Mom, I Feel You: Mother-Adolescent Emotional Synchrony and Adolescent Well-Being

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Individuals in close relationships can have a powerful influence on each other's emotions, and ultimately, their emotional well-being. The concept of two individuals' emotional experiences or underlying physiology being temporally linked is referred to as emotional synchrony. Emotional synchrony has been studied in parent-infant and romantic partners but very little work has examined emotional synchrony during adolescence, a period during which mental health risks increase and close relationships change significantly. The present study examined parent-child emotional synchrony during adolescence and its association with adolescent mental health and the parent-adolescent relationship. This was examined within a three-minute positive interaction context in a community sample of 32 adolescent girls and their mothers. Emotional synchrony was indicated by moment-to-moment temporal linkage, both concurrently and with a one second lag (i.e., adolescent following mother or vice versa) of heart rate or facial displays of positive affect between adolescents and their mothers. Synchrony was observed in 3.1% to 37.5% of dyads, depending on the time lag and heart rate versus positive affect. There was a very low occurrence of heart rate synchrony across time lags, and, on average across time lags, significant positive affect synchrony was observed in one third of dyads. There were no significant associations between synchrony and current adolescent depressive symptoms and there were unexpected associations with parent-adolescent relationship quality. Post-hoc analyses showed that dyads who endorsed indicators of adolescent risk for depression, such as mothers' depressive symptoms and

adolescent trait tendency to experience depressed mood, were less likely to display positive affect synchrony. The results of this study highlight the variability between dyads on the prevalence and patterns of synchrony and suggest that synchrony between parents and adolescents may not be as universally linked to well-being as theory may suggest.

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1.0 Introduction

The emotions of individuals in close relationships are often connected (Butler, 2011). Because of this, individuals in close relationships can have a powerful influence on each other's emotions, and ultimately, their emotional well-being. For example, if a person is feeling and expressing happiness, their partner might "catch" that emotion, or if a person is sad, their partner might try to cheer them up (Butler, 2015). The concept of two individuals' emotional experiences or underlying physiology being temporally linked is referred to as *emotional synchrony*. Studies have shown that emotional synchrony is associated with aspects of well-being such as individuals' mental health and quality of close relationships (e.g., Field, Healy, Goldstein, & Guthertz, 1990; Levenson & Gottman, 1983). However, much of this work has been conducted with parents and infants or romantic partners. Very little work has examined emotional synchrony during adolescence, a period during which mental health risks increase and close relationships, such as relationships with parents, change significantly (Steinberg & Silk, 2002).

The goal of the present study is to fill this gap in the literature by examining the associations between emotional synchrony of parents and adolescents and functioning within domains important for adolescents, such as mental health and parent-adolescent relationship quality. We will focus on emotional synchrony during a positive context because research has shown that when positive emotions are shared, positive individual and relationship outcomes result (Yee, Gonzaga, & Gable, 2014). In addition, because adolescents typically experience an increase in negative emotions and a decrease in positive emotions (Larson, Moneta, Richards, & Wilson, 2002), it may be especially important to capitalize on positive emotional contexts. Examining parent-adolescent emotional synchrony during positive contexts may provide a better understanding of how parental

relationships can be protective for adolescents and may inform treatment strategies for families in which adolescents are struggling with mental health problems, such as depression.

1.1 Emotional Synchrony

Emotion has traditionally been understood as an intrapersonal system consisting of experiential, behavioral, and physiological subcomponents which interact to give rise to an emotional response (Gross, 1999). However, emotions often arise in the context of social relationships and interactions, and research has shown that in these contexts, individuals' emotions are connected to and affected by the emotions of their partner (Butler, 2015). In close relationships, this is thought to occur through temporal interpersonal emotion systems in which subcomponents of emotions not only interact *within* an individual but also *across* individuals over time (Butler, 2011). One type of temporal interpersonal emotion systems is *emotional synchrony*, defined here as two individuals' emotional experiences or underlying physiology being temporally linked.

Emotional synchrony can operate on various timescales—it has been observed during brief interactions (e.g., Main, Paxton, & Dale, 2016) as well as over days (e.g., Butner, Diamond, & Hicks, 2007) or even years (e.g., Kim, Conger, Lorenz, & Elder Jr, 2001). It can manifest within the different subcomponents of emotion such as subjective experience (Butner et al., 2007), autonomic physiology (Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011), or behavioral/facial expressions (Field, Healy, & LeBlanc, 1989). It can also occur between emotions occurring at the same time (concurrent) or with one partner's emotions following the other's emotions (lagged; Butler, 2011).

Emotional synchrony is not fundamentally good or bad; rather it depends on the context and the emotions involved (Butler, 2011). For example, synchrony of negative emotions is associated with undesirable individual or relationship outcomes. One study demonstrated that couples who were more dissatisfied in their relationships displayed greater physiological and negative affect synchrony during a disagreement compared to couples who were more satisfied in their relationships (Levenson & Gottman, 1983). Another study showed that parent-child dyads with depressed mothers, compared to those with non-depressed mothers, displayed greater synchrony of negative affect and less synchrony of positive affect (Field et al., 1990). Synchrony of positive emotions, especially in a positive context, is associated with advantageous outcomes. For example, children from parent-infant dyads who display greater synchrony have better cognitive processing, later school adjustment, and a higher capacity for empathy in adolescence (Leclère et al., 2014).

Emotional synchrony has been studied mostly in parent-infant and romantic partners. Between parents and infants, emotional synchrony is said to be "a key element of early social relationships that underpins social-emotional growth" (Feldman, Bamberger, & Kanat-Maymon, 2013, pg. 408). By their emotional states being linked, parents can influence their infants' emotions and scaffold the infant's capacity to self-regulate (Harrist & Waugh, 2002). Emotional synchrony between romantic partners during interactions is thought to contribute to individuals' emotional and physiological stability (Butler & Randall, 2013). Considerably less research has been conducted in parents and adolescents, despite the importance of the adolescent period for children's development and the onset of mental health problems. Because the structure of parent-adolescent relationships differs from that of parent-infant and romantic relationships, an extended

understanding of emotional synchrony and the outcomes with which it is associated during adolescence is needed.

1.2 Adolescence

Adolescence, the developmental period between childhood and adulthood, is one of the most dynamic and influential periods of human development and is thus characterized by significant transformations in physical, psychological, and social domains (Steinberg & Silk, 2002). The period begins with the start of pubertal maturation—approximately age nine for girls and 10 for boys (Cabrera, Bright, Frane, Blethen, & Lee, 2014; Herman-Giddens et al., 2012). Adolescents experience a rapid acceleration in physical growth, changes in body composition and hormonal balance, and the development of primary and secondary sex characteristics (Susman & Rogol, 2004). Their cognitive abilities improve in many areas including abstract thinking, problem solving, reasoning, and information processing (Keating, 2004; Luna, Garver, Urban, Lazar, & Sweeney, 2004). With these new skills, adolescents begin to define who they are and how they fit into society (Harter, 2008). They become more independent as they spend more time with same-sex peers and romantic interests and less time with family (Larson & Richards, 1991; Larson, Richards, Moneta, Holmbeck, & Duckett, 1996). As their roles, responsibilities, and relationships change, adolescents face challenges that make the period a time of increased risk and vulnerability as well as an opportunity for positive development (Dahl, 2004).

1.2.1 Adolescent mental health

Although most adolescents navigate the transition to adulthood successfully without experiencing significant impairment or distress (Arnett, 1999), adolescents generally experience an increase in negative emotions (Larson et al., 2002). Risk for the development of a wide range of emotional and behavioral problems rises during adolescence and the first onset for many psychiatric disorders often occurs during this period (Kessler et al., 2007). Large epidemiologic studies have shown that between 22 and 37% of children ages nine through 18 met criteria for at least one psychiatric disorder, with mood and anxiety disorders being more common in females and behavior and substance use disorders being more common in males (Costello, Mustillo, Erkanli, Keeler, & Angold, 2003; Merikangas et al., 2010). From childhood to adolescence, rates of depression and social anxiety increase for females and rates of substance use disorders, generalized anxiety, and panic increase for both sexes (Costello et al., 2003). Adolescents also display higher rates of reckless behavior than children or adults and are more likely to engage in behaviors that may cause harm to themselves or others such as substance use, participation in dangerous activities, or risky sexual behavior (Arnett, 1999).

1.2.2 Parent-adolescent relationships

The normative developmental changes that take place during adolescence often destabilize parent-adolescent relationships and "challenge the emotional resources of even the most well-functioning families" (Steinberg & Silk, 2002, p. 103). As adolescents rapidly begin to look, think, and behave more like adults, parents' expectations about adolescents' behavior are often violated and they are tasked with adapting to adolescents' new characteristics and behavior patterns.

