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What's Mom Got to Do with It? Contributions of Maternal Executive Function and Caregiving to the Development of Executive Function Across Early Childhood

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Abstract

Executive functions (EFs; e.g., working memory, inhibitory control) are mediated by the prefrontal cortex and associated with optimal cognitive and socio-emotional development. This study provides the first concurrent analysis of the relative contributions of maternal EF and caregiving to child EF. A group of children and their mothers ($n = 62$) completed age-appropriate interaction (10, 24, 36 months) and EF tasks (child: 24, 36, and 48 months). Regression analyses revealed that by 36 months of age, maternal EF and negative caregiving behaviors accounted for unique variance in child EF, above and beyond maternal education and child verbal ability. These findings were confirmed when using an early child EF composite—our most reliable measure of EF—and a similar pattern was found when controlling for stability in child EF. Furthermore, there was evidence that maternal EF had significant indirect effects on changes in child EF through maternal caregiving. At 24 months, EF was associated with maternal EF, but not negative caregiving behaviors. Taken together, these findings suggest that links between negative caregiving and child EF are increasingly manifested during early childhood. Although maternal EF and negative caregiving are related, they provide unique information about the development of child EF.

Keywords

executive function; caregiving; early childhood; individual differences

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The ability to regulate memory and attention processes is essential to optimal social-emotional and cognitive development in childhood and beyond (Bell & Deater-Deckard, 2007; Blair, 2002; Nigg & Casey, 2005; Posner & Rothbart, 2007). Although we know that most children exhibit dramatic improvements in self-regulation between infancy and middle childhood, the etiology of individual differences in this developmental progression remains poorly understood. In the present study, we examine the contributions of maternal executive function (EF) and caregiving behaviors to the development of EF during early childhood.

EFs are higher-order cognitive and self-regulatory processes (e.g., working memory, inhibitory control, cognitive flexibility) that underlie goal-directed behaviors. The prefrontal cortex is intricately linked to EF (Kane & Engle, 2002; Osaka et al., 2003), and the development of both the prefrontal cortex and EFs are protracted through childhood and early adulthood. Substantial research has revealed that EFs are critical to aspects of optimal development. During early childhood, EFs are related to school readiness (Bierman, Torres, Domitrovich, Welsh, & Gest, 2009; Blair & Peters, 2003) as well as concurrent and future reading and mathematics performance (Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010; Espy et al., 2004; Mazzocco & Kover, 2007; St. Clair-Thompson & Gathercole, 2006). EF deficits, on the other hand, have been associated with difficulties in emotion regulation (Kochanska, Murray, & Harlan, 2000; Lemery, Essex, & Smider, 2002) and early-onset disorders, such as attention-deficit/hyperactivity disorder, autism spectrum disorder, and phenylketonuria (Berlin, Bohlin, & Rydell, 2003; Diamond, Prevot, Callender, & Druin, 1997; Semrud-Clikeman, Walkowiak, Wilkinson, & Butcher, 2010).

As an initial step in understanding individual differences in EF development during early childhood, we begin by examining maternal measures because mothers are more likely to be the primary caregiver and they share half of their genes with their children. In the following sections, we begin by reviewing the literature on the association between maternal caregiving behaviors and childhood EF. Next, we highlight evidence that maternal EF is associated with caregiving behaviors. We conclude by noting gaps in our understanding of how maternal measures are related to the emergence of EF during early childhood.

Maternal Caregiving and Child EF

Supportive, nurturing maternal interactions with children predict positive socio-emotional outcomes, whereas controlling, intrusive maternal interactions predict more negative outcomes (Thompson, 1998). Until recently, empirical evidence for the effects of maternal behaviors on child EF had focused on severe adverse environments (see review by Hughes, 2011) as opposed to variations in more typical environments. Research examining scaffolding (i.e., parental support during child problem-solving) with typically developing children has revealed that maternal scaffolding at 2 years of age is related to concurrent (Bibok, Carpendale, & Muller, 2009) as well as future (i.e., 4-year) EF (Hughes & Ensor, 2009). Furthermore, the association between maternal scaffolding at age 2 and 4-year EF remained robust even after controlling for 2-year EF (Hughes & Ensor, 2009).

Additional EF research has examined the contribution of a variety of positive caregiving behaviors during infancy, including maternal sensitivity (i.e., providing children with successful experiences of impacting on the environment), maternal mind-mindedness (i.e., using mental terms when speaking to children), and autonomy support (i.e., supporting children's decisions and goals; Bernier, Carlson, Deschenes, & Matte-Gagne, 2012; Bernier, Carlson, & Whipple, 2010). These positive infant caregiving behaviors were associated with better EF performance during toddlerhood (Bernier et al., 2010) and at 3 years of age (Bernier et al., 2012), with robust effects for 3-year EF remaining even after controlling for

2-year EF. Likewise, Kraybill and Bell (in press) have recently found that maternal positive affect at 10 months of age was related to child EF at 4 and 6 years of age. Together, these findings provide strong evidence for the beneficial effects of positive caregiving behavior on child EF within the average home environment.

Maternal EF and Caregiving

Calkins (2011) proposes that a psychobiological framework is critical for conceptualizing the multiple biological and behavioral levels at which caregiving affects children. She suggests that caregiver behavior must be *regulated* within the caregiver, affecting her own behavior, and that caregiver behavior must be *regulatory* between the caregiver and child. If we consider the construct of EF, many of its components are useful in the caregiving context. A mother must use inhibitory control to refrain from expressing “knee-jerk” negative reactions that are often elicited by undesirable child behaviors. She uses working memory to maintain and manipulate information, typically in the presence of multiple distractions, while interacting with her child. Last, but not least, in this highly stimulating environment, a mother must use cognitive flexibility to switch between different situations and their corresponding demands (Barrett & Fleming, 2011).

