Mother-daughter mutual arousal escalation and emotion regulation in adolescence

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Emotion dysregulation is a core transdiagnostic risk factor for psychopathology and adolescence may be a sensitive period for the development of emotion regulation. Mothers may socialize emotion dysregulation by engaging in frequent interactions with their adolescents that involve mutual increases in arousal. This study examined mother-adolescent mutual arousal escalation in a conflict discussion task in adolescent girls. Further, we tested associations between mutual arousal escalation and adolescent emotion regulation. Participants comprised 84 adolescent girls (M_{age}=12.3[0.78]; 69% White) and their biological mothers. Dyads completed a 5m conflict discussion task, during which skin conductance level was collected as a measure of arousal. Adolescent emotion regulation outcomes included self-reported rumination and problem-solving, arousal habituation to a stressful speech task, and real-world use of positive and negative emotion regulation strategies. Multilevel models for distinguishable dyads indicated a significant random effect of time, with individual differences in arousal slope throughout the task for both adolescents and mothers. There were significant fixed and random effects of mother-to-adolescent cross-lagged arousal, indicating that mothers "transmitted" arousal to adolescents on average, and there was significant dyadic variability. Dyadic mutual arousal escalation predicted adolescent rumination, indicating that for dyads high in mutual arousal escalation and high in mutual arousal de-escalation, adolescents reported higher rumination. Mother arousal slope during the conflict task significantly predicted adolescent physiological regulation during the speech task; as mothers exhibited higher slopes on the speech task, adolescent slopes on the speech task were higher, reflecting less habituation. Higher mother-to-adolescent arousal transmission was associated with

more use of positive and less use of negative emotion regulation strategies in the real world. Results suggest that mother-adolescent dyads vary in the degree to which they mutually escalate or de-escalate in arousal during stressful interactions, and in the degree to which mothers “transmit” arousal to adolescents. These differences in interaction style appear related to adolescents’ abilities to regulate their emotions. Adolescents in dyads who mutually escalate *or* de-escalate in arousal report more rumination, which may be indicative of a practiced dysregulatory response in stressful contexts (escalation) or a tendency toward cognitive processes that lead to withdrawal from aversive environments (de-escalation).

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1.0 Introduction

Emotion regulation has been conceptualized as a core transdiagnostic factor for psychopathology and has been implicated in both internalizing and externalizing disorders (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Compas et al., 2017; Schäfer, Naumann, Holmes, Tuschen-Caffier, & Samson, 2017). Hence, understanding the nature and development of difficulties with emotion regulation is a critical avenue for research in developmental psychopathology. More specifically, examining the influence of mutable factors on the development of emotion regulation, such as parental influence, is key, as such research may reveal fruitful targets for intervention and treatment. Elucidating the development of emotion regulation in adolescence is of particular importance, as many forms of psychopathology have their roots in adolescence and pathological patterns begin to emerge during this period (Kessler et al., 2007, 2005; Merikangas et al., 2010; Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015). Epidemiological studies have repeatedly illustrated that depression and anxiety, in particular, emerge during the adolescent years, with rates for girls increasing more quickly than for boys (Hankin et al., 2015; Merikangas et al., 2010). To this end, this study examined emotion regulation outcomes in a sample of adolescent girls ages 11-13 enriched for variability in risk for depression and anxiety, as predicted by mother-adolescent mutual escalation of physiological arousal during a negative affect-inducing task.

1.1 Adolescence as a sensitive period for emotion regulation development

Adolescence is a complex and extended developmental transition, encompassing a wide array of physical, emotional, and social changes that intersect to make adolescence a sensitive period for the development of emotion regulation. Recent behavioral and neuroimaging research illustrates that several brain regions undergo remodeling during adolescence that may contribute to increased socioaffective sensitivity and cognitive flexibility in this developmental period (Crone & Dahl, 2012). One of the most well-documented changes in adolescence is increases in the salience of the social context (Blakemore & Mills, 2014; Nelson, Leibenluft, McClure, & Pine, 2005; Smith, Rosenbaum, Botdorf, Steinberg, & Chein, 2018), as evidenced by research illustrating that adolescents are more sensitive to social reward than both children and adults (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Foulkes & Blakemore, 2016; Gardner & Steinberg, 2005; Smith, Steinberg, Strang, & Chein, 2015). Concomitantly, processing of affective stimuli intensifies in adolescence; this increase in salience of emotionally relevant information has been observed for both positive (approach-related) and negative (avoidance-related) stimuli (Crone & Dahl, 2012). Alongside these increases in social and affective salience, a number of changes in cognitive control abilities occur in adolescence. Rather than the relatively linear trajectory of prefrontal cortical development that had previously been theorized, more recent research points to an increase in cognitive *flexibility* and increased cognitive sensitivity to context in adolescence (Crone & Dahl, 2012).

As these social, emotional, and cognitive changes occur, adolescents also become more independent, assuming more responsibility for their physical and emotional well-being and making their first forays into adult roles (e.g., employment, romantic relationships, etc.). These new roles and changes may be challenging and tax adolescents' developing skills, laying the foundation for novel, emotionally evocative situations and interactions, and subsequently, opportunities to practice regulating one's emotions in social context. The increases in flexibility in executive function occurring in concert with these novel opportunities for emotion responding in affectively salient circumstances may result in adolescence being a sensitive period for emotion regulation more broadly, and for the establishment of both beneficial and problematic patterns of emotion responding in social interactions, specifically.

Emotion regulation is context-specific (Weisz, McCabe, & Dennig, 1994), and a strategy that is adaptive in one context may not be adaptive in another. Despite this context dependence, several emotion regulation strategies appear to be more problematic, on average, in terms of their association with anxiety and depression in adolescence, whereas others appear to be generally protective, as supported by two recent meta-analyses (Compas et al., 2017; Schäfer et al., 2017). Emotion regulation strategies focused on engagement and approach, such as problem-solving, cognitive reappraisal, and acceptance, appear to be negatively associated with depressive and anxiety symptoms, whereas avoidant or disengagement strategies such as avoidance, suppression, and rumination are positively associated with internalizing symptoms. Of note, the effects of some strategies varied depending on age; these moderation findings indicate more and stronger associations between emotion regulation strategies and psychopathology in adolescence compared to childhood (Compas et al., 2017). These findings solidify the critical role of emotion regulation strategies in the development and maintenance of depression and anxiety in adolescence and support the conceptualization of adolescence as a sensitive period for emotion regulation development.

1.2 Emotion regulation development through mother-child interaction

Given that emotion and emotion regulation are embedded in the social context, it is perhaps unsurprising that parents play an important role in the development of children's – and ultimately adolescents' – emotion regulation abilities (Morris, Silk, Steinberg, Myers, & Robinson, 2007). In infancy, emotion is effectively co-regulated within the parent-infant dyad (typically the mother), as the infant is only capable of rudimentary, physiological forms of independent self-soothing (e.g., diverting attention, sucking; Kopp, 1982; Sroufe, 1996). This co-regulation, often described as "synchrony", appears to be facilitated by physiological attunement between mother and infant (Feldman, 2012). Feldman and colleagues (Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011) illustrated that mothers and their three-month-old infants synchronized their heart rates during interaction, and this biological co-regulation was increased when mothers and infants engaged in behavioral co-regulation (e.g., co-regulation of affect). Throughout the course of early development, mothers gradually transition from serving in this intensive co-regulatory role to teaching, scaffolding, and modeling ever more sophisticated forms of emotion regulation (Morris et al., 2007; Perry & Calkins, 2018). As children age into adolescence and develop more independence as well as more sophisticated cognitive abilities, mothers continue to promote both positive (e.g., problem-solving, reappraisal) and negative (e.g., rumination, avoidance) emotion regulation strategies by modeling in their own emotional responding and, most pertinent to this study, through scaffolding and emotion coaching during dyadic interactions with the adolescent (Lougheed, 2019; Morris, Cui, Criss, & Simmons, 2018). Further, there is evidence, albeit limited, that similar forms of psychobiological attunement initially apparent in mother-infant co-regulatory processes continue into childhood (e.g., Woody, Feurer, Sosoo, Hastings, & Gibb, 2016) and adolescence (Amole, Cyranowski, Wright, & Swartz, 2017; Connell, Hughes-Scalise, Klostermann, & Azem, 2011; Connell, McKillop, Patton, Klostermann, & Hughes-Scalise, 2015).

