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It Takes Two: Infants' Moderate Negative Reactivity and Maternal Sensitivity Predict Self-regulation in the Preschool Years

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Abstract

The aim of this longitudinal study was to examine the association of infant fussing and crying with self-regulation in toddlerhood and the preschool years, as well as the moderating role of maternal sensitivity therein. When children (n = 149, 53.69% boys) were six months old, parents reported on their fussing and crying using a cry diary, and maternal sensitivity was coded during a novel toy procedure. Children participated in various tasks to assess self-regulation in toddlerhood (18 months) and the preschool years (4.5 years). Results indicated that the relation between infant fussing and preschool self-regulation took the shape of an inverted U, but only for children of highly sensitive mothers. For infants of less sensitive mothers, fussing was not related to later self-regulation. Crying was unrelated to preschool self-regulation. Neither fussing, crying, nor maternal sensitivity predicted self-regulation in toddlerhood. The findings support the optimal arousal theory, by demonstrating that for infants of highly sensitive mothers, moderate amounts of low intensity negative reactivity are associated with enhanced self-regulation in the preschool years.

Keywords

negative reactivity; self-regulation; early childhood; maternal sensitivity; optimal arousal

Self-regulation plays a crucial role in healthy child development, promoting a myriad of competencies including social skills (Eisenberg, Fabes, Guthrie, & Reiser, 2000) and school readiness (Blair & Razza, 2007). Together with reactivity, self-regulation forms the core of temperament, or constitutionally based individual differences (Rothbart, Sheese, Rueda, & Posner, 2011). Reactivity refers to emotional, motoric and attentional responses to changes in the external and internal environment and includes both negative (i.e., negative affect), and positive components (i.e., extraversion or surgency). Self-regulation serves to modulate these forms of reactivity and mainly depends on processes of executive attention (i.e.,

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higher-order coordination of attention orienting and alerting) and effortful control (i.e., the capacities to withhold a dominant response and substitute a more appropriate subdominant response, to ascertain errors, and to plan) (Rothbart, 1989; Rothbart et al., 2011).

Self-regulation develops rapidly throughout the first years of life, and this development is characterized by a progression from involuntary forms of regulation in early infancy to purposeful and flexible self-regulation from the preschool years on (Kopp, 1982; Rothbart et al., 2011). Infants often rely on external support to regulate emotions such as frustration and fear; however, they also have some rudimentary regulatory behaviors at their disposal. These behaviors are primarily classified as automatic approach and withdrawal behaviors, as they are hardly planned or effortful (Kopp, 1982; Rothbart et al., 2011). For instance, infants can avert their gaze or use thumb sucking to alleviate distress (e.g., Ekas, Lickenbrock, & Braungart-Rieker, 2013). Such behaviors are reflexive at birth and progress to voluntary techniques in later infancy (Kopp, 1982). In toddlerhood, early forms of self-regulation are mainly manifested as compliance with parental demands and the inhibition of prohibited behaviors (Kochanska, Coy, & Murray, 2001; Kopp, 1982). Over time, toddlers learn to comply and delay an act in the absence of caregivers and, by approximately 36 months, they are generally capable of modulating their behaviors in a relatively flexible manner (Kopp, 1982). Due to the rapid development of self-regulation, the first years of life form a window of opportunity for interventions targeting self-regulation. In the current study, we examine longitudinal associations between infant negative reactivity, maternal sensitivity, and self-regulation in early childhood.

As the regulation of negative reactivity is an important early manifestation of self-regulation, negative reactivity plays a central role in the development of self-regulation (Blair, 2002). The optimal arousal perspective on the development of self-regulation states that the relation between negative reactivity and self-regulation is expected to be curvilinear, taking an inverted U-shape (Blair & Ursache, 2011). Moderate and time-limited negative reactivity is associated with well-developed self-regulation, whereas both extreme ends (i.e., chronically low and high levels of negative reactivity) are related to poorly developed self-regulation. The optimal arousal theory shows many similarities with the Yerkes-Dodson law: i.e., the finding that complex cognitive performances show an inverted U-shaped relation with concurrent levels of arousal (Yerkes & Dodson, 1908). The optimal arousal theory is based on research demonstrating that neural activity in the prefrontal cortex, a brain region closely associated with goal-directed behavior, is dependent upon moderate and time-limited increases in neuromodulators such as noradrenaline and dopamine, which are released when experiencing negative reactivity. If neuromodulator levels increase too much or too little, prefrontal cortex functioning and self-regulation are impaired (see Arnsten, 2009 for a review).

It may also be that experiences of negative reactivity teach infants that they can recover from negative reactivity, progressively promoting self-regulation in increasingly challenging situations (Kopp, 1982; Sroufe, 2000). Infants who rarely experience moments of negative reactivity may not get the opportunities to practice and improve skills needed for self-regulation. On the other end of the spectrum, persistent and excessive negative reactivity may override infant’s ability to regulate themselves effectively or to be soothed by others, which could hamper the development of future regulatory capacities (Blair, 2002; Stifter & Braungart, 1995).

Prior animal studies indicate that short moments of increased negative reactivity (elicited by creating a controlled stressful event through a brief maternal separation) are related to enhanced self-regulation (e.g., Parker, Buckmaster, Justus, Schatzberg, & Lyons, 2005; Tang, Akers, Reeb, Romeo, & McEwen, 2006). This notion has also been referred to as stress inoculation, which proposes that controlled stressful experiences improve the development of regulation and resilience (Lyons, Parker, Katz, & Schatzberg, 2009). In human children, moderate fluctuations in cortisol (a physiological response associated with negative reactivity) between the ages of 7, 15, 24, and 48 months, combined with low cortisol levels, predict better preschool self-regulation. In contrast, both high cortisol levels and low cortisol levels that were highly stable or highly variable predicted lower levels of self-regulation.(Blair, Berry, & FLP Investigators, 2017). This suggests that time-limited, low-level negative reactivity in early childhood promotes the development of self-regulation.

Although cortisol is a reasonably good peripheral indicator of negative reactivity (e.g., Ursache et al., 2014), few studies have examined whether the optimal arousal perspective can be applied to observed indicators of negative reactivity. Most prior studies on the relation between behavioral observations of negative reactivity and self-regulation applied a linear perspective. A study with infants from 6 weeks to 10 months of age reported that excessively crying boys demonstrated the lowest levels of emotional self-regulation at ten months (Stifter & Spinrad, 2002). Similarly, longitudinal studies indicate that high levels of negative reactivity hamper the development of self-regulation (Bridgett et al., 2009; Raikes, Robinson, Bradley, Raikes, & Ayoub, 2007). On the other hand, another longitudinal study reported no predictive value of parent-reported negative reactivity for self-regulation (Gartstein, Bridgett, Young, Panksepp, & Power, 2013).

From the optimal arousal perspective, the linear approach applied in most studies is incomplete in capturing the full relation between negative reactivity and self-regulation. Related to this perspective, a small body of research demonstrates that the relation between observed negative reactivity in infancy and self-regulation later in development is moderated by early forms of emotion regulation. That is, infants displaying both high negative reactivity *and* behaviors to regulate this reactivity displayed better self-regulation later in development (Stifter, Spinrad, & Braungart-Rieker, 1999; Ursache, Blair, Stifter, & Voegtline, 2013). These infants experience negativity such as anger and fear, but they also display behaviors that could potentially maintain negative reactivity at a controllable level. A remaining question is whether observable indicators of negative reactivity show a curvilinear association with self-regulation, as the optimal arousal theory suggests. The goal of the current study is therefore to provide a direct examination of the optimal arousal theory using parent reports of negative reactivity.

