RESPIRATORY SINUS ARRHYTHMIA BASELINE AND REACTIVITY TO INTERPERSONAL CHALLENGE: A DYNAMIC SYSTEMS APPROACH

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Abstract: The current investigation examined associations between adolescent respiratory sinus arrhythmia (RSA) baseline and reactivity to interpersonal challenges (i.e., RSA during an angry event discussion) and adolescent emotion regulation and adjustment. This study also investigated whether parents' negative and positive affect influence adolescent RSA levels during parent-adolescent interactions (i.e., a conflict resolution task). Data were collected from 206 adolescents (mean age of 13.37) and their primary caregivers (predominantly biological mothers). Electrocardiogram (ECG) and respiration data were collected from adolescents and RSA variables were computed. Adolescent reported on parental acceptance, psychological control, and their depressive symptoms. Both parents and adolescents reported on adolescent emotion regulation and prosocial and aggressive behavior. Parent affect was coded during a parent-adolescent conflict resolution task. Multi-level latent growth modeling was employed to capture dynamic RSA changes and growth mixture modeling was employed to identify different RSA dynamic change patterns. Multi-level modeling was also used to distinguish the inter- and intra-individual effects of parent affect on adolescent RSA. Results indicate that higher RSA baseline was associated with more prosocial behavior among adolescents. Higher initial RSA decreases (RSA suppression) in response to challenge and then higher RSA increases (RSA recovery) were associated with better adolescent anger and sadness regulation (combined adolescent- and parent-report) and more prosocial behavior. Results of mixture modeling suggest that the group of adolescents who showed RSA suppression followed by RSA recovery was higher in parental acceptance, anger and sadness regulation, and prosocial behavior, and lower in parental psychological control, depressive symptoms, and aggressive behavior. These findings suggest that in response to interpersonal challenges, a dynamic pattern of initial RSA suppression followed by RSA recovery is an adaptive response, which indicates better emotion regulation abilities, and is related to better adjustment as well as positive parenting. Results also indicate that higher observed parent anger was associated with lower adolescent RSA levels, particularly among older adolescents, while higher observed parent positive affect was associated with higher RSA levels among adolescent girls. These findings imply that parent fluctuations in affect during social interactions may shape adolescents' development of vagal functioning.

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MANUSCRIPT

Respiratory Sinus Arrhythmia Baseline and Reactivity to Interpersonal Challenge: A Dynamic Systems Approach

Children and families face enormous developmental challenges in modern society, especially youth of color and those living in poverty (Jenson & Fraser, 2011). Many adolescents face adjustment difficulties and health problems such as delinquency, violent offending, illicit drug use, sexually transmitted diseases, pregnancy, anxiety, and depression. Because of this, and because adolescents experience more frequent and intense emotions and dynamic fluctuations than younger children or older individuals (Granic, Hollenstein, Dishion, & Patterson, 2003; Larson, Csikszentmihalyi, & Graef, 1980; Larson & Lampman-Petraitis, 1989), adolescence is a critical period for research (Steinberg, 2001; Steinberg & Morris, 2001). The ability to manage emotions behaviorally and physiologically plays a critical role in the development of various adjustment problems (Steinberg & Avenevoli, 2000). From the perspective of risk and resilience (Masten, 2007), biological vulnerability to stress is a risk factor that has drawn a lot of research attention and yet is in need of greater study (Thayer, Hansen, Saus-Rose, & Johnson, 2009).

In the past few decades, with the development of physiological measurement tools and quantification methods, various studies have focused on the neurophysiological mechanism of cardiac vagal control and on the effects of autonomic nervous system functioning on child and adolescent adjustment (e.g., Berntson, Cacioppo, & Quigley, 1991; Grossman & Kollai, 1993; Porges et al., 2007). Empirical studies have found meaningful relations between the functions of the autonomic nervous system (ANS) and psychopathology as well as a range of social-emotional behaviors (Bosch, Riese, Ormel, Verhulst, & Oldehinkel, 2009; Butler, Wilhelm, & Gross, 2006; Egizio et al., 2008; Gentzler, Santucci, Kovacs, & Fox, 2009). Many of these studies focus on respiratory sinus arrhythmia (RSA, i.e., the fluctuation in heart period at the respiratory frequency) as an indicator of parasympathetic regulation linked to both emotion and behavioral regulation (Beauchaine, 2001; Hastings, et al., 2008; Porges, 2007). One reason for this choice may be that obtaining RSA data is noninvasive, relatively easy to collect, and inexpensive (Ritz, 2009). However, the findings from these studies are often inconsistent and sometimes contradictory (Egizio et al., 2008; Hastings et al., 2008). Recently, researchers have noted some flaws in traditional RSA studies including: 1) ignoring respiration parameters (e.g., respiration rate and power), attention, and motor activity, especially in studies involving stress tasks requiring talking; 2) using a single stressor and a single psychophysiological indicator; and 3) ignoring timing issues and possibly different processes involved in task completion (Dennies, Buss, & Hastings, 2012; Egizio et al., 2008; Obradović et al., 2010; 2011). In order to shed light on some of the issues arising in such RSA studies, the current investigation used psychophysiological data collected from a low-income, ethnically diverse sample during social stress tasks in a laboratory setting, and examined RSA dynamics across time from a Dynamic Systems Theory (DST) perspective to 1) test the associations between dynamic RSA changes and parenting factors, adolescent emotion regulation and adjustment during an angry event discussion task; 2) test whether parent negative and positive emotions influence adolescent RSA dynamically during a parent-adolescent conflict resolution task; and 3) explore the possible moderating effects of adolescent sex and age in the aforementioned associations.

RSA and Empirical Studies of RSA

Berntson, Cacioppo, and Quigley (1993) defined RSA as "a rhythmical fluctuation in heart periods at the respiratory frequency that is characterized by a shortening and lengthening of heart periods in a phase relationship with inspiration and expiration, respectively" (p. 183). RSA reflects the fluctuations in heart periods and changes in heart rate (HR), known as heart rate variability (HRV). HRV at high respiratory frequency band (about 0.12-0.4 Hz for adults in resting state) is primarily the function of the myelinated vagal influence. Therefore, RSA is also called high frequency HRV (HF-HRV), and the quantity of RSA amplitude is considered a sensitive index of the influence of the myelinated vagus on the heart (Porges, 1995b). It has been theorized that RSA indicates an individual's physiological regulation of inner resources in response to challenges (Porges, 2007). Despite evidence linking RSA to psychological and behavioral problems and RSA being an indicator of regulation, talking and dramatic physical movements, which alter respiration, may seriously confound RSA measurement (Butler et al., 2006).

Tonic parasympathetic control of HR is called vagal tone or baseline RSA (Diamond, Fagundes, & Butterworth, 2012; Porges, 1995a), which is usually assessed when an individual is at rest with paced breathing, or sometimes when the individual is shown a calming film (e.g., a film showing dolphins swimming, Fabes & Eisenberg, 1997). It is posited that RSA baseline reflects individuals' ability to focus attention, engage in social communication, and maintain homeostasis under normal circumstance (El-Sheikh et al., 2009; Porges, 2007). Baseline RSA may also denote physiological potential for emotion regulation capacity, or a trait-like level of arousability (Beauchaine, 2001; Hastings, et al., 2008). Empirically, higher baseline RSA has been linked to higher effortful control scores and fewer aggressive behaviors among adolescents (Chapman, Woltering, Lamm, & Lewis, 2010). Studies find that individuals with higher anger and rumination tendencies have lower resting RSA (as HF-HRV) compared to individuals with better coping styles (Vögele, Sorg, Studtmann, & Weber, 2010). Similarly, parasuicidal adolescent girls showed lower baseline RSA compared to control group girls (Crowell et al., 2005), and aggressive adolescents with conduct problems, and adolescents with both conduct disorder and ADHD problems, showed lower baseline RSA than control groups (Beauchaine, Hong, & Marsh, 2008; Beauchaine, Katkin, Strassberg, & Snarr, 2001). A longitudinal study also found higher initial baseline RSA predicted significant declines in externalizing symptoms whereas lower initial baseline RSA predicted significant increases in externalizing symptoms among boys (El-Sheikh & Hinnant, 2011). However, other studies of baseline RSA have not found significant correlates of vagal tone or baseline RSA with adjustment indices (e.g., Diamond, Fagundes, & Butterworth, 2012; Egizio et al., 2008; El-Sheikh et al., 2009; Hinnant & El-Sheikh, 2009), so findings are somewhat mixed.

Vagal reactivity to challenge reflects changes in vagal control from baseline to challenging conditions and can be characterized as vagal augmentation (increases in vagal influence over heart) or vagal withdrawal (decreases in vagal influence over heart) (El-Sheikh et al., 2009). RSA reactivity (changes in RSA levels) is often used to indicate vagal reactivity under a challenging condition. RSA suppression (decrease in RSA) indicates vagal withdrawal, which generates increase in HR. RSA augmentation (increase in RSA) indicates vagal augmentation, which slows the HR and inhibits sympathetic nervous system (SNS) input (e.g., El-Sheikh et al., 2009; Obradović & Boyce, 2012) and implies increasing parasympathetic activation and more active regulation. RSA augmentation facilitates the maintenance of an internal equilibrium and social engagement, and RSA suppression signifies the readiness to respond to internal or external threat or challenge (Brooker & Buss, 2010; Porges, 2007). Studies have found that participants with greater RSA suppression during experimental challenges showed fewer behavioral problems, higher peer status, higher sociability, higher levels of social skills, and less need of parents to down regulate their children's emotion (e.g., Doussard-Roosevelt, Montgomery, & Porges, 2003; Gentzler, Santucci, Kovacs, & Fox, 2009; Gottman & Katz, 2002). However, other studies have found either no relation between RSA reactivity and emotion and behavior problems (e.g., Eisenberg et al., 2012; Quas et al., 2000) or contradictory results. For example, greater RSA suppression in response to challenges has been associated with poorer memory (e.g., Quas, Alkon, Goldstein, & Boyce, 2006), emotion lability, and panic attacks (e.g., Asmundson & Stein, 1994), whereas less RSA suppression was associated with better social functioning (Egizio et al., 2008). Additionally, higher RSA augmentation in response to social challenge has been associated with fewer internalizing and externalizing problems, and better behavior self-regulation among young children (Hastings et al., 2008).

In RSA studies, diverse lab stressors have been used, and different stressors in experimental tasks might evoke different levels of social and attentional vigilance or alter affective states differentially, which may have caused inconsistent findings in RSA studies (Egizio et al., 2008). Indeed, RSA suppression and augmentation may represent different processes in response to different lab stressors and can both be adaptive or maladaptive depending on the situation. As Obradović et al. (2011) suggested, the context of psychophysiological measurement is very important, and may determine the process of vagal activity and adaptivity of vagal withdrawal and augmentation. Although characteristics of stressors and stress types are critical in psychophysiological studies, they have been widely ignored (Dickerson & Kemeny, 2004). For example, Fabes and Eisenberg (1997) found that baseline RSA (called vagal tone in the study) was associated with negative emotional arousal and constructive coping only under conditions of moderate and high stressors; yet these conditions have been ignored in most RSA studies. Nugent et al. (2011) found that females with major depressive disorder showed attenuated parasympathetic withdrawal compared to healthy females *only* in response to mild physical stress. Thus, research may be problematic if it is assumed that psychophysiological markers can distinguish participants across all kinds of stimulus conditions (Beauchaine, 2012). In traditional RSA reactivity studies, for example, participants have been passively exposed to lab stressors such as physical (e.g., receiving special stimuli such as lemonade on the tongue), cognitive (e.g., tracing stars), or emotional (e.g., watching film clips) challenges. However, in "real life", most of the everyday stress that makes children and adolescents vulnerable to adjustment problems is *social* stress. Thus, in the current study, I used an angry event discussion task and a parent-adolescent conflict resolution task in which participants played an active role in choosing the topic and leading the discussion.

Another problem in traditional RSA studies involves the confounding of both parasympathetic and sympathetic activation during tasks. This is a problem because RSA reactivity has been found to be unstable across different stressors (e.g., Bornstein & Suess, 2000; El-Sheikh, 2005a; 2005b), is even unstable across time to the same stressors (e.g., Doussard-Roosevelt et al., 2003), and is not always in concordance with reactivity in other physiological systems (e.g., Bauer, Quas, & Boyce, 2002; Cacioppo, Uchino, & Berntson, 1994). In these studies, it is usually difficult to know the exact meaning of observed parasympathetic or sympathetic activation in response to a stressor. One way to solve this problem is to examine the processes in real time for specific tasks.

The Timing Issue and Study of the Processes

Traditional RSA studies are variable-based and typically tap only inter-individual differences. Studies of RSA and emotion rarely disentangled emotional reactivity from regulation, and various processes confound these underlying vagal activities. The stress-sensitive physiological systems such as the autonomic nervous system (ANS) are either acutely or chronically changing over time in accordance with changing internal and external contexts, which is called "allostasis" (Adam, 2012). These issues pose difficult questions about ANS functioning for researchers, such as: 1) What indexes of parasympathetic and sympathetic functioning are meaningful? 2) How should the intra-individual temporal changes of these indexes be studied? and 3) How should these changes during social interaction be interpreted?

Fortunately, in the last two decades, Dynamic Systems Theory (DST) has become prevalent in developmental psychology and has been applied to the study of a wide range of developmental phenomena (e.g., Hollenstein, 2011). Spencer, Perone, and Buss (2011) concluded that Dynamic Systems Theory (DST) has been extremely successful and perhaps even "revolutionary." DST emphasizes step-by-step processes, including second-to-second unfolding of behavior and longer time scale of development, and multilevel interactions of components in the system (Spencer, Perone, & Buss, 2011). DST has not only inspired new approaches or perspectives in studying various old or new phenomena, but also has spurred the development of new statistical methods and tools. Unlike traditional cross-sectional and longitudinal designs, time series research designs allow researchers to trace change over time within the same system and see the process of developmental change (Fogel, 2011). Recent advances in methodologies and statistical tools such as hierarchical growth modeling and multilevel modeling allow researchers to examine developmental trajectories in time series designs (Fogel, 2011). Dynamic systems methodologies emphasize smaller sample size and intensive observational studies that yield both group data and unique individual trajectory data (Witherington & Margett, 2011).

In the field of emotion, it is widely accepted that emotion and emotion regulation are rapid processes dependent on contextual demand, with each individual displaying fluctuations and flexibilities in emotion responses to unique situational contexts (Camras

& Witherton, 2005); these contexts also reflect distinct individual developmental histories (Fogel et al., 1992). Developmentally, researchers have used Multi-level Modeling (MLM) to model three-year changes in RSA reactivity at the transition to adolescence and found that the slopes in RSA reactivity across three years were associated with children's sadness regulation abilities. That is, as their RSA change scores from baseline in response to emotional challenge increased across the three years, they experienced fewer difficulties with emotion regulation (Vasilev, Crowell, Beauchaine, Mead, & Gatzke-Kopp, 2009). Brooker and Buss (2010) argued that both RSA and emotion are active responses and that the traditional methods of quantifying RSA changes (a difference score between task and baseline RSA values) are not sensitive enough to capture the temporal features of the processes. They further suggested that fluctuations in RSA should correspond to some degree with moment-to-moment changes in emotional expressions and behavior (Brooker & Buss, 2010). Brooker and Buss modeled dynamic fluctuations in RSA within individuals during a single emotion episode using growth curve models. Specifically, both linear and quadratic changes in RSA were estimated for each toddler during a two-and-a-half minute "stranger task". A two-level modeling method was used to see whether the linear and quadratic changes in RSA differed among high fear and non-high fear toddlers. They found that high fear toddlers showed greater linear increases and more negative quadratic change (an increase first and then a decrease in RSA) during the task than non-high fear children. The two groups did not differ on simple changes in RSA during the task from baseline. Moreover, they examined whether the linear and quadratic changes predicted emotion behaviors and found that, for high fear toddlers, more increases then decreases in RSA were related to more positive affect during the episode.