Parents may become distressed as adolescents challenge family rules and values, they may not be ready to grant the autonomy their adolescents are seeking, and they may struggle with becoming less salient figures in their children's lives (Steinberg & Silk, 2002). In fact, adjusting to the period is related to an increase in parental mental health problems (especially for mothers) and is a low point in parents' marital satisfaction (Silverberg & Steinberg, 1987; Whiteman, McHale, & Crouter, 2007). There is also an increase in parent-adolescent conflict as well as a decrease in shared activities and expressed positive affect (Laursen, Coy, & Collins, 1998; McGue, Elkins, Walden, & Iacono, 2005); however, by late adolescence, these levels re-stabilize (Montemayor, 1983).

Despite parents often thinking they have less influence on their children during adolescence, research shows that parents do play an important role in adolescent development and continue to influence their children's behavior and decisions (e.g., Fletcher, Steinberg, & Williams-Wheeler, 2004; Simons-Morton, Haynie, Crump, Eitel, & Saylor, 2001). Parent-adolescent relationship quality is the most consistent predictor of adolescent mental health and well-being (Helsen, Vollebergh, & Meeus, 2000). Similar to when children are young, parents can provide a secure base that allows adolescents to feel comfortable exploring the environment and returning when they need assistance (Allen et al., 2003). Adolescents who feel close to or supported by their parents experience fewer mental health problems, are less likely to engage in risky substance use or sexual behaviors, and have better self-esteem and coping skills (Howard & Medway, 2004; Parker & Benson, 2004; Stice, Ragan, & Randall, 2004). Better relationship quality is also likely to foster adolescents' desire or willingness to be influenced by their parents (Collins & Laursen, 2004). In addition, parents continue to play a role in scaffolding adolescents' emotion regulation (Morris, Silk, Steinberg, Myers, & Robinson, 2007).

Adolescents' relationships with their parents are also important because they lay the foundation for adolescents' relationships with peers and other close relationships later in life. According to social learning theory, by observing and participating in interactions with their parents, children develop interaction strategies that generalize to other relationships (O'Leary, 1988). Cross-sectional studies have shown that parent-adolescent interactions characterized by high levels of warmth are associated with better adolescent social competence and more positive experiences with peers (Lieberman, Doyle, & Markiewicz, 1999) whereas parent-adolescent interactions characterized by high levels of hostility are associated with adolescents' greater hostility toward and less positive interactions with peers (Allen, Hauser, O'Connor, & Bell, 2002). Two prospective longitudinal studies showed that hostility observed during parent-adolescent interactions predicted hostility observed in romantic relationships in late adolescence and early adulthood (Andrews, Foster, Capaldi, & Hops, 2000; Kim et al., 2001). A third longitudinal study showed that levels of both hostility and positive engagement observed in parent-adolescent interactions predicted levels of hostility and positive engagement observed in offspring's marital interactions 17 years later (Whitton et al., 2008).

1.3 Importance of Positive Affect in Relationships

The majority of research on emotion in close relationships is focused on negative affect or conflict (Fredrickson, 1998). However, the experience of positive affect has unique and powerful implications for individuals and relationships (Ramsey & Gentzler, 2015; Yee et al., 2014). For adolescents, it may be especially important to capitalize on positive emotions given that the

experience of positive emotions typically decreases during the adolescent period (Larson et al., 2002). *Synchrony* of positive emotions may then also be beneficial for adolescents.

Not only is experiencing positive affect related to many advantageous intrapersonal outcomes—such as better physical and psychological health, higher quality social relationships, and greater success and life satisfaction—it has been shown to precede and predict these outcomes (Lyubomirsky, King, & Diener, 2005). Although there is less research on the outcomes of positive affect specifically for adolescents, the pattern of association is consistent. Greater positive affect in adolescence is related to better mental health and adaptive coping skills, greater feelings of mastery, better school engagement, and more supportive friendships (Ben-Zur, 2003; McMakin et al., 2011; Reschly, Huebner, Appleton, & Antaramian, 2008; Weinstein, Mermelstein, Hedeker, Hankin, & Flay, 2006).

According to the influential broaden-and-build theory, positive affect confers benefits by broadening the scope of thoughts and behaviors which over time build enduring physical, intellectual, and social resources and increase the likelihood that positive opportunities will be identified and pursued (Fredrickson, 1998). Positive affect can also decrease the impact of and hasten the recovery from negative affect or events (Tugade & Fredrickson, 2004) as well as trigger "upward spirals" of well-being in which positive affect leads to positive experiences, which in turn lead to more positive affect (Fredrickson & Joiner, 2002; Kok et al., 2013).

In addition to having individual benefits, experiencing and expressing positive affect within a relationship may serve to strengthen and protect the relationship. For example, in adolescence, positive affect can limit potential damage of the natural increase in negative affect and conflict within the parent-adolescent relationship. A broadened mindset resulting from the experience of positive affect can facilitate better understanding of the other person's perspective

and promote pursuit of opportunities for relationship growth (Yee et al., 2014). Some researchers have referred to expressing positive affect toward a partner or sharing positive experiences together as making deposits into an "emotional bank account" that over time serve as an emotional buffer against relationship threats (Feeney & Lemay, 2012). This could be especially valuable during adolescence.

Discussing positive events with a relationship partner also has benefits. For example, merely telling one's partner about a positive event one experienced increases one's positive affect and the benefits derived from it (Gable, Reis, Impett, & Asher, 2004). Although this process has not been studied in adolescents, one can imagine that when adolescents discuss positive events with their parents, they present an opportunity for parents to further promote their positive affect. Parents' response to positive disclosures by their adolescents is important because research shows that the way a partner responds to positive disclosures predicts individuals' perceptions of the quality of available support for later stressors (Gable, Gosnell, Maisel, & Strachman, 2012)—for adolescents, this could have implications for the frequency with which they turn to parents in times of need and continue to disclose positive events.

1.4 Assessment of Emotional Synchrony

To further the understanding of parent-adolescent emotional synchrony and its potential benefits, the present study will focus on parent-adolescent emotional synchrony within an interaction primed for positivity. Emotions will be measured in parents and adolescents in tandem in the emotional channels of behavior and physiology via 1) facial expressions that indicate happiness and 2) physiological arousal (i.e., heart rate) that may underlie emotional experience.

Facial expressions have long been used as indicators of emotion (Darwin, Ekman, & Prodger, 1998; Ekman, 1992). Happiness is universally indicated by the facial muscles contracting and causing the lip corners to be pulled upward, the cheeks to be raised, and the skin above and below the eye to be pulled in toward the eyeballs (Ekman & Friesen, 1978). Synchrony of positive facial expressions/affective behavior have been measured in parent-infant dyads (e.g., Field et al., 1989; Field et al., 1990). Studies of parent-adolescent dyads have typically examined synchrony of positive affect using coding systems that include facial expressions along with other indicators of emotion such as voice and body posture (e.g., McMakin et al., 2011).

Autonomic nervous system activation is a well-validated measure of physiological arousal (Palumbo et al., 2017). Several theories suggest that physiological activity, especially of the autonomic nervous system, is associated with and may underlie emotion and emotion regulation (Appelhans & Luecken, 2006; Beauchaine, 2001; Porges, 2001; Thayer & Lane, 2000). Happiness and joy, along with other emotions such as anger and fear, have been associated with increased heart rate (for review, see Kreibig, 2010). Despite the limited specificity of heart rate to emotional valence, one reason it is used in studies of synchrony is because it can be measured second-by-second (e.g., Feldman et al., 2011; Levenson & Gottman, 1983). Compared to other measures of autonomic activity, heart rate provides a highly temporally sensitive measure of synchrony. In comparison, the lowest time interval that heart rate variability, another measure of autonomic activity, can be measured is 30-second intervals.

1.5 Emotional Synchrony, Relationship Quality, and Mental Health

Emotional synchrony is thought to be associated with relationship quality. From a dynamic systems perspective, in which close relationships can be seen as forming temporal interpersonal emotion systems, relationship states (i.e., relationship quality) change over time as a function of previous dyadic states and interactions among system elements (i.e., individuals' subjective experience, physiology, and behavior) (Butler, 2011; Granic & Hollenstein, 2003). Over repeated interactions within the system, stable patterns arise and constrain future dyadic emotion dynamics (Lougheed, 2016). In other words, repeated instances of emotional synchrony should contribute to a tendency for emotional synchrony in future interactions. Moment-to-moment emotional linkages become the "building blocks of dyadic attributes," such as relationship quality, which in turn influence later emotional linkages (Lougheed, 2016). Similar to the way positive affect and positive close relationships are associated bidirectionally and reciprocally (Ramsey & Gentzler, 2015), emotional synchrony and relationship quality may be related through bidirectional and reciprocal associations.

