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Assessing Biobehavioural Self-Regulation and Coregulation in Early Childhood: The Parent-Child Challenge Task

Erika Lunkenheimer[1], **Christine J. Kemp**[1], **Rachel G. Lucas-Thompson**[1], **Pamela M. Cole**[2], and **Erin C. Albrecht**[1]

[1]Colorado State University

[2]The Pennsylvania State University

Abstract

Researchers have argued for more dynamic and contextually relevant measures of regulatory processes in interpersonal interactions. In response, we introduce and examine the effectiveness of a new task, the Parent-Child Challenge Task, designed to assess the self-regulation and coregulation of affect, goal-directed behavior, and physiology in parents and their preschoolers in response to an experimental perturbation. Concurrent and predictive validity was examined via relations with children's externalizing behaviors. Mothers used only their words to guide their 3-year-old children to complete increasingly difficult puzzles in order to win a prize ($N = 96$). A challenge condition was initiated mid-way through the task with a newly introduced time limit. The challenge produced decreases in parental teaching and dyadic behavioral variability and increases in child negative affect and dyadic affective variability, measured by dynamic systems-based methods. Children rated lower on externalizing showed respiratory sinus arrhythmia (RSA) suppression in response to challenge, whereas those rated higher on externalizing showed RSA augmentation. Additionally, select task changes in affect, behavior, and physiology predicted teacher-rated externalizing behaviors four months later. Findings indicate the Parent-Child Challenge Task was effective in producing regulatory changes and suggest its utility in assessing biobehavioral self-regulation and coregulation in parents and their preschoolers.

Keywords

parent-child interaction; self-regulation; coregulation; externalizing behavior problems; respiratory sinus arrhythmia; dyadic methods

Early childhood is a time of particular importance for the development of self-regulation. Preschoolers experience rapid growth in the emotional, cognitive, behavioral, and social skills that service regulatory ability (Calkins, 2007) while also actively internalizing the capacity to self-regulate, bolstered by caregivers' attempts to shape these skills (Olson & Lunkenheimer, 2009). The complexity of rapid changes across multiple domains combined with dynamic regulatory responses driven by individual and relational goals can make it challenging to measure self-regulation in this age range. Given this complexity, it is not

Corresponding author: Erika Lunkenheimer, PhD, Human Development & Family Studies, Colorado State University, 1570 Campus Delivery, Fort Collins, CO, 80523-1570, Phone: (970) 491-2794, Fax: (970) 491-7975, erika.lunkenheimer@colostate.edu.

surprising that there are few experimental tasks designed to assess both individual and dyadic regulatory processes across domains (affect, goal-directed behavior, and physiology) in early childhood. However, parent-child coregulation is an important and formative developmental process with effects on multiple outcomes, including the child's internalization of rules, self-control, and behavior problems (Cole, Teti, & Zahn-Waxler, 2003; Feldman, Greenbaum, & Yirmiya, 1999; Kochanska, 1997). Changing patterns of parent-child coregulation also act as markers of treatment effectiveness in evidence-based family interventions (Granic, O'Hara, Pepler, & Lewis, 2007). Accordingly, we argue that an experimental paradigm that more effectively allows for the integrated study of child self-regulation and parent-child coregulation in early childhood is crucial.

Researchers have argued for more dynamic and contextually relevant measures of regulatory processes, and three specific methodological issues appear to be critical. First, researchers have emphasized that regulation should be measured in the context of challenge or stress (Cole, Martin, & Dennis, 2004). In other words, self-regulation is a process that cannot occur without an internal or external demand that requires the system to change. Second, self-regulation is a multidimensional process involving the active coordination of emotions, goal-directed behavior, and physiology (Thompson, Lewis, & Calkins, 2008) and thus a multi-method approach to measurement is preferred (Smith, Hubbard, & Laurenceau, 2011). Third, in infancy, toddlerhood, and early childhood in particular, self-regulation is largely a dyadic process in which caregiver and child each regulate, and are regulated by, one another's expressed affect, behavior, and physiology (Calkins, 2011; Fogel, 1993). Thus, studies of self-regulation in this age range should consider dyadic measures in addition to individual measures.

In line with these three guidelines (which we expand upon in the sections that follow), the first author developed the Parent-Child Challenge Task (PCCT), an experimental laboratory task with parents and preschoolers designed to induce regulatory changes. The present study examined the effectiveness of this task in producing real-time individual and dyadic changes in affect and goal-directed behavior and individual changes in parasympathetic processes (respiratory sinus arrhythmia) in parents and their preschoolers. Concurrent and predictive validity of the task was examined via relations with children's externalizing behavior problems, as they have been shown to be a reliable proxy of dysregulation in the child and have been empirically linked to individual and dyadic affective, behavioral, and physiological regulatory processes (Hastings et al., 2008; Lunkenheimer, Olson, Hollenstein, Sameroff, & Winter, 2011; Olson, Sameroff, Kerr, Lopez, & Wellman, 2005).

Regulation in the Context of Challenge

As a moving target, it is inherently difficult to measure when self-regulation has occurred. Regulatory processes are contingent upon the individual's goals and contextual demands (Cole, Michel, & Teti, 1994) and therefore may fluctuate as these goals and demands change in real time. Therefore, in order to detect a change in affect, behavior, or physiology that can be considered "regulatory," typically one must use an experimental perturbation that creates some pressure on the individual to change (Cole et al., 2004). Broadly, these sorts of experimental perturbations have been effective in examining the regulation of emotion, behavior, and physiology (Carlson & Wang, 2007; Papousek, Harald Freudenthaler, & Schulter, 2011; Schmitz et al., 2011; Tobin & Graziano, 2011). In the preschool period, prime examples of paradigms that assess individual child regulatory dimensions in response to changes in experimental conditions include the disappointment task (Cole, Zahn-Waxler, & Smith, 1994), the mishap task (Cole, Barrett, & Zahn-Waxler, 1992), effortful control tasks (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996), and cognitive- and attention-shifting tasks (Zelazo et al., 2013). Though these sorts of tasks have been essential to the study of self-regulation in early childhood, they are primarily designed to measure specific rather than multiple domains of regulation and they center on individual rather than dyadic task goals.

Dyadic tasks can also be effective at producing observable changes through experimental perturbation. With regard to parent-infant interactions, primary examples include the Strange Situation (Ainsworth & Bell, 1970) and the Still Face paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978). These tasks allow for the study of both individual and dyadic regulation across time and situational contexts based on changes within condition (e.g., the effect of a stressor on behaviors) or across conditions (e.g., comparison of behavior patterns from baseline to stressor conditions). For example, research has shown differences in infant physiological responding to conditions of the Still Face paradigm depending on maternal sensitivity (Conradt & Ablow, 2010) as well as changes in dyadic affective flexibility between parent and infant following experimental perturbation in the Still Face (Sravish, Tronick, Hollenstein, & Beeghly, 2013). These types of tasks also align with our theoretical frameworks about how regulatory processes operate: emotions, behaviors, and physiology are coordinated to meet individual or dyadic goals (Cole, Michel, et al., 1994), they fluctuate across time, relationships, and contexts (Lazarus, 1991), and they organize into predictable patterns that can reveal individual differences in individual or dyadic functioning (Hollenstein & Lewis, 2006). However, we lack common observational task paradigms that are developmentally appropriate for dyadic parent-child interactions during preschool.

