed to examine both (1) intrapersonal and (2) interpersonal regulation processes related to co-rumination among close-friend dyads. We focused on adolescent girls' friendships given that co-rumination is more common among female than male friendships (Rose 2002; Rose et al., 2007) and co-rumination accounts for girls' greater tendency to ruminate (Felton, Cole, Havewala, Kurdziel, & Brown, 2019), as well as girls' heightened risk for depression in adolescence (Stone et al., 2011). Specifically, adolescent girls and their same-sex close friend discussed ongoing problems (problem-talk) they each wanted support with in a controlled laboratory setting while continuous physiological data were collected. State co-rumination was behaviorally coded based on the length and content of problem-talk of each dyad. Each girl also self-rated their levels of happiness, sadness, anxiety and friendship closeness immediately before and after the discussion.

In terms of intrapersonal regulation processes, we hypothesized that problem-talk with a friend would correspond with increases in negative affect (sadness and anxiety) as well as friendship closeness, and that these effects would be significantly stronger among girls' with high trait co-rumination (i.e., adolescents who tend to co-ruminate in their daily lives). Given limited prior research on changes in positive affect during problem-talk, we did not have a specific prediction for how/whether problem-talk would coincide with changes in happiness. Regarding autonomic regulation, we hypothesized that support-seeking discussion would elicit within-person RSA withdrawal relative to baseline. Further, we predicted that high-trait co-ruminators, would respond more strongly than low-trait co-ruminators and exhibit greater RSA withdrawal. Given the lack of prior research on state co-rumination and low correlation observed between state and trait co-rumination (Rose, Schwartz-Mette, Glick, Smith, & Luebbe, 2014), exploratory analyses were utilized

to examine whether affect, closeness and RSA changes differed according to state co-rumination.

In regard to interpersonal regulation processes, we aimed to examine whether affective and physiological synchrony (interpersonal regulation) with peers differed as a function of state or trait co-rumination. With the range of possibilities for how the social vs affective adjustment tradeoffs of co-rumination (reviewed above) may influence physiological synchrony between friends, an a priori hypothesis on RSA synchrony was challenging. In contrast, with the extensive and consistent literature linking co-rumination with poor ER, depression contagion, and friendship quality, we anticipated that dyads who engaged in greater co-rumination would exhibit greater positive synchrony of negative affect (co-occurring increases in negative affect, or morphogenic change) as well as friendship closeness (co-occurring increases, morphostatic change).

Methods

Participants

Thirty-two adolescent girls (ages 11–16) and their close female friend (within one-year of the girl's age) were recruited from the community. Girls' mothers were also recruited as they participated with their daughters in another part of the study. For clarity, since the current study focused on peer tasks, henceforth we refer to the recruited girls as the 'targets' and their accompanying female friends as the 'peers'. Exclusion criteria included: ongoing or serious health problems, psychoactive or cardiovascular medications, and parent-reported history of their child's diagnosis of autism spectrum disorder, bipolar disorder, neurological disorder, psychosis, or active substance abuse. Of 64 adolescent girls, usable physiological data were collected from 61. Three participants' data were not collected due to equipment failure. Thus, the current study focused on 61 adolescents for within-person analyses, and the 30 dyads with intact data for dyadic analyses. The majority of adolescents' (age range 11–17, M=14.41, SD= 1.62) identified as White or of European descent (74%), followed by African American (16%), and Biracial (7%), and two (3%) opted not to answer. One participant identified as Hispanic or Latina. Sample demographic details are displayed in Table 1.

Procedure

Phone screens were used to determine inclusion criteria. Approved participants were then scheduled for a laboratory visit. Informed consent was obtained from parents/guardians, and assent was obtained from both girls. The full laboratory visit involved physiological assessments of interaction tasks between mothers and daughters, adolescent girls and their peers, self-report questionnaires, and individual computerized tasks. The present study is focused solely on the peer interactions.

Both girls completed questionnaires, which included asking them to list a current problem that they would like to discuss with their peer. For the peer interaction tasks, both girls were set up for physiological recording using Mindware Mobile wireless systems then seated in comfortable chairs facing one another. Physiological data were collected during

a resting baseline period, talking baseline, and support task respectively. For the resting baseline period, a room divider was placed between them, and both girls were asked to sit quietly for two minutes without speaking. Afterwards, the room divider was removed. To control for the influence of speech on respiratory changes, which can influence RSA, we also included a talking baseline during which the girls were asked to read an excerpt from *Little Women* as neutrally as possible, for two minutes. For the peer support task, the research assistant reminded each girl of the problem they had identified. They were asked to discuss the target's problem first, then the peer's problem for a total of five minutes. If they finished talking about both girls' problems, they were instructed to talk about something else for the remainder of the time. If they stopped speaking, a research assistant reminded them to continue speaking for the full five minutes. All study procedures were approved by University of Pittsburgh's Institutional Review Board.

Behavioral Assessment of Co-rumination

The peer support task was behaviorally coded for state co-rumination using the system developed by Rose and colleagues (2014). First each dyad's discussion was transcribed by trained research assistants. One advanced student researcher (also the third author on this manuscript) completed extensive training on the coding system with the first author (a co-rumination expert). Specifically, the student researcher coded the 32 interactions with the support of weekly supervision and consensus meetings with the first author. Any anomalies or ambiguous behaviors that were difficult to code were also reviewed by the first author to ensure coding was consistent with published metrics, which have demonstrated high interrater reliability with multiple coders (Rose et al., 2014). Each transcript was coded on four Likert scales ranging from *not at all/very little* (1) to *very much* (5). The scales assessed the degree to which each dyad: (a) rehashed problems, (b) speculated about the problems (e.g., causes/consequences), (c) dwelled on negative affect, and (d) encouraged one another to keep talking about problems. The fifth metric measured how many seconds of the five minutes were spent engaging in co-rumination based on the criteria above. Thus, dyads who spent less time engaged in problem-talk would receive a lower state co-rumination score. Each metric was then standardized using Z-scores (Rose et al., 2014). State co-rumination was computed by averaging across all five standardized metrics.