Emotional synchrony is also thought to be associated with mental health. Several studies have examined whether emotional synchrony is disrupted by mental health problems such as depression. An interference with synchrony is thought to occur because depression impacts the way an individual interacts with others (Joiner & Timmons, 2002). For example, research has shown that depressed mothers, compared to non-depressed mothers, display less positive affect and engagement behaviors and more negative affect and hostility when interacting with their children (Dietz et al., 2008; Lovejoy, Graczyk, O'Hare, & Neuman, 2000). One study of synchrony showed that mother-infant dyads with depressed mothers displayed less synchrony of positive affect (Field et al., 1990). Parent-adolescent studies have shown mixed results. Three studies

examined the effects of maternal depression on emotional synchrony and found no evidence for disruption of synchrony during a positive interaction (Connell, Hughes-Scalise, Klostermann, & Azem, 2011; McMakin et al., 2011; Woody, Feurer, Sosoo, Hastings, & Gibb, 2016). Although emotional synchrony has not been consistently related to maternal depression, it may be related to adolescent depression. For example, Woody and colleagues (2016) examined the link between physiological synchrony and self-reported sadness during a positive parent-adolescent interaction and found that greater synchrony was related to lower levels of sadness in children.

Another way that emotional synchrony is hypothesized to be related to mental health is that emotional synchrony may protect against the development of psychopathology. For example, greater emotional synchrony in the physiological channel between infants and their parents was correlated with lower levels of child behavior problems two years later (Feldman, 2007). A study of children ages 7-12 showed that greater synchrony of positive affect during a discussion between fathers and their children was significantly associated with fewer child symptoms of psychopathology (Thomassin & Suveg, 2014). In support of this, Connell and colleagues (2011) found that mutual positive affect between mothers and their adolescents was associated with greater adolescent heart rate variability (a physiological index of emotion regulation). Given that emotion dysregulation is a risk factor for mental health problems, having better emotion regulation abilities may be protective for adolescents.

1.6 Current Study Overview

Emotional synchrony has been studied in parent-infant and romantic partners but very little work has examined emotional synchrony during adolescence. Given previous evidence that

experiencing positive emotions is associated with many advantages, it was hypothesized that emotional synchrony during a positive context would be related to better adolescent well-being. However, evidence for associations between emotional synchrony and markers of well-being, such as mental health and relationship quality, during adolescence is lacking. Because adolescence is a critical developmental period, it is important to understand processes, such as emotional synchrony, that may be related to risk or resilience during this period. To address this limitation of the current literature, the present study examined emotional synchrony within a positive interaction context in a community sample of mothers and their adolescent daughters and examined the association of emotional synchrony with adolescent mental health and parent-adolescent relationship quality. The findings of this study may contribute to a better understanding of the complex process of emotional synchrony between parents and adolescents and provide a foundation for further research on how disruptions in emotional synchrony may be related to impairments.

Emotional synchrony was indicated by a temporal linkage of heart rate or facial displays of positive affect between adolescents and their mothers. It is important to note that a high degree of synchrony does not necessarily indicate that a dyad expressed high levels of positive affect or physiological arousal. It is possible for a dyad to display a high degree of synchrony even when expressing low levels of positive affect or exhibiting low levels of arousal as long as one's degree of expression or arousal is related to that of one's partner. Based on the idea that positive affect confers benefits, it was expected that emotional synchrony would only be associated with better well-being in the context of higher levels of positive affect. As exploratory analyses, the present study examined whether the level of observed positive affect displayed by the dyad during the discussion moderated findings.

Emotional synchrony during the discussion was expected to occur within seconds, however, the exact timescale at which it would be expected is unclear. It is possible that emotional channels between parents and adolescents are linked only at a specific time interval or at several time intervals. For example, synchrony of heart rate in parents and infants was shown to occur within a lag of one second (Feldman, 2007). However, other studies have found concurrent synchrony (i.e., no lag) (e.g., Woody et al., 2016). We tested whether emotional synchrony was present concurrently and at with one second lag (e.g., mothers' affect following adolescents' affect and vice versa). Subsequent analyses were conducted with both concurrent and lagged synchrony.

The specific aims of the study are outlined below:

Aim 1: To examine whether emotional synchrony was present between mothers and adolescents, concurrently and at a one second lag, within the emotional channels of behavior and physiology during a discussion primed for positive affect

Hypothesis 1a. The intensity of mothers' and adolescents' facial displays of positive affect would be positively correlated during the discussion.

Hypothesis 1b. Mothers' and adolescents' heart rates would be positively correlated during the discussion.

Aim 2: To examine the association between mother-adolescent emotional synchrony and adolescents' mental health

Hypothesis 2a. Synchrony of facial displays of positive affect would be negatively associated with adolescent depressive symptoms.

Hypothesis 2b (exploratory). The associations between synchrony of facial displays of positive affect and adolescent depressive symptoms would be moderated by the dyad's level of observed positive affect during the discussion

such that stronger synchrony would predict less symptoms only when observed positive affect was high.

Hypothesis 2c. Synchrony of heart rate would be negatively associated with adolescent depressive symptoms.

Hypothesis 2d (exploratory). The associations between synchrony of heart rate and adolescent depressive symptoms would be moderated by the dyad's level of observed positive affect during the discussion such that stronger synchrony would predict less symptoms only when observed positive affect was high.

Aim 3: To examine the relationship between mother-adolescent emotional synchrony and parent-adolescent relationship quality

Hypothesis 3a. Synchrony of facial displays of positive affect would be positively associated with parent-adolescent relationship quality.

Hypothesis 3b (exploratory). The associations between synchrony of facial displays of positive affect and parent-adolescent relationship quality would be moderated by the dyad's level of observed positive affect during the discussion such that stronger synchrony would predict better relationship quality only when observed positive affect was high.

Hypothesis 3c. Synchrony of heart rate would be positively associated with parent-adolescent relationship quality.

Hypothesis 3d (exploratory). The associations between synchrony of heart rate and parent-adolescent relationship quality would be moderated by the dyad's level of observed positive affect during the discussion such that stronger synchrony

would predict better relationship quality only when observed positive affect was high.

2.0 Method

2.1 Participants

Participants were 32 girls between the ages of 11 and 16 and their mothers aged 30 and older. Girls and their mothers were recruited through community advertisements and the University of Pittsburgh Research Participant Registry. Once initial study eligibility was determined via phone screen for mother and daughter, girls chose a same-age (within one year) female peer to participate in the study with them. The peers were not be included in the present analyses. Participants were excluded if they reported having any ongoing serious health problems, were being treated with psychoactive medications or medications that would interfere with the cardiovascular system, or reported a history of autism spectrum disorder, bipolar disorder, psychosis, or active substance abuse. Due to study procedures not described here, participants were also excluded if a) they had ocular conditions that would impede eye-tracking measurement, b) they were unable to see clearly without eye glasses or contact lenses, or c) had a history of a neurological disorder.

2.2 Procedure

All study procedures were approved by the University of Pittsburgh Institutional Review Board. Upon the start of the laboratory visit, girls, their mothers, and their peers provided consent and study procedures were explained. Girls, their mothers, and their peers first completed a battery

of questionnaires then the peer was taken to a separate room to complete other tasks. At this time, measurement equipment was attached for girls and their mothers and they were seated about five feet across from each other in preparation for a series of video-recorded interaction tasks. Measurement equipment included electrodes to measure electrocardiogram signals and skin conductance, a strain gauge to measure respiration rate, and glasses for eye-tracking and pupil dilation. At the end of the visit following other tasks, girls were asked to complete a battery of questionnaires at home within two days of the laboratory visit.

The present study focuses on an interaction task that girls engaged in with their mothers—the Plan a Fun Activity Task. It was a three-minute discussion task in which the dyads were asked to "plan a fun activity they would both enjoy doing together that doesn't have to be expensive or take a lot of time." This task was the last in a series of other parent-adolescent interaction tasks described in Table 1. Between each interaction task, participants completed brief sliding scale ratings of mood and closeness to the partner.

Table 1 Parent-Adolescent Interaction Tasks

Task	Description	Minutes
Resting Baseline	Rested quietly	2
Talking Baseline	Read scripts from a play aloud	2
Support Task	Mothers helped their daughters with a problem their daughters wanted to solve	5
Hot Topics Task	Discussed a relationship problem or disagreement	5
Rest Period	Rested quietly	4
Speech Preparation	Girls prepared to give a speech	2
Speech Task	Girls gave a speech in front of two judges about why they should be picked for a reality TV show	2
Comfort Task	Discussed the speech experience	2
Plan A Fun Activity Task	Discussed a fun activity they would both enjoy doing together	3

2.3 Measures

2.3.1 Heart rate

Heart rate was measured during the interaction via continuous ECG signals sampled at 1000 Hz with three spot electrodes placed in a 3-lead configuration using MindWare BioNex data collection system (MindWare Technologies Ltd, Gahanna, OH). Using the MindWare HRV Analysis 3.1.2 software, R-wave markers in the ECG signal were processed with an artifact detection algorithm. Additional suspected artifacts were corrected manually. Using the inter-beat

interval series, heart rate per second was computed for each individual for the full three minutes of the Plan a Fun Activity task.