Some studies have examined RSA processes by specific experimental design, separating specific components of a task (e.g., having a baseline task, a stressful public speech preparation and speech task, and a recovery period, Gunnar, Frenn, Wewerka, & van Ryzin, 2009; or breaking up watching a 3-min film clip into 30 second epochs; Crowell et al., 2005). Vögele et al. (2010) adapted the Ultimatum Game (UG- two players are provided with money, the proposer makes an offer to split the money, and the responder may accept or reject) to provoke unfairness and anger among a group of adolescents. They then examined four different phases: baseline before UG, provocation during UG, contemplation during UG, and recovery after UG. They found that the pattern of vagal augmentation (indexed by HR, blood pressure and HF-HRV) in response to UG anger provocation and vagal withdrawal during UG contemplation was observed among anger ruminators, while the pattern of little change in vagal activity in response to UG anger provocation but vagal augmentation during the UG contemplation and recovery phases was observed among cognitive reappraisers. Theoretically, differentiating emotional reactivity from regulation and modeling the RSA changes during these processes corresponds to the fact that emotion response and regulation are dynamic processes. By taking this approach, researchers are able to discern whether RSA suppression or augmentation is more adaptive. Methodologically, the Hierarchical Linear and Nonlinear Modeling (HLM) statistical package is a promising tool to monitor the dynamic changes in RSA. This approach has the potential to greatly contribute to RSA studies and is thus used in the current investigation.

Contextual Effects on Vagal Functioning

One of the mechanisms by which contextual factors could contribute to children's and adolescents' adjustment is through influences on their emotion regulation (Morris et al., 2007), including parasympathetic regulation (Hastings et al., 2008). According to Thompson (1994, pp. 27-28), "emotion regulation consists of the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotion reactions, especially their intensive and temporal features, to accomplish one's goals." Physical regulation of emotion is one facet of emotion regulation (Thompson, Lewis, & Calkins, 2008). Early life experiences, such as caregiving experiences, traumatic life events, the parent-child relationship, and family socioeconomic status, are important in shaping biological and psychophysiological systems. Based on the early life stress model (Loman, Gunnar, & The Early Experience, Stress, and Neurobehavioral Development Center, 2010), adverse early life experiences such as poor caregiving impact the development of the stress- and threat-response systems, which impact the development of central regulatory systems, resulting in higher risk for attention and emotion regulation problems. However, neurosystems are plastic: if the child's environment improves, the stress- and threat-response systems are able to re-organize to be more modulated (Loman et al., 2010). It can be inferred that the plasticity of these systems may continue for a prolonged period of time, until adolescence, another critical phase of life.

Normally, children increase in baseline RSA from preschool to middle childhood (Bornstein & Suess, 2000; Quas, Hong, Alkon, & Boyce, 2000; Rigterink & Katz, 2010), show stable increases across the childhood years (Calkins & Keane, 2004; El-Sheikh, 2005a), and maintain stable RSA baseline from late childhood to early adolescence (El-

Sheikh, 2005b). Adverse early life experiences and current contextual factors such as marital discord, domestic violence, negative parenting, and adverse life events, have been found to be related to less gain in baseline RSA by middle childhood (Katz & Rigterink, 2012; Rigterink, Katz, & Hessler, 2010). Adverse contextual factors can also contribute to abnormal RSA reactivity. For example, infants classified as insecure-avoidant showed greater RSA suppression and higher overall sympathetic responses during the Strange Situation Paradigm (Hill-Soderlund et al., 2008) than securely attached infants. In contrast, Burgess, Marshall, Rubin, and Fox (2003) found that avoidant attachment in infancy predicted under-arousal during an attentional task (indexed by lower HR and high levels of RSA) at 4 years of age. Preschool children with high levels of PTSD symptoms who were exposed to low levels of parent positive discipline showed RSA withdrawal during trauma memory recall epochs (Scheeringa, Zeanah, Myers, & Putnam, 2004). One study also found that smaller RSA increases from lab baseline in a socially challenging context were related to higher levels of observed maternal critical/negative parenting (Hastings et al., 2008).

Taken together, the above studies indicate that parenting impacts RSA reactivity, and negative, inconsistent parenting appears to impede adaptive sympathetic and parasympathetic responses. Nevertheless, there are few empirical studies focusing on how current contextual factors impact RSA, specifically RSA reactivity to challenges among adolescents. Using a dynamic systems approach, parent affect has been found to be related to adolescent affect during parent-adolescent interaction (Hollenstein, 2007; Hollenstein & Lewis, 2006). Researchers have also observed interdependence in heart rate and respiration signals between partner dyads (Ferrer & Helm, 2012; Helm, Sbarra,

& Ferrer, 2012). Using a dynamic systems approach, the current investigation aims to investigate how parent affect displayed during conflict resolution influences adolescent real time vagal reactivity.

Within the family context, specific parenting factors have been posited to affect adolescent behavioral emotion regulation (Morris et al., 2007). Parental psychological control, the use of psychological and emotional manipulation to change children and adolescents' behavior and feelings, has been found to be related to adolescent emotion regulation problems (McEwen & Flouri, 2009; Morris et al., 2002). It has been hypothesized that psychologically controlling parents create a coercive, unpredictable, and/or negative emotional climate of the family, which may hinder adolescents' development of effective emotion regulation skills (Morris et al., 2007; Steinberg, 2005). On the contrary, parental warmth and acceptance have been found to be related to effective emotion regulation strategies (Eisenberg et al., 2001; 2005; Ramsden & Hubbard, 2002). However, there are no empirical studies examining the relations between parental psychological control or parental acceptance and adolescents' physiological regulation of emotion. The current investigation aims to explore the associations between parental psychological control, parental acceptance, and adolescent RSA baseline and reactivity during an anger event discussion.

The Current Investigation

In summary, the next generation of the study of physiology and emotion regulation should 1) account for respiration parameters (Obradović et al., 2010); 2) consider the physiological measurement in an interpersonal challenging context (Obradović et al., 2011); and 3) bear the "timing" issue in mind when considering the affective processes (Dennies et al., 2012). The current investigation will shed light on these issues and aims to 1) test whether baseline RSA and RSA reactivity during an angry event discussion are associated with parental acceptance and psychological control, adolescent anger and sadness regulation, and adolescent prosocial and aggressive behavior and depressive symptoms in both a traditional statistical way, and using a dynamic systems approach; and 2) explore whether parents' negative and positive emotions during conflict resolution influence adolescent RSA levels dynamically. The current investigation will also account for respiration rate and power (Berntson et al., 1997; Berntson, Quigley, & Lozano, 2007; Kok & Fredrickson, 2010) because of the potential influence of respiration, which in my study is important because participants were talking during the interaction tasks.

Additionally, research shows that girls are generally more susceptible to depression (Galambos, Leadbeater, & Barker, 2004) while adolescent boys are generally more likely to show aggressive behavior (Card, Stucky, Sawalani, & Little, 2008). Importantly, a recent study among adolescents suggested that the moderating effects of baseline RSA and RSA suppression on the associations between family environments and various outcomes differ between boys and girls (Diamond, Fagundes, & Cribbet, 2012). Therefore, the adolescents' sex was included in all analyses to examine the possible moderating effects in the current investigation. Furthermore, because research indicates that baseline RSA develops from infancy to early adolescence (El-Sheikh, 2005a, 2005b; Rigterink & Katz, 2010) and contextual factors affect the development of RSA baseline and reactivity (Katz & Rigterink, 2012), adolescent age was also included in analyses.

This allows for examination of the possible moderating effects of age, which is particularly important given the wide range of age in the current sample.

Methodology

Participants

The sample consisted of 206 families with adolescents who participated in the Family and Youth Development Project (FYDP). The purpose of the FYDP was to examine predictors and outcomes of adolescent emotion regulation. Data were collected from both adolescents (*M* age = 13.37 years, *SD* = 2.32, Age Range = 10-18 years; 51% female; 29.6% European American, 32% African American, 19.4% Latino American, 19% other ethnic groups) and their primary caregivers (83.3% biological mothers, 10.7% biological fathers, 2% grandparents, 4% other caregiver). The sample was predominantly comprised of low-income (*Median* annual income = $40,000, 47.5% of families were receiving welfare or public assistance) families with an average of 4.35 people living in each home and 38.7% headed by single parents.

Procedure

Participants were recruited from disadvantaged communities through fliers and convenience and snowball sampling methods. Participants were asked to come to a university lab to participate in the study. Following the IRB approved procedures, the purpose and procedure of the study were explained to adolescents and their primary caregivers before they signed assent and consent forms, respectively. Next, they were taken to separate rooms where a packet of questionnaires was provided. Research assistants read questions while participants filled in the questionnaires on their own.

Parents were taken to the adolescents' room after both finished their questionnaires and completed some interaction tasks.

The adolescents were hooked up to Biopac MP150 (Biopac Systems, Santa Barbara, CA) cardiovascular and respiratory modules (ECG100C and RSP100C). Adolescents were then showed a 90-second documentary film clip about dolphins while ECG and respiration signals were recorded to get the baseline RSA (the last 60 seconds were used). Next, parents and adolescents were brought together for a six-minute parent-adolescent conflict resolution task. Specifically, parents and adolescents were asked to talk about disagreements or conflicts they have in daily life, and come up with solutions to the conflicts. The parent and the adolescent had identified and rated the frequency of the disagreements or conflict in the questionnaires they filled in prior to the discussion task. Five disagreements or conflicts rated high in frequency by both parent and adolescent were picked by researchers for the dyad to discuss (e.g., attitudes/respect, chores at home, fighting with brothers/sisters, keeping room clean, making too much noise at home).

The second observational task was an emotion conversation task where parents and adolescents talked about an angry, sad and happy emotional event (3 minutes for each emotion). Specifically, the adolescents were asked to talk about a time during the last year when they got angry/mad, sad/disappointed, and happy, while they were away from home and their parents were not around. Adolescents were asked to describe where they were, whom they were with, what they were doing, why they got angry/sad/happy, and what they did about it. The dyad talked about each emotional event separately, with specific instructions between each task designating which emotion to discuss. ECG and respiration signals were recorded during both the conflict resolution task and the emotion discussion task, and RSA was calculated minute-to-minute. In the current investigation, only the angry event discussion task data were used. The laboratory assessment lasted 2 hours on average. The parent and adolescent each received $60 compensation for their time spent in the lab and were debriefed after the research session was completed.

Measures

Parental acceptance. Adolescents reported on parental acceptance via the Child Report of Parent Behavior Inventory (CRPBI, Barber & Olsen, 1997; Schaeffer, 1965), which is a 10-item Likert-type scale and includes items such as "My mother/father is a person who makes me feel better talking over my worries with her/him," "…smiles at me very often" and "…makes me feel like the most important person in her/his life." Adolescents responded to this measure on a scale ranging from 1 (*not like her/him*) to 3 (*a lot like her/him*). Cronbach's α was .92 in the current sample.

Parental psychological control. Adolescents reported on parental psychological control via the Psychological Control Scale-Youth Self-Report (PCS-YSR, Barber, 1996), which includes 8 items such as "My mother/father is a person who is always trying to change how I feel or think about things," "…blames me for other family members' problems," and "…will avoid looking at me when I have disappointed her/him." The scale ranges from 1 (*not like her/him*) to 3 (*a lot like her/him*). This scale has demonstrated adequate reliability and validity in previous studies (see Barber et al., 2005; Bean & Northrup, 2009), and Cronbach's α was .78 in the current sample. The mean of all items was calculated and higher scores indicate more parental psychological control.

Adolescent emotion regulation. Both adolescents and parents reported on adolescents' abilities to regulate their emotions using the Children's Emotion Management Scale: Sadness and Anger scales (CSMS, Zeman, Shipman, & Penza-Clyve, 2001; CAMS, Zeman, Shipman, & Suveg, 2002). The sadness and anger coping scales were used in this study as indicators of adolescent emotion regulation. The sadness subscale included 5 items such as "When I am feeling sad, I control my crying and carrying on" and "I stay calm and don't let sad things get to me." One item ("When I am sad, I do something totally different until I calm down") was discarded to improve reliability (Cronbach's α was .61 for adolescent report, and .60 for parent report). The anger subscale included 4 items such as, "When I am feeling mad, I control my temper" and "I can stop myself from losing my temper" (Cronbach's α was .74 for adolescent report, .79 for parent report). The wording of these items was modified for parents' report on their adolescents. The scale ranged from 0 (*Not true*) to 2 (*Very true*). The parent and adolescent reports were averaged to obtain composite scores of anger ($r = .36$, $p < .001$, across parent and adolescent reports) and sadness regulation ($r = .25$, $p < .001$, across parent and adolescent reports) in the current investigation.

RSA, respiration rate and power. Adolescent electrocardiogram (ECG) and respiration pneumogram were recorded using Biopac MP150 system. ECG and respiration data were imported to MindWare HRV 3.0.9 to calculate RSA values and respiration rate and power. RSA values, respiration rate and power were calculated minute by minute during the neutral film baseline task, the 6-minute conflict resolution task, and the 3-minute anger conversation task. In the MindWare HRV 3.0.9 program, ECG artifacts were edited to get reliable measure of RSA. RSA values that were out of the high respiratory band, that is 0.12-0.40 Hz, were discarded and not used in further analyses.

Observed parent affect. Parents' anger, internalized distress (primarily sadness and anxiety), and positive affect were coded based on parents' facial expression, voice, and body language during the 6-minute conflict resolution task. Affect was coded every 15-second epoch based on a 5-point scale ranging from "1 (*no sign of the emotion*)" to "5 (*exceptionally strong display of emotion*)" using the Affect Coding Manual (adapted from Morris et al., 2011). About 22% of the videos were double-coded and the inter-coder reliabilities were high: intraclass correlations (ρ) were .82 for positive affect, .81 for anger, and .86 for internal distress. To allow matching with RSA and respiration data, parent affect of every four 15-second epochs were averaged to achieve a composite score for every minute of the task.

Adolescent prosocial behavior. Both parents and adolescents reported on adolescents' prosocial behavior during the past year based on a 3-point scale (0 = *Not true*, 1 = *Sometimes*, 2 = *True*). This measure (from the Strengths and Difficulties Questionnaires, SDQ, Goodman & Scott, 1999) included 5 items such as "I try to be nice to other people, I care about their feelings" and "I usually share with others." Cronbach's α was .81 for adolescent-report and .70 for parent-report. Adolescent and parent ratings ($r = .25$, $p < .001$) were averaged to obtain a composite score of adolescent prosocial behavior.

Adolescent depressive symptoms. Adolescents reported on their own depressive symptoms during the last two weeks using the Child Mood & Feelings Questionnaire (MFQ-C, Angold & Costello, 1987) using a 3-point scale (0 = *Not true*, 1 = *Sometimes*, 2

= *True*). This measure includes 33 items such as, “I felt miserable or unhappy,” “I was less hungry than usual,” and “I thought there was nothing for me in the future.” Cronbach’s α was .93 in the current investigation and item scores were averaged for a composite score.

Adolescent aggressive behavior. The Problem Behavior Frequency Scale (Farrell, Danish, & Howard, 1992; Farrell, Kung, White, & Valois, 2000) was administered in the current project, while the 14 items of adolescent aggressive behavior was used in the current investigation which assessed the frequency of physical, relational, and verbal aggression since aggressive behavior is the focus of the current investigation and the 14 items yielded high internal consistency as the full measure. Sample items include “Get in a fight in which someone was hit,” “Spread a rumor,” and “Insult someone’s family.” Both parents and adolescents were asked to indicate how frequently the adolescents engaged in each behavior during the past year using the following scale: 1 = *Never*, 2 = *1-2 times*, 3 = *3-4 times*, 4 = *5-6 times*, 5 = *7 or more times*. Cronbach’s α in the current investigation was .88 for adolescent report and .90 for parent report. The adolescent and parent ratings (r = .38, p < .001) were averaged to obtain a composite score of adolescent aggressive behavior.