Participants reported a range of problems to discuss with their friend, most of which (97%) would be considered episodic stressors with low objective threat (UCLA Life Stress Interview: Hammen & Brennan, 2001). Approximately a third of the sample reported academic or school-related problems (e.g., *failing a test; not getting along with a teacher or coach*; *not making band*). Another third reported peer or dating problems (e.g., *friend being mean; questioning partner's loyalty*). The final third was split between girls reporting family problems (*parents fighting; sibling is annoying me*) and girls identifying as aspect of themselves as the 'problem' such as '*lack of confidence; self-esteem; getting anxious over small things; jealous'*. Problem talk duration ranged from 1 minute 50 seconds to 5 minutes (*M*: 4 minutes, 15 seconds). Half the dyads discussed problems for the entire 5 minutes. Dyads that engaged in less problem-talk tended to move on to tangential aspects of the initial topic that were not perceived as problematic (e.g., another peer, teacher or sport at school) and thus did not include discussion focused on negative emotions, potential

causes or consequences. As noted above, the amount of time engaged in problem talk was accounted for in the state co-rumination scores.

Self-report Assessments of Co-rumination, Affect, and Friendship Closeness

Trait co-rumination with adolescents' participating peer was assessed via the nine-item version of the Co-rumination Questionnaire (CRQ) (Hankin et al., 2010). Each item assesses aspects of a more extreme form of discussing problems beyond mere self-disclosure, (e.g., "When we talk about a problem that one of us has, we usually talk about that problem every day even if nothing new has happened"). Participants answer on a Likert scale ranging from 1 '*not at all true*' to 5 '*really true*'. The scale is scored by computing an average across all items. Internal reliability in this study was excellent, $\alpha = .92$. CRQ means were dichotomized by median-split to examine differences according to high (1) vs. low (0) trait co-rumination among dyads.

Friendship quality was assessed via the Network of Relationships Inventory—Relationship Quality Version (NRI-RQV) (Furman & Buhrmester, 1985). The NRI-RQV assesses five positive aspects of the adolescent's relationship quality with their participating friend (i.e., companionship, disclosure, emotional support, approval, and satisfaction), and five negative relationship quality aspects (i.e., conflict, criticism, pressure, exclusion, and dominance). For example, companionship was assessed via items such as '*How often do you and this person go places and do things together?*'. Participants answered on a 5-point Likert scale ranging from 1 *'never or hardly at all'* to 5 *'always or extremely much'*. Friendship quality was calculated by averaging the score of the five positive relationship features (termed friendship closeness in the NRI-RQV manual). Overall friendship quality scores showed high internal reliability in our sample ($\alpha = .83$).

Current depressive symptoms were assessed via the Moods and Feelings Questionnaire (MFQ), (Angold, Erkanli, Silberg, Eaves, & Costello, 2002), a widely used measure of youths' current depressive symptoms with excellent psychometric properties, $\alpha = 91$. The MFQ is a 33-item scale that asks youth whether they have experienced a range of depressive symptoms and associated experiences in the past two weeks such as, '*I felt so tired that I just sat around and did nothing'* or *'I didn't enjoy anything at all'*. Answers options range from 0 *'not true'*, 1 '*sometimes*', to 2 *'true*'. The MFQ is scored by summing across all items. Of note, in the current sample only 2 of the 61 girls reported depressive symptoms at or above the clinical threshold (Jarbin, Ivarsson, Andersson, Bergman, & Skarphedinsson, 2020).

Visual analogue scales (VAS) were used to examine changes in affect and friendship closeness across tasks. Four VAS scales assessed happiness, sadness, anxiety, and friendship closeness three times: after the resting baseline, talking baseline, and peer support task. Participants rated current affect and closeness of four non-hatched 100mm VAS scales, with each end labeled '*Not at all*' and '*Very*'. Scores were measured in millimeters, with higher numbers indicating greater emotional intensity or friendship closeness.

Physiological Data Acquisition and Preprocessing

All physiological data were recorded at 1000 Hz via BioLab 3.1 software (MindWare Technologies, Gahanna, OH). Electrocardiogram (ECG) signals were sampled with three

disposable, pre-gelled electrodes placed in a Lead-II configuration (right clavicle, right and left lower ribcage).

RSA was derived using Mindware HRV 3.1 software to process the ECG data. Data were inspected visually in one-minute segments to ensure accurate R-wave detection. On rare occasions, suspected artifacts were corrected manually (< 1% of all beats). To calculate RSA, spectral power analysis was conducted via Fast Fourier transformations, with RSA (high frequency heart rate variability, HF-HRV) defined as power in the 0.12 – 0.40 Hz spectral bandwidth (ms^2) based on recommendations for capturing high frequency heart rate variability among children and their respiration rate (Shader et al., 2018). RSA was calculated per each 30-second segment, enabling sensitive synchrony analyses with adequate time to detect RSA whilst capturing changes across the interaction (Helm, Miller, Kahle, Troxel, & Hastings, 2018). To assess within-person changes across task, RSA was averaged across segments for each task.