2.3.2 Positive affect

Affect is typically measured by coding the movements of facial muscles. This is a labor-intensive process that requires a great deal of training and many hours of coding. Recent advances have led to automated facial coding systems, such as the FaceReader program used in this study. Through the Observer XT program (Noldus Information Technology, Inc., Leesburg, VA), cameras mounted on the wall opposite each participant were used to record the interaction. Videos were then imported into FaceReader 7.1 (Noldus Information Technology, Inc., Leesburg, VA). FaceReader first identifies the face and its position using a cascaded classifier algorithm. Then, the program uses two methods side-by-side for emotion classification (Loijens et al., 2016). The first, called the Active Appearance Method, is a model-based method that synthesizes an artificial face model which maps the location of over 500 key points on the face. The locations of these points are then used to infer the shape of facial features such as the mouth or the eyebrows and thus to classify facial expressions (Den Uyl & Van Kuilenburg, 2005). An artificial neural network is trained on the location of these points, using thousands of manually annotated images, to classify the six universal emotions (*happy, sad, angry, surprised, scared, disgusted*) and a neutral state. The second method uses a deep artificial neural network to recognize patterns in the face and classifies facial expressions from image pixels without face modeling (Loijens et al., 2016). The output of the two methods is combined for the classification results. The final output includes the intensity of each emotion, independent of each other, as a percentage (0-100%) 15 times per

second. The present study used intensity of *happy*, down-sampled to once per second, as a measure of facial displays of positive affect.

Several studies have provided initial evidence validating FaceReader. The designers of the program compared FaceReader's categorizations of facial expressions with manual annotators' categorizations and showed that FaceReader 6.1 could analyze facial expressions with 95% accuracy overall and 99% accuracy for *happy* (Loijens et al., 2016). Other researchers have found that FaceReader 6.0 accurately categorized 88-89% of unique images in two sets of established facial expression pictures, with 96% accuracy for *happy* (Lewinski, den Uyl, & Butler, 2014). Another study showed high agreement between the categorizations of FaceReader and manual annotators of the facial expressions that college students made while taking a test; agreement was 90% for *happy* (Terzis, Moridis, & Economides, 2013). A final study examined the association between FaceReader's *happy* categorization and movements of the zygomaticus muscle using facial electromyography (D'Arcey, 2013). The zygomaticus muscle is the muscle in the cheek that draws the corners of the mouth upward and back toward the posterior causing the appearance of a smile. A significant positive relationship was found between zygomaticus movement and *happy* and significant negative relationships were found between zygomaticus movement and *angry* and *disgust*.

Facial analysis in the present study may have been limited in several ways. For the purposes of eye-tracking and pupil dilation, the lighting in the room was dim and participants were wearing thick-rimmed glasses, both of which can reduce FaceReader's performance. In addition, during pilot testing we found that the program was unable to correctly map the faces of some participants with dark skin which is likely due in part to the dim lighting.

2.3.3 Adolescent mental health

Girls completed the 33-item Mood and Feelings Questionnaire (MFQ; Angold, Costello, Messer, & Pickles, 1995) at the start of the laboratory visit. Each item consists of a statement describing diagnostic criteria and related symptoms of depression. Participants reported the extent to which each statement described their experiences in the prior two weeks ("not true," "sometimes," "true"). Total scores range from 0 to 66, with higher scores denoting greater depressive symptom severity. The MFQ has good stability, high internal consistency, and is moderately correlated with other measures of adolescent depressive symptoms (Angold et al., 1995; Wood, Kroll, Moore, & Harrington, 1995).

2.3.4 Parent-adolescent relationship quality

Girls completed the 30-item Network of Relationships Inventory - Relationship Qualities Version (NRI; Furman & Buhrmester, 1985) about their mothers either at the end of the laboratory visit or at home within the two days following the visit. Participants reported on the frequency and magnitude of behavioral and observable qualities of the specified relationship on a scale of 1 (never or hardly at all) to 5 (always or extremely). Two factors, *closeness* and *discord*, can be computed by averaging the subscales, consisting of 3 items each, that correspond to five positive relationship features (companionship, disclosure, emotional support, approval, and satisfaction) and five negative relationship features (conflict, criticism, pressure, exclusion and dominance), respectively. Higher scores indicate greater closeness or discord. In a sample of 223 early adolescents, reliability was good for most subscales—Cronbach's Alpha coefficients were above

0.7 for all subscales, expect dominance and exclusion which fell below 0.7 (Buhrmester & Furman, 2008).

2.3.5 Dyadic positive affect

Dyadic positive affect was measured using ratings on the Interactional Dimensions Coding System, Revised (IDCS-R; Furman & Shomaker, 2008). Trained raters coded mothers and daughters separately on the overall level of positive affect displayed during the discussion based on facial expressions, tone of voice, and body posture. Guided by specific anchor points in the manual and considering both the frequency and intensity of the cues, coders provided a rating on a 1 (extremely uncharacteristic) to 5 (extremely uncharacteristic) Likert scale, with half-point intervals. Given that the system was designed for rating two and a half minute chunks of interactions, only the first two and a half minutes of the task were rated. Coders developed reliability on the IDCS-R after extensive training by an expert coder. Following the training phase, coders met regularly to prevent drift. Ten recordings (31%) were randomly selected for independent rating by all coders and inter-rater reliability was determined by intraclass correlation coefficients comparing each coder to a gold-standard coder. Reliability for Positive Affect was good (ICC = 0.619). The individual ratings for mothers and daughters were averaged per dyad to create the variable of dyadic positive affect. For moderation analyses described below, a dummy variable was created using 4 and above as an indicator of high dyadic positive affect and 3.5 and below was categorized as low dyadic positive affect. A rating of 4 in the coding manual is defined as “Highly characteristic: Individual displays strong signs of positive affect that are frequent, and consistent.”

2.3.6 Post-hoc measures

2.3.6.1 Adolescent characteristics

We examined the Affiliation and Depressive Mood subscales on the Early Adolescent Temperament Questionnaire-Revised (EAT-Q; Ellis & Rothbart, 2001), completed by mothers about their adolescents. The Affiliation subscale contains 5 items such as, "Likes to be able to share her private thoughts with someone;" a higher score reflects adolescents' greater desire for warmth and closeness with others. The Depressive Mood subscale also contains 5 items such as, "Sometimes seems sad even when she should be enjoying herself like at Christmas, or on a trip;" a higher score reflects more unpleasant affect, lowered mood, and loss of enjoyment and interest in activities. We also examined adolescents' typical cognitive responses (i.e., dampening, self-focus, emotion-focus) to positive affect using subscales of the Response to Positive Affect Scale for Children completed by adolescents (RPA; Bijttebier, Raes, Vasey, & Feldman, 2012). The Dampening subscale (7 items) reflects responses that are likely to counter positive affect, such as "I think: 'I don't deserve this.'" The Self-Focus subscale (4 items) reflects responses that involve the goal-oriented aspects of positive affect, such as "I think: 'I am the best I could be.'" The Emotion Focus subscale (5 items) reflects responses that focus on the affective and somatic experiences that accompany positive affect such as "I think about how happy I feel." Lower scores on the Self-Focus and Emotion Focus subscales, both indicators of positive rumination, and higher scores on the Dampening subscale have been shown to be related to more children's depressive symptoms over a three month interval (Bijttebier et al., 2012).

2.3.6.2 Maternal characteristics

We examined the severity of maternal depressive symptoms within the past two weeks using the 16-item self-report Quick Inventory of Depressive Symptomatology (Rush, Gullion, Basco, Jarrett, & Trivedi, 1996), with higher scores indicating greater symptom severity. We also assessed maternal history of childhood emotional abuse using the Emotional Abuse subscale (5 items) of the Childhood Trauma Questionnaire (Bernstein et al., 2003), with higher scores indicating greater severity. History of childhood emotional abuse has been shown to be related to depressive disorders (Gibb, Chelminski, & Zimmerman, 2007).

2.3.6.3 Post-task ratings

Adolescents and their mothers independently reported how happy, sad, and close to one another they were feeling immediately following the Plan a Fun Activity Task on a Visual Analog Scale (VAS) measuring 100-mm, ranging from "not at all" to "very much." A rating from 1 to 100 was recorded.

2.3.6.4 Global measures of synchrony

We were interested in how our index of positive affect synchrony related to other similar indices within dyadic interactions. We used dyadic codes from the IDCS-R—Positive Escalation, Negative Escalation, and Mutuality that are rated are based on how the dyad interacts together during the discussion. The Positive and Negative Escalation scales a defined as "how often positive/negative behaviors of one partner are responded to with positive/negative behaviors from the other partner." Mutuality is defined as "the degree to which these two people identify themselves as a dyad with a sense of 'we-ness' and reciprocity." Reliability was good for Positive

Escalation (ICC = 0.699) and Mutuality (ICC = 0.652); we were unable to calculate reliability for Negative Escalation due to low variability in ratings.