In order to develop more independent regulatory abilities, infants must receive support from their proximal environment. Sensitive mothers notice the cues of their infants in a timely manner, and provide responses that appropriately address the signaled needs of their infant (Ainsworth, 1969). Such responses may include adjusting the level of provided stimulation or mirroring the behavior of the infant (De Wolff & Van Ijzendoorn, 1997). In the moment, prompt and appropriate responses support the immediate modulation of infants' arousal. Over time, maternal behavior provides learning experiences on how to control arousal and emotional states in an autonomous manner (Beeghly & Tronick, 2011; Eisenberg, Cumberland, & Spinrad, 1998). For instance, prior research demonstrates that shifting attention away from a distressing stimulus is an important emotion regulation strategy in infancy (Ekas et al., 2013; Stifter & Braungart, 1995). At six months, this ability is still 'under construction', and contingency analyses demonstrate that infants benefit from their mothers' support in attention shifting (Crockenberg & Leerkes, 2004). Longitudinally, maternal support in attention shifting forms a buffer for infant reactivity to develop into anxious feelings (Crockenberg & Leerkes, 2006). Higher levels of maternal sensitivity in infancy also predict better self-regulation in toddlerhood (Bernier, Carlson, & Whipple, 2010), whereas negative parenting behaviors, including intrusive behaviors and negative reactivity, are related to diminished preschool self-regulation (Cuevas et al., 2014). Overall, these studies indicate that parental sensitivity can promote regulation in the moment, and also over time.

In addition, because resolving moments of negative reactivity is a key mechanism through which children internalize regulatory abilities (Beeghly & Tronick, 2011), it is likely that infants who experience moments of negative reactivity profit most from maternal sensitivity. Such ideas have been posited before in bioecological models of development (e.g., Bronfenbrenner & Ceci, 1994). These models predict that an enriched environment will promote potentials to be actualized, whereas risky environments will mask such individual differences. A variety of studies indeed report that the combination of high negative reactivity and (indicators of) sensitive parenting are related to improved self-regulation (Feldman, Greenbaum, & Yirmiya, 1999; Kim & Kochanska, 2012; Poehlmann et al., 2011; Kim, Stifter, Philbrook & Teti, 2014). However, these studies may have captured an effect of negative reactivity that occurs at low to moderate levels, without considering that this effect decays when negative reactivity reaches a certain threshold. As both linear and curvilinear associations can be significant within the same model (Cohen, Cohen, West, & Aiken, 2003), previous results may have been interpreted as representing linear effects, without considering potential quadratic effects.

In the current multimethod longitudinal study, we examined whether daily reports of 6-month-old infants' negative reactivity predicted self-regulation in toddlerhood and the preschool years, in manner consistent with the optimal arousal perspective. Typical manifestations of negative reactivity in infancy are fussing and crying. While fussing and crying may be seen as similar behavioral states that merely differ in intensity, there are some indications that they, at least partly, reflect qualitatively different behavioral states. When parents are instructed to report on both fussing and crying behavior of their infant, the majority of the reported behavior is in fact fussing (e.g., Alvarez, 2004; James-Roberts, 2001). Infants who fuss a lot do not necessarily cry a lot, and vice versa (James-Roberts & Plewis, 1996). In addition, infants who fuss a lot are more likely to preserve this characteristic, whereas crying has proven to be more transient over development (James-Roberts & Plewis, 1996). It has also been suggested that fussing signifies a behavioral state during which infants are not crying due to parents' extensive soothing efforts, but that these efforts are not fully effective (James-Roberts, 2001). Lastly, a small follow-up study with infants referred for excessive crying also indicated that hours of fussing, but not hours of crying, predicted a variety of maladaptive developmental outcomes, such as less efficient sensory processing and more attention and hyperactivity problems (DeSantis, Coster, Bigsby, & Lester, 2004). Overall, the small body of literature indicates that fussing may be a different, and perhaps more stable characteristic compared to crying. It should also be noted that fussing and crying during the first three months of life, also referred to as “colic”, are not reliable indicators of problems later in development (Stifter & Braungart, 1992). It is only after the first two to three months of life that fussing and crying predict future psychosocial and cognitive problems (Hemmi, Wolke, & Schneider, 2011; Rao, Brenner, Schisterman, Vik, & Mills, 2004). By examining fussing and crying at six months, we focus on the developmental period after the so-called “colic” period.

In line with the optimal arousal perspective, we hypothesized that parent-reported negative reactivity would be predictive of self-regulation in toddlerhood and in the preschool years in a nonlinear manner. Specifically, we expected a quadratic relation (inverted U-shaped curve; see Figure 1). We examined whether moderate amounts of negative reactivity in infancy, as opposed to low and high amounts of negative reactivity, predicted higher levels of self-regulation in toddlerhood and the preschool years. We mainly expected to find such a quadratic association for fussing, as opposed to crying, as fussing represents low level negative reactivity. In addition, fussing is found to better predict developmental outcomes compared to crying. Second, we hypothesized that maternal sensitivity in infancy would be positively related to self-regulation in toddlerhood and the preschool years. Third, combining the optimal arousal and the bioecological model, we expected maternal sensitivity to moderate the association between fussing and later self-regulation. Specifically, we expected the hypothesized quadratic relation between fussing and self-regulation to be most pronounced for children with highly sensitive mothers (see Figure 1). Further, we examined whether these prospective relations were found in predicting self-regulation both in toddlerhood and the preschool years.

Methods

Participants

Caregivers and infants (*N*=165) were recruited through birth announcements and a local community hospital in Central Pennsylvania. Inclusion criteria were full-term pregnancy, ability to speak and read English, and maternal age above 18. A total of 149 children (53.69% boys) provided data at six months and/or at follow-up waves (*n* = 149 at 6 months, *n* = 132 at 18 months, and *n* = 111 at 4.5 years) and were included in this study. No significant differences in terms of maternal or paternal education were found between included and excluded children. Within the selected sample, maternal age ranged between 21.22 and 41.68 (*M* = 30.94, *SD* = 4.60). Years of education ranged between 12 and 20 (*M* = 15.0, *SD* = 2.0) and between 8 and 17 (*M* = 14.4, *SD* = 2.1) for mothers and fathers respectively. A total of 139 infants (93.29%) were described as white or Caucasian, three infants (2.01%) as black or African American, two infants (1.34%) as Hispanic or Latino, and two infants (1.34%) as Asian. One infants was described as Native Hawaiian/

Pacific Islander, and one as American Indian/Alaskan Native. For one infant, a description of ethnicity was not provided. Annual family income varied between less than \$10.000 and more than \$100,000, with 55.03% having an income less than \$60,000, and 44.30% more than \$60,000. With the exception of two families, all families were intact when infants were six months of age. Parents provided written consent for their participation and the participation of their children in the study. All procedures in this study (Back to Baby Basics Project) were approved by the Pennsylvania State University Human Subjects Institutional Review Board, with approval number PRAMS00031155. A nonparametric test of homoscedasticity (Jamshidian, Jalal, & Jansen, 2014) indicated that data were missing completely at random (p = .084). Attrition analyses indicated that families who did not participate when children were 18 months old ($m = -0.37$, $sd = 0.88$) on average had a lower socio-economic status (SES; a composite of maternal and paternal years of education and family income) than families who did participate ($m = 0.06$, $sd = 0.83$), $t(37.83) = 2.30$, $p =$ .021. Similarly, families who did not participate when children were 4.5 years old also had a lower SES ($m = -0.27$, $sd = 0.93$) compared to families who did participate ($m = 0.10$, $sd = 0.79$), $t(79.90) = 2.44$, $p = .017$. Attrition was unrelated to children's sex, as well as to infant fussing and crying. SES was included in the final models, both to control for SES and to account for the missing data pattern related to SES.

Procedure

Data collection took place between December 2009 and January 2018. Infants and their parents took part in five assessments when children were within two weeks of being six months, 12 months, 18 months, 4.5 years, and 5.5 years of age. The present study includes data from when children were 6 months old, 18 months old and 4.5 years old, as the measures relevant for this study were obtained during these waves. Infant crying and fussing was assessed with a cry diary, whereas maternal sensitivity and children's self-regulation were observed and/or assessed during laboratory visits.