Data Analytic Plan

Given the developmental range in the sample, preliminary analyses were conducted to examine whether affect or baseline RSA levels differed according to age. Age accounted for significant variance in RSA segments across the support task, $\beta = 0.50$, $p = .029$, which is consistent with evidence that RSA levels change across adolescence (Dollar et al., 2020). Thus, age was covaried for in all RSA models (both within-person and dyadic analyses). Age was not associated with any affect levels (lowest $p = .291$) and thus was not covaried for in analyses of individual or dyadic affect in the interest of model parsimony and maximizing power.

Within-subject changes in affect (i.e., happiness, sadness, and anxiety) and friendship closeness during the support task were tested via four 2×2 repeated measures ANOVAs to examine changes in affect before (following talking baseline) and after the support task as well as between-subject effects of trait co-rumination (high vs. low). Then four identical 2×2 repeated measures ANOVAs were run to examine whether changes in affect and friendship closeness were moderated by state co-rumination. Next, within-person changes in RSA during the support task were examined via two similar 2×2 repeated measures ANOVAs to determine whether effects were moderated by trait or state co-rumination.

Dyadic RSA analyses between friends were run according to actor partner interdependence models (APIM: Kenny, Kashy, & Cook, 2006) via mixed linear models in SPSS. APIM models acknowledge the interdependence of within-subject data, accounting for within-person stability (actor effect) while examining whether the participating peer (partner) influence one another over time. Thus, data from both the target and peer were entered as both the dependent variable and predictor. More specifically, to examine variation across the ten, 30-sec RSA segments in the support task, we ran prospective change APIM models (e.g., McKillop & Connell, 2018; Randall, Post, Reed, & Butler, 2013). The dependent variable was lagged RSA at time t (removing the first segment). The two primary predictors were target RSA at $t-1$ (actor effect) and peer's RSA at $t-1$ (partner effect). Two models were run to examine the potential moderating effect of trait co-rumination and state co-rumination on the partner effect (synchrony). All three predictors were entered as fixed

effects with the interaction term as an additional predictor (moderator × peer RSA at $t-1$). To account for the nested nature of the data, dyad was entered as random effect on the intercept. For this dyadic analysis, individual's trait co-rumination was dichotomized. As a dyadic variable, state co-rumination of the dyad was entered as a continuous Z-score. All predictors were grand mean centered.

Finally, four MLM models were run to examine whether levels of happiness, sadness, anxiety and friendship closeness covaried between friends before and after the support task. Since there were only two timepoints, we examined correlations (rather than lagged analyses). Target's affect was entered as the dependent variable. Peer's affect was entered as a fixed variable and dyad was treated as a random effect on the intercept. Because state co-rumination was measured as a dyadic-level variable, we were able to examine potential moderating effects.

Results

Among the 61 participants with intact physiological data, we first screened variables for missing data and examined the distribution of variables to test model assumptions. Some self-report items were missing (<3%). To justify data estimation of missing data via maximum likelihood (ML) estimation, we examined whether their data were missing at random (Schafer & Graham, 2002). Little's missing completely at random test was non-significant, $\chi^2(7)=6.69$, $p = .462$, supporting the use of ML (Little & Rubin, 1987).

Correlations among study variables are presented in Table 2. Of note, the correlation between the CRQ (trait co-rumination) and behaviorally observed state co-rumination was low, $r = .09$, $p = .475$, supporting the need to examine both self-report and behavioral indices of co-rumination, as complementary methods may reflect different aspects of the construct. Further, depression symptoms were significantly correlated with state co-rumination but not trait co-rumination (see Table 2), further supporting the importance of examining co-rumination using a multi-modal approach. Both state co-rumination and trait co-rumination increased with age.

Intrapersonal regulation analyses

How do affect and closeness change during peer support and are changes moderated by co-rumination?—Ratings of sadness, happiness, and closeness all increased significantly during the support task relative to talking baseline (ps<.05) (see Table 3). For happiness, the task × trait co-rumination interaction trended to statistical significance ($p = .059$). The pattern of effects is displayed in Figure 1. Happiness increased during the support task only among high-trait co-ruminators. There were no significant effects of task on anxiety. None of the between-subject effects of trait co-rumination were significant (ps>05). We also explored whether state co-rumination would be a stronger moderator of changes in affect and perceived closeness. Re-running the four models and removing trait co-rumination, none of the task × state co-rumination interactions reached significance (lowest $p = .296$).

Do RSA levels change during peer support and are changes moderated by co-rumination?—As displayed in Table 3, the task effect of RSA was not significant, suggesting the support task did not elicit reliable changes in RSA across participants. However, the interaction between trait co-rumination and RSA levels across tasks was significant. As displayed in Figure 2, adolescent girls with high trait co-rumination displayed RSA withdrawal during the support task, whereas girls with low trait co-rumination displayed a trend for RSA activation during the support task.

In contrast, behaviorally coded state co-rumination was not associated with RSA levels or changes in RSA during the support task relative to the talking baseline (*p*s>.05).

Interpersonal Regulation Analyses

Do friends influence each other's parasympathetic regulation during peer support, and are these dyadic effects moderated by co-rumination?—We tested for evidence of RSA synchrony among peer dyads with prospective change APIM models via mixed linear models in SPSS. Results are displayed in Table 4. The first model (Model0) examined actor and partner effects prior to the inclusion of potential moderators. There was a significant actor effect but not partner effect across all peer dyads. Next examining potential moderators, trait co-rumination did not moderate the partner effect, but state co-rumination did, $F(509)= 6.15$, $p = .014$. The pattern of effects is displayed in Figure 3 according to ± 1 SD of peer RSA and state co-rumination. Dyads who co-ruminated more during the support task exhibited negative RSA synchrony whereas dyads who engaged in less co-ruminating exhibited positive RSA synchrony.