The PCCT includes aspects that have been previously used in experimental paradigms to produce challenge or stress (e.g., Hoffman, Crnic, & Baker, 2006): it is a challenging task that is above the natural ability level of the child given their age or developmental status, and it involves three puzzles that increase in difficulty as the task progresses. What is novel about the experimental design is combining these previous features with: a) a sudden time constraint midway through the task; b) specific instruction that the dyad must work together but that the parent can instruct the child with only his/her words and not physically assist the child; and c) the stipulation that the child will only win a prize if the task is completed (when, in actuality, all children receive the prize regardless). A task such as the PCCT that has a clear dyadic goal, includes a discrete, mildly stressful perturbation, and is developmentally appropriate for preschoolers has the advantage of revealing individual and dyadic differences in how parent-preschooler dyads regulate in response to contextual challenge.

Regulation is Multidimensional

Theorists agree that emotion, goal-directed behavior, and physiology are all involved in the service of self-regulation, and thus examining one in the absence of other dimensions may render an incomplete picture of regulatory processes (Smith et al., 2011). Various studies have illustrated the dynamic interdependence of affect and goal-directed behavior in parent-child coregulation (Del Vecchio & Rhoades, 2010; Dumas, LaFreniere, & Serketich, 1995; Kochanska, 1997; Lunkenheimer et al., 2011; Moore et al., 2013). For example, Dumas, Lemay, and Dauwalder (2001) demonstrated that in typical parent-child interactions, aversive emotions co-occurred with maternal control resulting in child noncompliance, whereas positive emotions co-occurred with maternal control resulting in child compliance. Other research using tasks that prompt for child self-regulation has shown that maternal positive emotion tends to increase as children's regulatory efforts increase over time (Cole, LeDonne, & Tan, 2013).

More recently, the inclusion of physiological measures has added to our understanding of self-regulation and coregulation in children and their parents (Feldman, 2012). Of particular relevance to regulation is respiratory sinus arrhythmia (RSA), an index of vagal tone/ reactivity and parasympathetic functioning (Porges, Doussard-Roosevelt, & Maiti, 1994). Vagal tone (during periods of low stress) arguably reflects the ability to maintain homeostasis when physiological systems are not perturbed and the capacity to react to stress; low resting vagal tone in particular has been considered an indicator of emotion dysregulation (Beauchaine, 2001). In the face of stress, an adaptive parasympathetic response is typically manifest as vagal suppression, resulting in decreased RSA (Porges, 2007). Vagal suppression reflects putting a "brake" on parasympathetic regulatory processes in order to activate the body's sympathetic (i.e., fight or flight) regulatory processes, thus representing a mobilization of resources to respond to environmental demands (Bornstein & Suess, 2000). Vagal augmentation, on the other hand, characterizes episodes of low social or environmental demand or stress (Porges, 2007), and thus vagal augmentation as a response to stress has been associated with dysregulated emotion and behavior (Hastings et al., 2008).

RSA suppression in response to stress may be coordinated with emotion or behavior in the service of self-regulation; for example, more expressed positive affect has been linked to greater RSA suppression across tasks in high-fear toddlers (Brooker & Buss, 2010). We may also see linkages between resting RSA profiles and affect and behavior during parent-child interactions (Mills-Koonce et al., 2009). For example, parents with dysregulated physiology as indexed by a consistent hyper- or hypo-arousal RSA profile were more likely to engage in harsh and intrusive behavior or disengaged behavior, respectively, in parent-child interactions (Sturge-Apple, Skibo, Rogosch, Ignjatovic, & Heinzelman, 2011). However, RSA suppression or augmentation can also occur in the absence of other expected behavioral or psychological indicators (Porges, 2007). Evidence also suggests that parents and children may coordinate parasympathetic processes during both typical and challenging situations (Lunkenheimer et al., 2015). For example, Moore and colleagues found that infants showed RSA suppression and parents showed RSA augmentation during the disrupted interaction condition in the Still Face Paradigm (Moore et al., 2009). However, Bornstein and Suess (2000) found mother-child concordance in vagal reactivity (baseline-to-task changes) from child ages 2 months to 5 years, but no concordance in baseline vagal measures. In sum, we have more to learn about how physiology is related to other domains of regulation and how it is coordinated between parents and children; accordingly, we took a multi-method approach by including affect, goal-directed behavior, and physiology in the present study.

It is also important to consider that regulatory processes may differ by other individual factors (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005), including the risk level of the child or family. In particular, research has shown consistent differences in affect, behavior, and physiological arousal related to children's externalizing problems (Hastings et al., 2008). Lower levels of basal RSA and greater RSA augmentation (as opposed to suppression) during stress or challenge have been associated with concurrent and later externalizing problems (Hinnant & El-Sheikh, 2009). We would also expect that parental behavior might differ by individual child factors, for example, that parents would adjust their guidance in problem-solving situations according to the child's competencies or difficulties in regulatory ability (Dennis, 2006). Accordingly, we examined whether changes in affect, goal-directed behavior, and physiology were related to the child's concurrent and later externalizing behavior problems, which also acted as a test of concurrent and predictive validity of the task.

Regulation as a Dyadic Process

In infancy, toddlerhood, and early childhood, child emotion regulation is largely a dyadic process, heavily dependent upon the caregiver's own self-regulation, affect, and goal-directed behavior (including discipline, socialization, and support) (Calkins, 2010; Cole et al., 2004). Although research has addressed coregulation between parents and infants (Cerezo, Trenado, & Pons-Salvador, 2012; Feldman, 2003; Moore et al., 2013; Weinberg, Olson, Beeghly, & Tronick, 2006), comparatively less research has taken a dynamic, dyadic analytic approach to examining coregulation patterns during the preschool years. An exception to this is research on dyadic affective and behavioral flexibility, rigidity, and variability in early parent-child interactions. Available empirical evidence suggests that baseline dyadic affective and behavioral rigidity during this developmental stage are markers of risk in the parent and child, associated with maternal depressive symptoms, maternal hostility, and children's externalizing problems (Dagne & Snyder, 2011; Dumas et al., 2001; Hollenstein, Granic, Stoolmiller, & Snyder, 2004; Lunkenheimer, Albrecht, & Kemp, 2013; Lunkenheimer et al., 2011). This evidence suggests that when dyadic measures are paired with individual measures, it provides additional information about the adaptive or maladaptive nature of regulatory processes.

Although stable dyadic patterns between parent and child are informative, the investigation of how these dyadic patterns then change in response to challenge allows us to gain even more insight into individual differences in functioning. For example, the use of State Space Grids (SSG; Lewis, Lamey, & Douglas, 1999) has revealed systematic dyadic changes in response to experimental perturbations in middle childhood and adolescence. Hollenstein and Lewis (2006) used SSG to show that lower flexibility across both positive and negative mother-daughter conversations characterized higher-stress dyads. In addition, Granic and colleagues demonstrated changes in parent-child interaction patterns using SSG that distinguished improvers from non-improvers in family intervention (Granic et al., 2007).

Despite this promising work, we still know little about how the parent-child dyad coregulates in response to an experimental perturbation in the preschool years. Coregulation in preschool has already been linked to multiple indices of concurrent and later child functioning (Cole et al., 2003; Hollenstein et al., 2004; Scaramella et al., 2008). Thus, given the importance of early coregulatory processes and the prior effectiveness of SSG in studying dyadic changes across task conditions, we used SSG to evaluate whether there were significant regulatory changes at the dyadic level in the context of this novel task. This aim was designed to validate the effectiveness of the task in prompting dyadic regulatory responses, as well as explore whether dyadic and individual regulatory patterns during the task informed one another.