Measures

Crying and fussing—When infants were six months of age, primary caregivers (n =149, 98.68% mothers) were asked to complete a 24-hour diary for three days (Barr, Kramer, Boisjoly, McVey-White, & Pless, 1988; St James-Roberts, Hurry, & Bowyer, 1993). Caregivers reported on the infants' state (awake and content, sleeping, feeding, fussing, and crying) on a ruler-like diary. The ruler had ticks specifying every five minutes. Parents received five colored pencils to specify the five states. To distinguish between crying and fussing, parents received the following descriptions: "Crying is generally loud and constant negative vocalizations that can be accompanied by breath holding and muscle tension. Fussing is low level negative vocalizations that are often accompanied by increased arm and leg movements." Parents were also requested to report whether a day was typical or not. Non-typical days (n = 78) were those days during which the infant was ill, teething, or participating in unusual events, such as travel. These days were removed, resulting in the exclusion of five infants with no available information on typical days. A total of 52 diaries were incomplete, of which 40 were incomplete due to deleting non-typical days. Data of incomplete diaries were still included in the analyses. Two measures were obtained from the diaries: percentage of time infants fussed and percentage of time infants cried over three (or fewer) days. Higher scores represented more fussing and crying. Previous studies have found that reports on a cry diary are related to audiotaped recordings, providing evidence for the validity of the cry diary (St. James-Roberts et al., 1993; Salisbury et al., 2001).

Maternal sensitivity—Mother-infant interaction was observed during a novel toy procedure (Crockenberg & Leerkes, 2004; Gunnar & Stone, 1984) in the laboratory when infants were six months of age. Mothers were asked to introduce one low-intensity toy (a stuffed octopus), one medium-intensity toy (a musical toy), and one high-intensity toy (a toy popper). Mothers and infants were seated on the floor and played with one toy at a time, each for one minute. Hence, the play session lasted three minutes. Maternal sensitivity was conceptualized as the level at which the mother contingently and appropriately responded to the infant's actions. Maternal sensitivity was coded every 10-seconds with a code that captured the frequency and intensity at which the mother responded to the baby's actions, with the scores 0 = "None: no sensitive or contingent responses. The mother does not respond to the baby's actions", 1 = "Low: one instance of sensitivity. Mother shows minimal sensitivity or a minimal response to the baby's actions", 2 = "Moderate: more than one instance of the behaviors above or one prolonged instance. Clear evidence that the mother is more than minimally tuned into the baby", and 3 = "High: mother is very aware of the infant and contingently responsive to the baby's interests and affect. Behavior occurs at a very high level, is quite intense or prolonged, or occurs repeatedly". The mean sensitivity level across the 10-second epochs was used, with higher scores representing more sensitivity. A team of coders was trained to reach a minimum inter-rater reliability of κ = .75. Drift reliability ranged between κ = .81–.95.

Toddler's self-regulation—During the 18-month laboratory visit, three age-appropriate measures of toddler's self-regulation were obtained. Compliance was coded during a *Clean-up task* (Kochanska, Tjebkes, & Fortnan, 1998). The instructor asked mothers to take out as many toys as possible, and to play with the child as they normally would. After five minutes, mothers were cued to instruct the child to clean up the toys. The clean-up task ended when all toys were put in the basket or three minutes had passed. Using an adapted coding scheme (e.g., Stifter et al., 1999), coders rated compliance and four forms of noncompliance in 10-second intervals. Codes were not mutually exclusive so that more than one code could be assigned. Compliance was coded when the child showed behaviors towards the goal of cleaning up, e.g., when the child was putting toys in the basket or otherwise following maternal instructions. In order for behavior to be coded as compliance, it had to be clear that the child was trying to comply with maternal requests, even if there were short pauses (e.g. looking briefly at the toy). Noncompliance was coded when the child ignored commands, verbally refused to comply, showed defiance, or actively moved away to avoid having to comply. The proportion of compliance was calculated by summing the number of intervals that reflected compliance and dividing this by the total number compliance and noncompliance codes. Reliability was assessed over 24 videos, with an ICC of .932.

Toddlers also participated in a *Delay procedure* (Kochanska & Knaack, 2003). The experimenter presented the child with an attractive toy and instructed the child not to touch the toy until the experimenter allowed it, i.e., after five seconds. This procedure was then repeated with a delay of 10 seconds and 15 seconds. Latency to touch scores were coded (ICC = .996). Standardized latency scores across three trials were averaged into a mean score.

Self-regulation across the laboratory visit was also rated by two experimenters post visit. (The visit lasted 1.5 hours overall and included various tasks designed to measure children's temperament and regulatory abilities, as well the quality of parent-child interactions). Three items from an adapted version of the *Infant Behavior Record* (IBR) were used: object orientation (degree of sustained interest in test materials), attention span (degree of continued interest in persons, toys, or activities), and compliance (degree of willingness to comply with requests from the experimenter or mother) (Stifter, Willoughby, & Towe-Goodman, 2008). Each item was scored on a 9-point scale with anchors specific to the range of behaviors, with ICC's ranging from .680 to .868. The rating of the two experimenters were averaged and a mean score of the three averaged scales were used, with higher scores indicating better self-regulation (α = .79). For data reduction purposes, a principal component analysis of the three self-regulation scores indicated that the first principal component explained 45.55% of the variance (λ = .54–.79). Both compliance and latency to delay correlated modestly with self-regulation across the laboratory visit, with *r*'s of .27 (p = .007) and .20 (p = .015) respectively. Compliance and latency to delay were poorly correlated (r = .06, p = .396). The three scores were standardized and an average score was computed, with higher scores representing better self-regulation.

Preschool self-regulation—During the laboratory visit at 4.5 years, children completed three executive functions tasks that tapped conflict inhibition (Carlson & Moses, 2001). The *Day-Night Stroop Task* required children to say "day" when they saw a black card with a moon, and "night" when they saw a white card with a sun (Gerstadt, Hong, & Diamond, 1994). A maximum of three practice trials were administered, followed by 14 test trials. The proportion of correct responses during the test trials was used. Self-correction was allowed.

During the *Tapping Task*, children were directed to tap once when the experimenter tapped twice (50% of trials) and to tap twice when the experimenter tapped once (Diamond & Taylor, 1996; Luria, 1959). One practice trial for each rule was administered. If at least one of the child's responses was wrong, a second practice trial was administered. Only if children responded correctly to each rule at least once during the practice sets were the test trials administered. The proportion of correct responses on 14 trials, and on the additional 1 or 2 practice trials, were used as the final score.

The *Dimensional Card Sort Task* required children to sort cards depicting coloured shapes (Frye, Zelazo, & Palfai, 1995; Zelazo, 2006). During practice trials, children first sorted six cards by one dimension (colour or shape; counterbalanced across participants). During the test trials, children had to sort six cards based on the other dimension. Performance was the proportion of correct responses during the test trials. The Day-Night task, Dimensional Change Card Sort task and Tapping task correlated sufficiently with each other (r = .20 – 34, all p <.07). Principal component analyses indicated that the first component explained 51.29% of the variance (λ = .64 – .77). Therefore, the mean of the three standardized scores was used to represent preschool self-regulation.

Data Analyses

Using the package Lavaan (Rosseel, 2012) in R (R Core team, 2019), four linear regression models were estimated using maximum likelihood estimation with robust (Huber-White) standard errors. An asymptotical equivalent of the Yuan-Bentler adjusted chi-square test was used to account for the non-normally distributed data. For both fussing and crying, a model predicting self-regulation at 18 months (toddlerhood model) and at 4.5 years (preschool model) was estimated. Missing data were handled with full information maximum likelihood estimation. For all analyses, an alpha level of .05 was used to determine the significance of parameters. We also inspected whether models contained influential cases, as indicated by Generalized Cook's Distances (GCD) higher than 1.00 (Cook & Weisberg, 1982).

For all models, SES was included as control variable. The models predicting preschool self-regulation also controlled for self-regulation in toddlerhood. All four models included the percentage negative reactivity (either fussing or crying), maternal sensitivity, the quadratic terms of percentage negative reactivity (i.e., $fussing^2$, or $crying^2$), the interaction terms for fussing or crying with maternal sensitivity (i.e., a two-way interaction), and the interaction term between the quadratic terms of fussing or crying and maternal sensitivity (i.e., a quadratic-by-linear interaction). A quadratic-by-linear interaction indicates that the shape of a quadratic effect depends on the level of the moderator, in this case maternal sensitivity.