In addition to these broad patterns of mother-adolescent emotion co-regulation and socialization, there may be individual differences in how mothers interact with their adolescents in heightened emotional contexts (e.g., conflict), and in the extent to which mothers are able to successfully scaffold emotion regulation abilities during dyadic interaction. These individual differences in dyadic emotion dynamics may lead to downstream differences in adolescent emotion responding. One particularly problematic pattern may be if the mother exacerbates arousal in the adolescent beyond a responsive, empathetic reaction during conflictual or stressful interactions. Experiencing repeated escalations of arousal during interpersonal conflicts with one's mother may, over time, lead to the adolescent to interpret relatively neutral events as negative (i.e., mood-congruent effects, Clark & Waddell, 1983), resulting in increased negative affect and subsequent difficulties with emotion regulation, such as overreacting to neutral events. Alternatively, if one's mother does not respond adequately to the adolescent's arousal (i.e., is not empathetic), the adolescent may exacerbate her behavioral emotional response in an attempt to receive the support desired.

One model for conceptualizing maternal influence on adolescent emotion regulation during dyadic interaction is Butler's temporal interpersonal emotion systems (TIES; 2011, 2015), which integrates the *inter*personal context into the typically *intra*personal components of emotion (behavior, physiology, experience; Butler, 2011). In the context of the mother-child relationship, TIES models aim to elucidate the ways in which mother and child emotion are related to one another, or covary, over time. Research has identified patterns of covariation in behavioral displays of negative affect in mothers and adolescents during stressful mother-adolescent interactions.

Multiple studies have shown that mothers and adolescents are temporally reciprocal in their behavioral displays of negative affect (Main, Paxton, & Dale, 2016; Sheeber, Allen, Davis, & Sorensen, 2000), with one study indicating that mothers drive this effect in interactions with young adolescents (ages 13-14; Main et al., 2016). Similarly, adolescents whose mothers displayed more aversive behaviors in a positively-valenced interaction task were more likely to reciprocate aversive and dysphoric behaviors in a conflict interaction task, and reported that they used more negative emotion regulation strategies (Yap, Schwartz, Byrne, Simmons, & Allen, 2010). Further, adolescents at high risk for depression and their mothers exhibited more dyadic negative affect escalation in a conflict task compared to low-risk adolescents and their mothers (McMakin et al., 2011), indicating that negative affect escalation may be implicated in psychopathological processes in at-risk dyads and highlighting the need to examine negative affect escalation as a predictor of emotion regulation. However, several limitations of these studies merit noting. These studies did not always examine change over time (i.e., examining negative affect synchrony rather than escalation) and those studies that did examine negative affect escalation did not examine the effect of such escalation on adolescent emotion regulation abilities.

As mentioned previously, in addition to covariation in behavioral displays of emotion in mothers and adolescents, there is evidence of covariation in *physiological* emotion response in mother-adolescent dyads. Compared to behavioral measures, physiological indices of emotion possess several characteristics beneficial for assessing mother-child covariation in emotion responding. First, many physiological indicators have high temporal resolution, producing measurements on the second scale, allowing researchers to capture sensitive, moment-to-moment measures of emotion response. Second, physiological measures of emotion response may reflect a wide array of interpersonal dynamics operating on very brief timescales, such as facial affect and body language, that may be communicated to an interaction partner before individuals have conscious awareness of their emotional response (e.g., Tooley, Carmel, Chapman, & Grimshaw, 2017). Third, physiological indicators provide a more objective (albeit less specific) measure of emotion response than self-report or observer-coded affect (Kassam & Mendes, 2013; Mauss & Robinson, 2009). Hence, physiological measures of emotion response are well positioned to capture the temporal interpersonal emotion dynamics between mother and adolescent. One frequently used physiological indicator of emotion that possesses the aforementioned characteristics is skin conductance level (SCL), a measure of electrodermal activity in which direct current is applied to the skin under conditions of constant voltage (Boucsein, 2012). SCL reflects tonic levels of sympathetic nervous system (SNS) activity and under negative-affect inducing conditions can reasonably be conceptualized as a physiological indicator of negative affect arousal.

There is ample research on the physiological emotional attunement of mothers and infants/young children and between adult romantic partners (see Palumbo et al., 2017, meta-analysis and Timmons et al., 2015, review). However, there is little research examining physiological covariation between mothers and adolescents, especially in negative affect-inducing contexts. The majority of the limited studies in this area have examined dyadic heart rate variability (or respiratory sinus arrhythmia [RSA]) as an index of parasympathetic nervous system response in clinical samples. The results of these studies paint a complex and occasionally contradictory picture regarding patterns of physiological covariation during stressful dyadic interaction (Davis, West, Bilms, Morelen, & Suveg, 2018). Several studies support the notion of blunted or dysregulated dyadic physiological response (e.g., lack of covariation, reduced RSA in response to aversiveness, reduced flexibility) in dyads with or at risk for depression (Amole et al., 2017; Crowell et al., 2014), although adolescent RSA may serve as a protective factor in the face of maternal depression (Connell et al., 2015). Conversely, one study indicates that maternal expressions of negative affect (anger) may lead to decreased adolescent RSA, which the authors interpreted as indicative of decreased regulatory ability (Cui et al., 2015).

To our knowledge, only two studies to date have examined dyadic patterns of mother-adolescent covariation in SNS arousal as assessed by SCL. In two separate studies conducted in a community sample of adolescent girls and their mothers, Lougheed and colleagues found varying "arousal transmission" effects dependent on the context (Lougheed & Hollenstein, 2018; Lougheed, Koval, & Hollenstein, 2016). Daughters transmitted arousal to mothers while they were undergoing a stressful performance task, but mothers transmitted arousal to daughters during two dyadic interaction tasks designed to elicit negative and positive emotion, respectively. Notably, the latter study did not examine change over time in physiological emotion responding during stressful dyadic interactions, nor did they investigate the relation between dyadic physiological covariation and emotion regulation abilities in the adolescent.

1.3 The current study

To address this gap in the literature, the current study examined how mutual escalation in arousal, as assessed by SCL, between adolescent girls ages 11-13 and their mothers, predicts emotion regulation strategy use in the adolescent. Several patterns of mother-adolescent emotion dynamics have been observed in the literature (Lougheed, 2019). First, mothers and children may track together concurrently over time around a *stable level* either with or without consideration of which partner is driving the change (e.g., concurrent or time-lagged synchrony). These synchronous processes, particularly those in which one or both partners "picks up on" the other partner's emotion, have been posited to reflect empathetic processes (Butler, 2011; Lougheed & Hollenstein, 2018) that may be disrupted in at-risk dyads or dyads with psychopathology (Amole et al., 2017). Alternately, and of particularly interest for this study, mothers and children may track together over time while one or both partners change in mean level of emotion, again with the possibility of examining which partner may be driving the effect (transmission, contagion, escalation, de-escalation with or without time lagged effects; here, mutual escalation of arousal). This mutual escalation of arousal may be symmetric, in which each partner influences the other to the same extent, or asymmetric, with one partner driving change in the other more than the reverse. Although dyadic covariation around a stable emotional level (synchrony) may reflect adaptive empathetic processes, such covariation may have different, potentially adverse, effects on adolescent functioning if the covariation reflects a pattern of, or results in, overall increases in adolescent arousal. This pattern may be particularly problematic if the mother, functioning in an emotion-scaffolding or emotion-coaching role, temporally drives these increases in arousal.

This study was conducted in two stages. First, the degree to which mothers and adolescents escalated in arousal over time – both individually and together – and the extent to which mothers and daughters drove changes in the other partner's arousal (cross-lagged effects) was examined via longitudinal growth curve modeling in a multilevel model for distinguishable dyads. Second, mutual arousal escalation and the interaction between cross-lagged effects and mutual arousal escalation were used to predict adolescent emotion regulation as assessed in three ways: 1) global self-report of emotion regulation; 2) real-world emotion regulation strategies as reported via ecological momentary assessment (EMA); and 3) physiological arousal habituation during a stressful lab task. In order to examine emotion regulation as it pertains to psychopathology risk, this study was conducted in a sample of adolescent girls recruited to ensure variability in temperamental risk for social anxiety and depression.