Present Study

The first research question was whether the challenge condition of the PCCT produced *individual changes* in affect (valence and intensity of affective expression), goal-directed behavior (mother teaching and intrusion, child compliance and noncompliance), and physiology (mean-level RSA) in mothers and their three-year-old children. The second research question was whether the challenge condition of the PCCT produced *dyadic changes* in affect and goal-directed behavior, specifically changes in variability in affective and behavioral dyadic states as measured with State Space Grids. Analyses included children's externalizing problems as a covariate to examine whether regulatory changes prompted by the task showed *concurrent validity* with individual indices of child dysregulation. The third research question was whether changes in mother and child affect, goal-directed behavior, and physiology during the PCCT (Time 1) showed evidence of *predictive validity* in predicting teacher ratings of the child's externalizing behavior problems at a four-month follow-up assessment (Time 2), controlling for externalizing problems at Time 1.

We made select hypotheses about the effect of the experimental challenge on individual changes in behavior and physiology. First, we hypothesized that mothers and children would show reduced adaptive behaviors, increased maladaptive behaviors, and RSA suppression (Porges et al., 1994) in response to the challenge. We also expected that adaptive and maladaptive behavior during the task would be negatively and positively related, respectively, to child externalizing problems concurrently and at follow-up (Cole et al., 2003). We also expected that greater RSA augmentation in response to the challenge would characterize children with higher externalizing problems concurrently and at follow-up, in line with past research (Hinnant & El-Sheikh, 2009). With regard to affect, we hypothesized that mothers would show decreases in positive affect and increases in negative affect in response to the challenge. However, we made no specific hypotheses about changes in child affect given that children may express positive or negative affect when dysregulated (Callender, Olson, Kerr & Sameroff, 2010).

Given the relative paucity of research using measures of dyadic variability, we did not make specific hypotheses about dyadic changes in affect and behavior across the two task conditions. However, we did generally expect that dyadic affective and behavioral variability would be negatively related to concurrent and later child externalizing problems given prior research showing a link between dyadic rigidity and child externalizing (Hollenstein et al., 2004). Further, one prior study on the baseline condition only of the PCCT showed a link between lower mother-child affective flexibility during this condition and children's higher externalizing problems (Lunkenheimer, Albrecht, & Kemp, 2013), so we expected that these relations might extend to the challenge condition and to individual and dyadic regulatory changes across conditions also. If these aforementioned hypotheses were supported, it would provide evidence that the PCCT was effective at invoking regulatory responses at individual and dyadic levels, and that the behaviors prompted by the task were in the expected direction of concordance with a proxy of dysregulation in children (i.e., externalizing problems).

Method

Participants

Participants were 96 children (54% female) and their families, identified as 86% White, 8% Biracial, 3% Asian, and 3% "other" race, and 10% Hispanic or Latino ethnicity. Children were 41 months old on average at Time 1 ($SD = 3$). Median annual family income was $65,000 and parental education was high on average (college graduate). Marital status was 79% married, 7% cohabiting, 7% single, 5% separated or divorced, and 1% remarried. Participants were recruited via flyers placed in day care centers, preschools, and businesses, and through email listserves of agencies serving families with young children. Families were excluded if the family could not speak or read in English, if children had a pervasive developmental disorder, or if mothers or children had a medical condition that interfered with heart rate data collection.

Procedure

During a 2.5-hour laboratory visit at Time 1, mothers filled out questionnaires on child externalizing problems while the child completed tasks with the experimenter. Mothers and children also completed four dyadic tasks, including the PCCT. Father-child interaction data was not available due to project constraints, but fathers completed questionnaires that were mailed home or brought to the laboratory. Families were compensated $50 for laboratory sessions and mother questionnaires, and an additional $20 for father questionnaires. Time 2 was conducted 4 months later and consisted of mothers, fathers, and teachers filling out online questionnaires only, including a measure of externalizing behavior problems. Parents and teachers were compensated with a $20 gift card for their participation at Time 2. Please see Lunkenheimer, Kemp, et al. (2013) for more information about the procedure and study. All study measures and procedures were approved by the Institutional Review Board.

Measures

The Parent-Child Challenge Task (PCCT)—The PCCT was developed by the first author to study dyadic patterns during a challenging, problem-solving situation in early childhood. The task was conducted and videotaped in the laboratory with mother and child seated at a table at child height. Mothers were instructed to help their children complete a puzzle using only their words (but to not physically help the child complete it). The puzzle (Castle Logix, Smart Games) was designed for children 5 years and older and thus 3-year-olds could not complete it without guidance. It was a three-dimensional puzzle made of 7 wooden pieces of varying colors and lengths. The pieces fit together in various configurations to create different castles as depicted in a guidebook. Dyads were directed to work on three specific puzzle designs from the guidebook in a particular order that increased in difficulty (one easy, one moderate, and one difficult) and were given no time limit. The dyad was told that if they completed all three of the specified designs, the child would win a prize. This incentive was designed to create a clear goal and encourage persistence at the task; however, in reality, children received the prize at the end of the task regardless of whether or not they finished all three designs. After four minutes, the experimenter knocked on the door and interrupted the dyad to provide a new time limit, telling mothers that they had only two minutes remaining to finish, which initiated the "challenge" condition. At the end of the two minutes, the experimenter returned and apologized, saying, "We discussed it and we don't think we gave you quite enough time to finish, and you worked so hard, so here's your prize!" The task was 6 total minutes in length. Given the deception involved, all mothers were debriefed verbally and in writing at the end of the session and given the option to remove their data if they were uncomfortable with the deception; no mothers chose this option. Of the original 100 families in the study, four were excluded due to equipment malfunction ($n = 2$) and speaking a language other than English for portions of the task ($n = 2$). This resulted in a valid N of 96 families for whom we had dyadic data.

Observational coding system—Mother and child behaviors were coded continuously in real time with the Dyadic Interaction Coding system (Lunkenheimer, 2009). Behavioral observations were recorded using the Noldus Observer XT 8.0 software. Mothers and children were coded in continuous time along two dimensions, "affect" and "behavior," and all codes were mutually exclusive. Three student coders were tested for reliability on 20% of the dataset in relation to a standard set by the first author and a trained graduate student. Reliability analysis was performed in the Noldus Observer 8.0 XT using a standard 3-second window. All affect and behavioral variables at the individual level were operationalized as the rate per minute, which allowed us to compare across task conditions of varying lengths.

Goal-directed behavior—There were nine codes for parent behavior: teaching, directive, proactive structure, positive reinforcement, emotional support, engagement, disengagement, intrusion, and negative discipline. There were seven codes for child behavior: compliance, persistence, social conversation, solitary/parallel play, noncompliance, disengagement, and behavioral dysregulation (i.e., tantrum). All of these behaviors were involved in the calculation of dyadic behavioral flexibility; however, for analyses of individual change, we could not examine all 16 possible behaviors and thus we selected specific mother and child behaviors to represent "adaptive" or "maladaptive" behaviors for parsimony. Considering that the PCCT is a teaching task that requires the parent to guide the child to complete a challenging puzzle without physically assisting the child, we selected behaviors that would be the most likely to be called for and would reflect adaptive and maladaptive responses in this particular situation. For mothers, we selected *teaching* (Landry, Smith, Swank, & Miller-

Loncar, 2000) to reflect the mother's adaptive approach to guiding her child to perform the task, and *intrusion* (Sturge-Apple et al., 2011) to reflect her choice not to teach or guide the child and instead complete the puzzle by herself. For children, we selected *compliance* and *noncompliance* as adaptive and maladaptive responses, respectively, to parental guidance as far as completing the task (e.g., Dennis, 2006; Kochanska & Aksan, 1995). We expected that adding time and other constraints on the dyad's ability to complete the teaching task would produce changes in these particular behaviors.