Whenever the quadratic-by-linear interactions proved to be significant, we visually inspected the simples slopes of self-regulation regressed on fussing and/or crying at −1 and +1 *SD* from the mean level of maternal sensitivity. In addition, we tested whether the quadratic effect was significant within the range of the observed variables. That is, we examined whether there was a true inverted U-shaped effect that both significantly increased and decreased, using an extension of the Johnson-Neyman (J-N) technique for quadratic-by-linear interactions (Miller, Stromeyer, & Schwieterman, 2013).

Results

Preliminary analyses

Descriptive statistics are reported in Table 1. As can be seen, we observed a restricted range of maternal sensitivity: mothers in the sample were moderately to highly sensitive. We could therefore only contrast infants of highly sensitive mothers with infants of relatively low sensitive mothers. There were no sex differences in self-regulation in toddlerhood, $t(134) = -1.34$, $p = .182$, or the preschool years, $t(109) = -0.90$, $p = .37$. No sex differences were found for percentage fussing, $t(130) = 0.72$, $p = .473$, and percentage crying, $t(130) = 0.89$, $p = .374$. Correlations for all parameters are depicted in Table 2 and indicate that higher SES was related to better self-regulation at both ages. Self-regulation was relatively stable from toddlerhood to preschool age. Fussing, crying, and maternal sensitivity in infancy were unrelated to self-regulation at either age.

Primary analyses

Toddler self-regulation—Inspection of influential cases showed that GCD values fell within a 0.00–0.98 range for the toddlerhood model with fussing as predictor. For the toddlerhood model with crying as predictor, two influential cases appeared (GCD = 1.09 and 1.25). However, removing these influential cases resulted in new influential cases, which indicates a general poor model fit (Pek & MacCallum, 2011). As the GCD values were also only slightly higher than 1.00, we did not remove any cases.

For the model in which fussing predicted self-regulation in toddlerhood (Table 3), chi-square test against the baseline model was significant ($\chi 2 = 22.27$, $df = 6$, $p = .001$), indicating that the regression model was more meaningful compared to a baseline model in which all parameters are uncorrelated with each other. The predictors explained 11.81% of the variance in toddler's self-regulation. Only SES was a significant positive predictor of self-regulation in toddlerhood. Neither fussing nor maternal sensitivity in infancy predicted self-regulation in toddlerhood. For the model in which crying predicted self-regulation in toddlerhood (Table 3), chi-square test against the baseline model was not significant ($\chi 2 = 12.33$, $df = 6$, $p = .055$), indicating that the regression model was not more meaningful compared to a baseline model in which all parameters are uncorrelated with each other.

Preschool self-regulation—For the preschool model with fussing as a predictor, two influential cases on the set of parameters were deleted (GCD: 1.95 – 4.25). After removal, new influential cases appeared, but these were lower (GCD: 1.23 – 1.65). For the preschool model with crying as a predictor, one influential case was detected (GCD = 5.10 and 1.21). After removal, three new influential case appeared, (GCD: 1.25–1.60) but these were not extreme.

For the model with fussing predicting preschool self-regulation, chi-square test against the baseline model was significant ($\chi 2 = 39.93$, $df = 7$, $p < .001$). The model explained 40.49% of the variance in preschool self-regulation. As can be seen in Table 4, SES and the quadratic term for fussing significantly predicted preschool self-regulation. These relations were subsumed by a significant interaction between the quadratic term for fussing and maternal sensitivity.

As hypothesized, the simple slopes indicated that the quadratic effect of fussing on preschool self-regulation was only evident for children of high sensitive mothers (see Figure 2). For this group, the quadratic effect was shaped as an inverted U, such that moderate amounts of fussing in infancy were predictive of better preschool self-regulation. The estimated peak of self-regulation was at a fussing value of 0.76. For children of low sensitive mothers, there was no association between fussing and self-regulation.

Follow-up analyses using an extension of the J-N technique (Supplementary material) showed that, for infants of highly sensitive mothers, there was a true inverted U-shaped effect of fussing on preschool self-regulation that both significantly increased and decreased. In addition, an amount of fussing in between −0.12 and 2.36 was associated with the highest level of self-regulation. Given that fussing was centered, this indicates that the highest level of preschool self-regulation was observed for children who showed an amount of fussiness in the range comparable to the mean of this sample and 1 *SD* higher. When maternal sensitivity was relatively low, the simple slope for self-regulation regressed on fussing was not significant.

For the model with crying predicting preschool self-regulation, chi-square test against the baseline model was also significant ($\chi 2 = 28.30$, $df = 7$, $p <.001$). The model explained 20.37% of the variance in preschool self-regulation. Only SES predicted higher levels of self-regulation (Table 4). Specifically, higher SES was associated with higher levels of preschool self-regulation. Maternal sensitivity and infant crying were unrelated to preschool self-regulation.

Discussion

The goals of the current multimethod longitudinal study were to examine whether infant negative reactivity, i.e., fussing and crying, predicted toddler and preschool self-regulation, and whether maternal sensitivity moderated this relation. To this end, we first tested the hypothesis that negative reactivity would predict later self-regulation in a manner consistent with the optimal arousal perspective. We examined whether moderate amounts of negative reactivity, as opposed to high and low amounts of negative reactivity, would predict higher levels of self-regulation in toddlerhood and the preschool years. We primarily expected to find such a quadratic association for fussing, as opposed to crying. Second, we tested the hypothesis that there would be a positive predictive relation between maternal sensitivity in infancy and self-regulation in toddlerhood and the preschool years. Finally, we examined whether the predictive association between negative reactivity and self-regulation was conditional on levels of maternal sensitivity.

Results indicated that the relation between infant fussing and preschool self-regulation took the shape of an inverted U, but only for children of highly sensitive mothers. As hypothesized, for infants of highly sensitive mothers, moderate amounts of fussing were associated with better self-regulation relative to low and high amounts of fussing. In contrast, when maternal sensitivity was relatively low, there was no association between fussing and self-regulation. Crying did not predict preschool self-regulation. Lastly, self-regulation in toddlerhood was neither predicted by fussing, crying, and sensitivity, nor by their interactions.

Informed by the theoretical notion that the relation between negative reactivity and self-regulation follows an inverted U-shape (Blair & Ursache, 2011), the results of the current study indicate that, within the context of high maternal sensitivity, moderate amounts of fussing but not crying predict better preschool self-regulation. The findings of this study are in keeping with prior animal studies indicating that experimentally induced, brief moments of negative reactivity are associated with enhanced self-regulation (e.g., Parker et al., 2005; Tang et al., 2006). In addition, the findings align with human studies demonstrating that infants with low levels and moderate fluctuations in cortisol show better self-regulation in the preschool years (Blair et al., 2017), as well as with studies showing that the combination of high reactivity and high regulation predicts more advanced self-regulation (Stifter et al., 1999; Ursache et al., 2013).

The importance of distinguishing between infant fussing and crying is clearly demonstrated with this study. The results fit well with the optimal arousal theory, which focusses not only on the amount, but also on the level of negative reactivity (Blair & Ursache, 2011).

Not only do relative low levels of negative reactivity support prefrontal cortex functioning (Arnsten, 2009), they may also provide a controlled practice opportunity for regulation. That is, during moments of fussing, six-month-old infants may be able to better handle their negative reactivity, while higher levels of distress would likely impede this opportunity to learn how to regulate. Based on operant conditioning principles, reductions in negative reactivity are proposed to be an enjoyable experience, which increases the chance that infants will repeat regulatory behaviors associated with such reductions in the future. Tronick and Beeghly (2011) refer to this process as meaning-making: the process in which infants acquire information by engaging with their inner world, and the world around them. Infants who fuss a lot most likely do not experience the positive effects of their regulatory actions. Additionally, during moments of crying, regulatory behaviors that would have been available to infants when they were less distressed may be disabled. There are indications that children use different regulatory behaviors depending on the level of negative reactivity (e.g., Ekas, Braungart-Rieker, Lickenbrock, Zentall, & Maxwell, 2011; Stifter & Braungart, 1995). Behaviors that are used at high levels of negative reactivity are generally more primitive, such as self-comforting behaviors (e.g., thumb-sucking), and these may be used at the expense of more mature attention based regulatory behaviors (Stifter & Braungart, 1995). Hence, infants may not be able to practice and further refine more mature forms of emotion regulation during moments of highly intensive negative reactivity, expressed as crying.