There is evidence that maternal EF is associated with a range of caregiving behaviors (see review by Barrett & Fleming, 2011; Deater-Deckard, Wang, Chen, & Bell, 2012). Deater-Deckard and colleagues have demonstrated that low maternal EF is linked with harsher, more reactive caregiving in the face of challenging child behaviors (i.e., noncompliance, inattention, hyperactivity; Deater-Deckard, Chen, Wang, & Bell, 2012; Deater-Deckard, Sewell, Petrill, & Thompson, 2010; Deater-Deckard, Wang, et al., 2012). Many challenging behaviors emerge during the first three years as children seek autonomy, and complex mechanisms potentially underlie how maternal factors, such as EF and caregiving, influence child EF. For instance, negative caregiving behaviors in addition to low maternal EF could potentially create a stressful environment for the child, one that affects the child’s development of EF, even without the environment being severe. Currently, we know little about the extended EF/caregiving context and basic questions about the relative contributions of these behaviors to the emergence of EF have yet to be answered.

Maternal EF and Child EF

We propose that the mechanism by which maternal EF impacts early childhood EF involves gene-environment transactions (Jester et al., 2011; Polderman et al., 2006) operating through the maternal EF and caregiving context that the child experiences. Our focus is on the EF/caregiving context and not on elucidating the gene-environment transactions. It is important, however, to review what is known about maternal-child EF association during early childhood.

The only examination of maternal and early childhood EF failed to find an association between biological mothers’ performance on the color Stroop task and their 27-month-old children’s (who were adopted by other families) performance on either the shape Stroop or gift delay tasks (Leve et al., in press). Although these null findings could indicate that maternal EF is not associated with early childhood EF outside of the caregiving context, it is plausible that the null findings are related to measurement problems. Specifically, EF task performance is also affected by non-EF demands (e.g., variance due to measurement error), and when possible it is highly preferred to form a composite score of a latent construct of correlated indicators (as opposed to using single tasks) because such composite scores provide more reliable measures of EF (Carlson, Mandell, & Williams, 2004; Rushton, Brainerd, & Pressley, 1983).

Previously, we formed EF composite measures for mothers and children in the current study and found evidence that mother and child EF are modestly correlated by 24 months of age, with this association remaining stable through 48 months (Cuevas et al., 2012). Importantly, we found that maternal-child EF associations remained robust after controlling for verbal ability (a potential indicator of verbal or crystallized intelligence) and maternal education (a correlate of socioeconomic status and verbal intelligence). However, it is plausible that this link is driven by underlying maternal EF-caregiving associations. Maternal caregiving has been found to mediate the link between childhood EF and other informative familial measures. For instance, recent evidence from a predominately low-income sample revealed that associations between socioeconomic status and 36-month EF were mediated by maternal caregiving behaviors (i.e., positive engagement and negative intrusiveness) at 7 months of age (Rhoades, Greenberg, Lanza, & Blair, 2011). To help elucidate the mechanism of maternal-child EF associations, in the present study, we examined whether maternal caregiving might mediate the association between maternal EF and early childhood EF.

The Current Study

The aims of the current study were (a) to examine the relative contributions of maternal EF and caregiving to child EF throughout early childhood; and (b) to determine whether maternal caregiving mediates the association between mom and child EF. In order to capture the emergence of EF as well as stability in individual differences in EF, we assessed EF from 2 (i.e., approaching the youngest assessment age) to 4 years of age (i.e., when there is moderate stability in individual differences in EF; Kochanska & Knaack, 2003). Mothers and children completed age-appropriate EF tasks (on separate occasions) that required a variety of EF skills (e.g., working memory, inhibitory control, cognitive flexibility). Children were tested at 24, 36, and 48 months of age.

As reviewed above, previous research has focused on either positive caregiving behaviors or adverse environments when examining child EF. In the present study, we were interested in whether negative caregiving behaviors, within a typical (as opposed to adverse) environment, would be negatively associated with child EF. To this end, a group of mother-child dyads completed age-appropriate interaction tasks when children were 10, 24, and 36 months of age. This developmental time span captures transitions in the caregiving context as children become more autonomous. Caregiving behaviors of interest were intrusiveness (i.e., imposing mother-centered interactions), negative affect (24 and 36 months; i.e., using negative tone, hostility, and harsh or power-assertive control), physical stimulation (10 months; i.e., frequency and intensity of stimulating infant's body to heighten arousal), and failure to facilitate attention (i.e., lack of appropriate attentive responses). To reduce measurement error, we used principal component analyses to verify that our individual EF and caregiving measures were associated, and then calculated EF and caregiving composite scores.

We hypothesized that maternal negative caregiving behaviors would negatively correlate with maternal EF as well as child EF. There is evidence that both verbal ability (a measure often used as an indicator of verbal or crystallized intelligence) and socioeconomic status (a broad indicator of family material and social resources) are associated with EF (e.g., Bernier et al., 2012; Kaler & Kopp, 1990). Thus, we controlled for maternal education (a correlate of socioeconomic status and verbal intelligence) and child verbal ability in our regression analyses. Finally, we included a second set of regression analyses in which we controlled for stability in child EF (i.e., EF from the previous assessment) to determine potential contributors to important changes in EF during early childhood.

Method

Participants

The initial sample included 63 biological mother-child dyads. Children were part of an ongoing longitudinal investigation and mothers were recruited to have their EF assessed when children were either 3 ($n = 55$) or 4 ($n = 8$) years old. One dyad was excluded because the child was premature at birth. Of the 62 children (25 boys, 37 girls; 4 Hispanic, 58 Non-Hispanic; 57 Caucasian, 5 Multi-Racial) in our final sample, all participated at 2 years ($M = 2.09$ years; $SD = 22$ days), 61 returned at 3 years ($M = 3.10$ years; $SD = 28$ days), and 57 returned at 4 years ($M = 4.11$ years; $SD = 29$ days). All mothers (1 Hispanic, 61 Non-Hispanic; 1 African American, 1 Asian, 60 Caucasian) graduated from high school (1.6% technical degree; 40.3% bachelor's degree; 35.5% graduate degree). Mothers were between 21 and 43 years ($M = 34$ years, $SD = 5$) during the maternal EF assessment and received an honorarium for each laboratory visit.