Results

Research Question 1

The first research question of the current investigation was: Are the baseline RSA and RSA reactivity during parent-adolescent angry event discussion associated with parental acceptance and psychological control, adolescent anger and sadness regulation, prosocial and aggressive behavior, and depressive symptoms? To answer this research question, bivariate correlations were computed between RSA, respiration rate and power, and parental acceptance, parental psychological control, adolescent sadness and anger regulation, prosocial and aggressive behavior, and depressive symptoms. Second, three specific hypotheses were investigated using: 1) the traditional way of focusing on the overall RSA changes from baseline to the angry event discussion; 2) dynamic linear and quadratic RSA changes across the challenging task; and 3) person-centered latent profiles of the dynamic linear and quadratic RSA changes across the angry event discussion. HLM was used to test the first two hypotheses in HLM 7, while Growth Mixture Modeling (GMM) was used to test the third hypothesis in Mplus 7.

Bivariate correlations between major variables. The zero-order bivariate correlations showed that during the baseline and the second minute of the anger task, higher respiration rate was significantly associated with lower RSA levels, and neither respiration parameters nor RSA were significantly related to adolescent sex and age (Tables 1). RSA levels were highly correlated with each other across baseline and the 3-minute anger task, but not significantly associated with parenting variables, adolescent emotion regulation, and adjustment. Parental acceptance and psychological control were significantly associated with adolescent emotion regulation, with the exception of the relation between psychological control and adolescent sadness regulation. Adolescent higher emotion regulation abilities were positively associated with prosocial behavior, and negatively associated with aggressive behavior and depressive symptoms. Finally, girls had higher levels of prosocial behavior and lower aggressive behavior than boys and older adolescents had lower levels of parental acceptance and higher levels of parental psychological control and depressive symptoms than younger adolescents (Table 2).

Hypothesis 1: It was expected that higher baseline RSA and greater RSA suppression (from baseline to anger task) would be associated with higher parental acceptance, lower parental psychological control, better emotion regulation ability, more prosocial behavior, less aggressive behavior, and fewer depressive symptoms. Following the traditional way of analyzing RSA data, the focus was on the baseline RSA and RSA reactivity from baseline to the anger task, which is the overall RSA change during the 3-minute task from the baseline.

The following model was tested in HLM 7. At level 1, adolescent respiration rate and respiration power were controlled for minute-to-minute. Adolescent RSA levels during the 3-minute anger task were contrasted with RSA baseline by incorporating a dummy code RSAC (RSA baseline was coded as 0 and RSA levels during the 3 minutes were coded as 1s). At level 2, parental acceptance, and psychological control, adolescent anger and sadness regulation, and adolescent prosocial behavior, aggressive behavior, and depressive symptom scores were entered separately to predict RSA baseline and RSAC (i.e., changes from baseline to the anger task).

Model:

Level 1: $RSA_{it} = b_0 + b_1 RR_t + b_2 RP_t + b_3 RSAC + \varepsilon_t$

Level 2: $b_0 = \gamma_{00} + \gamma_{01}\text{ Predictor} + \gamma_{02}\text{Sex} + \gamma_{03}\text{Age} + \upsilon_0$

$b_1 = \gamma_{10} + \gamma_{11}\text{ Predictor} + \gamma_{12}\text{Sex} + \gamma_{13}\text{Age}$

$b_2 = \gamma_{20} + \gamma_{21}\text{ Predictor} + \gamma_{22}\text{Sex} + \gamma_{23}\text{Age}$

$b_3 = \gamma_{30} + \gamma_{31}\text{ Predictor} + \gamma_{32}\text{Sex} + \gamma_{33}\text{Age} + \upsilon_1$

Notes. RR_t = Concurrent respiration rate, group-mean centered at level 1; RP_t = Concurrent respiration power, group-mean centered at level 1; RSAC = RSA change dummy code, RSA baseline was coded as 0 and RSA levels during the 3 minutes were coded as 1s; Sex was codes as 0 (girls) and 1 (boys); Predictors: parental acceptance, psychological control, two emotion regulation variables (viz., sadness and anger regulation), prosocial behavior, aggressive behavior, depressive symptoms. All predictors and adolescent age were grand-mean centered at level 2.

First, the model was estimated without predictors at the second level but controlled for respiration rate and power at level 1, and adolescent sex and age at level 2. The results suggested that there was a significant decrease in adolescent RSA from baseline to the anger task, $b_3 = -0.51$, $p = .004$, indicating RSA suppression from baseline to the challenging task. Next, all nine predictors were entered one at a time into the second level of the model to predict both the baseline RSA and RSA reactivity to the anger task from baseline. The results showed that higher baseline RSA was marginally associated with more prosocial behavior, $\gamma_{01} = 0.76$, $p = .07$. Higher anger regulation predicted significantly greater RSA suppression from baseline to the anger task, $\gamma_{31} = -0.58$, $p = .04$, and marginally higher baseline RSA, $\gamma_{01} = 0.49$, $p = .08$.

Hypothesis 2: It was hypothesized that higher negative linear and higher positive quadratic RSA dynamic change slopes during the anger task would be related to higher parental acceptance, lower parental psychological control, better emotion regulation abilities, more prosocial behavior, less aggressive behavior and more depressive symptoms. During the anger task, adolescents were expected (a) to be emotionally aroused with anger (due to retrieving the angry memories in the first minute); and (b) to regulate the corresponding emotions in the second and third minutes (due to having the parent's help in dealing with the emotional experience while discussing the event).

Therefore, the minute-to-minute changes in RSA were expected to correspond to dynamic processes of adolescent emotion response (RSA reactivity) and regulation (RSA recovery).

Generally, it is expected that overall adolescents would show RSA suppression first, and RSA recovery later in the task (e.g., Brooker & Buss, 2010; Vögele et al., 2010). By modeling the dynamic changes in RSA, a negative linear change and a positive quadratic change in RSA were expected to observe among adolescents. Higher RSA decrease followed by higher RSA increase would be related to adolescent better anger and sadness regulation, and more prosocial behavior, and lower parental psychological control, less aggressive behavior and fewer depressive symptoms.

The following model was tested in HLM 7. At level 1, a linear and a quadratic term were entered to model adolescent dynamic RSA changes. At level 2, parental acceptance, psychological control, adolescent anger and sadness regulation, aggressive behavior, and depressive symptoms were entered separately to predict the coefficients of linear and quadratic RSA change slopes. RR_t and RP_t were group-mean centered at level 1, while all predictors and adolescent age were grand-mean centered at level 2.

Model:

Level 1: $RSA_{it} = b_0 + b_1 RR_t + b_2 RP_t + b_3 Time_t + b_4 Time_t^2 + \varepsilon_t$

Level 2: $b_0 = \gamma_{00} + \gamma_{01}$ Predictor $+ \gamma_{02}$ Sex $+ \gamma_{03}$Age $+ \upsilon_0$

$b_1 = \gamma_{10} + \gamma_{11}$ Predictor $+ \gamma_{12}$ Sex $+ \gamma_{13}$Age

$b_2 = \gamma_{20} + \gamma_{21}$ Predictor $+ \gamma_{22}$ Sex $+ \gamma_{23}$Age

$b_3 = \gamma_{30} + \gamma_{31}$ Predictor $+ \gamma_{32}$ Sex $+ \gamma_{33}$Age $+ \upsilon_1$

$b_4 = \gamma_{40} + \gamma_{41}$ Predictor $+ \gamma_{42}$ Sex $+ \gamma_{43}$Age $+ \upsilon_2$

Notes: RR_t = Concurrent respiration rate, group-mean centered at level 1; RP_t = Concurrent respiration power, group-mean centered at level 1; Predictors: parental acceptance, psychological control, two emotion regulation variables (i.e., sadness and anger regulation), prosocial behavior, aggressive behavior, and depressive symptoms. All predictors and adolescent age were grand-mean centered at level 2.

First, we estimated the model without predictors at the second level but controlled for respiration rate and power at level 1, and adolescent sex and age at level 2. The results suggested that overall there was a significant decrease in adolescent RSA from baseline to the beginning of the anger event, $b_3 = -0.56$, $p = .004$, and a significant increase in adolescent RSA by the end of the task, $b_4 = 0.14$, $p = .008$, indicating RSA suppression from baseline to the anger task, and RSA recovery by the end of the task. Next, all nine predicting variables were entered one by one into the second level of the model to predict the baseline RSA and RSA linear and quadratic change slopes during the anger task. The results showed that higher adolescent sadness regulation was associated with higher decreases in RSA from baseline to the beginning of the anger task, $\gamma_{31} = -0.71$, $p = .05$, and higher increases in RSA to the end of the task, $\gamma_{41} = 0.20$, $p = .04$. Higher adolescent anger regulation was associated with marginally higher baseline RSA, $\gamma_{01} = 0.44$, $p = .097$; higher anger regulation was associated with higher decreases in RSA from baseline to the beginning of the anger task, $\gamma_{31} = -0.67$, $p = .02$, and higher increases to the end of the task, $\gamma_{41} = 0.18$, $p = .02$. Higher adolescent prosocial behavior was associated with higher adolescent RSA baseline, $\gamma_{01} = .76$, $p = .048$, higher decreases in RSA from baseline to the beginning of the anger event discussion, $\gamma_{31} = -1.01$, $p = .02$, and higher increases in RSA by the end of the task, $\gamma_{41} = 0.32$, $p = .008$. Taken together, these results suggest that a pattern of initial RSA suppression and later RSA recovery was associated with better sadness and anger regulation, and more prosocial behavior. Further, higher RSA baseline was associated with better anger regulation and more prosocial behavior. These results were consistent with the second hypothesis.

Hypothesis 3. It was expected that different RSA change patterns from baseline to the anger task would be associated with different levels of parental acceptance, psychological control, adolescent anger and sadness regulation, prosocial behavior, aggressive behavior and depressive symptoms. The aim of this test was to explore the RSA change patterns/profiles from baseline task to the anger task, and to explore how different levels of parenting variables, adolescent emotion regulation, and adjustment were associated with different RSA change profiles. Adolescents who are good at emotion regulation were expected to show initial RSA suppression and then RSA recovery (pattern B in Figure 1). Others adolescents were expected to show stable RSA across the task (pattern A in Figure 1), or show RSA suppression and never recover to baseline during the task (pattern C in Figure 1), and they may have emotion regulation problems.

First, the residualized scores of adolescent baseline RSA and RSA levels during the three-minute anger task were calculated by partialling out the variances of concurrent respiration rate and power. Next, growth mixture modeling was used in Mplus 7 to determine different patterns of RSA change patterns based on the four residualized RSA scores (Figure 2). The intercept and linear and quadratic slopes were specified in the growth model. The class membership was based on the intercept and linear and quadratic slopes of the growth model. The 1-step joint latent class model with auxiliary variables (i.e., adolescent sadness and anger regulation composite scores, Figure 2) was tested to determine the number of classes (Asparouhov & Muthén, 2013; Lanza, Tan, & Bray, 2013). Models with $k = 1$, 2, and 3 classes were tested and compared (Table 3) based on log-likelihood, BIC, AIC, entropy, and the p-value comparing the current model with the k-1 class model. The model with 2 classes had lower log-likelihood, BIC, and AIC, good entropy, and was significantly better than the 1-class model. The model with 3 classes was not significantly better than the model with 2 classes (the log-likelihood and AIC did not change much, and BIC increased). Thus, the model with 2 classes seemed to fit the data best and was chosen to be the final model. The results showed that 41.3% of adolescents ($N = 85$) belonged to class 1 and 58.7% of adolescents ($N = 121$) belonged to class 2. Adolescents from class 2 had slightly above-average baseline RSA, decreased RSA levels during the first and second minute of the anger task (RSA suppression), and increased RSA levels by the end of the anger task (RSA recovery), while adolescents from class 1 showed the opposite pattern (see Figure 3), although the baseline RSA and linear and quadratic slopes were not significantly different from zero. These results suggest that there were two distinguishable and meaningful RSA change trajectory patterns in response to interpersonal challenge among adolescents in the current sample.

Next, independent samples t-tests were conducted in SPSS 20 to test the mean differences on parental acceptance and psychological control, adolescent anger and sadness regulation, prosocial and aggressive behavior, and depressive symptoms between the two different classes. The results showed that adolescents in class 2 were significantly higher on sadness and anger regulation, parental acceptance, prosocial behavior, and significantly lower on parental psychological control, depressive symptoms, and aggressive behavior than those in class 1. They did not differ, however, on adolescent sex, age, or baseline RSA (Table 4).

Research Question 2

The second research question of the current investigation was: whether parents' negative and positive emotions influence adolescent RSA levels dynamically during a parent-adolescent conflict resolution task? The objective of this research question was to investigate parent's influences on adolescent's physiological reactivity during the conflict resolution processes. Specifically, I aimed to test the relations between parent minute-to-minute positive and negative affect (i.e., anger and distress) and adolescent minute-to-minute RSA levels.

Hypothesis: It was expected that parents' display of negative affect (anger and distress) would inhibit adolescents' parasympathetic nervous system, while parents' positive affect displayed would facilitate adolescents' physiological emotion regulation. Thus, more parent negative affect during the previous-interval was expected to predict lower RSA levels during the next-interval, while parents' display of positive affect during the previous-interval was expected to predict higher RSA levels during the next-interval, controlling for previous-interval RSA levels and concurrent respiration rate and power. To test this hypothesis, bivariate correlations between RSA, respiration parameters, adolescent sex and age, and parent affect were tested first. Second, HLM was used to investigate whether the previous-interval parent affect (anger, distress, and positive affect) significantly predicted next-interval adolescent RSA levels.

Bivariate correlations among major variables. The zero-order bivariate correlations showed that parents displayed more distress to their adolescent girls than boys during the first minute of the task but not later in the task. Parents showed significantly more positive affect to older adolescents than younger adolescents during each of the last 5 minutes of the 6-minute task (Tables 5-10). During the first three minutes, parent anger, distress and positive affect were not significantly correlated with each other (Tables 5-7). In the fourth minute, parent anger was negatively associated with parent distress (Table 8). In the fifth minute, parent distress was negatively associated with parent positive affect (Table 9). In the sixth minute, parent anger was negatively associated with parent positive affect (Table 10). These results suggested that the coded parent anger, distress, and positive affect (averaged minute by minute) were not always highly correlated. Parent anger and positive affect were significant positively associated with adolescent respiration power while parent distress was significant negatively associated with adolescent respiration power in some minutes (Tables 6, 8, 9, and 10). Parent anger, distress, positive affect, and adolescent RSA levels were relatively stable across the 6 minutes (Tables 11-14). Parent anger and distress were not significantly associated with adolescent RSA levels concurrently or during later minutes (Tables 15, and 16). Parent first-minute positive affect was significant positively associated with adolescent RSA levels in the first, second, fifth and sixth minutes. Finally, parent third minute positive affect was positively associated with adolescent fifth minute RSA and parent fifth minute positive affect was positively associated with current minute adolescent RSA (Table 17).

The associations between parent affect and adolescent RSA. To examine the associations between parent anger, distress, and positive affect and adolescent RSA, HLM 7.0 was used to test the hypothesis in the following model:

Level 1: $RSA_t = b_0 + b_1RR_t + b_2RP_t + b_3PA_{t-1} + b_4RSA_{t-1} + \varepsilon_t$

Level 2: $b_0 = \gamma_{00} + \gamma_{01}PA_{overall} + \gamma_{02}Sex + \gamma_{03}Age + \upsilon_0$

$b_1 = \gamma_{10} + \gamma_{11}Sex + \gamma_{12}Age$

$b_2 = \gamma_{20} + \gamma_{21}Sex + \gamma_{22}Age$

$b_3 = \gamma_{30} + \gamma_{31}PA_{overall} + \gamma_{32}Sex + \gamma_{33}Age$

$b_4 = \gamma_{40} + \gamma_{41}Sex + \gamma_{42}Age$

Note. PA = parent affect (i.e., anger, distress, and positive), group-mean centered at level 1; RR = respiration rate, group-mean centered at level 1; RP = respiration power, group-mean centered at level 1; $PA_{overall}$ = Mean parent affect within individual, grand-mean centered at level 2. Sex was as 0 (female) and 1 (male).