1.4 Hypotheses

Based on the literature in this area, we hypothesized that, on average, mothers and adolescents would increase in arousal from the beginning to the end of the conflict discussion task (hypothesis 1.1). Further, consistent with previous research (Lougheed & Hollenstein, 2018), we hypothesized that on average, mother's arousal would predict change in adolescent's arousal (above and beyond the adolescent's arousal at the previous time point; hypothesis 1.2), but adolescent's arousal would not predict change in mother's arousal (above and beyond the mother's arousal at the previous time point; hypothesis 1.3),. In addition to these fixed effects, we predicted there would be significant individual differences in the extent to which dyads mutually escalated (i.e., significant random effects of time for parents and adolescents; hypothesis 1.4). Further, we predicted that dyadic mutual arousal escalation would be positively associated with self-reported adolescent rumination (hypothesis 2.1) and adolescent use of negative emotion regulation strategies in the real world (e.g., rumination; hypothesis 2.2), negatively associated with self-reported adolescent problem-solving (hypothesis 2.3), negatively associated with adolescent use of positive emotion regulation strategies in the real world (e.g., problem-solving; hypothesis 2.4), and associated with slower habituation to stressful performance (hypothesis 2.5). Finally, we hypothesized cross-lagged effects of mother arousal on adolescent arousal would predict adolescent emotion regulation. Overall, maternal cross-lagged effects, theorized to reflect broadly empathetic processes, were expected to be associated with more adolescent problem-solving (hypothesis 3.1) and use of positive emotion regulation strategies in the real world (hypothesis 3.2). However, in the context of mutual arousal escalation, we expected maternal cross-lagged effects would be associated with more adolescent rumination (hypothesis 3.3) and more use of negative emotion regulation strategies in the real world (hypothesis 3.4).

2.0 Method

2.1 Participants

Participants were 84 adolescent girls and their participating biological mothers from the Girls' Interactions in Real Life Study of Brain Development (GIRLS: Brain Study), a longitudinal study examining emotional, neural, and social factors in the development of social anxiety and depression. The full sample of 129 adolescents was recruited such that two-thirds of the sample was high risk and one-third low risk for social anxiety and depression, as indicated by the Fear and Shyness subscales of the Early Adolescent Temperament Scale – Revised (EATQ-R). High-risk status was defined as scoring 0.75 SD above the mean on either the Fear or Shyness subscale (administered during a screening phone call). As the study aims to examine the development of social anxiety and depression, with emphasis on neural development as assessed through fMRI, exclusion criteria included: current or past DSM-5 diagnosis of an anxiety disorder (with the exception of specific phobia) or major depressive disorder; IQ less than 70 as assessed by the Wechsler Abbreviated Scale of Intelligence; lifetime presence of a DSM-5 diagnosis of psychotic disorder or autism spectrum disorder; lifetime presence of a neurological or serious medical condition; pregnancy; positive drug screen; presence of MRI contraindications (braces, metal in body); uncorrected visual impairment; left-handedness; presence of head injury or neurological anomalies; psychoactive or endocrine disrupting medications (with the exception of stimulants); acute suicidal risk or risk of harming self or others.

2.2 Procedure

The GIRLS: Brain Study was designed in three waves of data collection. All measures described in this study are from the first wave, for which participants completed a series of online questionnaires, three laboratory visits, and a 16-day EMA protocol. The first and third laboratory visits, which are not relevant to this study, comprised a structured clinical interview and fMRI scan, respectively. During the second laboratory visit, described in detail below, participants completed a number of behavioral tasks, including a stressful performance task, in which participants were required to give a brief speech, and several dyadic interaction tasks that the participant completed with her mother. Throughout the visit, a number of physiological indicators were measured, including SCL, as described below.

2.2.1 Laboratory tasks

2.2.1.1 Speech task

Participants were asked to prepare a two-minute speech arguing why they should be selected for a fictional reality TV show. The participant had the opportunity to prepare with her mother for two minutes. The speech was performed in front of two judges, who were instructed to respond in specific ways: one judge alternated between neutral expression and smiling, whereas the second judge maintained a neutral expression throughout. If the participant stopped speaking for over 30 seconds, she was prompted by research staff to continue, and if participants exhibited considerable distress (e.g., crying) at the prospect of completing the task, the task was skipped.

2.2.1.2 Conflict discussion task

At the outset of the second laboratory visit, each participant and her mother completed a modified version of the Issues Checklist (Prinz, Foster, Kent, & O'Leary, 1979), which constitutes a list of topics that adolescents and parents commonly disagree about, asking participants to identify the frequency with which they argued about a topic and the severity of the disagreements. Research staff reviewed the surveys and selected the top two areas in which the participant and her mother reported that they often disagreed. Dyads were instructed to "identify the main problem or disagreement and talk about what you think would be the best solution to this problem" and to discuss the topic for five minutes. If dyads got stuck or ran out of things to say about the first topic, they were instructed to discuss the second area of disagreement. A manipulation check of the conflict discussion task was conducted in order to ensure the task elicited primarily negative emotion. Mother and adolescent completed a brief mood rating at resting baseline and following the task, rating their feelings of happiness, sadness, and anxiety, as well as how close they feel to the other person, on a sliding scale from 1 to 100. Change scores from resting baseline to post-task were calculated to determine whether negative affect (less happiness, more sadness and anxiety) increased as a result of the task.

2.2.1.3 Physiological data collection

During the laboratory tasks (conflict discussion, speech), electrodermal activity (EDA) was acquired from both adolescent and mother using MindWare Mobile wireless systems and recorded with MindWare BioLab v3.1.2 software using a 500 Hz sampling rate. EDA was recorded using Ag/AgCl electrodes, which were attached to the thenar and hypothenar eminences of participants' right palms. EDA signal was inspected, filtered, and analyzed by MindWare EDA Analysis v3.1.3. A rolling filter with a 500 block size smoothed the signal and prevented identification of false skin conductance responses resulting from noise. Skin conductance level (SCL) was used as the tonic component of EDA and calculated through optimized Continuous Decomposition Analysis. SCL was calculated for each 10-second epoch of the tasks, resulting in 30 and 12 total measurements during conflict discussion and the speech task, respectively. For the purposes of this study, SCL was used as the primary index of tonic physiological arousal for both mother and adolescent. In order to reduce non-theoretically meaningful between-person differences resulting from dermal thickness, data were standardized within person using percent of maximum possible (POMP) scoring (Cohen, Cohen, Aiken, & West, 1999).

SCL data were visually inspected for artifacts and/or equipment malfunctions. In instances when participants had less than three segments (30s) with signal loss, data were overwritten as missing for those segments to allow participants to be retained. Fifteen participants' data were modified in this manner (14 adolescents; one parent). Seven participants did not complete the second lab visit, and eight participants had a participating parent who was not their biological mother (e.g. father, custodial grandparent). Thirty dyads were excluded due to conflict discussion task data that was missing (three dyads) or exhibited bad signal (16 dyads) or signal loss affecting more than three segments in either adolescent or parent (12 dyads). For the speech task, three participants were lost due to bad signal and eight participants were lost due to excessive signal loss. There were no significant differences in study variables between participants who were included in analyses and those who were not.

2.2.2 EMA protocol

After the second laboratory visit the child was provided with a study cellphone and instructions on completing the EMA protocol, which was designed to collect information about participant mood and social context in their lives. Over the course of the 16-day protocol, participants received three prompts on weekdays and four prompts on weekend days to complete the EMA questionnaire. Participants provided a time prior to the start of the school day for the first weekday prompt; the three remaining prompts were randomly delivered after the child's school end time (no prompts occurred during school hours). In addition to collecting information on what the participant was doing and who she was with at the time the prompt was received, in response to each prompt the participant reported on all interactions she had with other kids her age since the last prompt, and answered several questions about her most recent negative and positive social interactions.

2.2.3 Emotion regulation outcomes

2.2.3.1 Global self-reported rumination

Participants reported on their global tendency to ruminate using the Children's Response Style Scale (CRSS; Ziegert & Kistner, 2002), a 20-item questionnaire that assesses how often children respond to sadness with rumination ("I replay in my head what happened.") or distraction on a scale of *0 = Never* to *10 = Always*. For the purposes of this study, the 10-item rumination subscale (α = .89) was used as an index of maladaptive emotion regulation.