Procedure

Study procedures were approved by the institutional review board.

Maternal Caregiving Measures

Mothers were observed as they interacted with their children during a variety of tasks at 10, 24, and 36 months of age. For each interaction task, the experimenter instructed the mother to play with her child just as she would at home and then left the room. A camera was focused on both mother and child, and maternal behavior was videotaped for off-line coding by trained research assistants. Each aspect of maternal behavior was coded on a 4-point scale (i.e., 1 = low incidence of a behavior; 4 = high incidence). Scales were adapted from Calkins, Hungerford, and Dedmon (2004) and Eyberg and Robinson (1981). Behavior was coded in 30-s epochs, which were then averaged to create a mean score for that behavior across the entire task. An independent observer coded at least 19% of the dyads across the longitudinal sample to confirm reliability of coding. Intraclass correlations exceeded .76 for each maternal behavior in each age group.

10 months—Mothers and infants were observed in two interaction tasks adapted from Calkins et al. (2004). For the *toys task*, each mother and infant played together with two simple age-appropriate infant toys. During this 2-min task, the infant sat in a high chair and the mother sat in front and slightly to the left of her infant. Afterwards, mothers and infants were observed in a 2-min game of *peek-a-boo*.

Maternal behaviors of interest included *facilitating attention*, *physical stimulation*, and *intrusiveness*. Mother's ability to *facilitate attention* refers to her sensitivity to her child, namely through behavioral evidence of appropriate attentive responses to her child's arousal, interests, and abilities. *Physical stimulation* refers to the extent to which, in both frequency and intensity, a mother directly stimulates her infant's body to heighten the infant's arousal. Maternal *intrusiveness* refers to the extent to which an interaction is mother-centered, rather than child-centered, and is characterized by behaviors such as expressing negative affect, overstimulation or an overwhelmingly increased pace of activity, or intrusive physical interactions with the infant. Analogous maternal behaviors correlated across the *toys* and *peek-a-boo* tasks ($r_s = .43 - .57$) and were, thus, standardized and averaged to create a single measure for each of these three caregiving domains.

24 and 36 months—Mothers and children were observed as they played with age-appropriate puzzles for approximately 6 min (Smith, Calkins, Keane, Anastopoulos, & Shelton, 2004). During this interaction, mother and child sat on adjacent sides of a table.

Interactions were coded for *facilitating attention* and *intrusiveness*. The *physical stimulation* scale was replaced with the more developmentally appropriate *negative affect* measure, which describes a mother's use of negative tone, hostility, and harsh or power-assertive control.

Caregiving composite measure (10, 24, 36 months)—When possible, it is highly preferred to form a composite score of a latent construct of correlated indicators because such composite scores are most reliable (Rushton et al., 1984). Our caregiving composite included *failure to facilitates attention* (reverse score *facilitate attention* so that higher scores indicated less attention facilitating behaviors), *physical stimulation* (10 months), *negative affect* (24 and 36 months), and *intrusiveness* behaviors. At 10 months, the first principal component among the three maternal behaviors explained 68% of the variance ($\lambda = .59 - .96$). At 24 months, the first principal component among the three maternal variables explained 57% of the variance ($\lambda = .74 - .76$). Similarly, the first principal component at 36 months explained 45% of the variance ($\lambda = .51 - .79$). At each age, individual indicator scores were standardized, averaged, and standardized again to yield caregiving composite z-scores. Finally, an overall caregiving composite was formed by averaging the 10-, 24-, and 36-month composite z-scores, and the final overall composite standardized again to yield a z-score. The first principal component explained 47% of the variance ($\lambda = .67 - .72$). This is our most reliable measure of maternal caregiving behaviors because it includes multiple measures assessed at different time points.

Child EF Measures

For all EF tasks, interrater reliability (Cronbach's $\alpha = .90$) was established for at least 20% of our entire longitudinal sample.

A-not-B with invisible displacement (24 months)—The toddler A-not-B looking procedure is detailed in Morasch and Bell (2011). An attractive item was hidden under a cup (central location); the cup was shifted to one side (side A, counterbalanced left/right); and a barrier was placed in front of the cup. During the 5-s delay, the experimenter distracted the toddler (kept gaze at midline) and behind the barrier, placed a second cup (side B). The barrier was removed and toddlers were asked, "Where's the ball?" The first look toward either location was coded, and after two consecutive correct same-side searches, the hiding location was reversed (pattern AAB). Performance was the proportion of correct searches (Diamond et al., 1997).

Crayon delay (24 months)—The crayon delay procedure (Calkins, 1997) is detailed in Morasch and Bell (2011). Toddlers were presented with a box of crayons and a blank piece of paper. Before the child touched the crayons, the experimenter told him/her that she needed to leave the room. She instructed the toddler not to touch the crayons, box, or paper until she returned. The experimenter left the room for 60 s. Toddlers' behavior during the delay was scored a 0 (*does not touch*), 1 (*touches paper*), 2 (*touches box*), 3 (*picks up box*), 4 (*takes crayons out of box*), or 5 (*colors with crayons*).

Tongue task (36 months)—The tongue task (Kochanska et al., 2000) required children to hold a goldfish cracker on their tongue without chewing it (three trials with delays of 10, 20, and 30 s). Performance was the proportion of successful trials.