To test the robustness of the state co-rumination association, we considered the influence of relationship quality. Coregulation and co-rumination have both been associated with higher relationship quality in previous literature. Thus, the state-co-rumination APIM model was re-run covarying for actor's reported friendship closeness as a fixed effect. Friendship closeness was not a significant predictor of RSA variation across the task, $F(450) < .01$, $p = .989$, but with the addition of this predictor, the interaction (peer RSA $_{t\text{-}1}$ × state co-rumination) no longer met the threshold of statistical significance, $F(516)= 3.24$, $p = .072$, indicating the RSA synchrony associated with state co-rumination was partially attributable to friendship closeness.

Do friends with higher co-rumination exhibit affective covariation when seeking social support?—The MLM models examining correlations between target and peer's affect levels before and after the support task are displayed in Table 5. Target and peer sadness levels were positively correlated, indicating similar sadness reactivity. Contrary to expectation, this effect was not moderated by state-co-rumination, indicating all dyads exhibited similarly correlated changes in sadness with their peers across the task. No evidence of covariation in happiness, anxiety, nor closeness was found.

Discussion

Peer relationships increase in importance as a primary source of social support in adolescence, which is also a developmental period of vulnerability for depression onset.

Dyadic interpersonal processes, such as co-rumination, may contribute to maladaptive patterns of ER. However, prior physiological assessments of social regulation of emotion have examined interactions primarily among parent-child, non-friend peer, and romantic couple dyads. This study provides the first assessment of PNS synchrony among adolescent friends during supportive dyadic interactions. To clarify how co-rumination may alter ER, we assessed the effects of both state and trait co-rumination on intrapersonal RSA changes within adolescent girls, as well as RSA coregulation between friendship dyads.

Focusing on intrapersonal regulation first, our results support the adjustment trade-offs of co-ruminating with friends. Although all adolescent girls reported an increase in sadness and friendship closeness during the support task, trait co-rumination moderated RSA changes during the interaction. Only adolescent girls higher on trait co-rumination exhibited RSA withdrawal during the support task relative to baseline, whereas low-trait co-ruminators exhibited RSA activation relative to baseline. This finding extends prior research indicating that discussing problems with a peer corresponds with an increase SNS arousal and cortisol among undergraduates (Byrd-Craven et al., 2008; 2011; Cook, 2020). We interpret this pattern as aligning with polyvagal theory, such that discussing a problem with a peer increases SNS arousal, but only induces a stress response coupled with RSA withdrawal among individuals who over-rely on their friends to regulate their emotions. Thus, the decrease in PNS activation that occurs within a high-trait co-ruminator (who engages in these conversations often) may reflect an alteration in PNS arousal that contributes to poorer physiological regulation over time. It is worth noting that only individuals' trait co-rumination score was predictive of within-person RSA and affect changes whereas state co-rumination (a dyadic level variable), was not.

With regard to affect, the increases in sadness and closeness during peer support were unexpectedly not moderated by trait co-rumination. In contrast, only girls higher on trait co-rumination reported a significant increase in happiness. One the one hand, the increases in sadness and closeness align with prior research indicating that problem talk amplifies and maintains negative affect (Stone et al., 2019; Zelic et al., 2016), but is socially reinforced via fostering friendship closeness (Rose et al., 2007). However, we expected these effects to be stronger among adolescents higher on trait co-rumination. The increase in happiness reported by high trait co-ruminators may be due to the emotional validation and intimacy derived from the interaction, indicating co-rumination may also be reinforced via short-term effects on positive affect as well.

In our APIM analyses of coregulation, we found that state co-rumination moderated RSA synchrony between peer dyads. Specifically, dyads with lower state co-rumination displayed positive RSA synchrony whereas dyads who co-ruminated during peer support displayed negative RSA synchrony. With the prospective change APIM model, positive RSA synchrony indicates both peers' RSA changes are occurring in the same direction (co-activation or co-withdrawal), whereas negative RSA synchrony indicates changes in opposing directions, such that among dyads actively co-ruminating, one peer is experiencing RSA withdrawal while the other RSA activation. Thus, one potential interpretation is that the association negative RSA synchrony and state co-rumination may capture the maladaptive effects of co-ruminating on social regulation. Positive RSA synchrony has been

consistently associated with greater relationship quality and mental health within primary relationships during other developmental stages (Amole et al., 2017; Helm et al., 2014; McKillop & Connell, 2018; Woody et al., 2016). In contrast, negative RSA synchrony within mother and pre-teen dyads has been associated with maternal depression history and child internalizing symptoms (Suveg et al., 2019). State co-rumination was associated with higher depressive symptoms in the current sample, thus finding positive RSA synchrony during low co-rumination and negative synchrony during high co-rumination extends current models of how peer support may disrupt ER processes. Physiological coregulation is thought to be beneficial when dyadic partners help stabilize each other around an optimal set point (Butler and Randall, 2013). The current results may indicate that co-ruminating dyads took turns dysregulating as adolescent girls discussed one another's problems and reactions. Finally, only state co-rumination, a behaviorally coded dyadic variable was a significant predictor of dyadic RSA synchrony, whereas individual girls' trait co-rumination was not. This pattern further supports the necessity of multi-modal assessments for clarifying social regulation processes.