2.2.3.2 Global self-reported problem-solving

Adolescents reported on their global tendency to engage in problem-solving on the Responses to Stress Questionnaire, Social Stress Version (RSQ; (Connor-Smith, Compas, Wadsworth, Thomsen, & Saltzman, 2000) on three items scored from *1 = Not at all* to *4 = A lot.* To operationalize problem-solving, the three items from the problem-solving subscale were summed (“I tried to think of different ways to change the problem or fix the situation.”, “I asked other people for help or for ideas about how to make the problem better.”, “I did something to try to fix the problem or take action to change things.”; α = .55)

2.2.3.3 Real-world emotion regulation strategy use

As outlined above, participants were prompted up to four times daily to report on the most recent negative social interaction they had experienced (*“Think about the interaction with other kids your age that made you feel the worst since the last beep on [last sampling time]. What happened?”*). Participants were asked to briefly describe the nature of the interaction (e.g., in person, over the phone/text, online) as well as when and with whom the interaction occurred (e.g., friends, boyfriend/girlfriend/crush, other kids). Subsequently, the participant rated the extent to which she experienced four negative emotions (anger, worry, sadness, and stress) in response to the interaction on a sliding scale from *0 = not at all* to *100 = extremely* and reported which (if any) of a set of emotion regulation strategies she employed (see below for details). Two outcome variables were derived from the participant’s responses as follows.

2.2.3.4 Momentary positive and negative emotion regulation strategy use

After the participant reported the most recent negative social interaction she had experienced, she was asked, “Did you react in any of the following ways? (choose the one response that fits best)”. Responses to this question reflected a range of emotion regulation strategies and were developed for this study based on similar emotion regulation questionnaires in the literature. Options reflected acceptance (“I realized I just had to live with things the way they are”), problem-solving (“I did or planned something to make things better”), rumination (“I kept thinking about how bad I was feeling or how bad the situation is”), reframing (“I tried to think of the problem in a different way so it didn’t seem as bad”), cognitive avoidance (“I tried not to think about it or to forget all about it”), behavioral avoidance (“I tried to avoid being around the people or situation that was bothering me”), support-seeking (“I talked to someone about it”), emotional expression (“I cried or showed emotion another way”) or none of the above (“I didn’t do any of these things”).

Two variables were generated reflecting emotion regulation strategies 1) more likely to be protective against psychopathology (“positive” strategies), and 2) more likely to be promote risk for psychopathology (“negative” strategies). Positive strategies included acceptance, problem-solving, reframing, and support-seeking. Negative strategies included rumination, cognitive avoidance, and behavioral avoidance. As only three observations reported use of emotional expression this response was dropped from analyses. Considering emotion regulation presupposes the presence of a moderate to strong emotion, only prompts in which the participant reported experiencing a negative emotion of 30 or higher were included in analyses. Previous studies have used a cutoff of 40-60 (Silk, Steinberg, & Morris, 2003); however, visual inspection of data showed similar emotional events (e.g., “when my brother kept correcting me”) occurred at a negative emotion rating of 30. Only participants who responded to at least three prompts with a negative emotion rating of 30 or higher were included in analyses. This resulted in 1,565 observations nested within 103 participants.

As the amount of time since the most recent negative interaction may vary, the amount of time elapsed between the negative interaction and its report was included as a continuous person-mean centered covariate in all analyses of EMA-based outcomes. Participants reported when the interaction occurred on an ordinal scale ranging from 1 = within the last 15 minutes to 10 = before yesterday. Further, as an individual’s choice of regulatory strategy may depend on the strength of the negative emotion, individuals’ mean-centered momentary and average (i.e., person-mean) reactivity (see below) were included as covariates in analyses of regulatory strategies. Participants' momentary emotional reactivity was calculated as the intensity of negative emotion reported in conjunction with a negative event. All four negative emotions reported (anger, worry, sadness, stress) in response to a given negative event were composited.

2.2.3.5 Physiological regulation

Physiological response to a stressful performance task served as a third measure of emotion regulation. As described above, participants engaged in a two-minute speech task. Physiological regulation, or habituation, during stress was operationalized as slope of SCL over the two-minute task.

2.2.4 Covariates

In addition to the EMA-specific covariates described above, the following variables will be examined for associations with analysis variables (SCL, emotion regulation outcomes). Any variables significantly associated with any analysis variable will be included as a covariate in those analyses.

2.2.4.1 Age

Adolescent age was calculated to the day and included as a group-mean centered covariate.

2.2.4.2 Pubertal status

Pubertal status was assessed using the Pubertal Development Scale (PDS; Petersen, Crockett, Richards, & Boxer, 1988) and summed according to Shirtcliff and colleagues' (Shirtcliff, Dahl, & Pollak, 2009) method for approximating adrenarche and menarche and included as a group-mean centered covariate.

2.2.4.3 Race

As average SCL varies based on race (Janes, Hesselbrock, & Stern, 1978; Kredlow et al., 2017), adolescent and mother race (0 = *White; 1 = non-White*) were included as covariates.

2.2.4.4 Socioeconomic status

Socioeconomic status was operationalized as a group-mean centered continuous variable of annual gross income in dollars from *0 = 0 - 10,000* to *10 = 100,000+*.

2.3 Analytic approach

Analyses occurred in two stages: 1) a test of cross-lagged arousal escalation, and 2) a test of the effects of cross-lagged arousal escalation on adolescent emotion regulation outcomes.

2.3.1 Stage 1: Mutual escalation of arousal

Mutual escalation of arousal was tested using longitudinal growth curve modeling in a multilevel model for distinguishable dyads (Bolger & Laurenceau, 2013) in R using the nlme package (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2018). Consecutive model testing was conducted to evaluate model fit. Improvements in model fit were evaluated via Aikaike's information criterion (AIC), the Bayesian information criterion (BIC), and -2 log likelihood (-2LL) where smaller values indicate better fit. Where possible, likelihood ratio tests (LRT) were used to test the significance of improvements in model fit. In order to test the degree to which mothers and daughters escalated in arousal throughout the conflict resolution task, time was included as a predictor of arousal and individuals were allowed to vary in both their intercept and slope of time. Time was centered at the midpoint of the task in order to minimize intercept-slope covariation, which was high resulting from POMP scoring standardization. A 20s lag and cross-lag was used in all models.[1] The primary parameters of interest for negative affect escalation include mother and daughter random slopes, which can be interpreted as the degree to which mothers and daughters individually escalated in their arousal per unit time, as well as the interaction between mother and daughter random time slopes, which can be interpreted as the degree to which mother and daughter dyads increased or decreased in arousal together per unit time (mutual arousal escalation). Additionally, as the degree to which a dyad escalates in arousal may differ depending on whether the mother or daughter is driving the increase in arousal, the interaction between mutual arousal escalation and cross-lagged effects was examined. Multilevel models were specified as follows:

Level 1:

$$\text{Arousal}_{ti} = \beta_{0Mi} + \beta_{0Di} + \beta_{1Mti}(\text{time}_{ti}) + \beta_{1Dti}(\text{time}_{ti}) + \beta_{2Mi}(\text{Arousal}_{Mt\text{-}Xi}) + \beta_{2Di}(\text{Arousal}_{Dt\text{-}Xi}) + \beta_{3Mi}(\text{Arousal}_{Dt\text{-}Xi}) + \beta_{3Di}(\text{Arousal}_{Mt\text{-}Xi}) + \varepsilon_{ti}$$

Level 2:

$$\beta_{0Mi} = \gamma_{00M} + \upsilon_{0Mi} \qquad \beta_{0Di} = \gamma_{00D} + \upsilon_{0Di}$$

[1] Models were initially tested using a one-epoch lag (10s). Models did not converge, likely due to high autoregressive effects (*r*=.76); hence, a 20s lag was used.

$\beta_{1Mi} = \gamma_{10M} + \upsilon_{1Mi}$ $\beta_{1Di} = \gamma_{10D} + \upsilon_{1Di}$

$\beta_{2Mi} = \gamma_{20M} + \upsilon_{2Mi}$ $\beta_{2Di} = \gamma_{20D} + \upsilon_{2Di}$

$\beta_{3Mi} = \gamma_{30M} + \upsilon_{3Mi}$ $\beta_{3Di} = \gamma_{30D} + \upsilon_{3Di}$

Parameters:

β_{0Mi}, β_{0Di} = Random intercept for mothers, daughters

β_{1Mi}, β_{1Di} = Random slope of time for mothers, daughters

β_{2Mi}, β_{2Di} = Random autoregressive/lagged effect for mothers, daughters

β_{3Mi}, β_{3Di} = Random cross-lagged effect for mothers, daughters (arousal transmission effects)

γ_{00M}, γ_{00D} = Fixed arousal intercept for mothers, daughters

γ_{10M}, γ_{10D} = Fixed effect of time for mothers, daughters

γ_{20M}, γ_{20D} = Fixed slope of autoregressive effect for mothers, daughters

γ_{30M}, γ_{30D} = Fixed slope of lagged effect for mothers, daughters

υ_{1Mi}, υ_{1Di} = Between-person variance

ε_{ti} = Within-person residuals

2.3.2 Stage 2: Adolescent emotion regulation as predicted by degree of mutual escalation

The effects of mutual arousal escalation on emotion regulation outcomes were assessed using multiple regression (global rumination, global problem-solving, habituation) and multilevel modeling (momentary emotion regulation strategy use). Individual slopes of time for mother and daughter and individual cross-lagged effects were generated by saving the best linear unbiased predictors from the final multilevel model. Mother slope, daughter slope, and their interaction (i.e., mutual escalation) were entered into a multiple/multilevel regression model along with the random maternal cross-lagged effect, the three-way interaction between mother slope, daughter slope, and maternal cross-lagged effect, and any significant covariates to predict the five emotion regulation outcomes described above. Separate tests were conducted for each outcome, resulting in a total of five hypothesis tests. The familywise error rate for five tests is $p < .01$; as this method of correcting for the rate of false positives is highly conservative, findings that meet the standard of $p < .01$ cutoff will be considered robust, while findings in the range of $p < .05$–.01 will be interpreted with caution.