Simon-says (36 and 48 months)—The Simon-says task followed the Bear/Dragon procedure (Carlson, Moses, & Breton, 2002) and is detailed in Wolfe and Bell (2007). Children were instructed to do what the nice horse (48 months: pig) "tells us" and to not do what the mean cow (48 months: bull) "tells us." Children passed (36 months: $n = 29$; 48

months: $n = 51$) the practice trials if they followed the horse/pig's command but ignored the cow/bull's command. Ten test trials followed (half for each type, alternating order), and performance was the proportion of correct responses.

Day-Night (36 months) and Yes-No (48 months)—For the day-night task (Gerstadt, Hong, & Diamond, 1994), children were instructed to say “day” when shown a moon card and to say “night” when shown a sun card. The yes-no task was created in our research lab (e.g., Wolfe & Bell, 2007) and is conceptually and procedurally similar to the day-night task. Children were instructed to say “yes” when the experimenter shook her head no and to say “no” when the experimenter nodded her head yes. For each task, once children passed two learning trials, they received 16 test trials (half for each type) in a pseudorandom order. Correct responses received 1 point and incorrect responses followed by self-correction received .5 point. Performance was the proportion of points earned.

Dimensional Change Card Sort (DCCS: 48 months)—For this task (Zelazo, Frye, & Rapus, 1996), children were instructed to sort cards based on two dimensions (i.e., color, shape). Children first sorted six cards by one dimension (pre-switch; counterbalanced across participants) and then were instructed to switch and to sort the remaining six cards by the other dimension (post-switch). Performance was the proportion of correct post-switch responses.

EF composite measures (24, 36, 48 months)—Descriptive statistics for our child EF measures can be found in Table 1. The 24-month composite included crayon delay performance (reverse scored so that higher scores represented better performance) and A-not-B performance, $r(59) = .46$, $p(1\text{-tailed}) = .001$. At 36 months, the first principal component among the three tasks (tongue task, Simon-says, day-night) explained 53% of the variance ($\lambda = .68 - .77$). Likewise, the first principal component among the 48-month tasks (Simon-says, yes-no, DCCS) explained 58% of the variance ($\lambda = .74 - .79$). At each age, individual indicator scores were standardized, averaged, and standardized again to yield an EF composite¹ z-score. Finally, a child EF composite was formed by averaging the annual composite z-scores, and the final overall composite standardized again to yield a z-score. The first principal component explained 54% of the variance ($\lambda = .69 - .79$). This is our most reliable measure of child EF because it includes multiple measures assessed at different time points.

Mother EF Tasks

Mothers² visited the laboratory on a separate occasion for maternal assessment. All EF tasks except backward digit span were computer administered.

Stroop color-word task—Mothers were instructed to press the color-labeled key that matched the color word. They received congruent (i.e., color words in the same color ink) and incongruent (i.e., color words in a different color ink) trials (Stroop, 1935). Performance was the percent accuracy for a set of 20 words during a block of mixed congruent and incongruent trials.

Wisconsin Card Sorting Test (WCST)—Mothers were instructed to match a card (64 total) to one of four key cards (Heaton & PAR Staff, 2003). The images on the cards varied

¹In the case of missing data, composites consisted of the remaining performance measures.

²A subset of the mothers is also included in manuscripts examining maternal EF, household chaos, and child conduct problems (Deater-Deckard, Chen, et al., 2012; Deater-Deckard, Wang, et al., 2012). Mother and child EF correlations are reported in a manuscript examining the intergenerational transmission of EF (Cuevas et al., 2012).

in color, quantity, and shape, and participants must sort the cards according to an undisclosed rule (e.g., by shape) that they had to ascertain via feedback. The sorting rules changed several times. The age-standardized percentile score associated with conceptual level (i.e., consecutive correct responses occurring in runs of three or more) was the measure of interest.

Attention Network Test (ANT)—Mothers responded to a central target (an arrow) by hitting one of two keys to indicate if the arrow points left or right (Fan, McCandliss, Sommer, Raz, & Posner, 2002). Targets varied in the presence/absence of flankers as well as whether the flankers were congruent or incongruent. Performance was defined as the conflict score (i.e., executive attention measure)—the difference in reaction time between incongruent and congruent trials.

Backward digit span—An experimenter read a seemingly random series of single-digit numbers to participants. Mothers were instructed to repeat the sequence aloud in the reverse order, and they received 2-digit practice trials. Test trials began with two different 4-digit sequences, and digit span increased by a single digit until the participant failed to provide a correct response to both trials at a given span. Performance was defined as the highest digit span with a correct response.

EF composite measure—Descriptive statistics for our maternal EF measures can be found in Table 1. The first principal component among the four tasks (with ANT reverse scored so that higher scores indicated better performance) explained 44% of the variance ($\lambda = .57 - .81$). Scores were standardized, averaged, and standardized again to form a composite z-score.

Child Verbal Ability

MacArthur-Bates Communicative Development Inventory (MCDI: 24 months)—The MCDI “Words and Sentences” form (Fenson et al., 1992) was completed by toddlers’ mothers to provide a measure of toddler verbal ability. The MCDI is an inventory of common words and phrases. We used the percentile score associated with vocabulary production.

Peabody Picture Vocabulary Test (PPVT: 36 and 48 months)—The PPVT-III (Dunn & Dunn, 1997) or PPVT-IV (Dunn & Dunn, 2007) was administered to children individually to determine receptive vocabulary and verbal comprehension. The PPVT-III and -IV are nationally standardized instruments, and the measure of interest was participants’ percentile scores.