2.4 Analytic Plan

The primary analytic plan, utilizing a novel statistical modeling technique, is described below. Because this technique was fairly new (implementation in Mplus released in April 2017), there was a possibility that unexpected issues would arise preventing its use with the data from this study. In the event this would occur, an alternative method is also described.

2.4.1 Primary analytic plan

Dynamic structural equation modeling (DSEM; Asparouhov, Hamaker, & Muthén, 2018), which is implemented in Mplus, Version 8, is based on a multilevel extension of the time series model in which time points are nested within individuals at the within-person level (level 1) and individual differences in level 1 parameters such as the mean, variance, and autocorrelation are represented as random effects that are modeled at the between-person level (level 2). Allowing for the parameters at the within-person level to have a distribution at the between-person level can be seen as an extension of the cross-lagged panel model, in that instead of assuming all the parameters to be equal across all individuals, they are allowed to be random (Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018). Importantly, the model also includes random residual variances and covariances to account for individual differences in these parameters. Model estimation is carried out using Bayesian analysis.

Within the DSEM framework, two multilevel cross-lagged models were specified, one for positive affect synchrony and the other for heart rate synchrony. Level 1 included the time series of adolescents' and their mothers' moment-to moment data and level 2 included the individual difference variables: depressive symptoms and parent-adolescent closeness and discord. The residual covariance (i.e., autoregressive component removed) of adolescents' heart rate (or positive affect) and mothers' heart rate (or positive affect) represented emotional synchrony. Because the residual covariances are allowed to be random, they can predicted by or used as predictors of other variables at level 2 (i.e., adolescent mental health and relationship quality). See Figure 1 for a visual representation of the model.

2.4.2 Alternative analytic plan

For each participant's set of second-by-second heart rate and facial affect data, individual regressions were run to remove the linear and autoregressive components. The reasons for removing these components are that 1) both partners may naturally increase or decrease in heart rate and positive affect from the beginning to the end of the discussion, and 2) each individual's heart rate and positive affect at one second would be expected to be highly correlated with their heart rate and positive affect in the prior second. These components were removed from the data to reduce inflation of synchrony. The residuals of the individual regressions were then used in the next steps of analysis. Analytic plans for each aim are specified below. Given the small sample size, these data allowed only for detection of large effect sizes.

Aim 1: To examine whether emotional synchrony was present between mothers and adolescents, concurrently and at a one second lag, within the emotional channels of

physiology and behavior during a discussion primed for positive affect

Indices of the extent to which emotional synchrony was present between adolescents and their mothers was created separately for heart rate and facial displays of positive affect by running correlations between the sets of data for each dyad. These indices were then used in subsequent analyses. Statistically significant correlations, both positive and negative would indicate emotional synchrony.

Aim 2: To examine the association between mother-adolescent emotional synchrony adolescents' mental health

Heart rate and positive affect indices of emotional synchrony were separately regressed on the MFQ. A negative relationship was expected between emotional synchrony and depressive symptoms such that a stronger synchrony would be related to less symptoms. Moderation analyses were run to test whether stronger synchrony would predict less depressive symptoms only when observed positive affect was high.

Aim 3: To examine the relationship between mother-adolescent emotional synchrony and parent-adolescent relationship quality

Heart rate and positive affect indices of emotional synchrony were separately regressed on the two subscales (i.e., closeness, discord) of the NRI. A positive relationship was expected between emotional synchrony and closeness and a negative relationship was expected between emotional synchrony and discord. Moderation analyses were run to test whether stronger synchrony would predict higher closeness and lower discord only when observed positive affect was high.

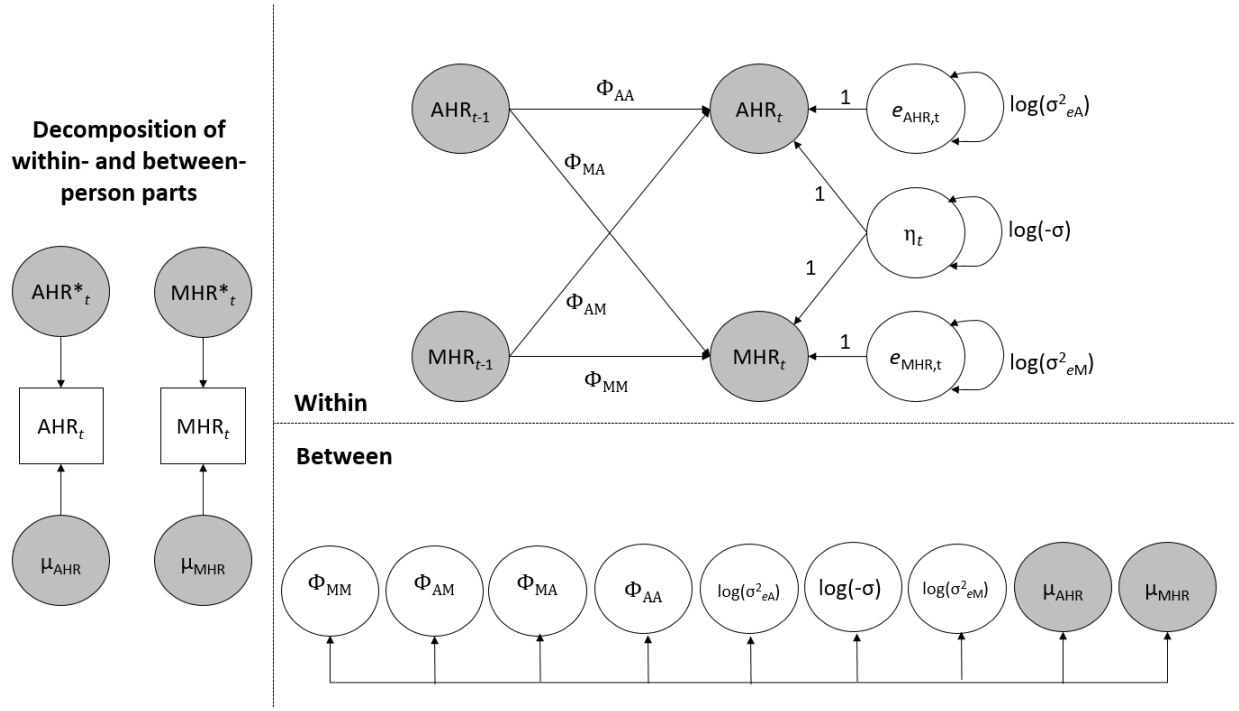

Figure 1 Representation of Dynamic Structural Equation Modeling

Note: Left contains the decomposition into within-person and between-person components. Top right contains the with-person model. Bottom right contains the between-person model, which includes that between-person components of the observed data as well as the random effects of the model. The parameters are specified as follows: μ's are the within-person means that form the between-person part of the model; AHR^*_{it} and MHR^*_{it} represent the temporal deviations of individual *i* at occasion *t* from these within-person means, with "A" representing adolescents and "M" representing mothers; $\Phi_{AA,i}$ is the autoregressive parameter for adolescents; $\Phi_{MM,i}$ is the autoregressive parameter for mothers; $\Phi_{AM,i}$ is the cross-lagged parameter for mothers to adolescents; $\Phi_{MA,i}$ is the cross-lagged parameter for adolescents to mothers; $e_{AHR,it}$ is the residual variance for adolescents; $e_{MHR,it}$ is the residual variance for mothers; η_t is the residual covariance between mothers and adolescents.

3.0 Results

3.1 Preliminary Analyses

Data from 32 dyads were included in analyses. Adolescents were about 14 years old (*SD* = 1.58) on average, mostly white (75%), and from families with a range of income levels. Mothers were about 45 years old (*SD* = 6.33), on average. See Table 2 for further details.

Descriptive statistics and bivariate correlations among study variables are reported in Tables 3 to 5. Heart rate data was unavailable for two dyads and positive affect data was unavailable for one dyad due to issues with data collection. One dyad was excluded from heart rate analyses due to the adolescent's arrhythmia. One adolescent did not complete the Network of Relationships Inventory. To calculate heart rate second-by-second using inter-beat interval data, the first and last second of each individuals' data are unavailable. There was no additional heart rate data missing. Instances in which participants' faces were obstructed during data collection (e.g., looking down, hand in face) or issues with lighting resulted in 4.63% of data across mothers and adolescents that was unable to be classified into emotions by FaceReader.

The DSEM approach was attempted by first examining separate models of heart rate and facial affect. When models failed to converge, the alternative analytic plan was pursued. There are several factors that may have contributed to convergence failure such as sample size, a lack of variability from moment to moment in the time intervals chosen, and dyadic variability in the strength of relationships between the many variables included.