Regarding affect covariation, we found adolescent girls' sadness reactivity correlated with that of peers across the support task. Contrary to expectations, this effect was not moderated by state co-rumination. This suggests that peers tended to experience similar increases in sadness based on the content of their discussion. It is difficult to parallel affective and physiological synchrony results in the current study since we only examined affect levels before and after the discussion. We suggest the current pattern with sadness reflects covariation more than synchrony, to the extent that target and peer sadness levels correlated before and after the task. Future research with finer assessments of affective change during discussions are needed to properly assess actor versus partner influences on affect regulation. Taken together with the intrapersonal analyses, while all girls experienced similar levels of sadness as their friend, only high trait co-ruminators exhibited RSA withdrawal during discussion, indicating low-trait co-ruminators are capable of empathizing with their peer without inducing autonomic stress response.

Interestingly, our measures of trait co-rumination and behaviorally-coded state co-rumination were not strongly associated with each other and showed differential effects with regard to physiological regulation and depression symptoms. Other studies have also noted the small correlation between observed and self-reported co-rumination (Rose et al., 2014). Modest correlations are not uncommon across multimethod assessments, as each method may magnify different facets of a construct. State co-rumination was associated with higher depressive symptom levels thus, the behavioral metric does appear to exhibit utility in capturing meaningful alterations in peer interaction that impact affective functioning. Further, in addition to replicating age effects with trait co-rumination (Rose 2002; Rose et al., 2007), we also found that state co-rumination tended to occur more among older peer dyads. Taken together, the current pattern of results, with individual's trait co-rumination predicting intrapersonal regulation and state co-rumination between peers capturing interpersonal regulation underscore the importance of assessing co-rumination (and other social regulation processes) comprehensively from multiple levels of analysis using a multimodal approach.

The current study does have a few notable limitations, including the modest sample size, use of a non-clinical sample, cross-sectional design, and inclusion of only adolescent girls. Our study is also limited to a single support task that differs from Rose's recommended 16-minute design (Rose et al., 2014). The possibility remains that findings may vary by task, context, and among high-risk samples. Thus, it would be premature to speculate how the current findings may generalize to daily life. Replications with larger samples that consider task differences, developmental stage, and clinical populations may reveal important distinctions in physiological coregulation patterns between adolescent friends. Further, although co-rumination is more common of adolescent girls' friendships (Rose 2002; Rose et al., 2007), research is mixed whether co-rumination confers the same affective risks among boys. On the one hand, there is evidence that both girls and boys that tend to co-ruminate are more vulnerable to current and future depressive symptoms, episodes, and contagion (Hankin et al., 2010; Schwartz-Mette & Rose, 2012; Stone & Gibb, 2015; Stone et al., 2011). Conversely, co-rumination has been found to only be associated with internalizing symptoms (e.g., Rose et al., 2007) and interpersonal stress generation (Rose, Glick, Smith, Schwartz-Mette, & Borowski, 2017) among adolescent girls, not boys. Given established gender differences in friendships roles (Rose & Rudolph, 2006) and expectations regarding self-disclosure with peers (Rose et al., 2012), future work is warranted to clarify whether social regulation strategies with peers differentially effects boy's autonomic regulation. Strengths of our study include our examination of dyadic physiology among adolescent friends using standardized laboratory tasks, our multi-method assessment of co-rumination, and APIM models that examined peer influence on physiological and affective regulation during peer support. A particular strength was our use of a talking RSA baseline for comparisons to the support task. Although RSA is known to be influenced by respiration rate (Berntson et al., 1997) many studies have not controlled for respiration, given concerns that it may control for the effect of interest (Quintana & Heathers, 2014).

Overall, findings may contribute to our understanding of how peer friendships influence ER during an important developmental period associated with both an increase in the importance of peer relationships and depression risk. Future research should also examine gender and age effects on dyadic interpersonal regulation processes, as well as utilize clinical samples longitudinally to determine how these processes relate to depression risk. It is also important for future work to examine the moderating influence of individual differences that may predict susceptibility to peer influences (Murray-Close, 2013b). Intervention and prevention research should consider the potential importance of peer influences in increasing or buffering risk for depression via dyadic regulation processes.

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Data Availability Statement:

Requests for the data or materials of this study can be sent via email to the corresponding author at lindseystone@georgiasouthern.edu