Results

First, we computed bivariate correlations to examine associations between early childhood EF and maternal EF as well as maternal caregiving behaviors. We hypothesized that maternal negative caregiving behaviors would be negatively correlated with child as well as maternal EF. Because of our directional hypotheses, we report 1-tailed *p*-values for our correlations as well as the *t*-tests for our regression weights. Two-tailed *p*-values are reported for regression *F*-tests. The maternal caregiving composite included 10 and 24 month caregiving behaviors in all analyses, with 36-month caregiving behaviors also being included for 36- and 48-month EF analyses. Next, we used hierarchical regression analyses, controlling for child verbal ability and maternal education, to determine the unique contribution of maternal EF and caregiving behaviors in predicting early childhood EF. We also performed mediation analyses to estimate the indirect effect of maternal EF on child EF

via maternal caregiving using Bias Corrected Bootstrapping (Preacher & Hayes, 2004, 2008) because it is considered to be the most accurate method for detecting indirect effect when sample sizes are small. The confidence interval (CI) was set to 95% with 1000 resamples. Finally, we examined the role of maternal EF and caregiving behaviors to the change in child EF (i.e., 24 to 36 months and 36 to 48 months) by controlling for EF at the previous assessment (i.e., 24 or 36 months).

Correlations Analyses

Previously, we reported that (a) our child EF composites were correlated over time across the three ages, with $r_s = .23 - .36$, p_s (one-tailed) $.04$; and (b) that child EF and maternal EF are positively correlated (Cuevas et al., 2012). Table 2 shows the results from bivariate correlations between child EF and maternal measures (EF and caregiving). As hypothesized, child EF was negatively correlated with negative maternal caregiving behaviors. The only exception was at 24 months, when child EF was not associated with maternal caregiving. Furthermore, these associations were confirmed when using the child EF composite, our most reliable measure of child EF. As hypothesized, maternal EF was negatively associated with negative caregiving behavior (10- and 24-month composite: $r = -.18$, $p = .08$; 10-, 24-, and 36-month composite: $r = -.26$, $p = .02$).

Regression Analyses

For each regression analysis, we began by controlling for the contribution of maternal education and child verbal ability to child EF (Step 1). Next (Step 2), we included our primary measures of interest—maternal EF and maternal education—to determine the relative contribution of each measure to child EF. Finally, we examined whether maternal caregiving mediated the association between maternal and child EF.

Predicting 24-month EF—The 24-month EF regression analysis was the only model that was not significant, $F(4, 56) = 1.82$, $p = .14$, although maternal EF and 24-month EF were correlated.

Predicting 36-month EF—The results of the 36-month EF regression analyses can be found in Table 3. Step 1 was not significant. Step 2 indicated that maternal EF and caregiving accounted for an additional 16% of the variance in 36-month EF. An examination of the regression weights revealed that maternal EF accounted for the majority of unique variance in 36-month EF (i.e., 6%). There were unique contributions of maternal caregiving and education to 36-month EF (i.e., 4% and 5% of the variance, respectively). Mediation analysis revealed a significant indirect effect of maternal EF on 36-month EF through maternal caregiving, with a point estimate of 0.08, S.E. = 0.06, and 95% CI [.0006, .2504].

Next, we controlled for 24-month EF to examine maternal contributors to 36-month EF over and above the stability in EF between 24 and 36 months. The results of the regression analyses can be found in Table 4. Step 2 indicated that 24-month EF accounted for an additional 8% of the variance in 36-month EF, above and beyond maternal education and 36-month verbal ability. Step 3 revealed that maternal EF and caregiving accounted for an additional 13% of the variance in 36-month EF. An examination of the regression weights indicated that maternal EF, maternal caregiving, and 24-month EF each accounted for 4%–5% of the unique variance in the final step. Mediation analysis revealed a significant indirect effect of maternal EF on the change in EF between 24 and 36 months via maternal caregiving, with a point estimate of 0.09, S.E. = 0.06, and 95% CI [.0051, .2697]. Thus, we found a similar pattern of findings as our initial analysis of 36-month EF when not controlling for 24-month EF (see Table 3 and Table 4).

Predicting 48-month EF—Table 5 shows the results of the 48-month EF regression analyses. Step 1 indicated that maternal education and 48-month verbal ability accounted for 21% of the variance in 48-month EF. Including maternal EF and caregiving in Step 2 accounted for an additional 18% of the variance in 48-month EF. An examination of the regression weights revealed that the majority of unique variance in 48-month EF was accounted for by maternal caregiving (10%) and 48-month verbal ability (6%). There was also a unique contribution of maternal EF (i.e., 3% of the variance). Mediation analysis revealed a significant indirect effect of maternal EF on 48-month EF through maternal caregiving, with a point estimate of 0.10, S.E. = 0.06, and 95% CI [.0141, .2887].

Next, we examined maternal contributors to 48-month EF over and above the stability in EF between 36 and 48 months (see Table 6). Step 2 indicated that 36-month EF accounted for an additional 5% of the variance in 48-month EF, above and beyond maternal education and 48-month verbal ability. As can be seen in Step 3, maternal EF and caregiving accounted for an additional 19% of the variance in 48-month EF. The majority of unique variance in 48-month EF, when controlling for stability in EF between 36 and 48 months, was accounted for by maternal caregiving (16%) and 48-month verbal ability (11%). This pattern was similar to our initial 48-month EF model, except there was no marginally significant trend for unique contribution of maternal EF when controlling for 36-month EF (see Table 5 and Table 6). Mediation analysis revealed a significant indirect effect of maternal EF on the change in EF between 36 and 48 months via maternal caregiving, with a point estimate of 0.11, S.E. = 0.08, and 95% CI [.0158, .3257].

Predicting child (24-, 36-, 48-month composite) EF—In the final regression analyses, we used our most reliable measure of child EF—the child EF composite. In order to control for the effects of verbal ability on concurrent EF, we created residualized EF composites with verbal ability removed at each age. Next, we averaged the residualized EF composites across ages to obtain a residualized child EF composite. The results of the regression analysis for residualized child EF are displayed in Table 7. Step 1 was not significant. An additional 23% of the variance in child EF was accounted for when maternal EF and caregiving were included in Step 2. An examination of the regression weights indicated that maternal EF and caregiving accounted for the majority of the unique variance in child EF (i.e., 14% and 5%, respectively). Mediation analysis revealed that the indirect effect of maternal EF on the childhood EF composite was not statistically significant, with point estimate = 0.45, S.E. = 0.04, and 95% CI [−.0028, .1578].