Maternal sensitivity was not directly associated with preschool self-regulation. In other words, infants of less sensitive mothers on average did not demonstrate lower levels of self-regulation than infants of more sensitive mothers. However, as this study was conducted with a relatively well-educated community sample, we observed a restricted range of variation in maternal sensitivity, a result commonly found in low-risk, middle class families in which most children grow up under conditions characterized by moderate levels of support (Ellis, Nederhof, & Oldehinkel, 2016). In these conditions, mothers may be generally sensitive to their children’s needs, but also temporarily express intrusiveness or less sensitivity. A growing body of research demonstrates that children of moderately sensitive parents will develop a buffered profile of stress responsivity, because they experience normative ups and downs that help them with developing appropriate stress responses (e.g., Berry et al, 2017; Ellis et al, 2016). Due to this buffered profile, they will be less susceptible to subsequent experiences. In contrast, children of highly sensitive and supportive parents have less experience with normative ups and downs and the accompanying activation and recovery of their stress response system. As a consequence, they will remain sensitive to subsequent experiences. Previous work indicates that the buffered and sensitive profiles that arise from respectively moderately and highly supportive contexts are both associated with favorable developmental outcomes compared to profiles that typically emerge when children grow up in very low supportive households (Ellis et al., 2016). This aligns with the finding in the current study that maternal sensitivity was not directly associated with preschool self-regulation. Future studies should test whether our results hold in more diverse samples, with a broader range of maternal sensitivity.

Although there was no direct relation between maternal sensitivity and preschool self-regulation in the study, mother behavior did moderate the association between infant fussing and preschool self-regulation. We found that individual differences in fussing were only important in predicting self-regulation in the context of high maternal sensitivity. Various previous studies have demonstrated that the combination of negative reactivity and parenting practices predicts later self-regulation (e.g., Feldman et al., 1999; Kim & Kochanska, 2012). Specifically, these studies demonstrated that the combination of high infant negative reactivity and high maternal sensitivity predicts higher levels of self-regulation. However, moderate levels of reactivity were not considered as was done in the current study. Our findings show that, within the context of high maternal sensitivity, infants who experience moderate amounts of fussing show the highest level of self-regulation in the preschool years. Moderately fussy infants create the opportunity for their mothers to help them learn how to regulate. Mothers can model and initiate regulatory behaviors or support and encourage infants' own regulatory efforts. Infants who show high amounts of fussing may not experience the modulating function of maternal attempts to modulate their distress, and they may therefore be less inclined to repeat modelled or encouraged regulatory behaviors. In contrast, infants who do not experience many episodes of fussing do not have the opportunity to profit from the prompt and appropriate responses to negative reactivity from their mothers. This pattern is important, as maternal sensitivity to negative reactivity is found to be particularly important for socioemotional adjustment (Leerkes, Blankson, & O'Brien, 2009; McElwain & Booth-LaForce, 2006). For mothers of infants who rarely display negative reactivity, there are few occasions for them to express their sensitivity to negative reactivity.

In contrast to preschool self-regulation, self-regulation in toddlerhood was unrelated to any of the measures in infancy. Whereas we operationalized self-regulation in the preschool years with executive function tasks, our measure for self-regulation in toddlerhood predominantly tapped the ability to delay and comply with adults. Possibly, the optimal arousal perspective is not applicable to these forms of regulation. In addition, as self-regulation is still 'under construction' in toddlerhood, individual differences at this age may be masked and difficult to predict. Previous longitudinal studies aimed at predicting self-regulation at various ages also found that self-regulation in toddlerhood was more difficult to predict than self-regulation in the preschool years (e.g., Cuevas et al., 2014; Johansson, Marciszko, Brocki, & Bohlin, 2016). It should be noted that self-regulation in toddlerhood was modestly associated with self-regulation in the preschool years, supporting the predictive validity of our self-regulation measure in toddlerhood.

There are many strengths to the current study, including the use of cry diaries over multiple days and reliance of observational measures to assess both toddler and preschool self-regulation. Yet, the results of the study should also be considered alongside some limitations. First, fussiness and crying were recorded by parents who may have been biased toward over-reporting or underreporting their infants' distress. Likewise, highly sensitive mothers may have been more reliable informants regarding infant fussing and crying than low sensitive mothers, which could also explain why the association between infant fussing and preschool self-regulation only took an inverted U-shape for children of highly sensitive mothers. Future studies should examine whether our results hold for measures of fussing that are independent of maternal reports, for instance by using auditory or video assessment procedures or by relying on different informants. Third, future studies may want to incorporate a larger test-battery to measure self-regulation and include longer assessments for compliance and maternal sensitivity. Lastly, larger and more diverse samples are needed to further confirm the robustness of the relatively complex moderated quadratic models tested in this study. We carefully tested whether the models fit the data well, by adopting a robust estimator and checking for influential cases. Nevertheless, there may be alternative approaches that reduce the risk of false positives, such as the recently proposed two-lines procedure (Simonsohn, 2018).

In summary, the current study is the first to demonstrate that the relation between fussing and self-regulation may take the shape of an inverted U, and that this association depends upon levels of maternal sensitivity. At six months, experiencing moments of fussing, but not crying, is integral to the development of self-regulation for infants of highly sensitive mothers. In this context of high maternal sensitivity, moderate amounts of fussing are associated with enhanced self-regulation in the preschool years. Our findings underscore the importance of distinguishing between levels of negative reactivity, and the need to consider the social context of infants.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

Ainsworth MDS (1969). Object relations, dependency, and attachment: A theoretical review of the infant-mother relationship. Child Development, 40, 969–1025. doi: 10.2307/1127008 [PubMed: 5360395]

Alvarez M (2004). Caregiving and early infant crying in a danish community. Journal of Developmental & Behavioral Pediatrics, 25, 91–98. doi: 10.1097/00004703-200404000-00003 [PubMed: 15083130]

Arnsten AF (2009). Stress signalling pathways that impair prefrontal cortex structure and function. Nature Reviews Neuroscience, 10, 410–422. doi: 10.1038/nrn2648 [PubMed: 19455173]

Barr RG, Kramer MS, Boisjoly C, McVey-White L, & Pless IB (1988). Parental diary of infant cry and fuss behaviour. Archives of Disease in Childhood, 63, 380–387. doi: 10.1136/adc.63.4.380 [PubMed: 3365007]

Beeghly M, & Tronick E (2011). Early resilience in the context of parent–infant relationships: A social developmental perspective. Current Problems in Pediatric and Adolescent Health Care, 41, 197–201. doi: 10.1016/j.cppeds.2011.02.005 [PubMed: 21757137]

Berry D, Blair C, Willoughby M, Granger DA, Mills-Koonce WR, & Family Life Project Key Investigators. (2017). Maternal sensitivity and adrenocortical functioning across infancy and toddlerhood: Physiological adaptation to context?. Development and Psychopathology, 29, 303–317. doi: 10.1017/S0954579416000158 [PubMed: 27065311]

Bernier A, Carlson SM, & Whipple N (2010). From external regulation to self-regulation: Early parenting precursors of young children's executive functioning. Child Development, 81, 326–339. doi: 10.1111/j.1467-8624.2009.01397.x [PubMed: 20331670]

Blair C (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. American Psychologist, 57, 111–127. doi: 10.1037/0003-066X.57.2.111

Blair C, Berry DJ, & FLP Investigators. (2017). Moderate within-person variability in cortisol is related to executive function in early childhood. Psychoneuroendocrinology, 81, 88–95. doi: 10.1016/j.psyneuen.2017.03.026 [PubMed: 28433801]

Blair C, & Razza RP (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Development, 78, 647–663. doi: 10.1111/j.1467-8624.2007.01019.x [PubMed: 17381795]

Blair C, & Ursache A (2011). A bidirectional model of executive functions and self-regulation In Vohs KD & Baumeister RF, Handbook of Self-Regulation: Research, Theory, and Applications,(pp. 300–320). New York: The Guilford Press.