3.0 Results

3.1 Preliminary analyses

Sample descriptives and correlations between study variables are presented in Table 1. Average change scores from baseline to post-conflict discussion of mother and child happiness, sadness, and anxiety were examined as a manipulation check to ensure that the task elicited negative emotion. Both mothers and adolescents reported decreases in happiness (Δ_{Mom}=-4.75; Δ_{Adol}=-5.63) and increases in sadness (Δ_{Mom}=3.55; Δ_{Adol}=1.84) from baseline to post-task. However, levels of anxiety decreased from baseline to post task for both mothers (Δ_{Mom}=-1.12) and adolescents (Δ_{Adol}=-2.33); this is likely due to higher levels of anticipatory anxiety at the outset of the lab visit to which participants habituated throughout the course of the visit.

3.2 Physiological regulation: Adolescent arousal slope

Adolescent physiological regulation during the speech task was generated by extracting individual linear slopes from multilevel models of adolescent SCL (lme4; Bates, Maechler, Bolker, & Walker, 2015). On average, adolescents decreased in arousal throughout the task, reflecting habituation to the stress of the task. Individual slope coefficients were extracted for use in regression analyses.

Table 1. Means, standard deviations, and correlations of study variables with confidence intervals

Variable	*M/%*	*SD*	1	2	3	4	5	6	7
1. Child age	12.25	0.78							
2. Parent age	43.06	7.03	.10 [-.10, .29]						
3. Child race (% White) (0=White; 1=nonWhite)	69%	--	-.07 [-.26, .13]	-.06 [-.25, .14]					
4. Parent race (% White) (0=White; 1=nonWhite)	79%	--	-.06 [-.26, .15]	-.07 [-.27, .14]	.78** [.68, .85]				
5.Socioeconomic status	7.24	2.95	.06 [-.14, .26]	.25* [.05, .43]	-.18 [-.36, .02]	-.25* [-.43, -.05]			
6. Puberty	3.57	1.00	.43** [.25, .58]	.00 [-.20, .20]	.06 [-.14, .26]	.02 [-.19, .22]	-.13 [-.32, .08]		
7. Rumination	49.60	21.10	.17 [-.03, .36]	-.17 [-.36, .02]	.13 [-.07, .32]	.12 [-.09, .31]	-.09 [-.29, .11]	.05 [-.15, .25]	
8. Problem-solving	7.90	1.88	.13 [-.07, .32]	-.05 [-.24, .16]	.02 [-.18, .22]	.02 [-.19, .22]	-.05 [-.25, .15]	-.04 [-.24, .17]	.34** [.15, .50]

Note. M and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$. Puberty=PDS (Shirtcliff et al., 2009); Rumination=CRSS rumination subscale; Problem-solving=RSQ problem-solving subscale.

3.3 Dyadic pattern exploration

A series of figures were generated in R using ggplot2 (Wickham, 2016) to visualize variability and dyadic patterns of arousal during the conflict discussion task. Figure 1 illustrates variability in SCL grouped by parents and adolescents. Overall, the figure indicates considerable within-person variability; further, loess-smoothed regression lines indicated that adolescents did not increase or decrease on average throughout the task, whereas parents exhibited a small decrease in arousal over the course of the task. Figure 2 depicts dyadic patterns of arousal for a subset of dyads. Substantial variability in dyadic patterns of arousal escalation is apparent; some dyads decreased in concert throughout the task whereas others mutually increased, and some dyads appeared to move in opposite directions.