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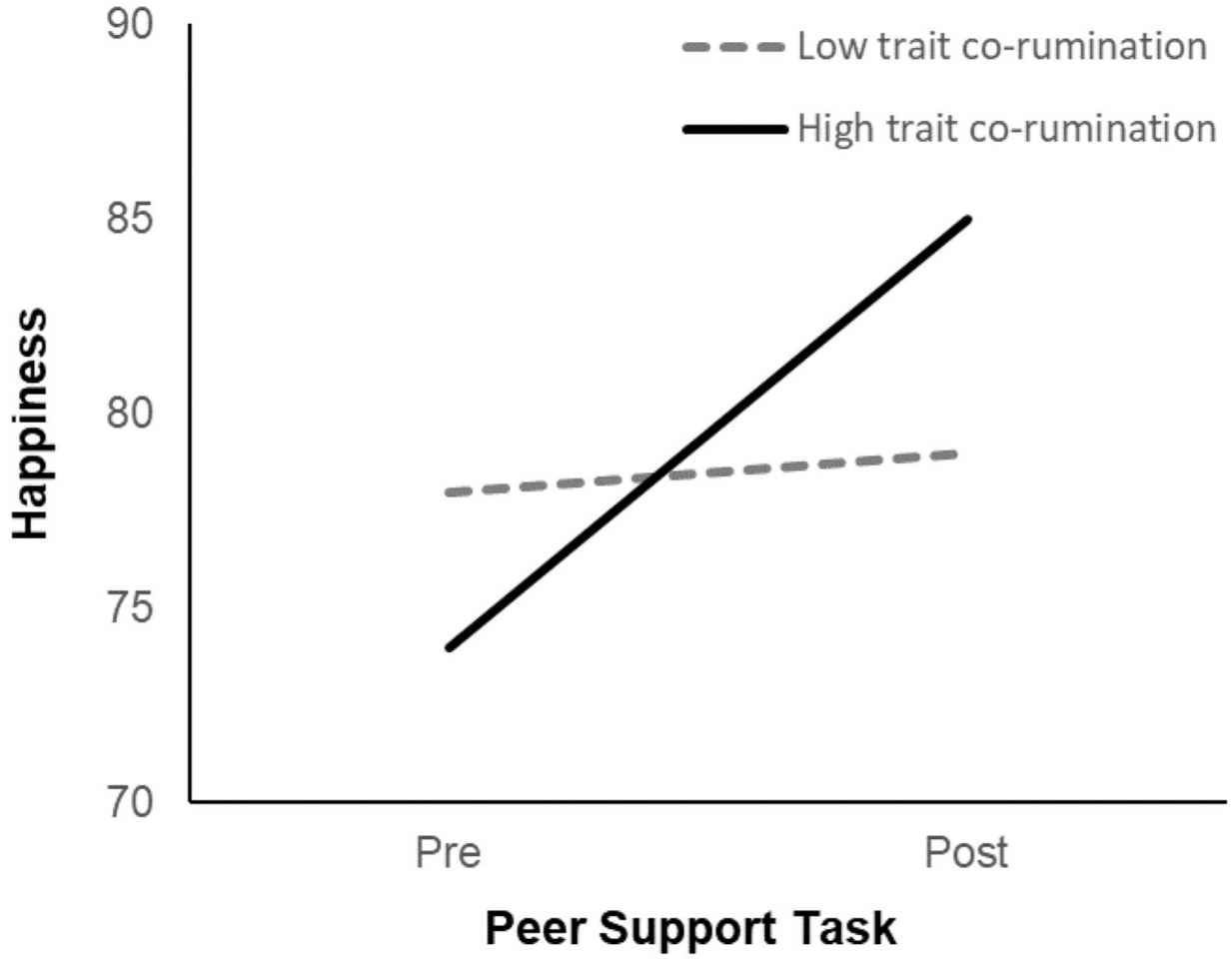

Figure 1.
Happiness increased during the peer support task only among high trait co-ruminators