Table 2 Sample Demographics

	N	Statistic
Adolescent age (*M, SD*)	32	14.29 (1.58)
Adolescent race (*n*, %)	32	
White, non-Hispanic		24 (75.0)
Black, non-Hispanic		6 (18.8)
Biracial		2 (6.3)
Mother age (*M, SD*)	30	45.10 (6.33)
Mother race (*n*, %)	32	
White, non-Hispanic		26 (81.3)
Black, non-Hispanic		6 (18.8)
Mother marital status (*n*, %)	31	
Married		18 (56.3)
Never married		4 (12.5)
Divorced/Separated		7 (21.9)
Widowed		2 (6.3)
Total family income (*n*, %)	32	
$0-$30,000		6 (18.8)
$30,001-$50,000		8 (25.0)
$50,001-$100,000		12 (37.5)
Greater than $100,001		6 (18.8)

Table 3 Descriptive Statistics of Questionnaires

	N	Mean	*SD*	Minimum	Maximum
Adolescent depressive symptoms	32	9.85	8.75	0.00	32.00
Relationship closeness	31	3.72	0.85	2.07	5.00
Relationship discord	31	2.26	0.59	1.27	3.73
Dyad positive affect	31	3.83	0.51	2.75	5.00

Table 4 Descriptive Statistics of Synchrony Variables

	Lag	*N*	Mean	*SD*	Minimum	Maximum
Heart rate	None	29	-0.06	0.11	-0.30	0.17
	Mother	29	-0.02	0.09	-0.18	0.14
	Adolescent	29	-0.03	0.11	-0.26	0.18
Positive affect	None	31	0.12	0.14	-0.24	0.47
	Mother	31	0.07	0.15	-0.25	0.45
	Adolescent	31	0.11	0.17	-0.05	0.34

Table 5 Bivarate Correlations Between Study Variables

Variable	1	2	3	4	5	6	7	8	9	10
1. MFQ	-									
2. Closeness	-0.212	-								
3. Discord	0.344^{+}	-0.630**	-							
4. Dyad PA	-0.062	0.025	-0.170	-						
5. PA, no lag	-0.045	-0.042	-0.028	0.026	-					
6. PA, mother lag	0.014	-0.540**	0.495**	0.054	0.394**	-				
7. PA, adol. lag	0.025	0.110	-0.100	0.181	0.512**	0.074	-			
8. HR, no lag	0.075	0.013	0.056	0.182	0.198	0.316	0.043	-		
9. HR, mother lag	-0.075	-0.154	0.073	0.035	0.221	0.329	0.042	0.425**	-	
10. HR, adol. lag	0.289	-0.172	0.333^{+}	0.062	-0.172	0.150	-0.128	0.676	0.122	-

Note. Dyad PA was entered as a continuous variable.
HR = heart rate synchrony; PA = positive affect synchrony
* $p<0.05$, $^{**}p<0.01$, $^{+}p<0.10$ (all two-tailed)

3.2 Aim 1: Presence of Synchrony

The number of dyads for whom synchrony met statistical significance is presented in Table 6. Across lags, the number of dyads with significant positive affect synchrony ranged from 9 to 12 and those with significant heart rate synchrony ranged from 1 to 6. The majority of significant values of positive affect synchrony were positive and the majority of significant values of heart rate synchrony were negative.

Table 4 contains the descriptive statistics for each measure of synchrony. Across lags, the average levels of both heart rate and positive affect synchrony were very low with the minimum mean correlation at -0.06 (*SD* = 0.11) and the maximum mean correlation at 0.12 (*SD* = 0.14). However, the range of values per synchrony measure suggest heterogeneity in the data. For example, the correlations for positive affect with the adolescent lagged ranged from -0.24 to 0.47 (*M* = 0.12, *SD* = 0.14).

Table 6 Types of Synchrony

	Lag	*N*	*n* (%) with $p < 0.05$	Positive, *n*	Negative, *n*
Heart rate	None	29	6 (18.8)	1	5
	Mother	29	1 (3.1)	0	1
	Adolescent	29	6 (18.8)	1	5
Positive affect	None	31	12 (37.5)	11	1
	Mother	31	9 (28.1)	7	2
	Adolescent	31	11 (34.4)	11	0

3.3 Aim 2: Synchrony and Adolescent Depressive Symptoms

No significant main effects emerged from linear regressions run for each synchrony measure on adolescent depressive symptoms; see Tables 7 and 8. There were also no significant interactions with observed positive affect; see Tables 9 and 10.

Table 7 Positive Affect Synchrony and Adolescent Depressive Symptoms

Lag	Parameter	*B* (*SE*)	*β*	R^2 (*SE*)
None	Constant	10.015 (1.614)**		0.002 (8.989)
	Synchrony	-0.396 (1.641)	-0.045	
Mother	Constant	10.015 (1.616)**		0.000 (8.997)
	Synchrony	0.126 (1.643)	0.014	
Adolescent	Constant	10.015 (1.616)**		0.001 (8.995)
	Synchrony	0.225 (1.642)	0.025	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 8 Heart Rate Synchrony and Adolescent Depressive Symptoms

Lag	Parameter	*B* (*SE*)	*β*	R^2 (*SE*)
None	Constant	10.250 (1.703)**		0.006 (9.168)
	Synchrony	0.674 (1.733)	0.075	
Mother	Constant	10.250 (1.703)**		0.006 (9.169)
	Synchrony	-.0673 (1.733)	-0.075	
Adolescent	Constant	10.250 (1.635)**		0.083 (8.802)
	Synchrony	2.607 (1.663)	0.289	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 9 Positive Affect Synchrony and Depressive Symptoms Moderated by Positive Affect

Lag	None		Mother		Adolescent	
	B (*SE*)	*β*	*B* (*SE*)	*β*	*B* (*SE*)	*β*
Constant	10.089 (2.218)		9.735 (2.210)**		9.751 (2.166)**	
Synchrony	-11.891 (17.879)	-0.202	1.767 (11.127)	0.033	-2.858 (24.861)	-0.037
Dyad PA	-0.907 (3.227)	-0.055	-1.028 (3.355)	-0.063	-1.204 (3.188)	-0.073
Interaction	19.743 (23.473)	0.252	-12.089 (34.803)	-0.075	23.073 (31.361)	0.234
R^2 (*SE*)	0.029 (8.673)		0.007 (8.770)		0.044 (8.605)	
ΔR^2	0.026		0.005		0.020	
F for ΔR^2	0.707		0.121		0.541	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 10 Heart Rate Synchrony and Depressive Symptoms Moderated by Positive Affect

Lag	None		Mother		Adolescent	
	B (*SE*)	*β*	*B* (*SE*)	*β*	*B* (*SE*)	*β*
Constant	9.623 (2.295)**		9.662 (2.230)**		9.683 (2.146)**	
Synchrony	-0.878 (23.482)	-0.012	-2.616 (26.519)	-0.027	12.911 (21.278)	0.172
Dyad PA	-0.267 (3.498)	-0.016	-0.501 (3.429)	-0.030	-0.155 (3.277)	-0.009
Interaction	10.181 (30.915)	0.104	-23.743 (39.422)	-0.165	16.869 (29.205)	0.164
R^2 (*SE*)	0.009 (8.988)		0.033 (8.876)		0.097 (8.578)	
ΔR^2	0.004		0.015		0.013	
F for ΔR^2	0.108		0.363		0.334	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

3.4 Aim 3: Synchrony and Mother-Adolescent Relationship Quality

Contrary to hypotheses, positive affect synchrony with the mother lagged *negatively* predicted mother-adolescent closeness (β = -0.540, p = 0.002) and *positively* predicted mother-

adolescent discord ($\beta = 0.495$, $p = 0.005$). These findings suggest that for dyads in which mothers' positive affect followed adolescents' positive affect, adolescents rated their relationship as less close and more discordant. There were no significant main effects for heart rate synchrony. See Tables 11 to 14. There were also no significant interactions with positive affect; see Tables 15 to 18.