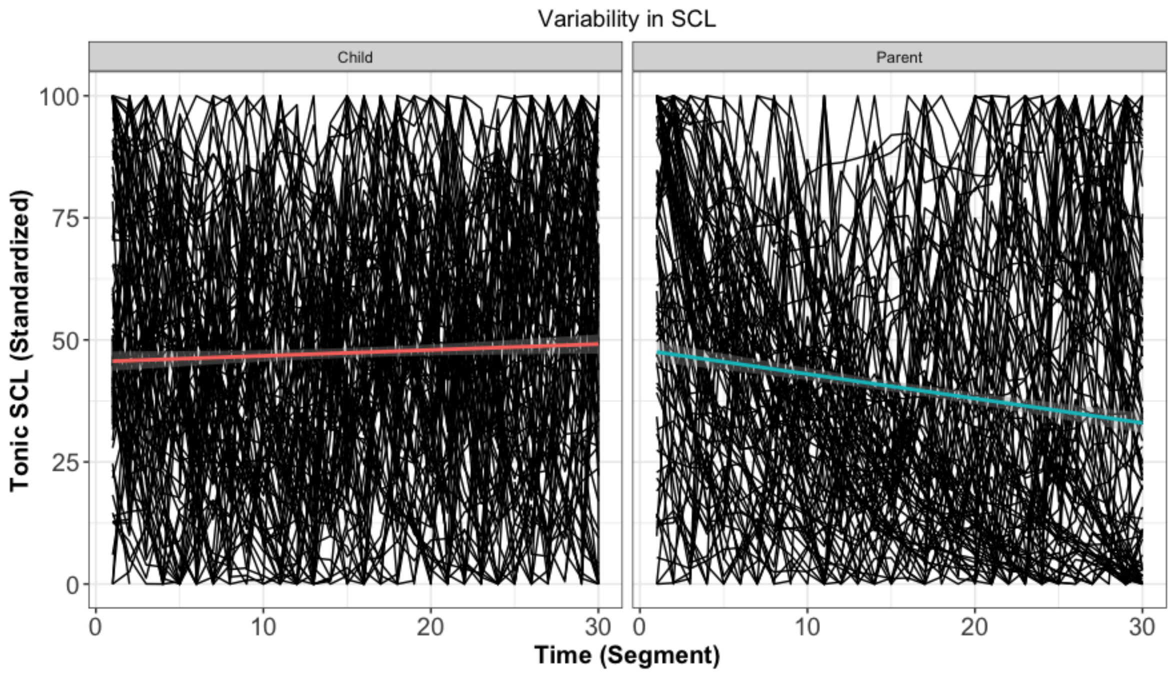

Figure 1. Variability in SCL by mothers and adolescents

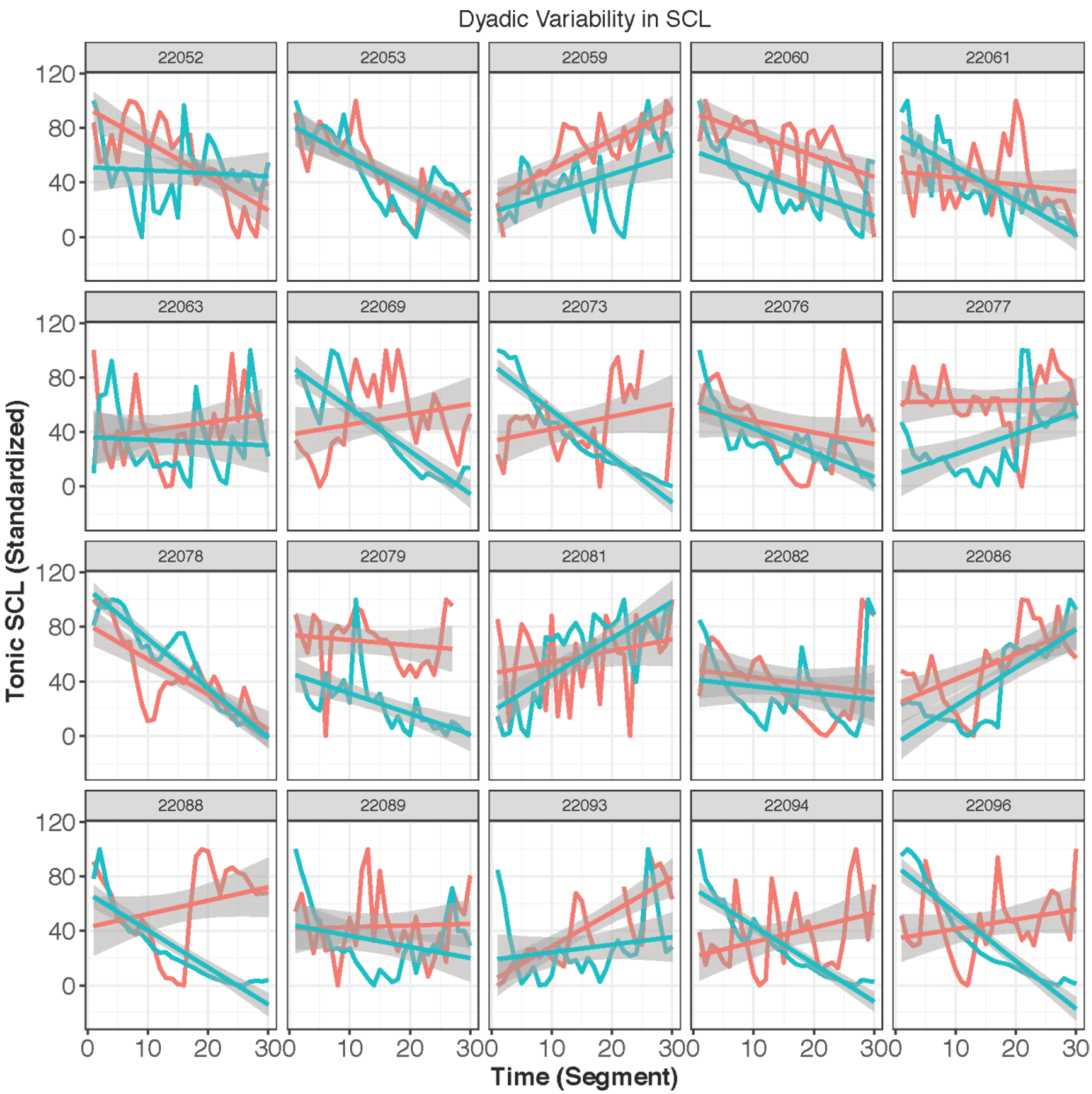

Figure 2. Dyadic variability in SCL with lines of best fit

3.4 Dyadic model building

3.4.1 Means-only model

Model fit statistics are depicted in Table 2. First, a means-only model was run specifying separate random intercepts for mothers and adolescents, to confirm that there were significant individual differences in mean levels of SCL over time and to generate intraclass correlation coefficients (ICC; ICC_{adol}=.09; ICC_{mom}=.11). ICCs indicated that 9% and 11% of the variance in SCL was due to between-person factors and 91% and 89% of the variance was due to within-person factors for adolescents and mothers respectively. ICCs were consistent with the POMP scoring approach implemented to maximize within-person differences and minimize theoretically non-meaningful between-person differences.

Table 2. Model relative fit statistics and comparison

	Model	N_{obs}	N_{dyads}	*df*	*AIC*	*BIC*	*-2LL*	*Test*	*L.Ratio*	*p*
1	Model for the means	5014	168	7	47465.69	46511.33	47451.68	--	--	--
2	Fixed effect of time	5014	168	9	47411.61	47470.29	47393.60	1 vs. 2	58.08	<.001
3	Random effect of time	5014	168	16	46096.65	46200.97	46064.66	2 vs. 3	1328.96	<.001
4	Fixed lagged effect	4662	168	18	41783.50	41899.55	41747.50	--	--	--
5	Fixed cross-lagged effect	4640	168	20	41573.42	41702.27	41533.42	--	--	--
6	Random cross-lagged effect	4640	168	25	41561.19	41722.25	41511.2	5 vs. 6	22.23	<.001

3.4.2 Growth models

A series of growth models were consecutively tested to evaluate the hypothesized mutual escalation model. First, an unconditional growth model was run with time as a fixed-effect predictor. A likelihood ratio test indicated significant model improvement ($p<.001$; Table 2). Contrary to hypotheses, on average SCL decreased slightly from the beginning to the end of the task for mothers ($t=-0.471$, $p=.030$; Table 3; hypothesis 1.1). Adolescent slope was not significant as a fixed-effect predictor, indicating adolescents did not increase or decrease through the task on average, contrary to hypotheses ($p=.37$; hypothesis 1.1). Second, a random effect of time was added to the model, resulting in significant model improvement ($p<.001$), indicating that there were significant individual differences in slope of arousal across the task. However, mother-adolescent slope covariance was zero, indicating that mothers and adolescents did not consistently covary in arousal throughout the task (hypothesis 1.4).

Table 3. Final dyadic model fixed effects

	Parameter	Est(SE)	95% CI	*p*
Mothers	Intercept (γ_{00M})	21.30(1.31)	18.70, 23.90	**<.001**
	Time (γ_{10M})	0.05(0.13)	-0.20, 0.29	.721
	Lag (γ_{20M})	0.44(0.02)	0.41, 0.48	**<.001**
	Adolescent to mother cross-lag (γ_{30M})	-0.02(0.02)	-0.05, 0.02	.330
Adolescents	Intercept (γ_{00D})	25.60(1.36)	23.00, 28.30	**<.001**
	Time (γ_{10D})	0.30(0.10)	0.10, 0.51	**.004**
	Lag (γ_{20D})	0.40(0.02)	0.36, 0.44	**<.001**
	Mother to adolescent cross-lag (γ_{30D})	0.06(0.02)	0.02, 0.10	**.005**

3.4.3 Lagged models

Finally, a series of models were run to evaluate the hypothesized lagged and cross-lagged effects of arousal. First, 20s lagged arousal was added to the model. AIC, BIC, and -2LL all decreased, indicating improved fit. Both mother and adolescent 20s lagged arousal were significant positive predictors of concurrent SCL (Table 3). Notably, when the 20s lag was added to the model, adolescent slope became significant, indicating a significant increase in arousal on average across the task for adolescents when adjusting for autoregressive effects. As no random effects of lagged arousal were hypothesized, those models were not tested.

Second, a model was run incorporating 20s cross-lagged arousal for both mother and adolescent. The model improved, as indicated by decreases in all relative fit indicators. Consistent with hypotheses, mother arousal at $time_{t-2}$ significantly positively predicted adolescent arousal at $time_t$ (Hypothesis 1.2), but adolescent arousal at $time_{t-2}$ did not significantly predict mother arousal at $time_t$ (Hypothesis 1.3). Mother and adolescent cross-lags were also tested as random effects. The model with a random effect of adolescent cross-lag (adolescent arousal at $time_{t-2}$ predicting mother arousal at $time_t$) did not converge. However, the model significantly improved via likelihood ratio test ($p<.001$) when a random effect of mother cross-lag (mother arousal predicting adolescent arousal) was added. This model was retained as the final dyadic model. Random effects coefficients were generated for mother slope, adolescent slope, and mother-to-adolescent arousal transmission and exported for use in regression analyses of emotion regulation outcomes.

Covariates were tested in final dyadic multilevel models; no covariates were significant.

3.5 Emotion regulation analyses

The effects of mutual arousal escalation on global rumination, global problem-solving, and physiological regulation were tested via multiple linear regression in R. First, covariates (child age, child race, puberty, SES) were tested for significance. Second, individual mother arousal slope, adolescent arousal slope, their interaction, and mother-to-adolescent cross-lag coefficients exported from dyadic multilevel models were entered into the model, along with any significant covariates. Third, the three-way interaction between adolescent slope, parent slope, and mother-to-adolescent cross-lag was tested.

3.5.1 Global rumination

Global self-reported rumination was significantly predicted by age, such that older adolescents reported higher levels of rumination (β=.311, p=.015). However, age was no longer significant when hypothesized predictors were entered into the model (Table 2). Mother and adolescent arousal slope interacted to predict global rumination (Figure 3). Simple slopes analyses and regions of significance tests indicated that when mother arousal slopes were greater than 1.16 *SD* above the mean, adolescents with positive arousal slopes reported higher levels of rumination (i.e., mutual arousal escalation was associated with higher rumination; hypothesis 2.1). Additionally, when mother arousal slopes were more than 0.71 *SD below* the mean, adolescents with negative arousal slopes reported higher levels of rumination (i.e., mutual arousal *de-escalation*). Maternal cross-lagged effects did not interact with mutual arousal escalation, indicating that the effect of mutual arousal escalation on rumination did not differ based on the degree of arousal transmission in the dyad (p= .125; hypothesis 3.3).