Two-level hierarchical linear modeling was used to test the relation between previous-interval parent affect (PA_{t-1}) and adolescent's next-interval RSA (RSA_t), controlling for the concurrent adolescent respiration parameters, i.e., respiration rate (RR_t) and respiration power (RP_t), and adolescent's previous-interval RSA (RSA_{t-1}). RSA_{t-1}, RR_t, and RP_t, were centered on the group mean since they were more meaningful within individual. PA_{t-1} was centered on the group mean at the first level, and $PA_{overall}$ has been centered on the grand mean and entered at the second level to predict the coefficient of previous-interval parent affect (PA_{t-1}), so that the interaction effects of inter-individual and intra-individual parent affect can be tested. Adolescent sex and age were also entered at the second level to be controlled for in all analyses. Age was grand-mean centered at level 2.

The effects of parent anger, distress, and positive affect were tested in three separate models. The results showed that intra-individual parent previous-interval anger significantly predicted adolescent next-interval RSA level, $\gamma_{30} = -0.30$, $p = .006$; while inter-individual parent anger did not significantly predict the coefficient of intra-individual parent anger, $\gamma_{31} = 0.03$, $p = .86$, indicating that higher levels of previous-interval parent anger (within-parent) were related to lower next-interval adolescent RSA levels, regardless of the overall parent anger levels across the 6 minutes. At the second level, adolescent age significantly predicted the coefficient of previous-interval parent anger, $\gamma_{33} = -0.07$, $p = .03$ (Table 18). A series of hypothesis testing in HLM was conducted to find the age point where parent anger significantly predicted adolescent RSA. The results suggested that the effect of parent anger on adolescent RSA was not significant for adolescents younger than 12.5 years old and it was significant for adolescents who were older than 12.5 years old, $\gamma_{30} = -0.23$, $p = .05$.

Intra-individual parent previous-interval distress did not significantly predict adolescent next-interval RSA, $\gamma_{30} = 0.12$, $p = .44$, neither did inter-individual parent distress in predicting the coefficient of intra-individual parent distress, $\gamma_{31} = 0.07$, $p = .75$, indicating that parent distress levels during the conflict resolution were not associated with adolescent RSA levels (Table 18). However, intra-individual parent previous-interval positive affect significantly predicted adolescent next-interval RSA level, $\gamma_{30} = 0.24$, $p = .003$, while inter-individual parent positive affect did not significantly predict the coefficient of intra-individual parent previous-interval positive affect, $\gamma_{31} = -0.07$, $p = .51$, indicating that higher levels of intra-individual parent positive affect were related to higher next-interval adolescent RSA levels. The overall parent positive affect levels across the 6 minutes significantly predicted the overall intercept of adolescent RSA levels, $\gamma_{01} = 0.37$, $p = .02$, indicating that higher levels of overall parent positive affect also were associated with higher next-interval adolescent RSA levels for both girls and boys. At the second level, adolescent sex marginally predicted the coefficient of previous-interval intra-individual parent positive affect, $\gamma_{32} = -0.\ 22$, $p = .055$ (Table 18). Further testing suggested that the effect of intra-individual parent positive affect was only significant for adolescent girls, $\gamma_{30} = 0.24$, $p = .003$, and not significant for adolescent boys, $\gamma_{30} = 0.02$, $p > .50$.

To further examine the effects of intra-individual parent anger and positive affect, both were entered into the first level of the model (group mean centered), and the overall means of parent anger and positive affect were entered into the second level of the model (grand mean centered):

Level 1: $RSA_t = b_0 + b_1RR_t + b_2RP_t + b_3Anger_{t-1} + b_4Positive_{t-1} + b_5RSA_{t-1} + \varepsilon_t$

Level 2: $b_0 = \gamma_{00} + \gamma_{01}Anger_{overall} + \gamma_{02}Positive_{overall} + \gamma_{03}Sex + \gamma_{04}Age + \upsilon_0$

$b_1 = \gamma_{10} + \gamma_{11}Sex + \gamma_{12}Age$

$b_2 = \gamma_{20} + \gamma_{21}Sex + \gamma_{22}Age$

$b_3 = \gamma_{30} + \gamma_{31}Anger_{overall} + \gamma_{32}Sex + \gamma_{33}Age$

$b_4 = \gamma_{40} + \gamma_{41}Positive_{overall} + \gamma_{42}Sex + \gamma_{43}Age$

$b_5 = \gamma_{50} + \gamma_{51}Sex + \gamma_{52}Age$

Note. Anger = Parent anger, Positive = Parent positive affect, RR = respiration rate, RP = respiration power. $Anger_{overall}$ = Mean parent anger within individual. $Positive_{overall}$ = Mean parent positive affect within individual.

The results showed that that intra-individual parent previous-interval anger significantly predicted adolescent next-interval RSA level, $\gamma_{30} = -0.29$, $p = .006$, while inter-individual parent anger did not significantly predict the coefficient of intra-individual parent previous-internal anger, $\gamma_{31} = 0.07$, $p = .70$; intra-individual parent previous-interval positive affect significantly predicted adolescent next-interval RSA level, $\gamma_{40} = 0.23$, $p = .004$; and inter-individual parent positive affect did not significantly predict the coefficient of the intra-individual parent previous-interval positive affect, $\gamma_{41} = -0.08$, $p = .47$, but it significantly predicted the overall intercept of the next-interval adolescent RSA levels, $\gamma_{02} = 0.38$, $p = .02$. The effect of adolescent age on intra-individual parent anger was significant, $b = -0.07$, $p = .03$, and the effect of adolescent sex on intra-individual parent positive affect was also marginally significant, $b = -0.21$, $p = .07$. The patterns of associations remained the same when parent anger and positive affect were tested separately, suggesting that the effects of parent anger and positive affect on adolescent RSA remained significant even after controlling for each other. Consistent with hypotheses, these results suggest that higher within-parent anger is associated with lower adolescent RSA although only for adolescents at least 12.5 years old, while parent higher within-parent positive affect is associated with higher adolescent RSA levels although only for girls, and parent higher between-parent positive affect is associated with higher adolescent RSA levels for both girls and boys.

Discussion

To shed light on some issues currently being raised among empirical RSA researchers, the current investigation revisited the physiological mechanisms of RSA by adopting a dynamic view of emotion regulation, focusing on dynamic changes in adolescent RSA during interpersonal challenging context and controlling for respiration parameters. Specifically, I aimed to answer two main research questions: 1) Are the baseline RSA and RSA reactivity during a parent-adolescent angry event discussion task associated with parenting, adolescent emotion regulation, and adolescent adjustment? and 2) Do parents' negative and positive emotions influence adolescent RSA levels dynamically during a parent-adolescent conflict resolution task?

Baseline RSA and RSA Reactivity and Parenting, Emotion Regulation, and Adjustment

Three hypotheses were developed in response to the first research question and three analytical approaches were utilized to test each hypothesis. First, the traditional way of focusing on the overall change from baseline to the anger task was followed and I found two marginally significant associations and one significant association. Second, when a dynamic systems approach was adopted to model dynamic changes during task, I found significant RSA suppression during the beginning of the task and RSA recovery by the end of the task. More meaningful associations were found with this approach than were found using the traditional approach. Third, a person-centered approach with growth mixture modeling was used to identify different patterns of adolescent RSA dynamic changes from the baseline to the anger task. Two classes of adolescents were identified and they reported significantly different levels of most of the focus variables in the current investigation.

Taken together, these results suggest that in the context of interpersonal challenge, such as talking about an actual anger event, a pattern of RSA suppression followed by RSA recovery indicates adaptive emotion regulation abilities, and tends to be related to positive parenting and fewer behavior problems. These findings support the notion that RSA suppression in response to challenges indicates a readiness to respond to stress (Brooker & Buss, 2010; Porges, 2007). Findings are also in line with recent empirical studies that found adaptive function of RSA suppression (Doussard-Roosevelt et al., 2003; Gentzler et al., 2009). Past studies that have found negative or null effects of RSA suppression used traditional methods of quantifying RSA change, which is a static measure of RSA (Egizio et al., 2008; Eisenberg et al., 2012; Quas et al., 2000, 2006), and therefore might not capture a real RSA suppression effect. Importantly, the current investigation showed the need to study dynamic RSA changes (Brooker & Buss, 2010; Miller et al., 2013). I found almost no significant results when I followed the traditional methods of using residualized RSA overall change scores in predicting emotion regulation and adjustment, and also did not find that parenting predicted the RSA changes. It was, instead, the dynamic RSA changes (i.e., initial RSA suppression followed RSA recovery) that were predictive of better emotion regulation and more prosocial behavior. This is an emerging approach that more researchers are beginning to utilize (Brooker & Buss, 2010; Gunnar et al., 2009; Miller et al., 2013). My findings were consistent with those of other researchers' who have used a similar dynamic approach. For example, Miller and colleagues' recent study about children's dynamic RSA change found that more initial RSA suppression and subsequent recovery to baseline were related to children's better regulation of aggression as well as to positive parenting styles (Miller et al., 2013). Similarly, Brooker and Buss (2010) observed a pattern of initial increases and then decreases in RSA in response to stress among high-fear toddlers.

This dynamic view of parasympathetic nervous system functioning also aligns with a process view of emotion regulation. Emotion regulation is generally defined as the internal and external processes by which the individual manages the occurrence, intensity, and expression of emotions to reach goals or situational demands (Eisenberg &

Morris, 2002; Thompson, 1994). Cole, Martin, and Dennis (2004) suggest more broadly that emotion regulation is "systematic changes associated with activated emotions" (p. 320). Thus, Cole et al. argue that researchers must examine emotion regulation in the context of emotional arousal, where emotions are activated, for there to be evidence of emotion regulation. Likewise, it can be argued that researchers should examine physiological regulation of emotion in process and in the context of emotional arousal, when RSA suppression corresponds to emotional arousal and RSA recovery indicates emotion regulation. Thus, my study findings indicate that a dynamic approach is a better way of studying physiological regulation of emotion, too.

Furthermore, by using a person-centered approach, I was able to identify adolescents who deviated from the adaptive dynamic RSA change patterns, which was the opposite of the adaptive pattern in the current investigation. I found that these two groups of adolescents were largely different in parenting, adolescent emotion regulation, and adjustment. Positive parenting such as parental acceptance may put adolescents at higher odds of developing adaptive dynamic RSA changes, while negative parenting such as psychological control may place adolescents at higher odds of developing maladaptive patterns (Burgess et al., 2003; Scheeringa et al., 2004). These findings suggest that the parenting context may continue to shape the development of parasympathetic function well into adolescence. As most of the past studies have focused on infants and children, more research investigating this association among adolescents is needed in the future. Second, in response to challenge, there might be various RSA change patterns besides the two patterns identified in my study, for example, RSA suppression without recovery, RSA augmentation without recovery, and stable RSA across the task. Because of the exploratory nature of the current investigation, future studies should use larger samples to identify other possible RSA dynamic changes in response to challenge, and their relations to emotion regulation and adjustment.

Generally, considering the inconsistent and sometimes contradictory findings of empirical RSA studies, it is too complicated to say vagal withdrawal or RSA suppression, or vagal or RSA augmentation, is adaptive, because it is necessary to consider the context of RSA measurement (Obradović et al., 2011). Some researchers argue that the socialization context must be considered in psychophysiological studies (El-Sheikh, 2005a; El-Sheikh et al., 2009; Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010). It is possible that whether baseline RSA is predictive and whether RSA reactivity to stress is adaptive or not depends on the context in which children and adolescents are residing (Obradović et al., 2010), and the context in which RSA is measured (Obradović, 2012). In the context of social challenges, such as a parent-adolescent discussion of an emotion event or a conflict resolution task, individuals are relatively emotionally aroused, resulting in sympathetic activation and parasympathetic inhibition in which RSA suppression can be observed (El-Sheikh et al., 2009; Obradović & Boyce, 2012). The RSA recovery period to the end of the anger event conversation in my study suggests adolescents' regulation efforts in the challenging context. Traditional ways of not distinguishing possible different RSA reactivity patterns might have yielded the inconsistent findings in previous studies. Thus, the context of measurement, which determines emotion regulation processes, should be considered for RSA reactivity to be meaningfully measured and understood. Recent calls for integrative approaches to studying physiology and emotion across multiple biological systems, such as across autonomic nervous systems---such as HPA systems, and central nervous systems; across emotion and cognition; and even across biological systems and environment (El-Sheikh et al., 2009; Hastings, Buss, & Dennis, 2012) ---point out the need to consider the functioning of different systems to understand each individual system better.

In the current study, I also found that adolescent baseline RSA, measured when watching a neutral film clip, was predictive (at trend level) of better anger regulation and positive development (i.e., prosocial behavior). Higher baseline RSA has been thought to indicate emotion regulation potentiality and has been linked to fewer behavior problems such as internalizing and externalizing problems (Beauchaine et al., 2008; Crowell et al., 2005; El-Sheikh & Hinnant, 2011). My findings add to the empirical evidence that higher baseline RSA can be associated with better emotion regulation and positive developmental outcomes. However, the effects of baseline RSA were not strong enough to predict sadness regulation, depressive symptoms, or aggressive behavior in the current investigation, which is consistent with other studies that found null effects of baseline RSA (Diamond et al., 2012; El-Sheikh et al., 2009; Hinnant & El-Sheikh, 2009). It is possible that laboratory baseline measures do not capture the actual baseline RSA of each individual since the laboratory setting is novel and may therefore be stressful to participants, despite the fact that they typically have spent some time in the laboratory before the baseline measure. Another reason for a lack of findings may be because my baseline measure was relatively short (only one minute of data were used). Third, there may be interaction effects between baseline RSA and the environmental contexts in which adolescents were residing. Some empirical studies support the notion that high baseline RSA may buffer the negative effects of adverse contexts. For example, high baseline RSA has been found to protect children from internalizing and externalizing problems associated with marital conflict (El-Sheikh, Harger, & Whitson, 2001), parents' drinking problems (El-Sheikh, 2005a), children's sleeping problems (El-Sheikh, Erath, & Keller, 2007), paternal antisocial personality disorder, and maternal melancholic symptoms (Shannon, Beauchaine, Brenner, Neuhaus, & Gatzke-Kopp, 2007). However, some studies have not found buffering effects or have found buffering effects of only low baseline RSA, contradictory to expectations (Blandon, Calkins, Keane, & O'Brien, 2008; Bosch et al., 2009; Oldehinkel, Verhulst, & Ormel, 2008). For example, Eisenberg et al. (2012) found that higher baseline RSA predicted less aggression among young children only when they had higher levels of environmental quality (i.e., SES and parents' marital adjustment). More research is needed to test possible moderating effects regarding RSA baseline in the future.

Parent Affect and Adolescent RSA

To answer the second research question, a two-level hierarchical model was used to test the intra- and inter-individual effects of parent affect on adolescent RSA. I found that higher intra-individual parent anger predicted lower RSA among adolescents who were older than 12 years of age, higher intra-individual parent positive affect predicted higher RSA among adolescent girls, and higher inter-individual parent positive affect predicted higher RSA for both girls and boys. These results suggest that parents' fluctuations in anger influence their adolescents' vagal functioning. It is possible that parents' anger displayed during the interaction in my study made adolescents emotionally aroused (e.g., Hollenstein, 2007; Hollenstein & Lewis, 2006), which resulted in RSA suppression, particularly among older adolescents. My results also suggest that parent's fluctuations in and overall levels of positive affect influence adolescent's vagal functioning. It is possible that parents' positive affect displayed during the challenging interaction provided a safe environment for adolescents so that they could engage in the social interaction, which resulted in RSA maintenance or even augmentation, particularly among adolescent girls, who may be more sensitive to positive parenting. However, I did not find similar effects of parent distress during the same interaction. It may be that, in my sample, it is more important for adolescents to identify anger in individuals with whom they are interacting. Most adolescents in my sample, many of whom were African Americans, were living in disadvantaged neighborhoods where they (especially the older adolescents) were exposed to frequent violence (Houltberg, Henry, & Morris, 2012). Such an environment may make these adolescents highly sensitive to anger and irritability. It is also possible that parent anger and positive (e.g., happy) emotions, which are more overt, are easier to detect by adolescents, resulting in a stronger influence on adolescents.