Table 11 Positive Affect Synchrony and Mother-Adolescent Closeness

Lag	Parameter	*B* (*SE*)	β	R^2 (*SE*)
None	Constant	3.705 (0.159)**		0.002 (0.872)
	Synchrony	-0.035 (0.160)	-0.042	
Mother	Constant	3.723 (0.134)**		0.292 (0.735)
	Synchrony	-0.466 (0.137)*	-0.540	
Adolescent	Constant	3.701 (0.159)**		0.012 (0.868)
	Synchrony	0.096 (0.164)	0.110	

* $p < 0.05$, ** $p < 0.01$, + $p < 0.10$ (all two-tailed)

Table 12 Heart Rate Synchrony and Mother-Adolescent Closeness

Lag	Parameter	*B* (*SE*)	β	R^2 (*SE*)
None	Constant	3.735 (0.166)**		0.000 (0.877)
	Synchrony	0.011 (0.166)	0.013	
Mother	Constant	3.733 (0.164)**		0.024 (0.866)
	Synchrony	-0.131 (0.164)	-0.154	
Adolescent	Constant	3.734 (0.163)**		0.030 (0.864)
	Synchrony	-0.146 (0.163)	-0.172	

* $p < 0.05$, ** $p < 0.01$, + $p < 0.10$ (all two-tailed)

Table 13 Positive Affect Synchrony and Mother-Adolescent Discord

Lag	Parameter	*B* (*SE*)	β	R^2 (*SE*)
None	Constant	2.280 (0.111)**		0.001 (0.608)
	Synchrony	-0.017 (0.111)	-0.028	
Mother	Constant	2.269 (0.097)**		0.245 (0.528)
	Synchrony	0.297 (0.099)*	0.495	
Adolescent	Constant	2.283 (0.111)**		0.010 (0.605)
	Synchrony	-0.061 (0.114)	-0.100	

* $p < 0.05$, ** $p < 0.01$, + $p < 0.10$ (all two-tailed)

Table 14 Heart Rate Synchrony and Mother-Adolescent Discord

Lag	Parameter	*B* (*SE*)	*β*	R^2 (*SE*)
None	Constant	2.243 (0.116)**		0.003 (0.612)
	Synchrony	0.033 (0.116)	0.056	
Mother	Constant	2.243 (0.116)**		0.005 (0.611)
	Synchrony	0.043 (0.116)	0.073	
Adolescent	Constant	2.244 (0.109)**		0.111 (0.578)
	Synchrony	0.197 (0.109)+	0.333	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 15 Positive Affect Synchrony and Mother-Adolescent Closeness Moderated by Positive Affect

Lag	None		Mother		Adolescent	
	B (*SE*)	*β*	*B* (*SE*)	*β*	*B* (*SE*)	*β*
Constant	3.540 (0.216)**		3.663 (0.181)**		3.554 (0.212)**	
Synchrony	0.578 (1.697)	0.102	-2.849 (0.904)**	-0.546	1.407 (2.623)	0.180
Dyad PA	0.426 (0.310)	0.266	0.234 (0.268)	0.146	0.452 (0.308)	0.282
Interaction	-1.462 (2.226)	-0.195	-0.273 (2.739)	-0.018	-2.318 (3.194)	-0.244
R^2 (*SE*)	0.091 (0.821)		0.363 (0.688)		0.092 (0.821)	
Δ R^2	0.016		0.000		0.019	
F for Δ R^2	0.432		0.010		0.527	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 16 Heart Rate and Mother-Adolescent Closeness Moderated by Positive Affect

Lag	None		Mother		Adolescent	
	B (*SE*)	*β*	*B* (*SE*)	*β*	*B* (*SE*)	*β*
Constant	3.623 (0.219)**		3.671 (0.214)**		3.643 (0.209)**	
Synchrony	-1.543 (2.174)	-0.224	-2.441 (2.473)	-0.269	-2.963 (2.003)	-0.422
Dyad PA	0.325 (0.328)	0.203	0.319 (0.323)	0.199	0.329 (0.313)	0.205
Interaction	2.564 (2.860)	0.280	3.595 (3.669)	0.267	3.328 (2.749)	0.345
R^2 (*SE*)	0.072 (0.831)		0.085 (0.825)		0.124 (0.807)	
ΔR^2	0.032		0.038		0.056	
F for ΔR^2	0.803		0.960		1.466	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 17 Positive Affect Synchrony and Mother-Adolescent Discord Moderated by Positive Affect

Lag	None		Mother		Adolescent	
	B (*SE*)	*β*	*B* (*SE*)	*β*	*B* (*SE*)	*β*
Constant	2.383 (0.143)		2.325 (0.118)**		2.387 (0.138)**	
Synchrony	0.171 (1.122)	0.045	1.594 (0.590)*	0.461	1.608 (1.707)	0.311
Dyad PA	-0.327 (0.205)	-0.308	-0.162 (0.175)	-0.152	-0.320 (0.200)	-0.301
Interaction	-0.434 (1.472)	-0.087	1.972 (1.787)	0.191	-1.860 (2.079)	-0.296
R^2 (*SE*)	0.097 (0.543)		0.384 (0.449)		0.126 (0.534)	
ΔR^2	0.003		0.030		0.028	
F for ΔR^2	0.087		1.217		0.801	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 18 Heart Rate and Mother-Adolescent Discord Moderated by Positive Affect

Lag	None		Mother		Adolescent	
	B (*SE*)	*β*	*B* (*SE*)	*β*	*B* (*SE*)	*β*
Constant	2.340 (0.143)**		2.320 (0.139)**		2.335 (0.128)**	
Synchrony	0.719 (1.416)	0.158	0.680 (1.611)	0.113	2.535 (1.228)+	0.546
Dyad PA	-0.330 (0.214)	-0.312	-0.323 (0.210)	-0.305	-0.320 (0.192)	-0.303
Interaction	-0.434 (1.863)	-0.072	-1.877 (2.391)	-0.211	-1.627 (1.685)	-0.256
R^2 (*SE*)	0.097 (0.541)		0.109 (0.537)		0.245 (0.495)	
ΔR^2	0.002		0.024		0.031	
F for ΔR^2	0.054		0.616		0.935	

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

3.5 Post-Hoc Analyses

Post-hoc analyses were examined only with positive affect synchrony, given the low number of dyads for whom heart rate synchrony was observed.

3.5.1 Associations with observational measures of synchrony

Positive affect synchrony with no lag was negatively correlated with negative escalation (r = -0.388, p = 0.034). Positive affect synchrony with no lag and with the adolescent lagged were positively correlated with mutuality (r = 0.382, p = 0.041; r = 0.380, p = 0.042). There were no significant correlations with positive escalation. See Table 19.

3.5.2 Group differences

To limit tests, these analyses were run only for positive affect synchrony with no lag. T-tests revealed that in dyads with significant positive affect synchrony (in the positive direction), mothers reported less depressive symptoms for themselves (t = 3.06; p = 0.005) and rated their adolescents lower on a trait measure of tendency to experience depressed mood compared to dyads without significant positive affect synchrony (t = 2.72; p = 0.011). There were no group differences on mother or adolescent emotion contagion or post-task ratings of happiness, sadness, or closeness to the partner. In addition, no group differences were found for maternal history of childhood emotional abuse, adolescent desire for closeness to others, or adolescent tendencies in response to positive emotion. See Table 20.

Table 19 Association of Positive Affect Synchrony with Observational Measures of Synchrony

Synchrony	Positive escalation	Negative escalation	Mutuality
PA, no lag	0.047	-0.388*	0.382*
PA, mother lag	0.122	-0.245	0.124
PA, adolescent lag	0.201	-0.208	0.380*

* p <0.05, ** p <0.01, + p <0.10 (all two-tailed)

Table 20 Positive Affect Synchrony Group Differences

	Variable	Mean for Dyads with Positive Synchrony (n=11)	Mean for Dyads Without Positive Synchrony (n=20)	*t*-value
Adolescent	EAT-Q: Depressive Mood	1.72 (0.27)	2.21 (0.70)	2.72*
	EAT-Q: Affiliation	3.80 (0.39)	3.88 (0.67)	0.37
	Emotional Contagion	44.82 (9.59)	49.84 (7.81)	1.56
	RPA: Dampening	14.00 (4.12)	15.47 (5.08)	0.82
	RPA: Emotion Focus	15.73 (3.41)	16.32 (3.18)	0.48
	RPA: Self Focus	10.55 (1.69)	11.21 (3.58)	0.69
	VAS: Happy	69.80 (27.00)	80.15 (22.39)	1.12
	VAS: Sad	3.00 (5.93)	5.11 (8.40)	0.70
	VAS: Close	81.80 (19.10)	79.10 (20.04)	-0.35
Mother	Depressive Symptoms	1.82 (1.08)	4.30 (3.33)	3.06**
	Childhood History of Emotional Abuse	6.55 (1.81)	8.45 (4.90)	1.24
	Emotional Contagion	52.27 (10.34)	51.30 (7.44)	-0.30
	VAS: Happy	75.30 (25.87)	83.80 (15.21)	0.96
	VAS: Sad	2.80 (5.41)	3.05 (7.34)	0.10
	VAS: Close	84.30 (21.05)	87.75 (13.48)	0.55

* $p < 0.05$, ** $p < 0.01$, + $p < 0.10$ (all two-tailed)

4.0 Discussion

The present study sought to examine parent-child synchrony during adolescence and its association with adolescent mental health and the parent-adolescent relationship. Results showed that synchrony was present only for some dyads and varied by time lags. There were no significant associations between synchrony and adolescent depressive symptoms and there were unexpected associations with parent-adolescent relationship quality. These results suggest that synchrony between parents and adolescents may be less prevalent and not as universally linked to well-being as theory may suggest.

This study is the first to examine the prevalence of synchrony in a community sample of parents and adolescents. Synchrony was observed in 3.1% to 37.5% of dyads, depending on the time lag and behavioral versus physiological channels. There was a very low occurrence of heart rate synchrony across time lags, and, on average across time lags, positive affect synchrony was observed in one third of dyads. The rate at which positive affect synchrony was observed is similar to that of a recent study of emotional synchrony in romantic couples (Sels, Ceulemans, Bulteel, & Kuppens, 2016). The researchers found that only 36% of the sample displayed synchrony of positive and negative emotions across several days and the strength of synchrony differed by time lag.