Teaching involved instances when mothers provided explanatory instruction (e.g., "The blue piece is the one that stands up" or "The green one goes in the middle") or when mothers posed open-ended questions that gave the child the opportunity to respond and/or learn about the task (e.g., "What do you see in the picture?" or "Where do you think this goes?"). Percentage interrater agreement for teaching was 83%.

Intrusion was defined as instances where mothers "took over" the child's efforts to complete the task in a way that was not supportive. Intrusion captured instances of mothers taking a toy away from their children in order to use it themselves, or when mothers completed a portion of the task for the child, even after receiving the experimenter's instructions not to do so. Furthermore, some instances of physical contact were also coded as intrusion, such as times when mothers restrained children from playing in a certain way (other than when the mother was ensuring the safety of the child). Percentage interrater agreement for intrusion was 86%.

Compliance was defined as the child's compliant response to the mother's agenda, which was typically conveyed via responding to maternal directives for specific behavior change (e.g., completing a task requested by the mother, stopping off-task behavior) or responding to maternal teaching (e.g., answering a mother's question, trying a solution to the puzzle after the mother provided instruction on how to do it). If the child's compliant response occurred within 10 seconds of the mother's prompt, this was coded as compliance; noncompliance was coded if 10 or more seconds had passed without a compliant response to the parental prompt. Percentage interrater agreement for compliance was 85%.

Noncompliance was defined as times when the child clearly ignored, disagreed, or refused to cooperate with the mother's directive, teaching, or proactive structure statement. Noncompliance could be demonstrated in a passive form (e.g., the child ignoring the mother's request), refusal (e.g., the child says "no" to the mother's request), or defiance (e.g., the child shows behavioral defiance such as throwing a tantrum after a request). Children were given a window of 10 seconds to comply with a request before their behavior was coded as noncompliance. Percentage interrater agreement for noncompliance was 80%.

Affect—*Affect* was captured with four codes, reflecting verbal and nonverbal expressions: negative, neutral, low positive, and medium-high positive affect. These same four codes were used for mothers and children, but reflected typical differences in intensity of expression between adults and preschoolers. *Negative affect* reflected any expression of negative affect at all, including irritation, annoyance, distress, anger, disgust, sadness, discomfort, fear, nervousness, or anxiety. For mothers, common examples included heavy sighs, eye rolling, sharp vocal tone, frowning, or narrowed eyes. For children, common examples included stomping, crying, yelling in anger, or frowning. *Neutral affect* reflected the absence of verbal or nonverbal affective expression. Examples included a lack of eye contact, the absence of a particular facial expression (e.g., smile or frown), and/or a relatively flat vocal tone with few fluctuations or lilts. *Low positive affect* reflected the expression of low intensity positive affect, such as positive lilts or warmth in vocal tone, a smile, and/or warm eye contact that conveyed interest or engagement. *Medium-high positive affect* reflected the expression of medium or high intensity positive affect, such as the use of a high pitch to express excitement or gain the other's attention, open mouth smiles, laughing, giggling, or hugging. Interrater agreement for the maternal negative, neutral, low positive, and medium-high positive affect codes was 96%, 93%, 91%, and 91%, respectively. Interrater agreement for the child negative, neutral, low positive, and medium-high positive affect codes was 100%, 95%, 85%, and 85%, respectively. For the purposes of the present study, only changes in positive and negative affect were examined, and low and high levels of positive affect were combined for parsimony. Thus, there were two variables each for mother and child: positive affect and negative affect.

Dyadic variability—Dyadic variability was derived using the aforementioned coding system and calculated using Gridware 1.15 (Lamey, Hollenstein, Lewis, & Granic, 2004). Mother and child affect or behavior, respectively, was mapped onto state space grids (Lewis, Lamey, & Douglas, 1999), with child affect or behavior along the X-axis and mother affect or behavior along the Y-axis. For affect, there were four codes each for mother and child, resulting in a 4 X 4 or a 16-cell grid. For goal-directed behavior, there were nine codes for the mother and seven for the child, resulting in a 9 X 7 or a 63-cell grid. The sequence of dyadic affective or behavioral states was plotted as it proceeded in real time on the grid, with a grid for each mother-child dyad. Subsequently, aggregate indices of dyadic patterns were exported from these grids. For more examples of how state space grids can be used to visualize parent-child coregulation, please refer to Lunkenheimer et al. (2011) and Lunkenheimer, Albrecht et al. (2013).

Dyadic variability was operationalized as the dispersion of dyadic affective or behavioral states across cells in the grid, with the more evenly distributed behavior representing greater variability. It was calculated as the sum of squared proportional durations across all cells, adjusted for the total number of cells in the grid matrix and inverted so that cell values range from zero (no dispersion; all behavior in one cell) to one (maximum dispersion; behavior equally distributed across the grid). The corresponding formula is $[\{n\Sigma\ (d_i/D)^2\}-1]/n-1$ where D is the total duration, d is the duration in cell i, and n is the total number of possible cells in the grid (Lamey et al., 2004). Other State Space Grid indices can be used to represent dyadic variability or flexibility such as the rate of transitions and the range of cells visited. However, dispersion was chosen for the present study because it takes the interaction duration into account, which allowed for the comparison of two conditions with varying time lengths.

Respiratory sinus arrhythmia (RSA)—Physiological data for mother and child was acquired via the Mindware 3000A Wireless System. Disposable electrocardiogram (ECG) electrodes were placed over the mother or child's right clavicle and the left side below the ribcage (the recording electrodes), as well as on the right side below the ribcage (the grounding electrode). A crystal respiratory effort belt was placed below the diaphragm to monitor respiration throughout the session. Both were connected to handheld computers placed in backpacks worn by each participant throughout the session that communicated wirelessly with a desktop computer in the adjacent observation suite. Interbeat interval data was edited for artifacts due to mother and child movement; epochs that required more than 10% editing were dropped from analysis. RSA magnitude was calculated as the natural logarithm of the variance of heart period within the frequency bandpass related to respiration (0.24–1.04 Hz for children and 0.12–0.40 for adults) (Fracasso, Porges, Lamb, & Rosenberg, 1994) using a software package (Biolab 2.5; Mindware Technologies, Columbus, OH). Mean RSA magnitude was calculated for each 30-second interval and statistical outliers of the resulting RSA values were dropped from analysis. RSA values were then averaged across baseline and challenge conditions, respectively (e.g., Bornstein & Suess, 2000). There were wireless interference problems in the laboratory space such that the wireless connection was often difficult to establish, or if the connection was broken, it was difficult to re-establish. Accordingly, only 45 families had complete and valid RSA data during the PCCT. On average, families with intact data differed such that they had higher annual income, $t = 2.32$, $p < .05$, their children were older, $t = 2.80$, $p < .01$, and these children were rated lower on externalizing problems by mothers, $t = -2.16$, $p < .05$. These families did not differ on any other study variables.

Externalizing problems (EXT)—Mothers and teachers reported on child externalizing problems via the Child Behavior Checklist (CBCL/1.5–5; Achenbach & Rescorla, 2000). This subscale reflects impulsivity, poor attentional control, and aggressive behavior. Convergent validity has been established with other measures of behavioral dysregulation (Olson et al., 2005). Cronbach's alpha was .89 for Time 1 mother ratings and .93 for Time 2 teacher ratings.