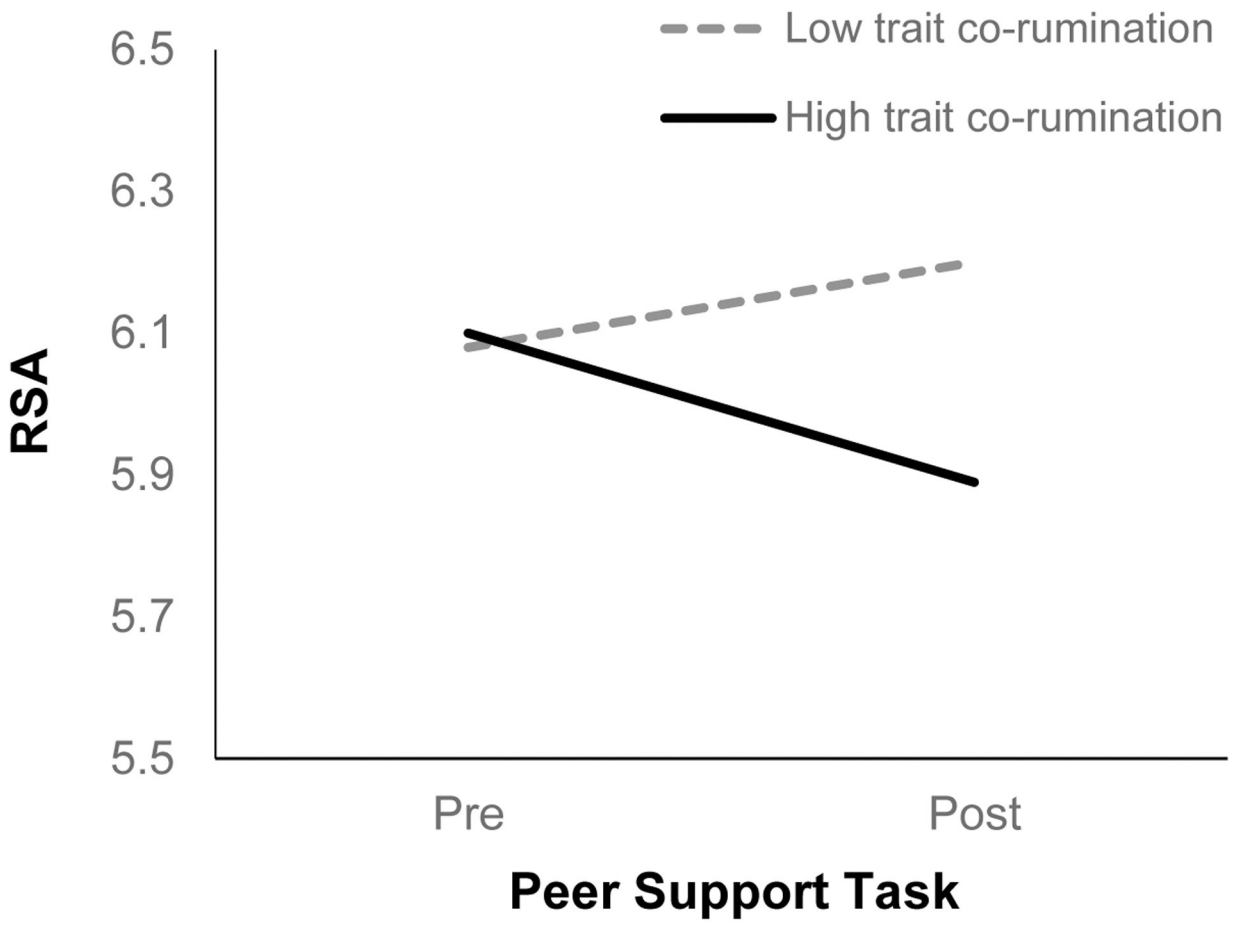

Figure 2.
RSA changes differed during peer support according to trait co-rumination

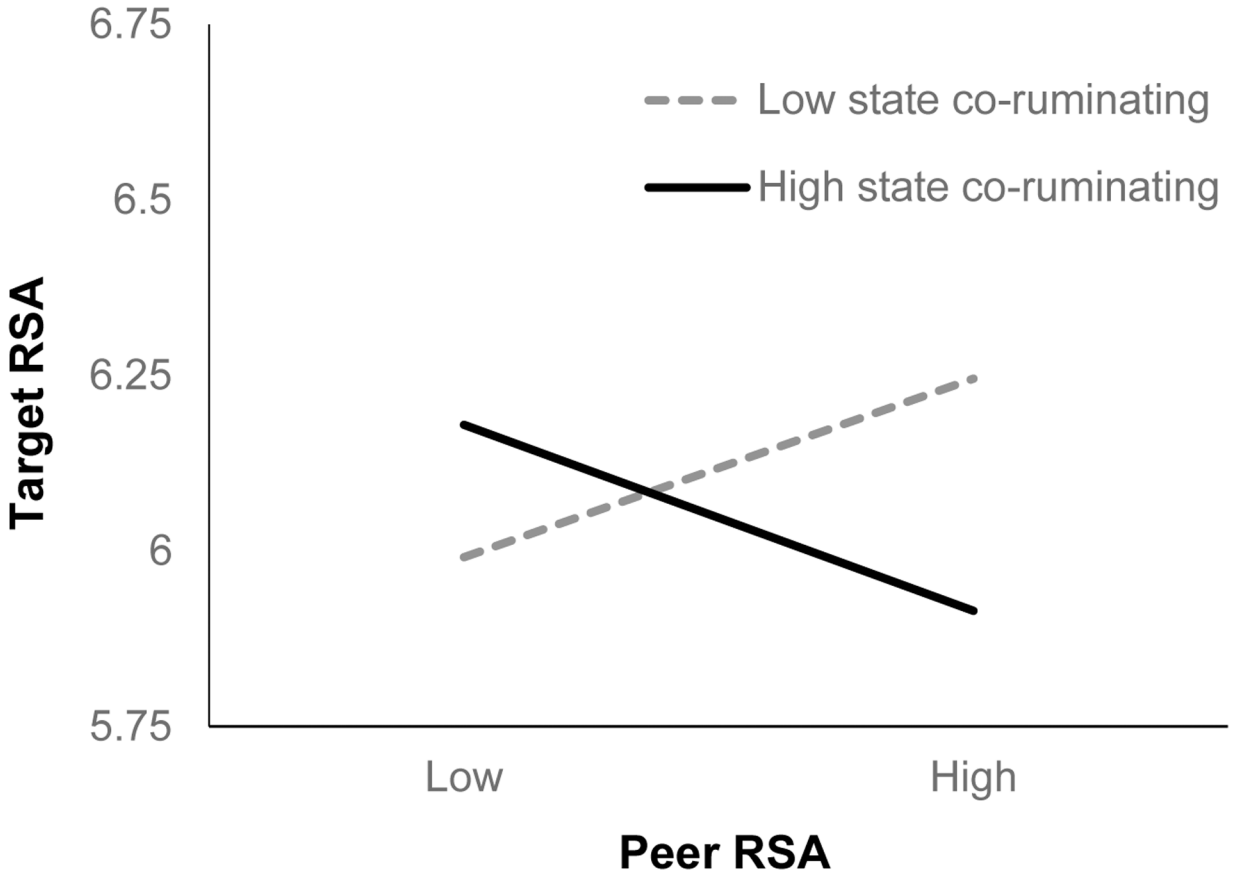

Figure 3.
State co-rumination moderated parasympathetic coregulation between friends.