These results suggest the short-term effects of contextual factors on vagal functioning during adolescence. Most of the studies focusing on this issue have been conducted among infants or young children, and were investigating the long-terms effects of early contextual factors. The findings of my study add to the literature by indicating that negative contextual factors such as increases in parents' negative affect have short-term adverse effects on adolescents' vagal reactivity. On the other hand, positive contextual factors such as increases in parents' positive affect were found to have short-term positive effects on adolescents' vagal functioning. It is possible that in the long run, if parents continue to display unpredictable high anger, adolescents may be constantly in a stressful context, which would dampen their emotion regulation abilities. On the other hand, if parents are able to show positive affect often in challenging contexts, their adolescents may benefit from the safe environment parents created and develop better vagal regulation of their emotions. However, more research on how contextual factors shape the development of vagal functioning during adolescence is needed in the future to further our understanding of such links.

Strengths and Limitations

In the current investigation, I included physiological and observational data in dealing with cutting-edge issues in the field. I focused on interpersonal challenging social settings (i.e., parent-adolescent discussion of a real anger event and conflict resolution), which represent typical adolescent daily stressors and have ecological validity. One of the strengths of the current investigation was that I used a dynamic systems approach to model the dynamic RSA changes across a challenging task, which allowed me to capture the processes of emotional arousal and regulation and understand the meaning of RSA reactivity. The second strength was the use of mixture modeling to distinguish different dynamic change patterns among adolescents, which confirmed the results of latent growth modeling and expanded the predictive validity of the dynamic RSA changes. A third strength of the current investigation was that I differentiated inter- and intra-individual variations of parent affect in predicting adolescent RSA levels in HLM and found specific effects of the intra-individual and inter-individual variations in parent affect. A fourth strength of the current investigation was that I accounted for respiration parameters (i.e., respiration rate and power) in all analyses. RSA is usually confounded with respiratory parameters and most traditional studies have not corrected the respiratory confounds. Some researchers have pointed out the need to distinguish the between- and within-individual associations with RSA (Grossman & Kollai, 1993; Ritz, 2009). In my study, respiration rate and power were controlled for at the within-individual level. Controlling for respiration parameters allowed me to obtain a better measure of RSA, particularly in my study where adolescents were talking from time-to-time and had some physical movement while sitting in the chair.

I also had some limitations in the current investigation. One limitation was that the baseline measure of RSA was relatively short and it was measured while adolescents were passively watching a neutral film clip. A longer baseline measure and measuring baseline while adolescents are sitting still and on paced breathing are needed to obtain better measures of RSA in the future. A second limitation was that the baseline measure of RSA was not immediately preceding the anger task and the anger task did not have a specific clear recovery period. A third limitation of the current investigation was that I only had measures of parasympathetic nervous system functioning. Because of these two limitations, it is hard to clearly know whether adolescents were emotionally aroused or not during the beginning of the anger task and were recovering to the initial baseline by the end of the task. It is important to obtain a measure of sympathetic nervous system functioning in future studies as well, and to consider the functioning of multiple systems in response to interpersonal challenge concurrently, so that we will have a better understanding of the physiological processes.

The fourth limitation was that the 1-step joint mixture modeling with two auxiliary variables (adolescent anger and sadness regulation) was used to identify adolescent RSA change patterns and the intercept and linear and quadratic slopes were not statistically significant. It is argued that adding auxiliary variables would help better distinguish class memberships (Asparouhov & Muthén, 2013; Lanza, Tan, & Bray, 2013). However, it is possible that these two auxiliary variables drove the distinguishing of the two classes identified in the current sample. Traditional method of identifying change patterns first and then testing the differences on other variables among classes can be used to confirm the current findings in the future. One other limitation was the cross-section nature of the current investigation. It is possible that adolescents who are better in emotion regulation (e.g., higher RSA baseline, showing RSA suppression in response to challenge and RSA recovery afterwards) may be easier to parent (e.g., showing more positive emotions and/or less negative emotions). The direction of the effect of parent affect on adolescent RSA levels has not been determined, but can be examined in future studies. Lastly, the sample of the current investigation has a disadvantaged background with a high percentage of African American families and other ethnic minorities. Different results may be found for a more middle-class, European American sample.

Conclusions and Implications

Methodologically, the current investigation contributes to the field of RSA literature by adopting the most advanced statistical analysis approaches to illustrate the dynamic systems perspective of emotion regulation. The new generation of research on physiology and emotion should treat physiological regulation of emotion as processes under the influences of multiple systems. Future research would also benefit from the use of person-centered analysis to better understand the complex patterns of physiology of emotion, and also would benefit from distinguishing inter- and intra-individual effects of respiration confounds and parental influences. Theoretically, the current investigation clarifies that a pattern of initial RSA suppression followed by RSA recovery is adaptive in response to interpersonal stress, and also adds to the literature by suggesting that parental fluctuations in affect may shape adolescents' vagal functioning.

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Table 1

Correlations between Sex, Age, RSA, Respiration Rate and Power

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*
1. Sex	0. 51	0.50	--					
2. Age	13.46	2.31	-.01	--				
3. Baseline RSA	7.09	1.32	-.03	-.12	--			
4. Baseline RR	18.70	4.99	-.04	-.02	-.15*	--		
5. Baseline RP	21.78	38.50	-.02	-.06	-.02	-.07	--	
6. RSA M1	7.01	1.17	.03	-.10	.65***	.04	.06	--
7. RR M1	21.64	6.28	-.03	-.01	-.04	.08	.03	-.05
8. RP M1	14.67	15.88	.09	.06	-.06	.00	.14+	.00
9. RSA M2	6.90	1.23	.10	-.07	.73***	-.04	.10	.81***
10. RR M2	21.63	5.37	.01	-.03	-.01	.03	-.03	-.03
11. RP M2	18.44	25.02	.00	.03	.05	-.03	.26***	.04
12. RSA M3	6.95	1.10	.05	-.11	.64***	.11	.07	.77***
13. RR M3	21.50	5.59	-.07	-.12	-.02	.17*	.07	-.00
14. RP M3	17.39	22.54	-.06	.01	.02	.07	.19*	.06

Table 1 continued

	7	*8*	*9*	*10*	*11*	*12*	*13*
7. RR M1	--						
8. RP M1	-.11	--					
9. RSA M2	-.00	-.00	--				
10. RR M2	.12	.02	-.16*	--			
11. RP M2	-.01	.50***	.07	.02	--		
12. RSA M3	-.08	-.01	.78***	-.13	.03	--	
13. RR M3	.19*	.01	.04	.27***	.02	.04	--
14. RP M3	-.06	.40***	.06	.01	.59***	-.02	-.05

Note. RR = Respiration rate; RP = Respiration power; M1 = First minute of anger task; M2 = Second minute of anger task; M3 = Third minute of anger task.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2

Means, Standard Deviations and Correlations of Major Variables

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*
1. Sex	0. 51	0.50	--					
2. Age	13.46	2.31	-.01	--				
3. Baseline RSA	7.09	1.32	-.03	-.12	--			
4. RSA M1	7.01	1.17	.03	-.10	.65***	--		
5. RSA M2	6.90	1.23	.10	-.07	.73***	.81***	--	
6. RSA M3	6.95	1.10	.05	-.11	.64***	.77***	.78***	--
7. PA	2.51	0.51	-.06	-.26***	.08	.07	.13	.09
8. PC	1.46	0.41	-.08	.18*	-.12	-.03	-.11	-.14
9. SR	1.17	0.36	.05	.03	.03	.06	.03	.07
10. AR	1.10	0.43	-.10	-.05	.04	.03	.02	.09
11. Depressive	0.37	0.33	.05	.15*	-.05	.10	-.02	-.04
12. Prosocial	1.60	0.31	-.31***	-.13	.14	.01	.00	.08
13. Aggression	1.49	0.47	.14*	.12	-.06	-.08	-.10	-.06

Table 2 continued

	7	*8*	*9*	*10*	*11*	*12*
7. PA	--					
8. PC	-.47***	--				
9. SR	.21**	-.08	--			
10. AR	.25***	-.26***	.56***	--		
11. Depressive	-.23**	.45***	-.17*	-.33***	--	
12. Prosocial	.38***	-.17*	.38***	.49***	-.13	--
13. Aggression	-.31***	.35***	-.33***	-.57***	.30***	-.49***

Note. M1 = First minute of anger task; M2 = Second minute of anger task; M3 = Third minute of anger task; PA = Parental acceptance; PC = Parental psychological control; SR = Sadness regulation; AR = Anger regulation. Sex was as 0 (female) and 1 (male).
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 3

Comparison of Models with 1, 2, and 3 Classes

	1-class	2-class	3-class
Log-likelihood	-904.62	-868.91	-862.02
# of parameters	17	23	29
BIC	1899.81	1860.37	1878.54
AIC	1843.24	1783.83	1782.03
Entropy	NA	0.682	0.784
Tech 11 CRT *p*-value	NA	0.00	0.37

Table 4

Mean Differences on Major Variables between Adolescents from the Two Classes

	C	*N*	*Mean*	*SD*	*t*	*df*	*p*
Sex	1	85	0.51	0.50	0.37	204	.71
	2	121	0.48	0.50			
Age	1	85	13.59	2.38	1.11	204	.27
	2	121	13.22	2.28			
PA	1	85	2.35	0.54	-3.84***	204	<.001
	2	121	2.62	0.45			
PC	1	85	1.53	0.46	1.97*	204	.05
	2	121	1.42	0.37			
SR	1	85	0.84	0.22	-18.22***	204	<.001
	2	121	1.41	0.22			
AR	1	85	0.77	0.32	-12.07***	204	<.001
	2	121	1.33	0.33			
Depressive	1	85	0.46	0.40	3.43**	204	.001
	2	121	0.31	0.26			
Prosocial	1	85	1.45	0.34	-6.61***	202	<.001
	2	121	1.71	0.24			
Aggressive	1	85	1.70	0.59	5.69***	202	<.001
	2	121	1.35	0.30			
Baseline RSA	1	85	6.97	1.32	-1.00	186	.32
	2	121	7.17	1.32			

Note. PA = Parental acceptance; PC = Parental psychological control; C = Class; SR = Sadness regulation; AR = Anger regulation.
* $p <= .05$. ** $p < .01$. *** $p < .001$.

Table 5

Correlations between Sex, Age, RSA, Respiration and Parent Affect (1st Minute)

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0. 51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M1	1.58	0.50	.10	.02	--				
4. Distress M1	1. 33	0.51	-.16*	.07	.02	--			
5. Positive M1	2.04	0.69	.01	.13	-.14	-.07	--		
6. RSA M1	6.97	1.12	-.06	-.04	-.10	.08	.16*	--	
7. RR M1	20.28	4.38	.09	-.11	-.03	-.08	.02	-.03	--
8. RP M1	21.55	28.73	.05	.13	.03	.00	-.01	-.08	-.06

Note. M1 = First minute of conflict resolution task; RR = Respiration rate; RP = Respiration power.
* $p < .05$.

Table 6

Correlations between Sex, Age, RSA, Respiration and Parent Affect (2nd Minute)

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M2	1.61	0.51	.04	.00	--				
4. Distress M2	1.37	0.53	-.08	.05	-.07	--			
5. Positive M2	1.94	0.70	-.06	.25**	-.06	-.08	--		
6. RSA M2	6.91	1.13	-.07	-.00	.02	-.01	.16	--	
7. RR M2	20.09	4.05	-.08	-.13	-.14	-.06	-.03	-.14	--
8. RP M2	21.75	33.41	.08	.04	.08	-.09	.17*	-.03	-.20*

Note. M2 = Second minute of conflict resolution task; RR = Respiration rate; RP = Respiration power.
* $p < .05$. ** $p < .01$.

Table 7

Correlations between Sex, Age, RSA, Respiration and Parent Affect (3rd Minute)

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M3	1.67	0.52	.02	.03	--				
4. Distress M3	1.37	0.50	-.07	-.06	-.09	--			
5. Positive M3	1.92	0.69	-.02	.24**	-.05	-.11	--		
6. RSA M3	7.02	1.16	-.09	-.12	.05	.05	.15	--	
7. RR M3	19.77	4.17	-.02	-.07	-.09	.05	.07	.04	--
8. RP M3	24.61	41.45	.11	.13	.05	-.13	.12	-.05	-.27*

Note. M3 = Third minute of conflict resolution task; RR = Respiration rate; RP = Respiration power.
* $p < .05$. ** $p < .01$.

Table 8

Correlations between Sex, Age, RSA, Respiration and Parent Affect (4th Minute)

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M4	1.67	0.51	.02	.05	--				
4. Distress M4	1.41	0.53	-.10	-.07	-.15*	--			
5. Positive M4	1.90	0.72	-.05	.23**	.02	-.09	--		
6. RSA M4	6.88	1.18	-.06	-.15	.05	.05	.05	--	
7. RR M4	19.91	4.10	.04	-.08	-.02	.13	.02	.05	--
8. RP M4	18.86	25.36	.03	.00	.17*	-.20*	.16*	.10	-.26**

Note. M4 = Fourth minute of conflict resolution task; RR = Respiration rate; RP = Respiration power.

* $p < .05$. ** $p < .01$.

Table 9

Correlations between Sex, Age, RSA, Respiration and Parent Affect (5th Minute)

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M5	1.65	0.56	-.02	-.06	--				
4. Distress M5	1.35	0.50	-.07	-.06	-.14	--			
5. Positive M5	1.87	0.62	-.02	.19**	-.12	-.15*	--		
6. RSA M5	6.94	1.16	-.04	-.06	-.02	-.04	.22**	--	
7. RR M5	20.65	4.43	.07	.03	-.09	-.02	.16	-.01	--
8. RP M5	20.76	24.07	.05	.09	.02	-.17*	.16	.06	-.09

Note. M5 = Fifth minute of conflict resolution task; RR = Respiration rate; RP = Respiration power.
* $p < .05$. ** $p < .01$.

Table 10

Correlations between Sex, Age, RSA, Respiration and Parent Affect (6th Minute)

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M6	1.65	0.54	.04	.02	--				
4. Distress M6	1.38	0.49	-.06	-.01	.04	--			
5. Positive M6	1.86	0.73	-.07	.20**	-.18*	-.05	--		
6. RSA M6	6.97	1.14	.08	-.10	.04	.08	.06	--	
7. RR M6	20.00	4.05	.07	.09	-.06	-.01	.06	-.02	--
8. RP M6	21.74	45.68	.10	.02	-.00	-.09	.18*	.06	-.25**

Note. M6 = Sixth minute of conflict resolution task; RR = Respiration rate; RP = Respiration power.
* $p < .05$. ** $p < .01$.