Analytic Plan

The present study was designed to explore the effectiveness of a novel task (PCCT) in producing differences in individual and dyadic responses to an experimental perturbation. According to this aim and its descriptive nature, multiple analyses were conducted using change scores, in which baseline condition scores were subtracted from challenge condition scores. First, repeated measure analyses of variance (RM ANOVA) were conducted to explore changes from the baseline to the challenge condition separately for all individual and dyadic variables of interest. Concurrent child externalizing problems were entered as a covariate in these models. Second, linear regression analyses were conducted to explore the utility of the PCCT in predicting later child externalizing problems. Thus, regulatory responses to the task (i.e., change scores) were used to predict children's externalizing problems at T2, controlling for baseline externalizing problems at T1, separately for each variable of interest. Given that multiple analyses were performed, a false discovery rate methodology (Benjamini & Hochberg, 1995) was applied in order to adjust alpha values to guard against Type I error. This method utilizes the number of analyses performed and a model's relative rank in significance compared to other analyses in order to determine the appropriate alpha value per analysis.

Results

Preliminary Analysis

Please see Table 1 for raw descriptive data on all variables. There were significantly skewed and/or kurtotic distributions for some of the observed individual-level variables (mother and child positive and negative affect, child noncompliance, and maternal intrusion). Thus, these variables were log transformed prior to conducting primary analyses.

Primary Analyses

Individual changes in the PCCT—The first research question was whether there were individual-level changes in mother and child response to the experimental perturbation in terms of affect, goal-directed behavior, and physiology. In each analysis, the main effect of condition (baseline vs. challenge) and the effect of an interaction between condition and children's concurrent mother-rated externalizing problems were examined using RM ANOVA. Please see Table 2 for all RM ANOVA results.

With respect to affect, there was an increase in the rate of mother positive affect, child positive affect, and child negative affect from the baseline to the challenge condition. There were no significant changes in mother negative affect. The change in child positive affect was marginally related to child externalizing such that children rated higher on externalizing problems showed a greater increase in positive affect from the baseline to the challenge condition. Results for mother positive affect and child negative affect remained significant after applying the false discovery rate adjustment, though results for child positive affect fell to non-significance ($p = .032$, adjusted $\alpha = .025$).

With respect to goal-directed behavior, there was a decrease in the rate of maternal teaching and child compliance, as well as an increase in the rate of maternal intrusion, from the baseline to the challenge condition. There were no significant changes in child noncompliance. In this analysis, changes in maternal teaching remained significant after adjusting for the false discovery rate; changes in maternal intrusion ($p = .034$, adjusted $\alpha = .029$) and child compliance ($p = .047$, adjusted $\alpha = .033$) no longer met criteria for significance. Maternal teaching showed a trend towards a steeper decline from the baseline to the challenge condition with children rated higher on externalizing problems (Figure 1a). Otherwise, these changes did not differ significantly by the child's externalizing behavior.

With respect to physiology, there were no significant changes in mother or child average RSA from the baseline to the challenge condition. However, as hypothesized, analyses showed that the child's RSA augmentation in response to the perturbation was associated with higher maternal ratings of child externalizing problems. Thus, there was an interaction between condition and externalizing problems such that children with low levels of externalizing problems displayed RSA suppression from baseline to challenge conditions, whereas children with high levels of externalizing problems displayed RSA augmentation (Figure 1b). However, this finding did not meet criteria for significance using the false discovery rate method ($p = .045$, adjusted $\alpha = .004$). There were no significant differences in mother RSA change by children's externalizing problems.

Dyadic changes in the PCCT—The second research question was whether there were dyadic-level changes in response to the experimental perturbation in terms of affect and goal-directed behavior. Again, RM ANOVA was used for all analyses (Table 2). Once again, the main effect of condition (baseline vs. challenge) and the effect of an interaction between condition and children's concurrent, mother-rated externalizing problems were examined. With respect to affect, there was an increase in dyadic affective variability from the baseline to the challenge condition as indicated by a higher dispersion of dyadic affective states utilized. Please see Figure 2 for an illustration of the increase in affective variability for the entire sample from the baseline to the challenge condition. With respect to goal-directed behavior, there was a decrease in dyadic behavioral variability from the baseline to the challenge condition as indicated by a lower dispersion of dyadic behavioral states utilized. Thus, affective variability increased and behavioral variability decreased in response to the experimental challenge. These changes did not differ by the child's externalizing problems, and remained significant after making adjustments for the false discovery rate.

PCCT changes predicting teacher ratings of child externalizing—The third research question was regarding the predictive validity of the PCCT. We examined whether change from baseline to challenge conditions (in individual and dyadic measures of affect, behavior, and physiology) predicted children's externalizing problems as rated by teachers at a 4-month follow-up assessment (Time 2). We controlled for Time 1 maternal ratings of child externalizing problems to determine whether PCCT measures predicted children's externalizing behavior controlling for stability in child behavior over time. Also, in analyses of physiological regulation only, we controlled for baseline RSA values as a proxy for resting RSA, given that resting RSA has been shown to relate to children's externalizing problems (Hinnant & El-Sheikh, 2009). Thus, linear regressions were performed with Time 1 externalizing entered first (followed by baseline RSA in analyses of physiology only), and then the respective change score variable of interest (Challenge Score minus Baseline Score). Please see Table 3 for regression results.

In analyses of *individual affect*, change in child positive affect was predictive of teacher ratings of externalizing at Time 2, controlling for maternal ratings of externalizing at Time 1, $F(65) = 4.77$, $p < .05$, $R^2 = .13$. Specifically, when children increased in positive affect in response to the perturbation, this was associated with higher externalizing problems at Time 2. To interpret this effect, we conducted a median split on Time 2 externalizing (adjusted for Time 1 externalizing) and plotted the mean child positive affect scores for high and low externalizing groups in the baseline and challenge PCCT conditions (Figure 3a). When children showed lower levels of positive affect at baseline and then increased in positive affect in response to the challenge, this was associated with higher externalizing problems at Time 2. In contrast, children with lower externalizing problems showed higher positive affect at baseline that did not change from the baseline to the challenge condition (Figure 3a). This finding held when the false discovery rate adjustment was applied. Changes in child negative affect and mother positive and negative affect during the PCCT did not predict children's later externalizing problems as rated by teacher.

In analyses of *individual goal-directed behavior*, changes in child noncompliance predicted teacher ratings of externalizing at Time 2, controlling for maternal ratings of externalizing at Time 1, $F(65) = 3.09$, $p = .05$, $R^2 = .09$. Specifically, when children decreased noncompliance in response to the experimental perturbation, it was associated with higher levels of later externalizing problems. To interpret this effect, we conducted a median split on Time 2 externalizing (adjusted for Time 1 externalizing) and plotted the mean child noncompliance scores for high and low externalizing groups in the baseline and challenge PCCT conditions (Figure 3b). When children showed higher levels of noncompliance at baseline and then decreased noncompliance in response to the challenge, it was associated with higher externalizing problems. Comparatively, children in the low-externalizing group started out with low noncompliance at baseline, which increased in response to the challenge (Figure 3b).

Changes in maternal teaching also predicted teacher ratings of externalizing at Time 2, $F(65) = 5.40$, $p < .01$, $R^2 = .15$. Specifically, when mothers increased teaching from the baseline to the challenge condition, their children had higher teacher-rated externalizing problems at Time 2. To interpret this effect, we conducted a median split on Time 2 externalizing (adjusted for Time 1 externalizing) and plotted the mean parent teaching scores for high and low externalizing groups in the baseline and challenge PCCT conditions (Figure 3c). Specifically, when mothers showed low levels of teaching at baseline and therefore showed less decrease in teaching from the baseline to the challenge condition, their children were rated by teachers as having higher levels of externalizing problems at Time 2. Comparatively, mothers of children in the low-externalizing group showed higher levels of teaching at baseline (Figure 3c). When adjusted for the false discovery rate, the finding regarding teaching held, but the finding regarding child noncompliance was no longer significant ($p = .021$, adjusted $\alpha = .013$). Maternal intrusion and child compliance during the PCCT were not predictive of children's later externalizing problems.