Table 1

Sample demographics

Variables	Range	Mean	SD
Age	11 – 17	14.46	2.80
Race, *n*(%)			
White or European American		45	74%
Black or African American		10	16%
Multi-racial		4	7%
Missing		2	3%
Hispanic or Latina, *n*(%)		1	2%
Parents Marital Status, *n*(%)			
Married, living together		42	72%
Single Parent household		6	10%
Divorced or Separated		8	14%
Widow/Widower		2	3%
Head of Household Employment, *n*(%)			
Full-time		50	82%
Part-time		5	8%
Unemployed		4	
Head of Household Education			
Some High School		1	2%
High School Graduate		3	5%
Some College		11	18%
Baccalaureate Degree		22	36%
Graduate Training		21	34%
Annual Household Income (k)	$10 – $400	$89	$67.5

Table 2

Bivariate Associations

Variables	1	2	3	4	5	6	7	8
1 Trait co-rumination	—							
2 State co-rumination	0.09	—						
3 RSA resting baseline	−0.13	0.02	—					
4 RSA talking baseline	−0.09	0.05	0.85***	—				
5 RSA peer support	−0.21	0.01	0.84***	0.87***	—			
6 Friendship Quality	−0.01	0.15	0.20	0.19	0.15	—		
7 Depressive symptoms	0.08	0.26*	0.16	0.19	0.20	0.26*	—	
8 Age	0.35**	0.27*	0.08	0.18	0.12	0.09	0.17	—
Mean	3.07	0.00	6.42	6.09	6.05	2.32	10.27	14.46
SD	0.98	1.00	1.30	1.20	1.67	0.48	8.94	1.60

Note: raw scores are presented for clarity

* $p < .05$,

** $p < .01$,

*** $p < .001$

Table 3

Repeated ANCOVAs examining intrapersonal changes during social support with a friend

Affect DV	Predictor	Type	*F*	*df*	*P*	*Partial* η^2
Sad	Task	W	7.48	1	**.008**	.12
	Trait co-rumination	B	1.09	1	.302	.02
	Task × Trait co-rum	M	0.65	1	.800	<.01
Anxious	Task	W	0.36	1	.551	.01
	Trait co-rumination	B	0.02	1	.901	<.01
	Task × trait co-rum	M	0.10	1	.753	<.01
Happy	Task	W	6.85	1	**.011**	.11
	Trait co-rumination	B	0.04	1	.837	<.01
	Task × trait co-rum	M	3.72	1	.059	.06
Close	Task	W	8.95	1	**.004**	.14
	Trait co-rumination	B	0.63	1	.430	.01
	Task × trait co-rum	M	0.52	1	.472	.01
Physiology DV						
RSA	Task	W	0.33	1	.568	.01
	Trait co-rumination	B	0.24	1	.628	<.01
	Age	B	1.62	1	.208	.03
	Task × trait co-rum	M	4.62	1	**.036**	.07
	Task × age	M	0.42	1	.520	.01
RSA	Task	W	0.68	1	.415	.01
	State co-rumination	B	0.01	1	.953	<.01
	Age	B	1.46	1	.233	.02
	Task × state co-rum	M	1.37	1	.246	.02
	Task × age	M	0.80	1	.476	.01

Note: Type: Within (W), Between Subjects (B), Mixed (M) predictor. Task: two levels, talking baseline and peer support. Close = reported friendship closeness.

Table 4

APIMs testing whether trait and state co-rumination moderate parasympathetic coregulation

Fixed Effects		**Model0 Main effects**			**Model1: Trait Co-rumination**			**Model 2: State Co-rumination**		
		β	**SE**	***p***	**β**	**SE**	***P***	**β**	**SE**	***p***
β_{00}	Intercept	6.08	(0.13)	< **.001**	6.05	(0.15)	< **.001**	6.08	(0.13)	< **.001**
β_{10}	RSA_{t-1}	0.10	(0.04)	**.017**	0.38	(0.04)	< **.001**	0.10	(0.04)	< **.014**
β_{20}	Peer RSA_{t-1}	>.01	(0.04)	.940	−0.32	(0.05)	< **.001**	−0.01	(0.04)	.787
β_{30}	Age	0.22	(0.13)	.105	0.14	(0.09)	.146	0.23	(0.14)	.095
β_{40}	Moderator				0.08	(0.10)	.412	−0.05	(0.19)	.815
β_{41}	Peer RSA_{t-1} × Moderator				0.10	(0.07)	.126	−0.14	(0.06)	**.022**
Random Effects										
r_{oi}	Intercept	0.95	(0.22)	< **.001**	0.58	(0.20)	**.003**	1.00	(0.23)	< **.001**
e_{ti}	Level 1-Error	0.50	(0.03)	< **.001**	0.64	(0.04)	< **.001**	0.50	(0.03)	< **.001**

Notes: DV= RSA_t. RSA_{t-1}= actor effect. Peer RSA_{t-1} = partner effect. Main effects model establishes actor and partner effects.

Table 5

Adolescent friends' sadness reactivity covaries during the support task

Fixed Effects		Happiness		Sadness		Anxiety		Closeness	
		β	SE	β	SE	β	SE	β	SE
β_{00}	Intercept	80.91	(3.23) ***	6.35	(2.08) **	17.24	(3.89) ***	86.74	(2.79) ***
β_{10}	Peer Affect$_t$	0.10	(0.14)	0.51	(0.12) ***	0.08	(0.14)	0.25	(0.16)
β_{20}	State co-rum	2.17	(4.58)	−1.05	(2.91)	−0.84	(5.60)	4.09	(4.14)
β_{11}	Peer Affect $_t$ × State co-rum	0.07	(0.14)	0.01	(0.22)	0.18	(0.24)	0.12	(0.16)
Random Effects									
r_{oi}	Intercept	221.89	(84.85) **	121.20	(34.62) ***	397.83	(127.94) ***	126.64	(63.66) **
e_{ti}	Level-1 Error	160.83	(42.93) ***	13.38	(3.77) ***	82.82	(23.08) ***	171.45	(46.23) ***

* $p < .05$,

** $p < .05$,

*** $p < .001$