Table 11

Correlations between Sex, Age, and Parent Anger during the 6-Minute Conflict Task

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Anger M1	1.58	0.50	.10	.02	--				
4. Anger M2	1.61	0.51	.04	.00	.68***	--			
5. Anger M3	1.67	0.52	.02	.03	.62***	.62***	--		
6. Anger M4	1.67	0.51	.02	.05	.60***	.58***	.63***	--	
7. Anger M5	1.65	0.56	-.02	-.06	.61***	.56***	.52***	.59***	--
8. Anger M6	1.65	0.54	.04	.02	.55***	.52***	.57***	.58***	.55***

Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 12

Correlations between Sex, Age, and Parent Distress during the 6-Minute Conflict Task

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Distress M1	1.33	0.51	-.16*	.07	--				
4. Distress M2	1.37	0.53	-.08	.05	.75***	--			
5. Distress M3	1.37	0.50	-.07	-.06	.66***	.77***	--		
6. Distress M4	1.41	0.53	-.10	-.07	.62***	.68***	.76***	--	
7. Distress M5	1.35	0.50	-.07	-.06	.61***	.62***	.62***	.76***	--
8. Distress M6	1.38	0.49	-.06	-.01	.56***	.61***	.57***	.75***	.81***

Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 13

Correlations between Sex, Age, and Parent Positive Affect during the 6-Minute Conflict Task

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. Positive M1	2.04	0.69	.01	.13	--				
4. Positive M2	1.94	0.70	-.06	.25**	.63***	--			
5. Positive M3	1.92	0.69	-.02	.24**	.64***	.64***	--		
6. Positive M4	1.90	0.72	-.05	.23**	.62***	.55***	.65***	--	
7. Positive M5	1.87	0.62	-.02	.19*	.56***	.51***	.60***	.59***	--
8. Positive M6	1.86	0.73	-.07	.20**	.53***	.58***	.66***	.57***	.70***

Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 14

Correlations between Sex, Age, and RSA during the 6-Minute Conflict Task

	Mean	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Sex	0.51	0.50	--						
2. Age	13.46	2.31	-.01	--					
3. RSA M1	6.97	1.12	-.06	-.04	--				
4. RSA M2	6.91	1.13	-.07	-.00	.77***	--			
5. RSA M3	7.02	1.16	-.09	-.12	.80***	.80***	--		
6. RSA M4	6.88	1.18	-.06	-.15	.77***	.78***	.81***	--	
7. RSA M5	6.94	1.16	-.04	-.06	.75***	.83***	.81***	.84***	--
8. RSA M6	6.97	1.14	.08	-.10	.74***	.76***	.76***	.77***	.80***

Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 15

Correlations between Parent Anger and Adolescent RSA during the 6-Minute Conflict Task

	Anger M1	Anger M2	Anger M3	Anger M4	Anger M5	Anger M6
1. RSA M1	-.10					
2. RSA M2	-.03	.02				
3. RSA M3	.01	-.03	.05			
4. RSA M4	.00	.04	.02	.05		
5. RSA M5	-.07	-.04	-.03	-.05	-.02	
6. RSA M6	-.07	-.05	-.02	.06	-.08	.04

Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.

Table 16

Correlations between Parent Distress and Adolescent RSA during the 6-Minute Conflict Task

	Distress M1	Distress M2	Distress M3	Distress M4	Distress M5	Distress M6
1. RSA M1	.08					
2. RSA M2	.05	-.01				
3. RSA M3	.04	.01	.05			
4. RSA M4	-.04	-.05	.01	.05		
5. RSA M5	.03	-.07	.02	.01	-.04	
6. RSA M6	-.02	.00	.06	.07	.05	.08

Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.

Table 17

Correlations between Parent Positive Affect and Adolescent RSA during the 6-Minute Conflict Task

	Positive M1	Positive M2	Positive M3	Positive M4	Positive M5	Positive M6
1. RSA M1	.16*					
2. RSA M2	.26**	.16				
3. RSA M3	.16	.11	.15			
4. RSA M4	.16	.04	.05	.05		
5. RSA M5	.20*	.08	.17*	.14	.22**	
6. RSA M6	.16*	.09	.12	.12	.10	.06

Note. Note. M1 = First minute; M2 = Second minute; M3 = Third minute; M4 = Fourth minute; M5 = Fifth minute; M6 = Sixth minute.
* $p < .05$. ** $p < .01$.

Table 18

Hierarchical Linear Model of How Parent Affect Predicted Adolescent RSA

	Anger Model		Distress Model		Positive Model	
	Coefficient	*SE*	Coefficient	*SE*	Coefficient	*SE*
Intercept						
γ_{00}	6.94***	0.12	6.93***	0.12	6.93***	0.12
$PA_{overall}$	0.08	0.20	0.05	0.19	0.37*	0.15
Sex	-0.07	0.17	-0.06	0.17	-0.05	0.17
Age	-0.04	0.04	-0.04	0.04	-0.06	0.04
RR_t						
γ_{10}	-0.01	0.01	-0.01	0.01	-0.01	0.01
Sex	0.02	0.01	0.02	0.01	0.02	0.01
Age	-0.00	0.00	-0.00	0.00	-0.00	0.00
RP_t						
γ_{20}	-0.00	0.00	-0.00	0.00	-0.00	0.00
Sex	0.00	0.00	0.00	0.00	0.00	0.00
Age	-0.00	0.00	-0.00	0.00	-0.00	0.00
RSA_{t-1}						
γ_{40}	-0.18**	0.06	-0.18**	0.07	-0.19**	0.07
Sex	0.08	0.09	0.07	0.09	0.07	0.09
Age	-0.04*	0.02	-0.04*	0.02	-0.04*	0.02
PA_{t-1}						
γ_{30}	-0.30**	0.11	0.12	0.15	0.24**	0.08
$PA_{overall}$	0.03	0.17	0.07	0.21	-0.07	0.11
Sex	0.13	0.14	-0.22	0.19	-0.22*	0.11
Age	-0.07*	0.03	0.00	0.04	-0.03	0.03

Note. RR = Respiration rate; RP = Respiration power; PA = Parent affect (i.e., anger, distress, positive affect). Sex was as 0 (female) and 1 (male).
* $p < .05$. ** $p < .01$. *** $p < .001$.

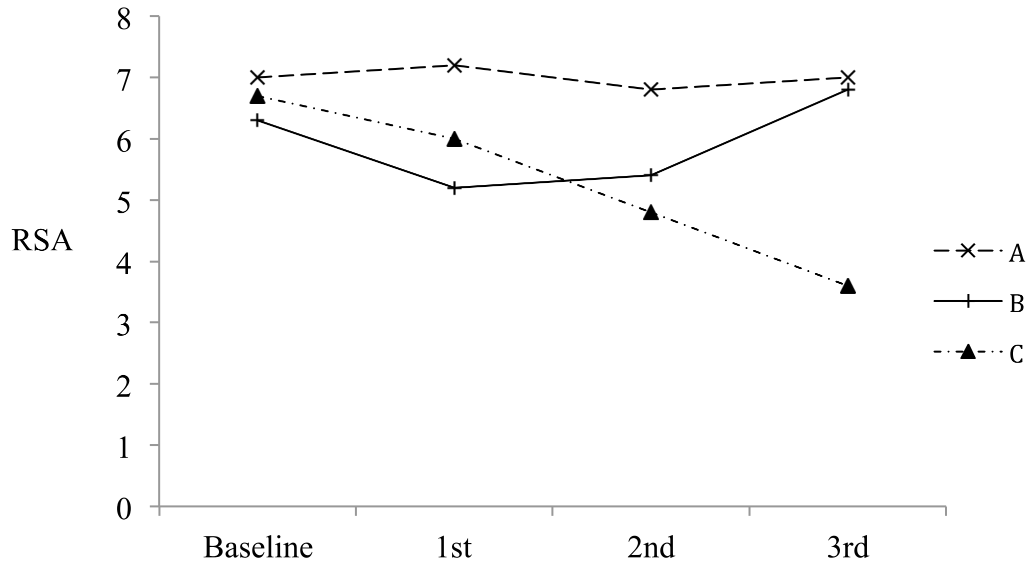

Figure 1. Hypothesized dynamic changes in RSA.

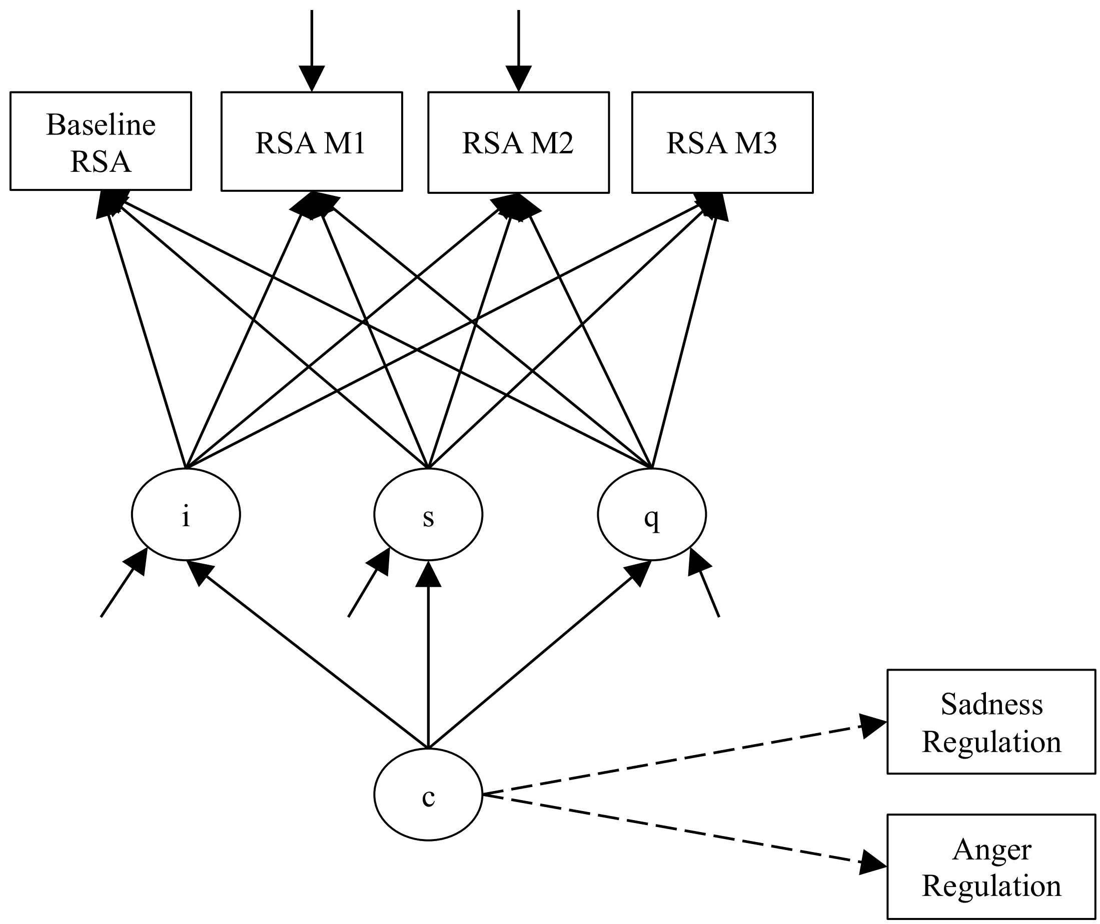

Figure 2. The 1-step joint growth mixture model with auxiliary outcome variables.

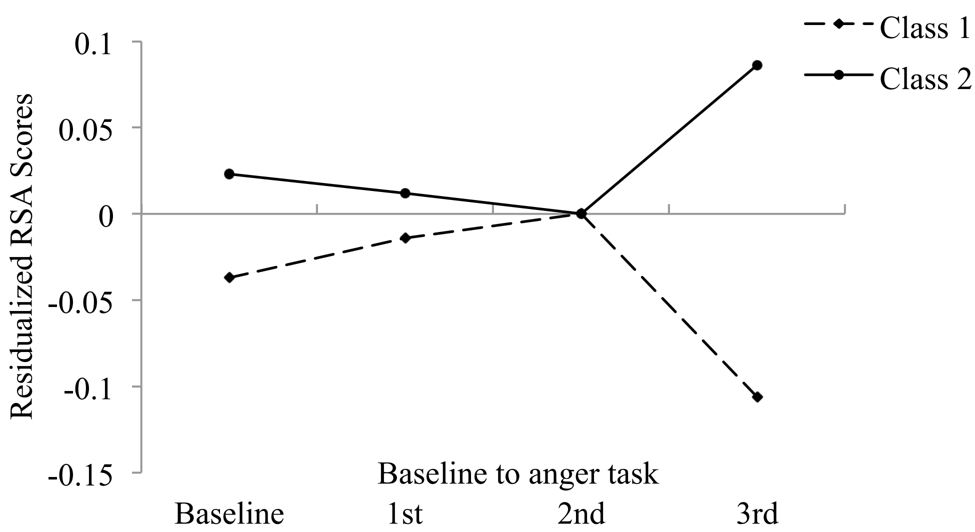

Figure 3. Two RSA change patterns during anger task.

APPENDICES

Appendix A

Literature Review

Children and families face enormous developmental challenges in modern society, especially youth of color and those living in poverty (Jenson & Fraser, 2011). Many adolescents face adjustment difficulties and health problems such as delinquency, violent offending, drug use, sexual transmitted diseases, teen pregnancy, anxiety and depression. Adolescence is a critical period for research (Steinberg, 2001; Steinberg & Morris, 2001). Adolescents experience more frequent and intense emotions and dynamic fluctuations than younger children or older individuals (Granic, Hollenstein, Dishion, & Patterson, 2003; Larson, Csikszentmihalyi, & Graef, 1980; Larson & Lampman-Petraitis, 1989). The ability to manage emotions behaviorally and physiologically plays a critical role in the development of various adjustment problems (Steinberg & Avenevoli, 2000). From the perspective of risk and resilience (Masten, 2007), biological vulnerability to stress is a risk factor, that has drawn a lot of research attention and is in need of greater study (Thayer, Hansen, Saus-Rose, & Johnson, 2009).

In the past few decades, with the development of physiological measurement tools and quantification methods, various studies have focused on the neurophysiological mechanism of cardiac vagal control and the effects of the autonomic nervous system functioning on child and adolescent adjustment (e.g., Aysin & Aysin, 2006; Berntson, Cacioppo, & Quigley, 1991; Grossman & Kollai, 1993; Porges et al., 2007). Empirical studies have found meaningful relations between the functions of autonomic nervous systems and psychopathology as well as a range of social-emotional behaviors (Bosch, Riese, Ormel, Verhulst, & Oldehinkel, 2009; Butler, Wilhelm, & Gross, 2006; Egizio et al., 2008; Gentzler, Santucci, Kovacs, & Fox, 2009). Many of these studies focus on Respiratory Sinus Arrhythmia (RSA, i.e., the fluctuation in heart period at the respiratory frequency), since getting RSA data is noninvasive and relatively easy and inexpensive (Ritz, 2009). However, the findings from these studies are often inconsistent and sometimes contradictory (Egizio et al., 2008; Hastings et al., 2008). Recently, researchers have noted some of the flaws of traditional RSA studies including: 1) ignoring respiration parameters (e.g., respiration rate and depth), attention, and motor activity, especially in studies involving stress tasks requiring talking; 2) using a single stressor and a single psychophysiological indicator; and 3) ignoring timing issues and possibly different processes involved in task completion (Dennies, Buss, & Hastings, 2012; Egizio et al., 2008; Obradović et al., 2010; 2011). In order to shed light on some of the issues arising in RSA studies, the current study will use psychophysiological data during social stress tasks in the lab and adopt the Dynamic Systems approach, 1) to test the associations between dynamic RSA changes and adolescent emotion regulation during an emotionally charged conversation task; and 2) to test whether parent negative emotions influence adolescent RSAs dynamically during a parent-adolescent conflict resolution task, among a low income, ethnically diverse sample.

RSA, Cardiac Vagal Control of Heart, and the Effects of Respiration

Berntson, Cacioppo, and Quigley (1993) defined RSA as "a rhythmical fluctuation in heart periods at the respiratory frequency that is characterized by a shortening and lengthening of heart periods in a phase relationship with inspiration and expiration, respectively" (p. 183). Its amplitude represents visceromotor tone and its period represents the common cardiorespiratory drive frequency. The mammalian heart has an intrinsic pacemaker, the sino-atrial node. Heart rate (HR) is multi-determined and influenced by both sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) (Fox, Kirwan, & Reeb-Sutherland, 2012). PNS usually pre-dominates in the autonomic control of heart at resting state. Due to the tonic vagal influences on this node, resting HR is lower than the intrinsic heart rate of the pacemaker. Both intrinsic and extrinsic challenges can cause HR to change beat to beat, which is called Heart Rate Variability (HRV). Moderate challenges may be largely modulated by the activation or withdrawal of myelinated vagus. The myelinated vagal efferent pathways acting on the sino-atrial node via nicotinic preganglionic receptors are the only pathways responsible for the rapid instantaneous changes in HR (Porges, 2007). The functional consequence of these actions is called RSA (Porges, 1995b). Strong stressors can reverse the relative dominance and shift the control of the heart to the SNS (Berntson et al., 1991).