In sum, with the exception of the 24-month analysis, all analyses revealed unique contributions of maternal EF and maternal caregiving to early childhood EF above and beyond child verbal ability and maternal education. Furthermore, there was evidence that maternal EF had significant indirect effects on changes in child EF through maternal caregiving.

Discussion

These data provide the first concurrent analysis of the relative contributions of maternal EF and caregiving in predicting child EF. As hypothesized, we found that negative caregiving behaviors were negatively associated with child EF as well as maternal EF. This finding supports previous evidence from a predominately low-income sample of links between negative caregiving behaviors and child EF at 36 months (Rhoades et al. 2011), and reveals that these associations are also present in nonadverse contexts. In the present study, regression analyses revealed that by 36 months of age, maternal EF and negative caregiving (i.e., a composite from 10, 24, and 36 months) each accounted for unique variance in child EF, above and beyond maternal education (a correlate of socioeconomic status and verbal

intelligence) and child verbal ability (a potential indicator of verbal or crystallized intelligence). These findings were confirmed when using an early childhood EF composite, our most reliable measure of EF. Thus, measures of maternal EF and negative caregiving, although related, provide unique information about the development of child EF.

Mediation models revealed that the links between maternal EF and child EF at 36 and 48 months of age were at least partially explained by associated variations in caregiving behaviors. Likewise, maternal EF had statistical indirect effects on changes in child EF (from 24 to 36 months and from 36 to 48 months) through maternal caregiving. These findings are consistent with a growing body of research demonstrating associations between maternal EF and caregiving behaviors (see review by Barrett & Fleming, 2011; Deater-Deckard, Wang, et al., 2012). Furthermore, our findings confirm that maternal caregiving is an important mediator between familial measures, such as socioeconomic status (Rhoades et al., 2010), and child EF, and extend these mediated findings to include maternal EF-child EF associations. Based on Calkin's (2011) psychobiological framework, we posit that maternal EFs are critical to regulating maternal caregiving behaviors, especially negative caregiving behaviors such as those examined in the present study.

Although 24-month EF was associated with maternal EF, we found no link between negative caregiving behaviors and child EF prior to 36 months. This null result contrasts with evidence of associations between positive maternal caregiving behaviors and 24-month EF (Bernier et al., 2010; Bibok et al., 2009; Hughes & Ensor, 2009). To help understand this pattern, we (a) confirmed that the 10- and 24-month negative caregiving composite was associated with EF at 36 and 48 months (i.e., the null result does not appear to be related to the number of caregiving assessments or the informative value of infant and toddler negative caregiving behaviors); and (b) completed exploratory analyses of both individual and composite caregiving and EF measures to ensure that we had not overlooked a potential association at 24 months. One potential explanation for the lack of association between 24-month EF and negative caregiving behaviors would be that the effects of the potential mechanisms that underlie this association (reviewed below) are not substantial enough to be manifested in the rudimentary forms of EF that are present at 2 years of age. Furthermore, challenging child behaviors (e.g., noncompliance) associated with children's autonomy are exhibited increasingly during the first 3 years. Perhaps opportunities for negative (as compared to positive) interactions may be only recently on the 24-month-horizon, and associations between negative caregiving behaviors and child EF might be less immediately detectable. This null finding highlights the importance of including multiple maternal measures when assessing associations with toddler EF.

At 3 and 4 years of age, maternal EF and negative caregiving accounted for an additional 16–18% of the variance in child EF, above and beyond maternal education and child verbal ability. We also found that, at both ages, negative caregiving behaviors mediated the association between maternal EF and child EF³. When examining the amount of unique variance accounted for by each maternal measure, we see different patterns at each age. Maternal EF and negative caregiving accounted for approximately the same amount of variance in 36-month EF (6% and 4%, respectively) even when controlling for stability in EF (4% and 5%, respectively). For 48-month EF, on the other hand, negative caregiving accounted for more unique variance (10%) than maternal EF (3%) and controlling for stability in EF enhanced this pattern with unique contributions of negative caregiving only (16% of the variance). Taken together with the 24-month null findings, we see a pattern of negative caregiving accounting for more unique variance in EF throughout early childhood.

³Although mediation was not present in our childhood EF composite, this finding is likely related to the lack of association between 24-month EF and negative caregiving behaviors (see previous paragraph).

To better understand this trend, we begin by considering the specific behaviors that were coded as mothers played games/puzzles with their children. Negative caregiving included behaviors that were high in intrusiveness and negative affect/physical stimulation and low in facilitating attention. This pattern of interaction during a relatively stress-free interaction (i.e., age-appropriate games that were not intended to elicit frustration) does not appear conducive to promoting child learning and autonomy. For instance, when mothers are intrusive, the interaction becomes focused on meeting the mother's needs and goals as compared to facilitating the needs and goals of the child by providing appropriate attentive responses.

An examination of negative intrusive parenting behaviors revealed that the rate of growth in language development between 18 and 36 months was associated with the amount of negative caregiving behaviors (Pungello, Iruka, Dotterer, Mills-Koonce, & Reznick, 2009). The authors concluded such caregiving behaviors do not support autonomy and development of the child. Although we controlled for child verbal ability in the present study, we found a similar pattern of negative caregiving behaviors accounting for the growth in early childhood EF. It has been posited that because EF development exhibits a linear trend, small changes in early EF can shift the entire developmental trajectory (Moffitt et al., 2011). This hypothesis was directed towards potential EF interventions, but the same concept can be applied to factors that potentially hinder early EF.