Bridgett DJ, Gartstein MA, Putnam SP, McKay T, Iddins E, Robertson C, … Rittmueller A (2009). Maternal and contextual influences and the effect of temperament development during infancy on parenting in toddlerhood. Infant Behavior and Development, 32, 103–116. doi: 10.1037/0012-1649.34.6.1428 [PubMed: 19111913]

Bronfenbrenner U, & Ceci SJ (1994). Nature-nuture reconceptualized in developmental perspective: A bioecological model. Psychological Review, 101, 568–586. doi: 10.1037/0033-295X.101.4.568 [PubMed: 7984707]

Carlson SM, & Moses LJ (2001). Individual differences in inhibitory control and children's theory of mind. Child Development, 72, 1032–1053. doi: 10.1111/1467-8624.00333 [PubMed: 11480933]

Cohen J, Cohen P, West SG, & Aiken LS (2003). Applied multiple correlation/regression analysis for the behavioral sciences. New York, N.Y: Routledge..

Cook RD, & Weisberg S (1982). Residuals and influence in regression. NY: Chapman and Hall.

Crockenberg SC, & Leerkes EM (2004). Infant and maternal behaviors regulate infant reactivity to novelty at 6 months. Developmental Psychology, 40, 1123. doi: 10.1037/0012-1649.40.6.1123 [PubMed: 15535761]

Crockenberg SC, & Leerkes EM (2006). Infant and maternal behavior moderate reactivity to novelty to predict anxious behavior at 2.5 years. Development and Psychopathology, 18, 17–34. doi: 10.1017/S0954579406060020 [PubMed: 16478550]

Cuevas K, Deater-Deckard K, Kim-Spoon J, Watson AJ, Morasch KC, & Bell MA (2014). What's mom got to do with it? contributions of maternal executive function and caregiving to the development of executive function across early childhood. Developmental Science, 17, 224–238. doi: 10.1111/desc.12073 [PubMed: 24410963]

De Wolff MS, & Van Ijzendoorn MH (1997). Sensitivity and attachment: A meta-analysis on parental antecedents of infant attachment. Child Development, 68, 571–591. doi: 10.2307/1132107 [PubMed: 9306636]

DeSantis A, Coster W, Bigsby R, & Lester B (2004). Colic and fussing in infancy, and sensory processing at 3 to 8 years of age. Infant Mental Health Journal, 25, 522–539. doi: 10.1002/imhj.20025

Diamond A, & Taylor C (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "Do as I say, not as I do". Developmental Psychobiology, 29, 315–334. doi: 10.1002/(SICI)1098-2302(199605)29:4<315::AID-DEV2>3.0.CO;2-T [PubMed: 8732806]

Eisenberg N, Cumberland A, & Spinrad TL (1998). Parental socialization of emotion. Psychological Inquiry, 9, 241–273. doi:10.1207/s15327965pli0904_1 [PubMed: 16865170]

Eisenberg N, Fabes RA, Guthrie IK, & Reiser M (2000). Dispositional emotionality and regulation: Their role in predicting quality of social functioning. Journal of Personality and Social Psychology, 78, 136–157. doi: 10.1037/0022-3514.78.1.136 [PubMed: 10653511]

Ekas NV, Braungart-Rieker JM, Lickenbrock DM, Zentall SR, & Maxwell SM (2011). Toddler emotion regulation with mothers and fathers: Temporal associations between negative affect and behavioral strategies. Infancy, 16, 266–294. doi: 10.1111/j.1532-7078.2010.00042.x [PubMed: 21552335]

Ekas NV, Lickenbrock DM, & Braungart-Rieker JM (2013). Developmental trajectories of emotion regulation across infancy: Do age and the social partner influence temporal patterns. Infancy, 18, 729–754. doi: 10.1111/infa.12003

Ellis BJ, Oldehinkel AJ, & Nederhof E (2017). The adaptive calibration model of stress responsivity: An empirical test in the Tracking Adolescents' Individual Lives Survey study. Development and Psychopathology, 29, 1001–1021. doi: 10.1017/S0954579416000985 [PubMed: 27772536]

Feldman R, Greenbaum CW, & Yirmiya N (1999). Mother–infant affect synchrony as an antecedent of the emergence of self-control. Developmental Psychology, 35, 223–231. doi: 10.1037/0012-1649.35.1.223 [PubMed: 9923477]

Frye D, Zelazo PD, & Palfai T (1995). Theory of mind and rule-based reasoning. Cognitive Development, 10, 483–527. doi: 10.1016/0885-2014(95)90024-1

Gartstein MA, Bridgett DJ, Young BN, Panksepp J, & Power T (2013). Origins of effortful control: Infant and parent contributions. Infancy, 18, 149–183. doi: 10.1111/j.1532-7078.2012.00119.x [PubMed: 26269695]

Gerstadt CL, Hong YJ, & Diamond A (1994). The relationship between cognition and action: Performance of children 312–7 years old on a stroop-like day-night test. Cognition, 53, 129–153. doi: 10.1016/0010-0277(94)90068-x [PubMed: 7805351]

Gunnar MR, & Stone C (1984). The effects of positive maternal affect on infant responses to pleasant, ambiguous, and fear-provoking toys. Child Development, 55, 1231–1236. doi: 10.2307/1129992

Hemmi MH, Wolke D, & Schneider S (2011). Associations between problems with crying, sleeping and/or feeding in infancy and long-term behavioural outcomes in childhood: a meta-analysis. Archives of Disease in Childhood, 96, 622–629. doi: 10.1136/adc.2010.191312 [PubMed: 21508059]

Jamshidian M, Jalal SJ, & Jansen C (2014). MissMech: an R package for testing homoscedasticity, multivariate normality, and missing completely at random (MCAR). Journal of Statistical software, 56, 1–31. doi: 10.18637/jss.v056.i06

Johansson M, Marciszko C, Brocki K, & Bohlin G (2016). Individual differences in early executive functions: A longitudinal study from 12 to 36 months. Infant and Child Development, 25, 533–549. doi: 10.1002/icd.1952

Kim BR, Stifter CA, Philbrook LE, & Teti DM (2014). Infant emotion regulation: Relations to bedtime emotional availability, attachment security, and temperament. Infant Behavior and Development, 37, 480–490. doi: 10.1016/j.infbeh.2014.06.006 [PubMed: 24995668]

Kim S, & Kochanska G (2012). Child temperament moderates effects of parent–child mutuality on self-regulation: A relationship-based path for emotionally negative infants. Child Development, 83, 1275–1289. doi: 10.1111/j.1467-8624.2012.01778.x [PubMed: 22670684]

Kochanska G, Coy KC, & Murray KT (2001). The development of self-regulation in the first four years of life. Child Development, 72, 1091–1111. doi: 10.1111/1467-8624.00336 [PubMed: 11480936]

Kochanska G, & Knaack A (2003). Effortful control as a personality characteristic of young children: Antecedents, correlates, and consequences. Journal of Personality, 71, 1087–1112. doi: 10.1111/1467-6494.7106008 [PubMed: 14633059]

Kochanska G, Tjebkes JL, & Fortnan DR (1998). Children's emerging regulation of conduct: Restraint, compliance, and internalization from infancy to the second year. Child Development, 69, 1378–1389. doi: 10.1111/j.1467-8624.1998.tb06218.x [PubMed: 9839422]

Kopp CB (1982). Antecedents of self-regulation: A developmental perspective. Developmental Psychology, 18, 199–214. doi: 10.1037/0012-1649.18.2.199

Leerkes EM, Blankson AN, & O'Brien M (2009). Differential effects of maternal sensitivity to infant distress and nondistress on social-emotional functioning. Child Development, 80, 762–775. doi: 10.1111/j.1467-8624.2009.01296.x [PubMed: 19489902]

Luria AR (1959). The directive function of speech in development and dissolution. Word, 15, 341–352. doi: 10.1080/00437956.1959.11659703

Lyons DM, Parker KJ, Katz M, & Schatzberg AF (2009). Developmental cascades linking stress inoculation, arousal regulation, and resilience. Frontiers in Behavioral Neuroscience, 3, 32. doi: 10.3389/neuro.08.032.2009 [PubMed: 19826626]