High respiratory frequency band (about 0.12-0.40 Hz for adults in resting state) is mostly the function of the myelinated vagal influence. Therefore, RSA is also called High Frequency HRV (HF-HRV), and the quantity of RSA amplitude is considered as a sensitive index of the influence of the myelinated vagus on the heart (Porges, 1995b). The low frequency HRV (i.e., LF-HRV, frequency range between 0.04-0.12 Hz) is considered as reflecting both the functions of SNS and PNS. The LF/HF HRV ratio, that is, (sympathetic + vagal)/vagal, may reflect relative autonomic balance (iow, relative sympathetic to parasympathetic dominance; Malliani, 2005; Nugent, Bain, Thayer, Sollers III, & Drevets, 2011). High LF/HF values putatively indicate high sympathetic control, whereas low LF/HF values indicate high parasympathetic control (Berntson et al., 2008). Respiration has a significant effect on the HR oscillations and parasympathetic activity is very closely related to RSA (Aysin & Aysin, 2006). Talking and dramatic physical movements, which alter respiration, may seriously confound RSA (Butler et al., 2006). The present study will account for respiration rate and power while calculating RSA reactivity using residualized change scores (Berntson et al., 1997; Berntson, Quigley, & Dave, 2007; Kok & Fredrickson, 2010) because the potential influence of respiration in our study especially when talking was involved.

Effects of Baseline RSA and RSA Reactivity to Challenges

Studies of the main effects of baseline RSA and RSA reactivity to environmental challenges, as well as interaction effects with socialization contexts, have found mixed results. Overall, the meaning of baseline RSA is unclear, especially among adolescents. In studies of RSA changes in response to challenges, self-regulatory process is often confounded by emotion reactivity, which makes it difficult to interpret the findings.

Tonic parasympathetic control of HR is called vagal tone or baseline RSA (Diamond, Fagundes, & Butterworth, 2011; Porges, 1995a), which is usually assessed when the individual is at rest with paced breathing, or sometimes when the individual is shown a calming film (e.g., dolphin film, Fabes & Eisenberg, 1997). It is posited to reflect an individuals' ability to focus attention, engage in social communication, and maintain homeostasis under normal circumstance (El-Sheikh et al., 2009; Porges, 2007); it may also denote children's physiological reservoir of emotion regulation capacity, or their trait-like level of arousability (Beauchaine, 2001; Hastings, et al., 2008). Normally children increase in baseline RSA from preschool to middle childhood (Bornstein & Suess, 2000; Quas, Hong, Alkon, & Boyce, 2000; Rigterink & Katz, 2010), and show stable increases across the childhood years (Calkins & Keane, 2004; El-Sheikh, 2005a), and remains stable from late childhood to early adolescence (El-Sheikh, 2005b). Adverse early life experiences such as marital discord, domestic violence, negative parenting, and adverse life events, have been found to be related to less gain in baseline RSA by middle childhood (Katz & Rigterink, 2012; Rigterink, Katz, & Hessler, 2010).

Low baseline RSA might indicate emotion inflexibility or dysregulated emotions, which may be manifested as aggression or depression. Among adolescents, baseline RSA has been linked to temperamental features and adjustment. For example, among 8- to 17-year-olds, higher resting RSA was associated with higher effortful control scores (measured by the Early Adolescent Temperament Questionnaire, EATQ), while lower resting RSA was associated with more aggressive behaviors (measured by the EATQ aggression subscale; Chapman, Woltering, Lamm, & Lewis, 2010). Adolescents who ruminated over anger and injustice showed lower vagal activity than cognitive reappraisers (Vögele, Sorg, Studtmann, & Weber, 2010). In other studies, parasuicidal adolescent girls showed attenuated baseline RSA compared to control group girls (Crowell et al., 2005), and aggressive adolescents with conduct problems, or adolescents with both conduct disorder and ADHD problems showed lower baseline RSA than a control group (Beauchaine, Hong, & Marsh, 2008; Beauchaine, Katkin, Strassberg, &

Snarr, 2001). A longitudinal study also found higher initial baseline RSA predicted significant declines in externalizing symptoms whereas lower initial baseline RSA predicted significant increases in externalizing symptoms among boys (El-Sheikh & Hinnant, 2011). However, other studies of baseline RSA have not found significant correlates of vagal tone or baseline RSA with adjustment indices (e.g., Diamond, Fagundes, & Butterworth, 2012; Egizio et al., 2008; El-Sheikh et al., 2009; Hinnant & El-Sheikh, 2009).

Vagal reactivity to challenge reflects changes in vagal control from baseline to challenging conditions and can be characterized as vagal augmentation (increases in vagal influence over heart) and vagal withdrawal (decreases in vagal influence over heart) (El-Sheikh et al., 2009). Changes in RSA levels (RSA reactivity) are often used to indicate vagal reactivity under such challenging conditions. A decrease in RSA (also called RSA suppression) indicates vagal withdrawal, which generates increase in HR and SNS input to the heart. An increase in RSA (also called RSA augmentation) indicates vagal augmentation, which slows the HR and inhibits SNS input (e.g., El-Sheikh et al., 2009; Obradović & Boyce, 2012).

Higher RSA suppression to stressful laboratory challenges has been linked to more sustained attention, better emotion regulation, and increased engagement in the task. Some studies found that participants with greater RSA suppression during experimental challenges showed fewer behavioral problems, higher peer status, higher sociability, higher levels of social skills, and less need of parents to down regulate their children's emotion (e.g., Doussard-Roosevelt, Montgomery, & Porges, 2003; Gentzler, Santucci, Kovacs, & Fox, 2009; Gottman & Katz, 2002). Studies also found that low

RSA reactivity under social challenge was related to maternal negative control (Hastings et al., 2008) and to externalizing problem. However, other studies found either no relation between RSA reactivity and emotion and behavior problems (e.g., Eisenberg et al., 2012; Quas et al., 2000) or contradictory results. For example, higher RSA suppression in response to challenges was associated with poorer memory (e.g., Quas, Alkon, Goldstein, & Boyce, 2006), emotion lability and panic attacks (e.g., Asmundson & Stein, 1994), internalizing problems, and parasuicidal behaviors among adolescent girls (Crowell et al., 2005). Less RSA suppression was evident among children of mothers with stable mild depression than children of chronic depressed mothers (Ashman, Dawson, & Panagiotides, 2008), was associated better social functioning (Egizio et al., 2008). Hastings et al. (2008) found that higher vagal augmentation in response to social challenge was associated with fewer internalizing and externalizing problems, and better behavior self-regulation among young children.

Because of the inconsistent or contradictory findings about main effects of RSA studies, some researchers argue that the socialization contexts must be considered (El-Sheikh, 2005a; El-Sheikh et al., 2009; Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010). It is possible that whether baseline RSA is predictive or not and whether RSA reactivity to stress is adaptive or not, depends on the context in which children and adolescents are residing (Obradović et al., 2010). However, findings from studies of interaction effects are as mixed or complicated as the main effects findings (see review by Obradović & Boyce, 2009).

Theoretically, high baseline RSA may buffer the negative effects of adverse contexts, and some empirical studies support this notion. For example, higher baseline

RSA protected children from internalizing and externalizing problems associated with marital conflict (El-Sheikh, Harger, & Whitson, 2001), parents' drinking problems (El-Sheikh, 2005a), child's sleeping problems (El-Sheikh, Erath, & Keller, 2007). In another study, above-median baseline RSA buffered the adverse effect of paternal antisocial personality disorder on conduct problems, and also buffered the adverse effect of maternal melancholic symptoms on depression, among 8- to 12-year-old children (Shannon, Beauchaine, Brenner, Neuhaus, & Gatzke-Kopp, 2007). However, some studies did not find the buffering effects or found contradictory effects. For example, among a group of Dutch early adolescents, baseline RSA did not modify the effects of stressors in predicting behavior problems (Oldehinkel, Verhulst, & Ormel, 2008). Other studies found contradictory results, for example, low baseline RSA buffered the effects of maternal depression on child emotion regulation skills among 4- to 7-year-old children (Blandon, Calkins, Keane, & O'Brien, 2008). Another study found that higher levels of baseline RSA predicted less anxiety, more somatic symptoms, but had no effects on depression among young adolescents who reported high exposure to stressful life events (Bosch et al., 2009). Eisenberg et al. (2012) found that higher baseline RSA predicted less aggression among young children only when they had higher levels of environmental quality.

Some studies have suggested that whether children's RSA reactivity is related to emotion regulation and adjustment depends on what context they are living in. As the "biological sensitivity to context" theory assumes, biologically more sensitive children will be more reactive to adverse environments such as family adversity, as well as to supportive environments such as positive parenting and high socioeconomic status

(Boyce & Ellis, 2005). Empirically, researchers have found that, in the context of low family adversity, children with high RSA reactivity in response to challenges showed the lowest levels of externalizing problems, and highest levels of prosocial behavior and school engagement. In the context of high family adversity, low RSA reactivity buffered the harmful effects of adversity on externalizing problems, prosocial behavior, and school engagement (Obradović et al., 2010), which supports the biological sensitivity to context theory. However, some studies have found the opposite effect or no effect (e.g., Eisenberg et al., 2012; Quas, Bauer, & Boyce, 2004). For example, higher RSA suppression buffered the adverse effect of poor sleep efficiency on externalizing problems (El-Sheikh et al., 2007), also buffered the adverse effect of marital conflict on child internalizing problems (El-Sheikh & Whitson, 2006) and boys' externalizing problems ((El-Sheikh et al., 2001).

In sum, vagal withdrawal and augmentation can both be adaptive or maladaptive because they may represent different processes in response to different lab stressors. Higher vagal withdrawal may indicate better readiness for emotion regulation efforts, but also may indicate higher sensitivity to negative emotional stimuli. As Obradović et al. (2011) suggested, the context of psychophysiological measurement is very important, which may determine the process of vagal activity and adaptivity of vagal withdrawal and augmentation.

The Integration SNS and PNS Functioning

Egizio et al. (2008) argued that one of the reasons for inconsistent findings in RSA studies is that the stressors in experimental tasks might evoke different levels of social and attentional vigilance or alter affective states differentially. Characteristics of stressors and stress types are critical in psychophysiological studies, which have been widely ignored previously (Dickerson & Kemeny, 2004). Fabes and Eisenberg (1997) found that baseline RSA (being called vagal tone in the study) was associated with negative emotional arousal and constructive coping only under conditions of moderate and high stressors. Empirically, researchers are incorrect if they assume that psychophysiological markers can distinguish participants across all kinds of stimulus conditions (Beauchaine, 2012). Nugent et al. (2011) found that females with major depressive disorder showed attenuated autonomic activities compared to healthy females only in response to mild physical stress. Theoretically, not all kinds of stressors are able to activate the SNS or PNS system, or to activate both SNS and PNS systems at the same time. The same changes observed in RSA levels indicating PNS functioning may have different meanings with or without the activation of SNS system. This idea is supported by the empirical evidence that RSA reactivity is unstable across different stressors (e.g., Bornstein & Suess, 2000; El-Sheikh, 2005a; 2005b), is even unstable across time to the same stressors (e.g., Doussard-Roosevelt et al., 2003), and is not always in concordance with reactivity in other physiological systems (e.g., Bauer, Quas, & Boyce, 2002; Cacioppo, Uchino, & Berntson, 1994).

The basic neurophysiological mechanisms of autonomic control of the heart, and the Polyvagal Theory, suggest how and when the environmental stressors impact on both SNS and PNS branches. According to Polyvagal Theory, there are three phylogenetic stages of the development of the vertebrate autonomic nervous system: the unmyelinated vagus, which supports immobilization (freezing, death feigning, or passive avoidance) behavior; the sympathetic-adrenal system which supports mobilization (fight or flight, active avoidance) behavior; and the myelinated vagus, which supports social communication, self-soothing, calming, and "arousal" inhibiting behaviors (Porges, 1996; 2007). The Polyvagal Theory assumes that functional organization of the mammalian ANS is phylogenetically hierarchical: if vagally-mediated social affiliative responses fail in coping with a threat, they shift to fight/flight responses or even freezing responses which are mediated by the phylogenetically older systems (Beauchaine, Gatzke-Kopp, & Mead, 2007).

When the environmental stressor is intense or chronic, the risk will be appraised as high, the SNS will be activated to produce autonomic shifts such as heart rate and blood pressure increases to parallel the potential defensive behaviors such as fight and flight. Meanwhile, the myelinated vagus, which functions as a vagal "brake" (Porges, 1996), is involved to inhibit the SNS's influences on the heart (Porges, 2007). This serves to downregulate negative emotions, stabilize the organism, and restore a physiological equilibrium (Miskovic & Schmidt, 2012). When an individual encounters moderate challenge in the environment, the vagal "brake" withdraws to produce high cardiovascular outcome to meet the environmental needs, without the involvement of sympathetic nervous system. If the environmental challenge diminishes, the vagal "brake" comes back to act on the heart to reduce metabolic expenditure. When the risk is appraised as extremely high, the sympathetic response fails to meet the environmental challenge and the unmyelinated vagus participates to support immobilization behavior such as "freezing" (El-Sheikh et al., 2009; Porges, 1998). In this sense, stressors of different intensity activate the SNS and/or PNS differently. Some stressors activate the SNS and require the action of the PNS, while other stressors only activate the PNS. Vagal augmentation when only PNS is being activated is different from when both SNS and PNS are activated.

To complicate issues further, the SNS and PNS can be both activated at the same time, because autonomic control modes do not lie along a single continuum. Berntson, Cacioppo, and Quigley (1991) proposed a 2-dimensional conception of autonomic space (Figure 1), the SNS function and the PNS function, which may be either coupled (there are negative or positive relations between the two divisions) or uncoupled (SNS and PNS work independently, increase or decrease in one division but do not change in the other). Coupled responses can also either be reciprocal (SNS activates, PNS withdraws, or vice versa) or nonreciprocal (SNS and PNS both activate or inhibit, i.e., coactivation and coinhibition; see also Berntson et al. 2001; Berntson & Cacioppo, 2004). As described earlier, autonomic reciprocity is the common mode of autonomic control of certain dually innervated muscles and organs corresponding to central nervous system control. Empirical studies have documented that strong negative emotions or distressing or aversive stimuli as well as simple attentional stimuli evoke coactivation in non-human animals and humans (see Berntson et al., 1991). Uncoupled modes happen when the two ANS divisions have different thresholds for activation. Only the division with a lower threshold exerts functional effects when the provocation is at a moderate level. The two branches may function nonreciprocally, especially in response to psychological stressors in daily life, including either coactivation or coinhibition of the two branches (Berntson, Norman, Hawkley, & Cacioppo, 2008; El-Sheikh et al., 2009). Berntson et al. (1994) found that one fourth of their participants showed nonreciprocal autonomic responses to stressors in a sample of children and adolescents.