In analyses of *individual physiology*, changes in child RSA showed a trend in significance that paralleled earlier findings, $F(37) = 2.60$, $p = .06$, $R^2 = .19$. Specifically, when child RSA increased in response to the challenge condition (i.e., RSA augmentation), this augmentation pattern was associated with higher levels of teacher-rated externalizing problems at Time 2. However, this parameter fell to non-significance once the false discovery rate was applied ($p = .041$, adjusted $\alpha = .017$). With regard to mother RSA, changes in mother RSA were not predictive but maternal baseline RSA did predict teacher ratings of children's externalizing problems, $F(37) = 3.09$, $p < .05$, $R^2 = .22$. Specifically, lower maternal RSA during the baseline condition predicted higher child externalizing problems at Time 2, B = −4.43, $p < .01$, CI = −5.51 – 6.68. With respect to changes in *dyadic variability in affect and behavior*, neither analysis was significant in predicting children's later externalizing behavior problems.

Discussion

The present study provided preliminary evidence for the effectiveness of a new observational task, the Parent-Child Challenge Task, in prompting individual and dyadic regulatory changes in parents and their preschoolers. The majority of measures of affect and behavior showed changes as a result of the experimental perturbation. Further, select measures of affect, goal-directed behavior, and physiology showed expected relations with children's externalizing problems, suggesting partial evidence for concurrent and predictive validity with measures of child dysregulation. This suggests the PCCT has utility as a tool with which to assess biobehavioral regulation and coregulation in parents and their preschoolers. This is notable given that there are few experimental paradigms available designed to prompt regulatory changes in the parent-child dyad that are developmentally relevant to early childhood. These findings also offer implications for the utility of measuring multiple domains of regulation concurrently as well as examining both individual and dyadic responses to challenge in real time.

Individual Changes in the PCCT

At the individual level, the findings followed expectations that the PCCT's experimental challenge would result in reduced adaptive behaviors, increased maladaptive behaviors, and a physiological regulatory response. Mothers showed declines in teaching and increases in intrusion from the baseline to the challenge condition, suggesting that the challenging condition prompted less optimal strategy use in guiding children to complete the task. Children showed declines in compliance and increases in positive and negative affect, suggesting both behavioral and affective dysregulation in response to the perturbation. Though we might expect children to show both positive and negative affect when dysregulated (Callender et al., 2010), surprisingly, mothers also increased in positive affect upon entering the challenging condition. Considering the aforementioned changes in teaching and intrusion, it is possible that when under pressure, mothers compensated for their less effective guidance strategies with greater positive affect to keep their children engaged. It follows from dynamic systems theory (Thelen & Smith, 1998) that when one component of a dynamic system is constrained, such as a parent offering fewer resources to her child in a challenging situation, that these constraints would lead to corresponding reorganization in other aspects of the parent's and the child's behavior.

Once the false discovery rate methodology was applied to account for Type I error, the most robust of these changes at the individual level were those in maternal teaching, maternal positive affect, and child negative affect. It was also notable that there were no changes in maternal negative affect or maternal RSA between the two task conditions. Collectively, these findings may suggest that when this task is used in a typical sample of preschoolers and their mothers, it is the children (rather than the parents) who are more likely to manifest dysregulated behavior, and mothers respond by altering their affect and behavior according to task demands and the child's needs. Perhaps in a reasonably well-functioning sample of mother-preschooler dyads, we are less likely to see the majority of mothers show physiological or affective regulatory responses to this type of challenge, but we can expect preschoolers to show variability in regulatory responses. It would be useful in future work to include other indices of parent self-regulation to determine if they are associated with differential responding to the task. It will also be important to replicate the use of this task in higher-risk families to determine if the magnitude or direction of these changes is altered by higher levels of life stress. Our current and future work involves examining the PCCT with respect to higher-risk families, father-child interactions, and modifying it to include a new, third "repair" condition following the challenge condition. The ability to repair interpersonal conflicts is an important index of individual and dyadic regulatory processes (Hollenstein & Lewis, 2006), and in some cases can be more revealing of differences in functioning than the frequency of interpersonal conflicts (Skowron et al., 2010).

Dyadic Changes in the PCCT

An examination of dyadic changes in response to the PCCT complemented our investigation of individual regulatory responses, and was a novel contribution given the relative paucity of research on dyadic changes in response to experimental challenge in this age range. The experimental perturbation brought on increased dyadic affective variability, which corresponded with individual measures given that both mothers and children showed increases in positive and/or negative affect. It also prompted reduced variability in goal-directed behavior, signifying that mothers and children used fewer strategies and behaviors to complete the task during the challenging condition. This combination of reduced behavioral variability and increased affective variability is particularly interesting. Theory would suggest that the repertoire of affect and behaviors is narrowed in the service of tackling a challenge (Fredrickson & Losada, 2005), suggesting that the lower variability in dyadic *goal-directed behavior* was a reflection of the fact that the PCCT prompted dyadic coregulatory changes in response to the challenge. But why did dyadic *affective* variability increase? Rigid parenting has been shown to result in children's emotional dysregulation (Chang, Schwartz, Dodge, & McBride-Chang, 2003; Snyder, Stoolmiller, Wilson, & Yamamoto, 2003), so it is likely that the narrower parental agenda and correspondingly reduced availability prompted emotional dysregulation in children. Coordinating emotions with young children requires effort on the parent's part (Calkins, 2011), and parents likely have fewer resources to do so when there are greater contextual demands on their behavior. Theorists have also suggested that the extremes of too much or too little variability in emotion could each reflect stress or dysfunction in the dyad (Hollenstein, Lichtwarck-Aschoff, & Potoworski, 2013). Thus, it is possible that by integrating measures of dyadic affect and dyadic goal-directed behavior, the present findings shed new light on how parent-preschooler dyads coregulate in the face of challenge: When environmental or parental demands for specific behaviors are high, there may be less energy or opportunity to coordinate emotions, and accordingly, dyadic affect may become more chaotic and disorganized.

Concurrent and Predictive Validity

Individual or dyadic regulatory patterns in response to challenge may differ by children's regulatory skills, particularly at a developmental stage when we should expect variation in these skills. Thus, we examined relations between a proxy of children's dysregulation (externalizing problems) and changes invoked by the PCCT as a preliminary examination of its concurrent and predictive validity. As expected based on prior research (Hinnant & El-

Sheikh, 2009), there was a trend of children showing RSA augmentation in the face of contextual challenge when they were also rated higher on externalizing problems by mothers. There was also a trend such that child RSA augmentation in response to the challenge predicted higher teacher-rated externalizing problems at Time 2. Thus, partial evidence of concurrent and predictive validity was demonstrated through expected patterns of children's physiological responding to the task.