Bio-social mechanisms—both genetic as well as co-occurring socialization experience (environment)—are theorized to support optimal regulatory development (Rueda, Posner & Rothbart, 2004). There is evidence that EF is heritable (Friedman et al., 2008; Jester et al., 2011; Polderman et al., 2006), and we cannot discount this potential genetic mechanism underlying maternal-child EF associations. Furthermore, the prefrontal cortex is critical to EFs, and it is the most likely candidate through which mechanisms associated with maternal EF and caregiving influence early childhood EF. The development of the frontal cortex is protracted, and there are many aspects of development (e.g., synaptogenesis, dendritic and axonal growth, myelination, glucose metabolism) that could potentially be influenced by bio-social mechanisms (Chugani, Phelps, & Mazziotta, 1987; Deoni et al., 2011; Huttenlocher & Dabholkar, 1997; Tsekhnistrenko Vasil'eva, Shumeiko, & Vologirov, 2004). Empirical evidence for parenting having an effect on children's brain development has focused on rodents (Barrett & Fleming, 2011) or on maltreated children (Belsky & de Haan, 2011; Hughes, 2011).

One potential way in which maternal caregiving and EF could influence child EF is via stress reactivity. Stress hormone levels affect synaptic plasticity in PFC neurocircuitry (Mizoguchi, Ishige, Takeda, Aburada, & Tabira, 2004), which is critical for EF. Accordingly, there is evidence that stress hormone levels are related to EF during early childhood (Blair, Granger, & Razza, 2005; Davis, Bruce, & Gunnar, 2002). Using a predominately low-income sample, Blair and colleagues (2011) found evidence that associations between caregiving behaviors and child EF at 36 months were mediated by stress hormone levels. Surprisingly, the mediated association was only found for positive caregiving behaviors (i.e., lower levels of stress hormones in children; higher 36-month EF). It is plausible that the link between negative caregiving behaviors and child EF in children not subjected to economic adversity (similar to the present sample) might be mediated by stress hormone levels. Clearly, additional research is necessary to understand how stress reactivity mediates associations between caregiving and child EF across a variety of familial contexts.

From the perspective of the mother, stress physiology is also related to caregiving behaviors and maternal EF. An examination of maternal stress hormone levels and maternal vagal

stress reactivity revealed that these measures were associated with negative intrusive caregiving behaviors, but not positive caregiving behaviors (Mills-Koonce et al., 2009). Other evidence, however, has found that maternal sensitivity is related to maternal stress hormone levels (Gonzales, Jenkins, Steiner, & Fleming, 2012). Furthermore, this research revealed that the maternal stress hormone-caregiving link was mediated by maternal EF. Together, these findings suggest that stress reactivity in both mother and child could potentially underlie associations among maternal caregiving, maternal EF, and child EF.

Research focusing on the genetic underpinnings of EF has revealed that polymorphisms in multiple genes associated with the production and utilization of the neurotransmitter dopamine, which is associated with EF, are likely related to individual differences in early childhood EF (for reviews see Barnes, Dean, Nandam, O'Connell, & Bellgrove, 2011; Bell & Deater-Deckard, 2007; Deater-Deckard & Wang, 2012). A potential mechanism for the influence of early life experiences on child EF would involve epigenetic changes, such as DNA methylation (for review see Szyf & Bick, 2013). In this way, genes in the central and peripheral nervous could be “activated” and “inactivated” by changes in methylation. In rodents, typical variations in maternal care have been associated with alterations in stress hormone receptors in the hippocampus as well as changes in DNA methylation of associated genes (for review, see Jensen Pena & Champagne, 2012); thus, providing a potential mechanism via which early life experience could have long lasting effects on stress sensitivity, neurodevelopment, and behavior. Although we still have much to learn about epigenetics and its relation to EF, it is a potential mechanism that should not be overlooked. Will epigenetic changes related to EF only occur in genes associated with stress reactivity or will they also be found in genes associated with dopamine?

Although our sample varied in verbal ability and maternal education, our sample was predominately Caucasian and all mothers graduated from high school. A test of whether this effect is consistent across ethnic groups and across the full socio-economic spectrum is essential in determining the generalization of our findings. Furthermore, maternal education is only a single component of socioeconomic status and additional indicators (i.e., income, occupation) are essential to establishing a reliable indicator of socioeconomic status. Consistent with classical applications of probability theory, we used 1-tailed *p*-values because we had directional hypotheses for effects. Although it has become common for researchers to use 2-tailed *p*-values when testing directional hypotheses, this practice nevertheless can inflate type-II error by reducing statistical power (e.g., Hays, 1988, pp.276–277).

In sum, these data reveal that maternal EF and negative caregiving behaviors are uniquely associated with EF during early childhood, and suggest that associations with negative caregiving are increasingly manifested during early childhood. Importantly, these associations were present in the context of “typical” parenting behaviors as compared to severe adverse environments. Our findings suggest that regardless of maternal EF and education, an environment that is low in negative caregiving behaviors will help promote optimal EF development.