McElwain NL, & Booth-LaForce C (2006). Maternal sensitivity to infant distress and nondistress as predictors of infant-mother attachment security. Journal of Family Psychology, 20, 247–255. doi: 10.1037/0893-3200.20.2.247 [PubMed: 16756400]

Miller JW, Stromeyer WR, & Schwieterman MA (2013). Extensions of the johnson-neyman technique to linear models with curvilinear effects: Derivations and analytical tools. Multivariate Behavioral Research, 48, 267–300. doi: 10.1080/00273171.2013.763567 [PubMed: 26741727]

Parker KJ, Buckmaster CL, Justus KR, Schatzberg AF, & Lyons DM (2005). Mild early life stress enhances prefrontal-dependent response inhibition in monkeys. Biological Psychiatry, 57, 848–855. doi: 10.1016/j.biopsych.2004.12.024 [PubMed: 15820705]

Pek J, & MacCallum RC (2011). Sensitivity analysis in structural equation models: Cases and their influence. Multivariate Behavioral Research, 46, 202–228. doi: 10.1080/00273171.2011.561068 [PubMed: 26741328]

Poehlmann J, Schwichtenberg A, Shlafer RJ, Hahn E, Bianchi J, & Warner R (2011). Emerging self-regulation in toddlers born preterm or low birth weight: Differential susceptibility to parenting? Development and Psychopathology, 23, 177–193. doi: 10.1017/s0954579410000726 [PubMed: 21262047]

Raikes HA, Robinson JL, Bradley RH, Raikes HH, & Ayoub CC (2007). Developmental trends in self-regulation among low-income toddlers. Social Development, 16, 128–149. doi: 10.1111/j.1467-9507.2007.00375.x

Rao MR, Brenner RA, Schisterman EF, Vik T, & Mills JL (2004). Long term cognitive development in children with prolonged crying. Archives of Disease in Childhood, 89, 989–992. doi: 10.1136/adc.2003.039198 [PubMed: 15499048]

Rosseel Y (2012). Lavaan: An R package for structural equation modeling and more. version 0.5–12 (BETA). Journal of Statistical Software, 48, 1–36. doi: 10.18637/jss.v048.i02

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Austria.

Rothbart MK (1989b). Temperament in childhood: A framework. In Kohnstamm GA, Bates JA, & Rothbart MK (Eds.), Temperament in childhood (pp. 59–73). New York: Wiley.

Rothbart MK, Sheese BE, Rueda MR, & Posner MI (2011). Developing mechanisms of self-regulation in early life. Emotion Review, 3, 207–213. doi: 10.1177/1754073910387943 [PubMed: 21892360]

Salisbury A, Minard K, Hunsley M, & Thoman EB (2001). Audio recording of infant crying: Comparison with maternal cry logs. International Journal of Behavioral Development, 25, 458–465. doi: 10.1080/016502501316934897

Simonsohn U (2018). Two lines: A valid alternative to the invalid testing of U-shaped relationships with quadratic regressions. Advances in Methods and Practices in Psychological Science, 1, 538–555. doi: 10.1177/2515245918805755

Sroufe LA (2000). Early relationships and the development of children. Infant Mental Health Journal, 21(1-2), 67–74. doi: 10.1002/(sici)1097-0355(200001/04)21:1/2<67::aid-imhj8>3.0.co;2-2

St James-Roberts I, Hurry J, & Bowyer J (1993). Objective confirmation of crying durations in infants referred for excessive crying. Archives of Disease in Childhood, 68, 82–84. doi: 10.1136/adc.68.1.82 [PubMed: 8435015]

St. James-Roberts I, & Plewis I (1996). Individual differences, daily fluctuations, and developmental changes in amounts of infant waking, fussing, crying, feeding, and sleeping. Child Development, 67, 2527–2540. doi: 10.2307/1131638 [PubMed: 9022254]

St. James-Roberts IS (2001). Infant crying and its impact on parents. In: Barr RG, St. James-Robert I, & Keefe MR (eds.), New Evidence on Unexplained Early Infant Crying (pp. 5–24). Johnson & Johnson Pediatric Institute: Miami, Fla: Johnson & Johnson Pediatric Institute.

Stifter CA, & Braungart J (1992). Infant colic: A transient condition with no apparent effects. Journal of Applied Developmental Psychology, 13, 447–462. doi:10.1016/0193-3973(92)90012-7

Stifter CA, & Braungart JM (1995). The regulation of negative reactivity in infancy: Function and development. Developmental Psychology, 31, 448–455. doi: 10.1037/0012-1649.31.3.448

Stifter CA, & Spinrad TL (2002). The effect of excessive crying on the development of emotion regulation. Infancy, 3, 133–152. doi: 10.1207/s15327078in0302_2 [PubMed: 33451205]

Stifter CA, Spinrad T, & Braungart-Rieker J (1999). Toward a developmental model of child compliance: The role of emotion regulation in infancy. Child Development, 70, 21–32. doi: 10.1111/1467-8624.00003 [PubMed: 10191513]

Stifter CA, Willoughby MT, & Towe-Goodman N (2008). Agree or agree to disagree? assessing the convergence between parents and observers on infant temperament. Infant and Child Development: An International Journal of Research and Practice, 17, 407–426. doi: 10.1002/icd.584

Tang AC, Akers KG, Reeb BC, Romeo RD, & McEwen BS (2006). Programming social, cognitive, and neuroendocrine development by early exposure to novelty. Proceedings of the National Academy of Sciences, 103, 15716–15721. doi: 10.1073/pnas.0607374103

Tronick E, & Beeghly M (2011). Infants' meaning-making and the development of mental health problems. American Psychologist, 66, 107–119. doi: 10.1037/a0021631

Ursache A, Blair C, Granger DA, Stifter C, Voegtline K, & Investigators FLP (2014). Behavioral reactivity to emotion challenge is associated with cortisol reactivity and regulation at 7, 15, and 24 months of age. Developmental Psychobiology, 56, 474–488. doi: 10.1002/dev.21113 [PubMed: 23918193]

Ursache A, Blair C, Stifter C, & Voegtline K (2013). Emotional reactivity and regulation in infancy interact to predict executive functioning in early childhood. Developmental Psychology, 49, 127–137. doi: 10.1037/a0027728 [PubMed: 22563678]

Yerkes RM, & Dodson JD (1908). The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology, 18, 459–482. doi: 10.1002/cne.920180503

Zelazo PD (2006). The dimensional change card sort (DCCS): A method of assessing executive function in children. Nature Protocols, 1, 297–301. doi: 10.1038/nprot.2006.46 [PubMed: 17406248]