Change in PCCT variables also showed evidence of predictive validity. Specifically, children with higher teacher-rated externalizing problems at Time 2 displayed lower positive affect at baseline and their mothers showed lower levels of teaching at baseline; there was also a trend that these children were more noncompliant at baseline (see Figure 3). These differences washed out upon entering the challenge condition. Also, lower mother RSA at baseline was marginally significant in predicting child externalizing problems at Time 2. In combination, these findings suggest that the baseline condition of the PCCT, and not only changes from the baseline to the challenge condition, was important in revealing differences by child externalizing problems over time. Families with children higher on externalizing problems may be characterized by parents who have difficulty guiding children to complete a challenging task (Landry et al., 2000). Parents of these children may show lower resting RSA levels, which would indicate regulatory difficulties (Beauchaine, 2001), or they may be more physiologically stressed than other parents by being asked to complete a problem-solving task with their children in the first place. In addition, prior research has shown that risk can be revealed by the absence of expected behaviors in baseline or positive situations, as compared to the presence of problematic behaviors in challenging situations (e.g., Hollenstein & Lewis, 2006). Taken together, the results suggest that both baseline levels and changes in various regulatory domains were informative in terms of understanding the concurrent and predictive validity of the PCCT.

It was surprising that changes in dyadic affective and behavioral variability between baseline and challenge conditions did not differ by children's externalizing problems. The link between dyadic affective flexibility and children's externalizing problems has been demonstrated in prior research on the PCCT baseline condition in the same dataset (Lunkenheimer et al., 2013), and we might expect a challenging condition to be even more likely to invoke dyadic regulatory processes in dyads at higher risk. However, prior work has also illustrated that dyadic regulatory patterns may be sensitive to multiple time-invariant and time-covarying parameters (e.g., Snyder et al., 2003). Therefore, more comprehensive and sophisticated analyses may be warranted in future work in the examination of relations between changes in dyadic coregulation over time and children's externalizing problems.

Limitations

The current study involved a typical community sample and therefore replicating these findings with higher-risk families will be important in verifying whether these same patterns are evident when more contextual regulatory challenges are present. These sample characteristics may also have explained why findings were not more robust, if levels of regulatory difficulties and child externalizing problems were lower overall in typical mothers and their preschoolers. Analyses were performed separately by study variable due to sample size and multicollinearity considerations, which meant that we could not evaluate the unique predictive value of particular variables in comparison to one another. Although we found significant or trending results with respect to many individual variables, they did not all retain significance when our more conservative alpha adjustment protocol was applied. Our power to detect statistical effects may have been diminished by the fact that only 2/3 of the children's teachers agreed to participate, which may have impacted the results of predictive analyses. We did not have externalizing ratings by teacher available at Time 1 so mother ratings were used instead; teacher ratings would have offered a more robust control variable. Finally, statistical power may have been diminished by the fact that only roughly half of the sample had valid physiological data for both parent and child throughout this task due to wireless interference difficulties.

There are limitations to the use of average RSA values and RSA difference scores when studying physiological regulation. Recent research has demonstrated that this approach, while common, typically involves measurement error and the use of latent variable models are preferred (Burt & Obradovic, 2013). Further, in the present study, we examined differences between a baseline problem-solving interaction and a challenging problem-solving interaction, but the use of an antecedent condition could also be useful to determine changes from an individual's resting state. In other words, it is possible that some mothers and children were stressed or challenged by engaging in the puzzle task in the first place, thus reducing power to detect differences between baseline and challenge if their RSA was already suppressed.

Conclusions

Self-regulation and its sub-components operate at the nexus of multiple developmental processes, and adaptive self-regulation is essential for optimal developmental, mental, and physical health (Thompson et al., 2008). The study of regulatory processes is particularly crucial during early childhood when these skills come online quickly in coordination with one another and require heavy socialization by caregivers for optimal development (Calkins, 2011). The direct study of parent-child coregulation processes has become increasingly important in understanding typical and atypical child development (Cerezo et al., 2012; Cole et al., 2003; Dumas et al., 2001; Hollenstein et al., 2004; Kochanska, 1997; Kochanska & Aksan, 1995; Lunkenheimer et al., 2011; Lunkenheimer et al., 2013; Moore et al., 2013; Sravish et al., 2013; Weinberg et al., 2006). Our abilities to understand these processes will be limited unless we begin to develop methods that adequately reflect and capture their dynamic, relational, and contextually-dependent nature. Taken together, the results of the current study suggest that the PCCT is an experimental paradigm that helps to capture the complex multi-dimensionality of self-regulation and coregulation in this critically important developmental period.

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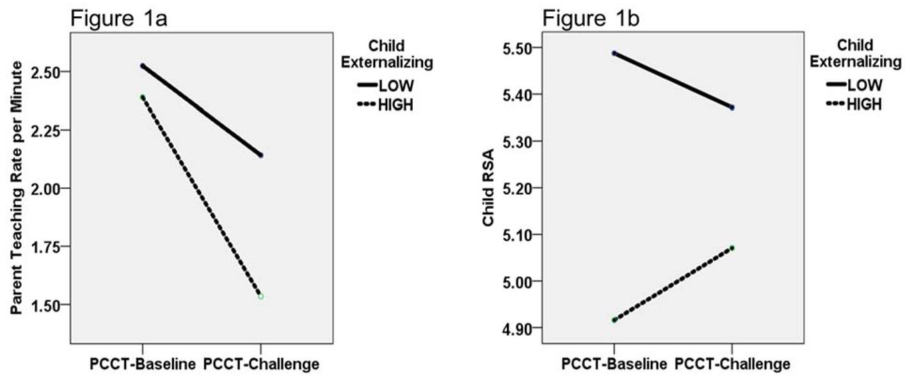

Figure 1.

Effects of interactions between PCCT condition and mother-rated externalizing problems at Time 1 on observed parent behavior and child physiology.

Note: High and low child externalizing groups were computed via median split.

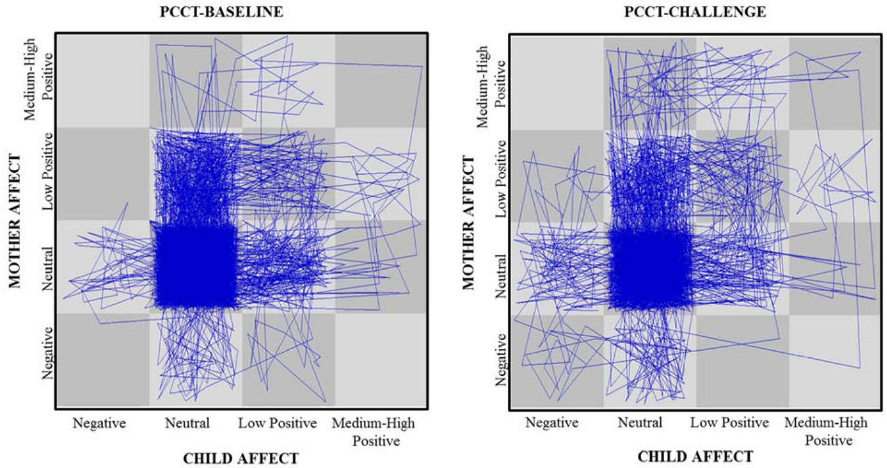

Figure 2.

Changes in affective variability between baseline and challenge conditions of the PCCT for the entire sample using State Space Grids (SSG).