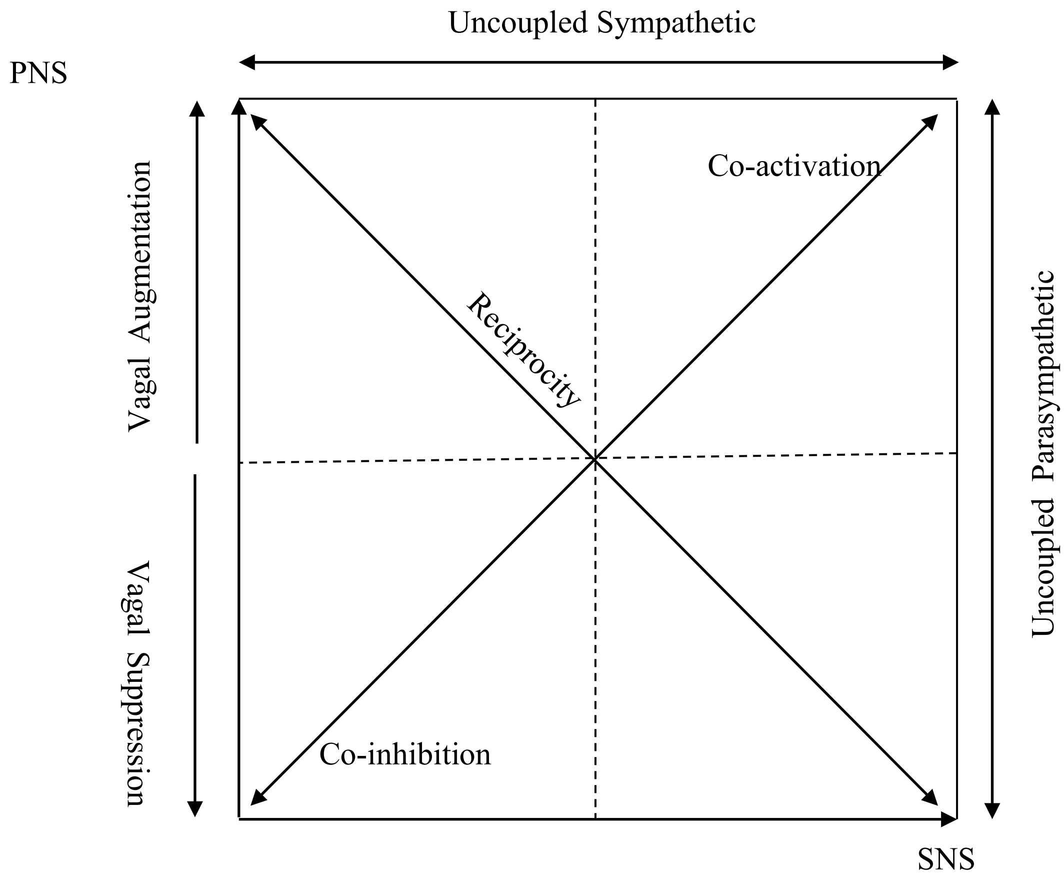

Figure 4. Autonomic Space: Two-dimensional model of autonomic control (adapted from Berntson, Caccipo, & Quigley, 1991).

The importance of the RSA measurement context and the multiple autonomic control modes suggest the need to consider multiple psychophysiological indicators at the same time, in this case, both SNS and PNS functioning (e.g., Bauer et al., 2002; Cacioppo et al., 1994; El-Sheikh et al., 2009; Keller & El-Sheikh, 2009; Quas et al., 2006), and also to consider both autonomic nervous system functioning and socialization contexts simultaneously (Diamond, Fagundes, & Cribbet, 2012; El-Sheikh et al., 2009; El-Sheikh, Keiley, Erath, & Dyer, 2012). El-Sheikh and colleagues (2009) proposed an integrated model of ANS functioning. The interaction of SNS and PNS reactivity may reflect trait-like characteristic and provide a substrate for behavioral and emotional regulation. In their empirical study, they used RSA to index PNS activity and skin conductance level (SCL) to index SNS activity, and conceptualized the effects of marital conflict as an aversive context. They found that coactivation or coinhibition of PNS and SNS functioned as a vulnerability factor for externalizing behavior in the context of marital conflict, while reciprocal PNS or SNS activation functioned as protective factors (El-Sheikh et al., 2009).

Beauchaine (2001) found that under-responsive central reward system (behavioral activation system, i.e., BAS, under control of SNS) interacts with deficient vagal modulation of emotion, resulting in sensation seeking and aggressive behaviors as characteristics of externalizing problems. An over-responsive inhibition system (behavioral inhibition system, i.e., BIS, also under control of SNS) interacts with deficient vagal modulation of emotion, resulting in withdrawal behaviors as characteristics of internalizing problems. Beauchaine, Gatzke-Kopp, and Mead (2007) found that both SNS underarousal at baseline and SNS insensitivity to reward (PEP non-reactivity to incentives) interacted with PNS deficiencies and lead to increased emotion lability. Six- to seven-year-old children with externalizing problems showed lower reactivity in both sympathetic and parasympathetic systems (higher RSA/PEP change scores) than low-symptom children (Boyce et al., 2001). These results confirmed that the coinhibition of PNS and SNS activity is related to child externalizing behavior. Berntson et al.’s (2008) study considered the activities of both ANS divisions at the same time too and created two new measures: cardiac autonomic balance (CAB, the difference in the normalized parasympathetic index minus the sympathetic index) and cardiac autonomic regulation (CAR, the normalized parasympathetic index plus the sympathetic index). They found that CAR predicted the prior occurrence of a myocardial infarction whereas CAB predicted concurrent diabetes among a group of old adults (Berntson et al., 2008).

The Timing Issue and Study of the Processes

Traditional RSA and RSA reactivity studies are variable-based and tap only inter-individual differences. The studies of RSA and emotion have never disentangled emotional reactivity from regulation, and various processes confound the underlying vagal activities. According to Thompson (1994, pp. 27-28), "emotion regulation consists of the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotion reactions, especially their intensive and temporal features, to accomplish one's goals." Physical regulation of emotion, which is one facet of emotion regulation (Thompson, Lewis, & Calkins, 2008), is also a dynamic process which manifests across time. The stress-sensitive physiological systems such as ANS are either acutely or chronically changing over time in accordance with the changing internal and external contexts, which is called "allostasis" (Adam, 2012). These issues pose difficult questions for researchers of ANS functioning such as: 1) What indexes of PNS and SNS are meaningful? 2) How should the intra-individual temporal changes of the indexes be studied? and 3) How should these changes during social interaction be interpreted?

Fortunately, in the last two decades, Dynamic Systems (DS) approaches have become prevalent in developmental psychology and have been applied to study a wide range of developmental phenomena (e.g., Hollenstein, 2011). Spencer, Perone, and Buss (2011) concluded that Dynamic Systems Theory (DST) has been extremely successful and perhaps even "revolutionary." DST emphasizes the step-by-step processes, including second-to-second unfolding of behavior and longer time scale of development, and multilevel interactions of components in the system (Spencer, Perone, & Buss, 2011). DST not only inspires new approaches or perspectives in studying various old or new phenomena, but also inspires the development of new statistical methods and tools. Other than traditional cross-sectional and longitudinal designs, microgenetic research designs allow researchers to trace change over time within the same system and see the process of developmental change (Fogel, 2011). Recent advances in methodologies and statistical tools such as hierarchical growth modeling and multilevel modeling allow researchers to examine developmental trajectories in microgenetic designs (Fogel, 2011). DS methodologies emphasize smaller sample size and intensive observation studies that yield both group data and unique individual trajectory data (Witherington & Margett, 2011).

Emotion and emotion regulation processes are rapid and dependent on contextual demand, with each individual displaying fluctuations and flexibilities in emotion responses to unique situational contexts (Camras & Witherton, 2005); these contexts also reflect distinct individual developmental histories (Fogel et al., 1992). RSA augmentation facilitates the maintenance of an internal equilibrium and social engagement, and RSA suppression signifies the readiness to respond to internal or external threat or challenge (Brooker & Buss, 2010; Porges, 2007). Developmentally, researchers have used HLM to model three-year changes in RSA reactivity at the transition to adolescence and found that the slopes in RSA reactivity across three years were associated with children's sadness regulation abilities, that is, as their RSA change scores from baseline (showed RSA withdrawal in first year but RSA augmentation in third year) in response to emotional challenge increased across the three years, they experienced fewer difficulties with emotion regulation (Vasilev, Crowell, Beauchaine, Mead, & Gatzke-Kopp, 2009). Brooker and Buss (2010) argued that both RSA and emotion are active responses and the traditional methods of quantifying RSA changes (a difference score between task and baseline RSA values) are not sensitive enough to capture the temporal features of the processes. They further suggested that fluctuations in RSA should correspond to some degree with moment-to-moment changes in emotional expressions and behavior (Brooker & Buss, 2010). Brooker and Buss modeled dynamic fluctuations in RSA within individuals within a single emotion episode using growth curve models. Specifically, both linear and quadratic changes in RSA were estimated for each toddler during the two and a half minute Stranger task. The linear changes in RSA reflect epoch-to-epoch increases or decreases in RSA, while the positive quadratic changes in RSA reflect decreases in RSA followed by increases in RSA and negative quadratic changes in RSA reflect increases in RSA followed by decreases in RSA (Brooker & Buss, 2010). A two-level modeling method was used to see whether the linear and quadratic changes in RSA differed among high fear and non-high fear toddlers:

Level 1: $RSA = \beta_{0ij} + \beta_{1ij}\text{time linear} + \beta_{2ij}\text{time quadratic} + e_{ij}$

Level 2: $\beta_{0ij} = \gamma_{00} + \gamma_{01}\text{group} + \omega_{0j}$

$\beta_{1ij} = \gamma_{10} + \gamma_{11}\text{group}$

$\beta_{2ij} = \gamma_{20} + \gamma_{21}\text{group}$

They found that high fear toddlers showed greater linear increases and more negative quadratic change (increase first and then decrease in RSA) during the task than non-high fear children. The two groups did not differ on simple changes in RSA during the task from baseline. Later, they examined whether the linear and quadratic changes predict emotion behaviors and found that for high fear toddlers, more increases first, then decreases in RSA were related to more positive affect during the episode. In Vögele et al.'s (2010) study, they used the Ultimatum Game (UG) to provoke anger among a group of adolescents and differentiated four consecutive steps: baseline, provocation and contemplation during UG, and recovery. They found that anger ruminators showed vagal augmentation in response to anger provocation and vagal withdrawal during contemplation before recovering to baseline, while cognitive reappraisers showed little changes in vagal activity in response to anger provocation but vagal augmentation during contemplation and recovery (Vögele et al., 2010).

Theoretically, differentiating emotional reactivity from regulation and modeling the RSA changes during these processes, matches the fact that emotion response and regulation are dynamic processes. By doing so, researchers are able to discuss whether vagal withdrawal or augmentation is adaptive. Methodologically, the HLM statistical method is a promising tool to monitor the dynamic changes in RSA. This approach may greatly contribute to RSA studies.

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Appendix B

Questionnaires

Parental acceptance: items 1, 3, 5, 7, 9, 12, 14, 16, 17, 18.

Parental psychological control: items 2, 4, 6, 8, 10, 11, 13, 15

Directions: Read each question carefully and select the answer that best describes your mother. There are no right or wrong answers, as we know that there are many ways to raise children and adolescents today. Please let the interviewer know if there are any questions that you do not understand. Remember that everything that you say will remain confidential.

1 Not like her   2 Somewhat like her   3 A lot like her

My mother is a person who…

1. makes me feel better after talking over my worries with her.
2. is always trying to change how I feel or think about things.
3. smiles at me very often.
4. changes the subject whenever I have something to say.
5. is able to make me feel better when I am upset.
6. often interrupts me.
7. enjoys doing things with me.
8. blames me for other family members' problems.
9. cheers me up when I am sad.
10. brings up past mistakes when she criticizes me.
11. is less friendly with me if I do not see things her way.
12. gives me a lot of care and attention.
13. will avoid looking at me when I have disappointed her.
14. makes me feel like the most important person in her life.
15. if I have hurt her feelings, stops talking to me until I please her again.
16. believes in showing her love for me.
17. often praises me.
18. is easy to talk to.

Adolescent emotion regulation

Directions: Reflecting on the past year, to what extent were the following statements true about ***you***:

0 Not True 1 Somewhat True 2 Very True

Adolescent-report sadness regulation:

1. When I am feeling sad, I control my crying and carrying on.

3. I stay calm and don't let sad things get to me.

6. When I'm sad, I do something totally different until I calm down.

8. I can stop myself from losing control over my sad feelings.

10. I try to calmly deal with what is making me feel sad.

Adolescent-report anger regulation:

13. When I'm feeling mad, I control my temper.

15. I stay calm and keep my cool when I'm feeling mad.

20. I can stop myself from losing my temper.

22. I try to calmly deal with what is making me feel mad.

Prosocial behavior

Directions: Reflecting on the past year, to what extent were the following statements true about ***you***:

0 Not True 1 Somewhat True 2 Very True

1. I try to be nice to other people. I care about their feelings.
2. I usually share with others.
3. I am helpful if someone is hurt, upset, or feeling ill.
4. I am kind to other people.
5. I often volunteer to help others.

Depressive symptoms

Directions: This form is about how you might have been feeling or acting recently. For each question, please check how much you felt or acted this way in the **PAST TWO WEEKS.** If a sentence was **not true**, fill in the bubble for **not true**. If it was **sometimes true**, fill in the bubble for **sometimes.** If a sentence was **true most of the time**, fill in the bubble for **true.**

0 Not True 1 Sometimes 2 True

1. I felt miserable or unhappy.
2. I didn't enjoy anything at all
3. I was less hungry than usual.
4. I ate more than usual.
5. I felt so tired I just sat around and did nothing.
6. I was moving and walking more slowly than usual.
7. I was very restless.
8. I felt I was no good anymore.
9. I blamed myself for things that weren't my fault.
10. It was hard for me to make up my mind.
11. I felt grumpy and cross with my parents.
12. I felt like talking less than usual.
13. I was talking more slowly than usual.
14. I cried a lot.
15. I thought there was nothing good for me in the future.
16. I thought that life wasn't worth living.
17. I thought about death or dying.
18. I thought my family would be better off without me.
19. I thought about killing myself.
20. I didn't want to see my friends.
21. I found it hard to think properly or concentrate.
22. I thought bad things would happen to me.

23. I hated myself.
24. I felt I was a bad person.
25. I thought I looked ugly.
26. I worried about aches and pains.
27. I felt lonely.
28. I thought nobody really loved me.
29. I didn't have any fun at school.
30. I thought I could never be as good as other kids.
31. I felt I did everything wrong.
32. I didn't sleep as well as I usually sleep.
33. I slept a lot more than usual.

Aggressive behavior

Directions: During the past year, how many times did you…

1 Never 2 1-2 times 3 3-4 times 4 5-6 times 5 7 or more times

7. Get in a fight in which someone was hit?
8. Threaten to hit another kid?
9. Threaten a teacher?
10. Threaten someone with a weapon?
11. Shove or push another kid?
12. Hit or slap another kid?
13. Throw something at someone?
14. Put down someone?
15. Spread a rumor?
16. Pick on someone?
17. Exclude someone?
18. Insult someone's family?
19. Give mean looks?
20. Start a fight between others?

Appendix C

Institutional Review Board Approval

Oklahoma State University Institutional Review Board

Date: Wednesday, February 13, 2013 **Protocol Expires: 2/12/2014**

IRB Application No: HE0886

Proposal Title: Family and Youth Development Project - Lab Visit

Reviewed and Processed as: Expedited (Spec Pop) **Continuation**

Status Recommended by Reviewer(s) **Approved**

Principal Investigator(s)

Amanda Morris
1110 Main Hall
Tulsa, OK

Michael Criss
233 HES
Stillwater, OK 74078

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modifications to the research project approved by the IRB must be submitted for approval with the advisor's signature. The IRB office MUST be notified in writing when a project is complete. Approved projects are subject to monitoring by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

The reviewer(s) had these comments:

Approval is granted for continued analysis of previously collected data.

Signature : Shelia M. Kennison

Shelia Kennison, Chair, Institutional Review Board

Wednesday, February 13, 2013
Date

VITA

Lixian Cui

Candidate for the Degree of

Doctor of Philosophy

Thesis: RESPIRATORY SINUS ARRHYTHMIA BASELINE AND REACTIVITY TO INTERPERSONAL CHALLENGE: A DYNAMIC SYSTEMS APPROACH

Major Field: Human Sciences

Biographical: Born in Jiangxi, China to Rensheng Cui and Jinding Huang. Brother to Qin Cui and uncle to Yishuo Li.

Education:

Completed the requirements for the Doctor of Philosophy in Human Sciences at Oklahoma State University, Stillwater, Oklahoma in July 2013.

Completed the requirements for the Master of Science in Applied Psychology at Sun Yat-sen University, Guangzhou, China in June 2005.

Completed the requirements for the Bachelor of Science in Psychology at Southwest Normal University, Chongqing, China in June 2003.

Experience: Completed undergraduate study and obtained Master's Degree in China. Moved to the United States to pursue Doctoral Degree.

Professional Memberships: Society for Research on Adolescence (SRA); Society for Research in Child Development (SRCD); Society for Research in Human Development (SRHD); National Council on Family Relations (NCFR); Southwestern Psychological Association (SWPA); Oklahoma Council on Family Relations (OCFR)