Table 4. Regression results of mutual escalation models predicting adolescent emotion regulation

	Adolescent Self-Reported Rumination			**Adolescent Self-Reported Problem-Solving**			**Physiological Regulation**		
Predictors	*ß*	*CI*	*p*	*ß*	*CI*	*p*	*ß*	*CI*	*p*
(Intercept)	0.14	-0.09 – 0.37	.228	0.03	-0.21 – 0.27	.794	0.02	-0.22 – 0.25	.894
Age	0.20	-0.01 – 0.42	.064	0.18	-0.05 – 0.40	.132			
Cross lag (par to adol)	-0.01	-0.36 – 0.35	.978	0.07	-0.31 – 0.45	.715	0.40	0.03 – 0.76	**.035**
Parent slope	-0.14	-0.49 – 0.20	.415	0.05	-0.32 – 0.41	.805	0.50	0.15 – 0.86	**.006**
Adolescent slope	-0.06	-0.30 – 0.18	.604	-0.15	-0.40 – 0.11	.259	0.08	-0.17 – 0.34	.533
Mutual escalation	0.35	0.12 – 0.58	**.004**	0.07	-0.17 – 0.32	.550	0.06	-0.19 – 0.30	.657
Observations	83			82			81		
R^2 / R^2 adjusted	0.141 / 0.086			0.050 / -0.012			0.105 / 0.057		

Note: All variables are standardized for ease of interpretation.

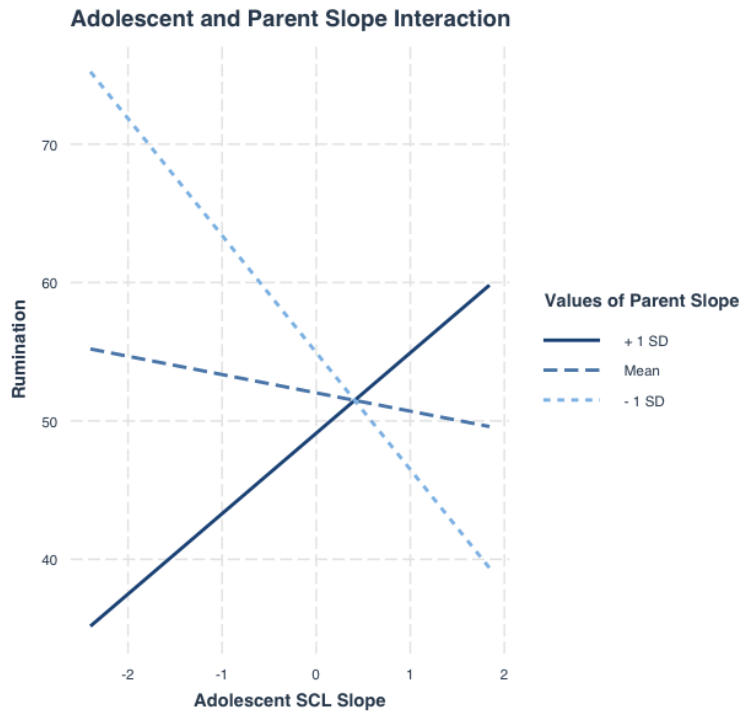

Figure 3. Simple slopes analysis of mutual escalation and rumination

3.5.2 Global problem-solving

Global self-reported problem-solving was significantly associated with age (β=.298, *p*=.023), indicating that older adolescents reported more problem-solving than younger adolescents. However, age was no longer significant when hypothesized predictors were included in the model (Table 2). Global problem-solving was not significantly associated with mother arousal slope, adolescent arousal slope, mutual arousal escalation (hypothesis 2.3), or mother-to-adolescent arousal transmission (hypothesis 3.1).

3.5.3 Physiological regulation

Adolescent physiological regulation, operationalized as slope of arousal during the speech task, was not significantly associated with any covariates (Table 2). On average, adolescents decreased in arousal throughout the speech task (as expected), reflecting habituation to the stress of the task. Mother arousal slope during the conflict discussion significantly predicted adolescent physiological regulation during the speech task; as mothers exhibited higher arousal slopes during the conflict discussion, adolescent slopes on the speech task were higher (i.e., less negative), reflecting less habituation. Additionally, mother-to-adolescent arousal transmission during the conflict discussion was significantly associated with adolescent arousal slope during the speech task, indicating that for adolescents whose mothers' arousal at $time_{t-2}$ was more strongly associated with their own arousal levels at $time_t$, those adolescents exhibited greater slopes (less habituation) during the speech task. However, this finding did not reach significance at the corrected level of p<.01, and, hence, must be interpreted with caution. Adolescent physiological regulation during the speech task was unrelated to adolescent arousal slope during the conflict discussion and mutual arousal escalation (hypothesis 2.5).

3.5.4 Momentary emotion regulation strategy use

A similar model building approach as described above was taken for examining effects of mutual escalation on momentary emotion regulation strategy use. Means-only models with a random person-level intercept indicated that, for positive strategy use, 37% of variability was due to between-person factors and 68% was due to within-person factors (ICC=.37). For negative strategy use, 32% and 68% of the variance was due to between- and within-person factors respectively (ICC=.32). Analyses were run using the glmer() function using a logit link for logistic outcomes in lme4 in R (Bates et al., 2015).

3.5.4.1 Positive strategy use

Race was a significant predictor of momentary positive strategy use, such that nonWhite participants were less likely to report use of a positive emotion regulation strategy in the moment (Table 5). Momentary use of a positive emotion regulation strategy was positively associated with parent-to-adolescent arousal transmission from the conflict discussion task. The association indicates that those adolescents whose parents' arousal at $time_{t-2}$ was more strongly associated with their arousal at $time_t$ were more likely to choose a positive emotion regulation strategy in the moment (hypothesis 3.2). Of note, however, this finding was not significant at the corrected level ($p<.01$) and should be interpreted with caution as a result. Mutual escalation was not associated with momentary positive strategy use (hypothesis 2.4).

Table 5. Results from multilevel models of momentary emotion regulation strategy use

	Momentary use of positive strategy			**Momentary use of negative strategy**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	1.51	0.85 – 2.67	0.162	0.06	0.01 – 0.24	**<0.001**
Parent slope of time	1.06	0.98 – 1.14	0.121	0.94	0.88 – 1.00	0.068
Adolescent slope of time	1.01	0.96 – 1.06	0.740	1.00	0.95 – 1.05	0.911
Mutual escalation	0.99	0.94 – 1.05	0.689	1.00	0.95 – 1.05	1.000
Parent-to-adolescent cross lag	1.09	1.00 – 1.18	**0.044**	0.92	0.86 – 0.99	**0.026**
NonWhite	0.26	0.09 – 0.71	**0.009**			
Time elapsed (person-mean)				1.20	0.92 – 1.57	0.183
Time elapsed (PMC)				1.11	1.04 – 1.19	**0.003**
Random Effects						
σ^2	3.29			3.29		
τ_{00}	2.56 $_{ID\_Num}$			1.66 $_{ID\_Num}$		
ICC	0.44			0.34		
N	70 $_{ID\_Num}$			70 $_{ID\_Num}$		
Observations	1091			1091		
Marginal R^2 / Conditional R^2	0.082 / 0.484			0.062 / 0.377		

3.5.4.2 Negative strategy use

The amount of time adolescents reported had elapsed since their worst negative social interaction was a significant predictor of momentary negative emotion regulation strategy use (Table 5). When adolescents reported more time had elapsed since the event, they were more likely to report using a negative emotion regulation strategy. Negative strategy use in the moment was negatively associated with parent-to-adolescent cross-lagged arousal from the conflict discussion task. Adolescents with stronger parent-to-adolescent arousal transmission were less likely to report use of a negative emotion regulation strategy in the moment. However, this finding did not reach the corrected significance level ($p<.01$) and should be interpreted cautiously. Mutual escalation was not associated with momentary positive strategy use (hypothesis 2.2). Maternal cross-lagged effects did not interact with mutual arousal escalation, indicating the effects of dyadic mutual arousal escalation on momentary negative strategy use did not differ dependent on the degree of arousal transmission in the dyad ($p= .40$; hypothesis 3.4).