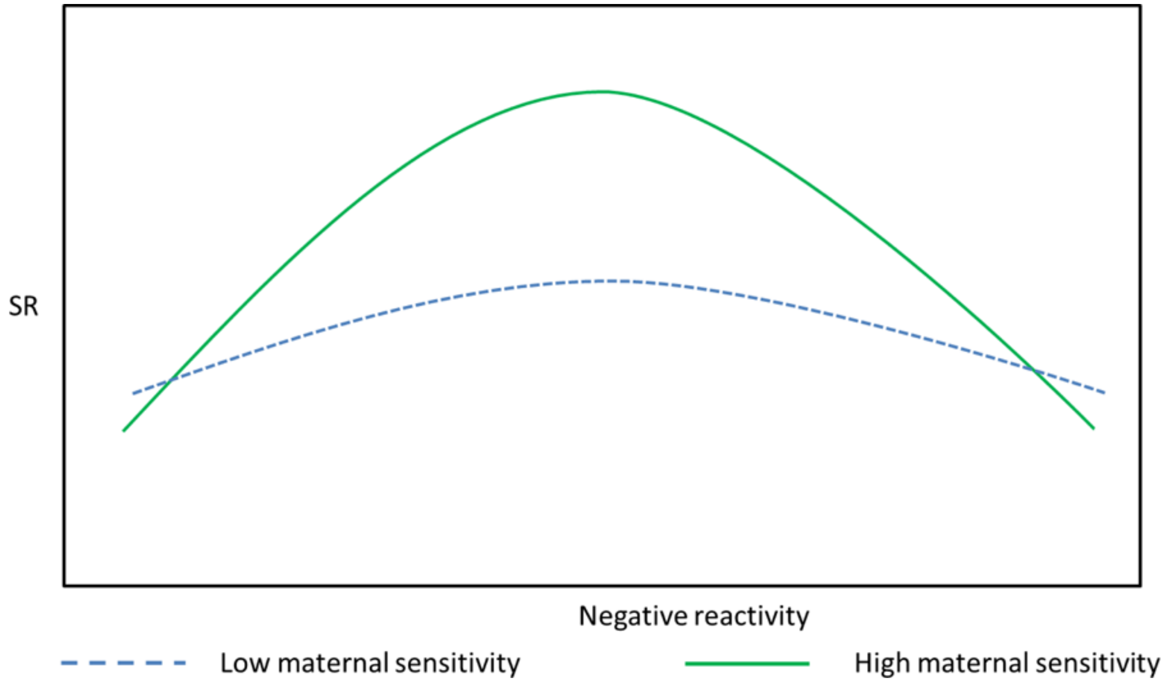

Figure 1.
Hypothesized Predictive Value of Negative Reactivity in Infancy for Self-Regulation in Toddlerhood and the Preschool Years. These Predictive Values are Conditional on Maternal Sensitivity, Such that the Quadratic Association is Stronger at Higher Levels of Maternal Sensitivity.
Note. SR: self-regulation.

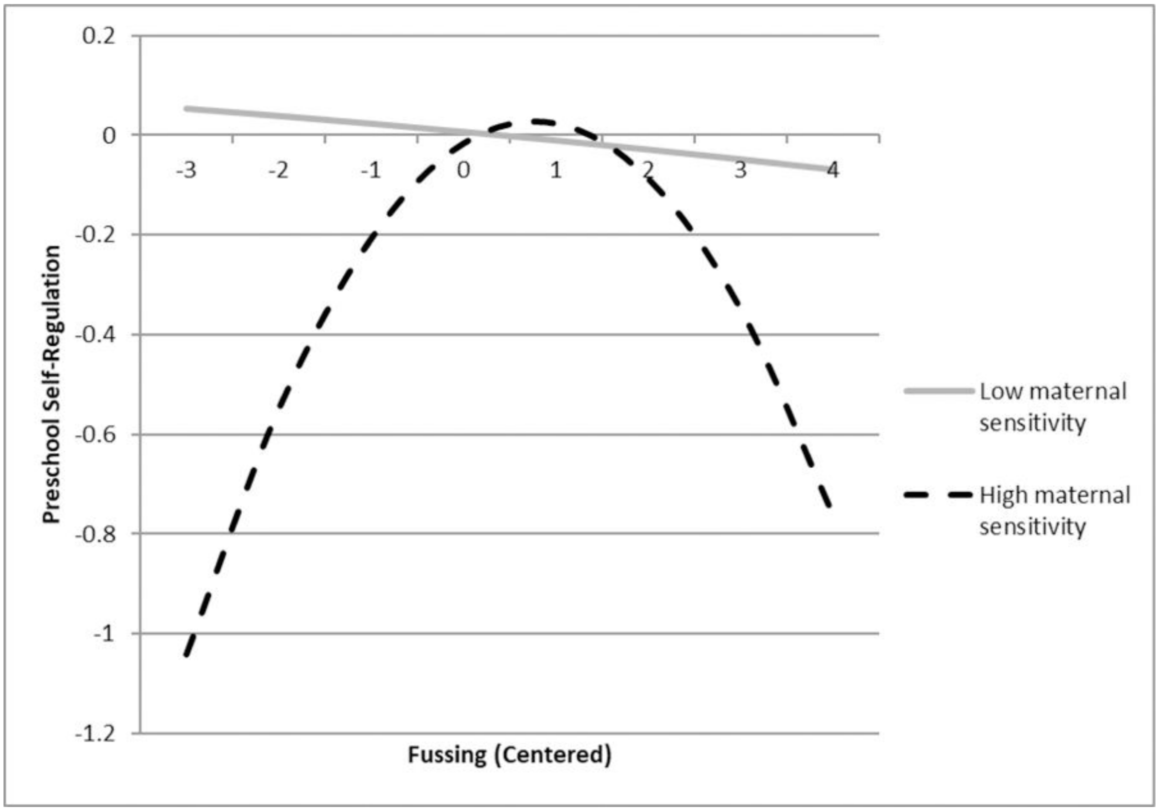

Figure 2.
Simple Slope of Self-Regulation on Fussing Conditional on Maternal Sensitivity.

Table 1.

Descriptive statistics

Measure	***n***	**Mean (*SD*)**	**Range**
Infancy			
Fussing: percentage	132	3.84 (2.52)	0.00–14.51
Crying: percentage	132	1.24 (1.19)	0.00–5.56
Maternal sensitivity	148	2.07 (0.14)	1.55–2.54
Toddlerhood			
Compliance	136	0.34 (0.24)	0.00–1.00
Experimenter-rated regulation	136	5.39 (0.82)	3.17–7.67
Delay of gratification	136	0.01 (0.91)	−1.40–1.07
Mean score	136	0.00 (0.67)	−1.67–1.80
Preschool years			
Day-Night task	110	0.70 (0.27)	0.00–1.00
Tapping task	110	0.64 (0.31)	0.00–1.00
Dimensional Change Card Sort task	106	0.83 (0.34)	0.00–1.00
Mean score	111	−0.01 (0.73)	−2.39–1.12

Table 2.

Correlations matrix

	1.	2.	3.	4.	5.
1. SES					
2. Fussing: percentage – 6 months	−.10				
3. Crying: percentage– 6 months	−.08	.23*			
4. Maternal sensitivity– 6 months	.03	−.02	.01		
5. Self-regulation – 18 months	.21*	.14	−.09	.15	
6. Self-regulation – 4.5 years	.32**	.12	−.07	.12	.25*

*<.05.

**<.01. n = 99–148, depending on missing data

Table 3.

Multiple Regression of Fussing, Crying and Maternal Sensitivity in Infancy on Self-Regulation in Toddlerhood

	Fussing			**Crying**		
	***b* (*SE*)**	**β**	***p***	***b* (*SE*)**	**β**	***p***
Socio-Economic Status	0.20 (0.07)	.25	.006	0.16 (0.07)	.20	.022
Negative reactivity	0.02 (0.02)	.06	.460	−0.11 (0.07)	−.20	.088
Maternal sensitivity	0.58 (0.38)	.12	.122	0.67 (0.41)	.14	.106
Negative reactivity^2	0.01 (0.00)	.12	.076	0.04 (0.03)	.18	.128
Sensitivity* negative reactivity	−0.13 (0.16)	−.06	.420	0.39 (0.46)	.09	.390
Sensitivity*negative reactivity^2	−0.05 (0.04)	−.08	.293	−0.07 (0.22)	−.03	.749

Note. $n = 149$ with Full Information Maximum Likelihood. Negative reactivity refers to percentage fussing in the fussing model and to percentage crying in the crying model.

Table 4.

Multiple Regression of Fussing, Crying and Maternal Sensitivity in Infancy on Self-Regulation in the Preschool Years

	Fussing			**Crying**		
	***b* (*SE*)**	**β**	***p***	***b* (*SE*)**	**β**	***p***
Self-regulation in toddlerhood	0.08 (0.09)	.07	.389	0.10 (0.10)	.10	.313
Socio-Economic Status	0.28 (0.06)	.33	<.001	0.29 (0.07)	.37	<.001
Negative reactivity	0.02 (0.03)	.09	.436	0.07 (0.08)	.13	.358
Maternal sensitivity	−0.08 (0.46)	−.02	.866	0.60 (0.46)	.13	.199
Negative reactivity^2	−0.02 (0.01)	−.44	.019	−0.04 (0.03)	.16	.178
Sensitivity* negative reactivity	0.47 (0.28)	.21	.092	0.53 (0.59)	.12	.366
Sensitivity*negative reactivity^2	−0.27 (0.06)	−.44	<.001	−0.21 (0.21)	−.09	.321

Note. n = 147 with Full Information Maximum Likelihood. Negative reactivity refers to percentage fussing in the fussing model and to percentage crying in the crying model.