There were several unexpected results in this study. First, the very low occurrence of heart rate synchrony was surprising, given that other studies have demonstrated this type of synchrony. One possible explanation is that the nature of the planning discussion between parents and adolescents did not elicit heart rate synchrony in the way that other interactions might. For example, Levenson and Gottman (1983) observed heart rate synchrony during conflict interactions

in romantic couples. Conflict is likely associated with more changes in heart rate and more regulation of arousal than is a neutral to positive discussion. Additionally, Feldman and colleagues (2011) observed heart rate synchrony in parent-infant dyads during free play interactions; this type of interaction, which may involve physical touch and calls for high engagement from the parent, may be more likely to elicit coordination of heart rates.

Another unexpected result was that there was not a significant association between the strength of synchrony during the discussion and adolescents' depressive symptoms at the time of the visit. However, post-hoc analyses suggest that indicators of depression (i.e., mothers' depressive symptoms, adolescent trait tendency to experience depressed mood) were related to the presence of synchrony in the discussion. Specifically, dyads with greater indications of depressive symptoms were less likely to display positive affect synchrony. The idea that depressive history or traits may underlie differences in synchrony has also been suggested by other studies. For example, Kudinova and colleagues (2018) found that positive affect synchrony during a positive discussion task was stronger for parent-child dyads without parental depression history, regardless of the dyad's current symptoms or sadness during the discussion. Two other studies demonstrated that physiological synchrony also differed by the dyad's depression history (Amole, Cyranowski, Wright, & Swartz, 2017; Woody et al., 2016). It will be important for future studies to include measures of depression history. Longitudinal studies would also allow for an examination of potential changes in synchrony in the context of the development of depressive symptoms.

Finally, associations between synchrony and the parent-adolescent relationship were contrary to our expectations. We found that greater positive affect synchrony was associated with less closeness and more discord, however, only when mothers' affect followed adolescents' affect. It is important to note that only seven dyads displayed significant positive affect synchrony (in the

positive direction). If these unexpected associations are replicated, they may suggest that for dyads with worse relationship quality, mothers may have made efforts to reciprocate their adolescents' positive affect in the laboratory which may not be representative of their typical interactions. It is also possible that for these dyads, the facial affect that was displayed and categorized as "happy" may instead have been expressions of sarcasm or ingenuine smiles. Future studies could include other positive affect indicators such as vocal tone, body posture, and verbal content in addition to facial expressions. It is of note that Sels and colleagues (2016) failed to find a significant association between positive affect synchrony and relationship satisfaction in romantic couples; therefore, it may be that our unexpected findings are a result of our small sample and would not be replicated.

The results of this study suggest that synchrony during an interaction primed for positive affect may not be a salient contributor to adolescent mental health or parent-adolescent relationship quality. Perhaps parent-adolescent synchrony in the context of conflict would be more closely linked to these outcomes. In fact, Coutinho and colleagues (2019) compared the degree of synchrony of electrodermal activity between romantic partners during positive and conflict discussions and found that the degree of synchrony was higher during the conflict discussion. It may also be that the use of other types of emotional influence by parents, such as emotion socialization (Eisenberg, Cumberland, & Spinrad, 1998) are more closely related to our outcomes. For example, Silk and colleagues (2011) found that certain maternal responses to children's emotions were associated with children's later internalizing symptoms.

Synchrony is often considered a characteristic of healthy relationships, however, very few studies have examined the prevalence and basic characteristics of synchrony within normative samples. Many studies have demonstrated the presence of synchrony in various types of close

relationships (e.g., for review, see Palumbo et al., 2017) and have shown its potential benefits by taking a nomothetic approach, with one model being fit to data from all dyads, and comparing groups of dyads. The type of approach in which data are aggregated across dyads provides information about group trends but does not accurately represent the characteristics of the dyads that make up the group, unless the sample is relatively homogeneous (Molenaar, 2004). Sels and colleagues (2016) reviewed recent studies of synchrony which have shown the heterogenous nature of synchrony as being influenced by various factors such as culture (Schoebi, Wang, Ababkov, & Perrez, 2010), the amount of time a dyad spends together (Papp, Pendry, Simon, & Adam, 2013), individuals' level of distress (Randall & Schoebi, 2015), attachment style (Randall & Butler, 2013), and the possession of a variant of the serotonin transporter gene (Schoebi, Way, Karney, & Bradbury, 2012). The results of this study also point to the variability between dyads on the prevalence and patterns of synchrony and therefore underscore the recent interest in conducting psychological research using an idiographic, or dyad-specific, approach in which separate analyses are run per dyad (Beltz, Wright, Sprague, & Molenaar, 2016; Molenaar, 2004; Molenaar & Campbell, 2009; Velicer, Babbin, & Palumbo, 2014).

One strength of the present study is our use and combination of nomothetic and idiographic statistical approaches. Specifically, the degree of synchrony was individually calculated for each dyad as opposed to examining the average degree of synchrony at the group level, then the associations between synchrony and the outcomes were examined at the group level. Creating a dyad-specific synchrony variable allowed us to capture the various patterns of synchrony (e.g., positive vs. negative) across dyads and to generate hypotheses about dyadic and individual characteristics that may have influenced the pattern. Several recent studies have taken a similar approach and have demonstrated differences when comparing findings from nomothetic and

idiographic approaches within the same dataset. For example, Manini and colleagues (2013) demonstrated that the idiographic approach resulted in statistically significant synchrony at various time lags, however, the nomothetic approach yielded null results.

We examined several factors in an exploratory fashion that we hypothesized to be related to synchrony. We expected that measures related to risk for depression such as adolescent responses to positive affect, adolescent desire for closeness to others, and maternal history of childhood emotional abuse may have been more proximally related to differences in positive affect synchrony compared to current depressive symptoms, however they were not. We also did not find group differences on post-task ratings of happiness, sadness, or closeness to the partner, suggesting that positive affect synchrony may not have been perceived as significant by the dyad. Finally, dyadic positive affect was not a significant moderator for any of the main analyses.

To better understand the process being captured by our measure of positive affect synchrony, we examined its association with global observational measures of synchrony. We found that positive affect synchrony was related to scales indicating the dyad was perceived as being "in-sync" and not exhibiting reciprocal negative behaviors. However, it was surprising that the lagged representations of positive affect synchrony were not related to the observational measure of reciprocal positive behaviors. One possible explanation is that the global code of positive escalation and our measure of positive affect synchrony were measuring different types of synchrony, given their different timescales. The global code is meant to capture more overt reciprocal behaviors that raters could observe (e.g., smiles, laughs, nodding), typically unfolding over several seconds, and our measure of positive affect synchrony with only a one second lag may have been too short to reflect these behaviors. We also failed to find an association between positive affect synchrony and emotional contagion.

The range of observed synchrony over different time lags points to the significance of choosing a time interval at which to examine emotional influence between interacting partners and constitutes an area for future research. Making this choice requires a balance between capturing change at the smallest interval at which it can be detected and capturing a general level of influence over a longer time interval (Thorson, West, & Mendes, 2018). Using the smallest interval at which change can be detected is highly precise, however, the interval at which influence occurs varies both between and within dyads. Longer intervals have the advantage of aggregating the influence that may occur at different intervals, however, they may mask meaningful changes (Thorson et al., 2018). The process by which partners influence each other's emotions is highly complex and the field would benefit from research investigating optimal time intervals for capturing emotional influence.

Another area for future research will be to examine the association between behavioral, physiological, and subjective emotional channels. In this study, we observed differences in the degree of behavioral and physiological synchrony. Given theories which suggest complex, bidirectional relationships between emotional channels both within and across individuals in a dyad, it is important to better understand the ways in which these emotional channels influence each other throughout the course of a parent-adolescent interaction. For example, Feldman and colleagues (2011) found that heart rate synchrony was higher during periods of affect and vocal synchrony during parent-infant interactions.

There are several important limitations of this study such as the cross-sectional nature and the small sample size. Results should therefore be interpreted as preliminary, especially given the very small synchrony correlations. It will be important for future studies to utilize larger samples to detect smaller effects as well as longitudinal designs to better understand the direction of

influence between emotional synchrony and its correlates. The participant sample also limits the generalizability of the study results to mother-daughter dyads; it is possible that results would differ in other parent-adolescent gender combinations.

In conclusion, the results of this study show that emotional synchrony during positive contexts is not a universal characteristic of healthy parent-adolescent relationships. This study adds valuable information to the literature on emotional synchrony during adolescence, given the very few studies published in this area. The present study also underscores that emotional synchrony is heterogenous both between and within dyads, which provides an exciting opportunity for future research to more closely examine.

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