4.0 Discussion

As individuals move through adolescence, they become increasingly independent of their parents and responsible for their own emotion regulation. Concurrently, the increased salience of social and emotional information results in an environment ripe for emotionally taxing events requiring regulation (e.g., Crone & Dahl, 2012). Interactions between adolescents and their mothers may support adolescents' development of successful emotion regulation skills (Morris et al., 2018); however, for some dyads, mother-adolescent interaction may result in the promotion of problematic emotion regulation strategies that have detrimental influence on adolescents' attempts to regulate independently.

To our knowledge, this was the first investigation of dyadic physiological arousal escalation. The findings of this investigation highlight that physiological responses to stressful interpersonal interactions vary widely at both the individual and dyadic levels. During the conflict discussion interaction task examined here, some individuals increased in arousal, some decreased, and dyads varied significantly in the extent to which they moved together or independently (i.e., mutual escalation) throughout the interaction. These dyadic differences are wide ranging, as indicated by the lack of parent-adolescent random slope correlation; that is, there does not appear to be an overarching trend with regard to whether parents and adolescents track upwards or downwards together, or track together at all, for that matter. These findings emphasize the importance of considering variability and dynamic change over time when examining dyadic processes (Butler, 2015). Although there were few average effects of individual change in arousal over time or dyadic covariation in arousal, there were random effects, and as will be discussed below, these individual and dyadic differences appear to be associated with adolescents' independent emotion regulation.

In addition to individual and dyadic variation in arousal change over time, mothers also "transmitted" arousal to adolescents throughout the task on average, such that increases or decreases in mothers' arousal were followed by corresponding increases or decreases in adolescent arousal, consistent with hypotheses and with previous literature (Lougheed & Hollenstein, 2018). Dyads also varied in the degree to which adolescents were influenced by their mothers' arousal, a novel finding. A previous study found that mother-daughter dyads did not differ in mother-to-adolescent arousal transmission, either in general or dependent on self-reported relationship closeness or experimentally manipulated physical closeness (Lougheed & Hollenstein, 2018); however, this study was conducted in a community sample of older adolescents (14-17). It may be that there is more variability in these processes earlier in adolescence and patterns solidify by mid- or late-adolescence. Some research on the transmission of behaviorally coded negative affect indicates that mothers typically "drive" negative interactions in early adolescence, whereas the pattern reverses in older adolescence, with adolescents driving the effect (Main et al., 2016). Alternatively, it may be that the additional variability observed here is a reflection of the increased risk for anxiety and depression in this sample. Conversely, adolescent arousal did not systematically predict mothers' future arousal on average, and there do not appear to be meaningful dyadic differences in the extent to which adolescents transmit arousal to mothers. These findings are broadly consistent with past research, although one study found evidence of variability in adolescent-to-mother arousal transmission dependent on experimental manipulation of physical closeness (Lougheed & Hollenstein, 2018).

There are several possible explanations for these findings. As theorized above, greater adolescent responsivity to mother arousal may be indicative of empathetic relationships between parent and child, in line with developmental theories of psychobiological attunement (Feldman, 2006). Previous research in this area with mother-adolescent dyads found that adolescents transmitted arousal to mothers when giving a stressful speech (Lougheed et al., 2016) but mothers transmitted to adolescents in the context of both positive and negative interpersonal interactions (Lougheed & Hollenstein, 2018). It may be that when an adolescent is engaged in a stressful activity in the presence of their mothers, mothers are more attuned to adolescent arousal in an effort to provide social support. However, in stressful interpersonal discussions, such as that presented in this study, mothers may serve an emotion-coaching or emotion-scaffolding role, communicating to adolescents socially appropriate up- and/or down-regulation of arousal (Morris et al., 2018). Alternately, parents may be better at regulating their emotions in the moment, and/or may be more habituated to adolescent displays of negative affect or arousal, which become more frequent during this developmental stage (Casey et al., 2010). Adolescents, on the other hand, may be broadly more reactive to social input, consistent with developmental theories of adolescence (Crone & Dahl, 2012), or less used to displays of arousal or negative affect by their mothers. Hence, they may more sensitive to arousal changes in their mothers and more likely to react in kind.

Further, the nature of adolescents' interactions with their mothers is associated with adolescents' own independent emotion regulation, globally and in the moment. More specifically, patterns of maternal and adolescent arousal – both independently and in conjunction – are associated with adolescent rumination and physiological regulation, as well as adolescent use of adaptive and maladaptive regulatory strategies in everyday life. Mother-adolescent mutual escalation of arousal was associated with higher adolescent rumination, supporting hypotheses. As theorized, these higher levels of adolescent rumination may result from adolescents frequently "practicing" a dysregulatory style in stressful interactions with their mothers that ultimately translates to the adolescent attempting similar approaches when regulating negative emotion independently. It is important to note, however, that given this was a sample enriched for variability for social anxiety and depression, this finding may be related to shared genetic risk for internalizing disorders, which may also account for the higher levels of adolescent rumination observed (Moore et al., 2013).

Conversely, and rather surprisingly, high levels of mutual *de-escalation* of arousal were also associated with higher adolescent rumination. One possibility is that these mothers and adolescents experienced the highest anticipatory arousal prior to the task, which may be evidence of higher emotional reactivity, and it is this increased emotional reactivity that ultimately accounts for adolescent reports of greater rumination. Alternately, the decrease in arousal observed may be evidence of the use of cognitive processes that promote withdrawal from stressful or distressing situations, such as disengaging from the conflict task to avoid uncomfortable interactions or emotions. Rumination has been theorized to function similarly (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008).

Additionally, the degree to which mothers transmit arousal to adolescents is related to adolescent physiological regulation and momentary use of regulatory strategies in everyday life. More arousal transmission from mother to adolescent was associated with less adolescent habituation in arousal during a socially stressful speech. It may be that these adolescents are more physiologically reactive overall, hence they exhibited greater responsivity to mothers' arousal during the conflict discussion and were also more aroused throughout the speech task. More arousal transmission from mothers to adolescents was also associated with greater likelihood of using a positive strategy and decreased likelihood of using a negative strategy in the moment. This finding is somewhat at odds with the previous finding on habituation during the speech task; however, it may be that, although these adolescents may be more physiologically reactive, they may also be better equipped with behavioral and cognitive strategies to cope with distressing situations in the real world, perhaps due to increased need to regulate more frequent elevations in arousal.

It is worth noting that the relation between mother-to-adolescent arousal transmission and physiological regulation was not hypothesized, and none of these findings reached the corrected significance level adjusting for multiple testing. Further, the confidence intervals for the effects extend very close to 1, indicating that, if this is a true effect, it is likely very small. However, if these effects do prove reliable upon replication, even a small difference in the degree to which an adolescent chooses typically adaptive versus maladaptive emotion regulation strategies in the moment may, in the long run and over many emotionally salient events, prove to be protective against psychopathology.

4.1 Limitations

Several limitations of this study are worth noting. The sample is limited to adolescent girls and enriched for risk for anxiety and depression, which limits generalizability. Similarly, only biological mother-adolescent dyads were included in this investigation, because dyadic patterns between non-biological mothers and adolescents differed from those observed between mothers and daughters. This may be indicative of differing interpersonal patterns with fathers and other caregivers that may influence adolescent emotion regulation in different ways than those presented here. In other words, it may be something unique about mother-adolescent relationships that is producing these results. The use of arousal as the primary dyadic indicator may also be limiting in as much as SNS arousal is valence-independent; it is unclear that this physiological marker is specifically picking up on negative affect or dysregulation, although manipulation checks indicated that the negative affect task examined did increase negative affect overall.

4.2 Future directions

As this study was one of the first to test a model of arousal escalation and transmission in mothers and adolescents, and the first to extend those dyadic patterns to adolescent independent emotion regulation, these results should be considered preliminary; replication will be necessary to confirm the robustness of these effects. An important next step will be evaluating concurrent measures of behaviorally expressed emotion to determine whether the escalation in arousal examined here tracks with emotional response in the moment. It would also be worth evaluating whether behaviorally coded measures of negative escalation, similar to those used in previous studies of negative affect escalation (e.g., McMakin et al., 2011), track with these physiological measures. Finally, future research examining individual and/or dyadic differences that may result in these dyadic patterns of arousal over time may aid in elucidating what factors contribute to these interactional styles as it relates to arousal. For example, examining whether behaviorally coded avoidance or withdrawal relates to adolescent rumination in a similar fashion as the mutual arousal de-escalation reported here may shine light on potential mechanisms of that effect.

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