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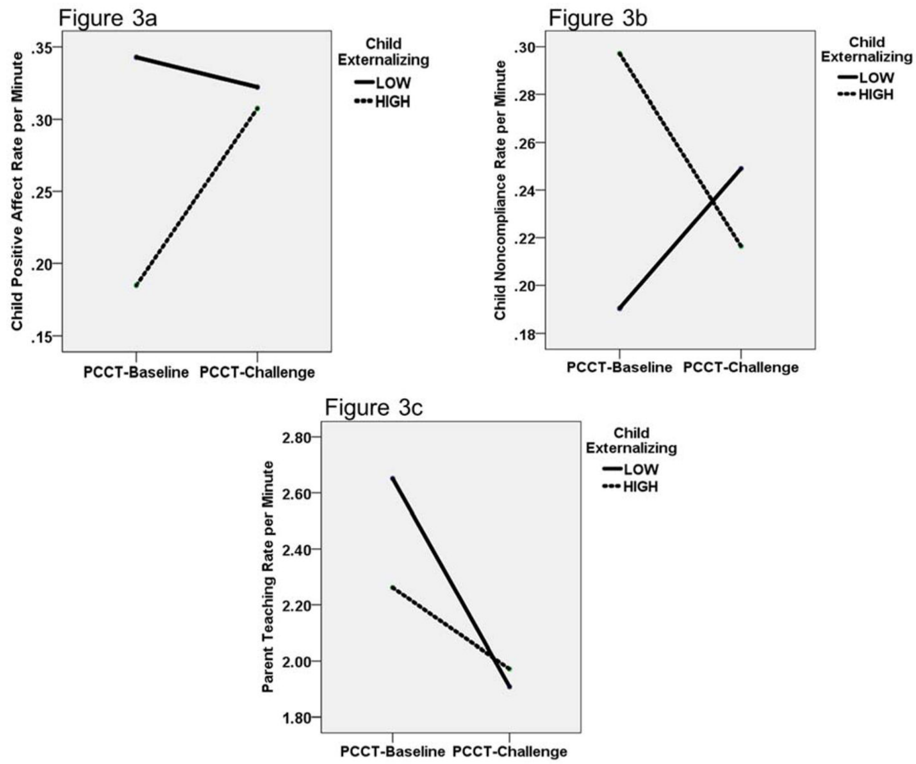

Figure 3.

Changes in observed parent and child behavior in the PCCT at Time 1 predicting teacher-rated externalizing problems at Time 2.

Note: To interpret the results of regression analyses with PCCT change scores as the predictor variable, differences between baseline and challenge scores for high- and low-externalizing children are shown. High and low child externalizing groups were computed via median split.

Table 1

Descriptive data for study variables

PCCT Variables	PCCT-Baseline			PCCT-Challenge		
	M	***SD***	***Range***	***M***	***SD***	***Range***
Child Positive Affect	.29	.33	1.35	.43	.51	2.20
Child Negative Affect	.05	.16	.97	.12	.28	1.74
Mother Positive Affect	.63	.56	3.18	.84	.69	2.85
Mother Negative Affect	.09	.24	1.83	.12	.32	2.10
Child Compliance	1.81	.76	3.89	1.67	.84	3.92
Child Noncompliance	.43	.58	2.42	.40	.55	2.17
Mother Teaching	2.46	1.10	4.90	1.84	1.12	4.50
Mother Intrusion	.33	.50	2.42	.48	.78	3.48
Dyadic Affective Variability	.15	.15	.61	.21	.21	.76
Dyadic Behavioral Variability	.80	.11	.60	.74	.17	.76
Child Average RSA	5.30	1.08	5.13	5.27	1.14	5.16
Mother Average RSA	6.08	.93	4.01	6.00	.94	3.54
Covariate/Outcome	**Mother Rating Time 1**			**Teacher Rating Time 2**		
	M	***SD***	***Range***	***M***	***SD***	***Range***
Child Externalizing Behaviors	7.81	7.37	31	8.03	9.03	41

NOTE: Observed affect and behavior variables are measured in terms of rate per minute values. The *N* for all variables was 96, except for mother and child RSA (*n*=45), mother externalizing rating (*n*=88), and teacher externalizing rating (*n*=66).

Table 2

Repeated measures ANOVA results for individual and dyadic changes in the PCCT, separately by study variable

PCCT Changes: Main Effects	**F**	**df**	**p**	**Adj. α**	**Partial η^2**
Child Positive Affect	4.75^{*} (+)	95	.032	.025	.05
Child Negative Affect	5.97^{*} (+)	95	.016	.021	.06
Mother Positive Affect	9.44^{**} (+)	95	.003	.017	.09
Mother Negative Affect	1.12	95	.292	.038	.01
Child Compliance	4.07^{*} (−)	95	.047	.033	.04
Child Noncompliance	.55	95	.459	.046	.01
Mother Teaching	26.26^{***} (−)	95	.000	.004	.22
Mother Intrusion	4.62^{*} (+)	95	.034	.029	.05
Dyadic Affective Variability	10.91^{**} (+)	95	.001	.013	.10
Dyadic Behavioral Variability	14.40^{***} (−)	95	.000	.008	.13
Child Average RSA	.09	43	.769	.050	.00
Mother Average RSA	1.11	43	.298	.041	.03
PCCT Changes: Effects Moderated by Externalizing	***F***	***df***	***p***	***Adj. α***	***Partial η***
Child Positive Affect	$3.35^{\dagger}$(+)	95	.070	.013	.03
Child Negative Affect	.62	95	.434	.021	.01
Mother Positive Affect	.07	95	.796	.041	.00
Mother Negative Affect	.05	95	.817	.046	.00
Child Compliance	1.88	95	.173	.017	.02
Child Noncompliance	.24	95	.623	.033	.00
Mother Teaching	$3.81^{\dagger}$(−)	95	.054	.008	.04
Mother Intrusion	.16	95	.693	.038	.00
Dyadic Affective Variability	10.91	95	.458	.025	.10
Dyadic Behavioral Variability	14.40	95	.950	.050	.13
Child Average RSA	4.26^{*} (+)	43	.045	.004	.09
Mother Average RSA	.28	43	.600	.029	.01

Note: Twelve analyses were conducted, each with two predictors: the main effect of condition and the interaction effect of condition by child externalizing. A false discovery rate methodology was applied to guard against Type I error, reflected in the adjusted α column. The main effects are presented in the top half of the table and the interaction effects are presented in the bottom half of the table. Increases in the variable are denoted by (+) and decreases in the variable are denoted by (−) in response to the challenge.

† $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$

Table 3

Regression results for PCCT changes at T1 predicting child externalizing problems at T2, separately by study variable

Variables	B	df	p	Adj. α	CI
Child Positive Affect	9.17**	65	.004	.008	3.04, 15.29
Child Negative Affect	.81	65	.830	.046	−6.66, 8.27
Mother Positive Affect	1.20	65	.677	.041	−4.52, 6.91
Mother Negative Affect	−1.69	65	.656	.038	−9.24, 5.85
Child Compliance	1.31	65	.415	.029	−1.88, 4.49
Child Noncompliance	−5.15*	65	.021	.013	−9.50, −0.80
Mother Teaching	2.88**	65	.002	.004	1.08, 4.68
Mother Intrusion	1.38	65	.518	.033	−2.85, 5.61
Dyadic Affective Variability	.23	65	.970	.050	−11.94, 12.40
Dyadic Behavioral Variability	6.44	65	.368	.021	−7.75, 20.64
Child Average RSA	7.39*	43	.041	.017	.32, 14.47
Mother Average RSA	2.81	43	.382	.025	−3.64, 9.27

Note: Twelve analyses were conducted, each with two predictors: the variable's respective change score (Challenge score – Baseline score) and the control variable of child externalizing at T1. A false discovery rate methodology was applied to guard against Type I error, reflected in the adjusted ***α*** column. *Positive B* parameters indicate that an *increase* in the variable in response to the challenge was predictive of higher externalizing problems; *Negative B* parameters indicate that a *decrease* in the variable in response to the challenge was predictive of higher externalizing problems. T1 = Time 1, T2 = Time 2;

† $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$