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References

- Barnes J, Dean A, Nandam LS, O'Connell R, Bellgrove M. The molecular genetics of executive function: Role of monoamine system genes. *Biological Psychiatry*. 2011; 69:e127–e143. [PubMed: 21397212]
- Barrett J, Fleming AS. All mothers are not created equal: Neural and psychobiological perspectives on mothering and the importance of individual differences. *Journal of Child Psychology and Psychiatry*. 2011; 52:368–397. [PubMed: 20925656]
- Bell MA, Deater-Deckard K. Biological systems and the development of self-regulation: Integrating behavior, genetics, and psychophysiology. *Journal of Developmental & Behavioral Pediatrics*. 2007; 28:409–420. [PubMed: 18049327]
- Belsky J, de Haan M. Annual research review: Parenting and children's brain development: the end of the beginning. *Journal of Child Psychology and Psychiatry*. 2011; 52:409–428. [PubMed: 20626527]
- Berlin L, Bohlin G, Rydell AM. Relations between inhibition, executive functioning, and ADHD symptoms: a longitudinal study from 5 to 8(1/2) years. *Child Neuropsychology*. 2003; 9:255–266. [PubMed: 14972704]
- Bernier A, Carlson SM, Deschênes M, Matte-Gagné C. Social factors in the development of early executive functioning: A closer look at the caregiving environment. *Developmental Science*. 2012; 15:12–24. [PubMed: 22251288]
- Bernier A, Carlson SM, Whipple N. From external regulation to self-regulation: early parenting precursors of young children's executive functioning. *Child Development*. 2010; 81:326–339. [PubMed: 20331670]
- Bibok, MB.; Carpendale, JIM.; Müller, U. Parental scaffolding and the development of executive function. In: Lewis, C.; Carpendale, JIM., editors. *New Directions in Child and Adolescent Development*. Vol. 123. 2009. p. 17-34. Social interaction and the development of executive function
- Bierman KL, Torres MM, Domitrovich CE, Welsh JA, Gest S. Behavioral and cognitive readiness for school: Cross-domain associations for children attending Head Start. *Social Development*. 2009; 18:305–323.
- Blair C. School readiness: Integrating cognition and emotion in a neurobiological conceptualization of child functioning at school entry. *American Psychologist*. 2002; 57:111–127. [PubMed: 11899554]
- Blair C, Granger D, Razza RP. Cortisol reactivity is positively related to executive function in preschool children attending Head Start. *Child Development*. 2005; 76:554–567. [PubMed: 15892778]
- Blair C, Granger DA, Willoughby M, Mills-Koonce R, Cox M, Greenberg MT. FLP Investigators. Salivary cortisol mediated effects of poverty and parenting on executive functions in early childhood. *Child Development*. 2011; 82:1970–1984. [PubMed: 22026915]
- Blair C, Peters R. Physiological and neurocognitive correlates of adaptive behavior in preschool among children in Head Start. *Developmental Neuropsychology*. 2003; 28:561–571. [PubMed: 16144427]
- Blair C, Razza RP. Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*. 2007; 78:647–663. [PubMed: 17381795]
- Bull R, Espy KA, Wiebe SA. Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*. 2008; 33:205–228. [PubMed: 18473197]
- Bull R, Scerif G. Executive functioning as a predictor of children's mathematic ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*. 2001; 19:273–293. [PubMed: 11758669]
- Calkins SD. Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. *Developmental Psychobiology*. 1997; 31:125–135. [PubMed: 9298638]

- Calkins, SD. Caregiving as coregulation: Psychobiological processes and child functioning. In: Booth, A.; McHale, SM.; Landale, NS., editors. *Biosocial foundations of family processes*. New York: Springer; 2011. p. 49-59.
- Calkins SD, Hungerford A, Dedmon SE. Mothers' interactions with temperamentally frustrated infants. *Infant Mental Health Journal*. 2004; 25:219–239.
- Carlson SM, Mandell DJ, Williams L. Executive function and theory of mind: Stability and prediction from ages 2 to 3. *Developmental Psychology*. 2004; 40:1105–1122. [PubMed: 15535760]
- Carlson SM, Moses LJ, Breton C. How specific is the relation between executive function and theory of mind? Contributions of inhibitory control and working memory. *Infant and Child Development*. 2002; 11:73–92.
- Chugani HT, Phelps ME, Mazziotta JC. Positron emission tomography study of human brain functional development. *Annals of Neurology*. 1987; 22:487–497. [PubMed: 3501693]
- Clark CAC, Pritchard VE, Woodward LJ. Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology*. 2010; 46:1176–1191. [PubMed: 20822231]
- Cuevas K, Deater-Deckard K, Wang Z, Kim-Spoon J, Morasch KC, Bell MA. A longitudinal intergenerational analysis of executive functions during early childhood. Manuscript submitted for publication. 2012
- Davis EP, Bruce J, Gunnar MR. The anterior attention network: Associations with temperament and neuroendocrine activity in 6-year-old children. *Developmental Psychobiology*. 2002; 40:43–56. [PubMed: 11835150]
- Deater-Deckard K, Chen N, Wang Z, Bell MA. Socioeconomic risk moderates the link between household chaos and maternal executive function. *Journal of Family Psychology*. 2012; 26:391–399. [PubMed: 22563703]
- Deater-Deckard K, Sewell MD, Petrill SA, Thompson LA. Maternal working memory and reactive negativity in parenting. *Psychological Science*. 2010; 21:75–79. [PubMed: 20424026]
- Deater-Deckard, K.; Wang, Z. Development of temperament and attention: behavioral genetic approaches. In: Posner, MI., editor. *Cognitive neuroscience of attention*. 2nd ed.. New York: Guilford; 2012. p. 331-344.
- Deater-Deckard K, Wang Z, Chen N, Bell MA. Maternal executive function, harsh parenting, and child conduct problems. *Journal of Child Psychology and Psychiatry*. 2012; 53:1084–1091. [PubMed: 22764829]
- Deoni SCL, Mercure E, Blasi A, Gasston D, Thomson A, Johnson M, ...Murphy DGM. Mapping infant brain myelination with magnetic resonance imaging. *The Journal of Neuroscience*. 2011; 31:784–791. [PubMed: 21228187]
- Diamond A, Prevor M, Callender G, Druin DP. Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the Society for Research in Child Development*. 1997; 62(4, Serial No. 252)
- Dunn, LM.; Dunn, L. *Peabody Picture Vocabulary Test*. 3rd ed.. Circle Pines, MN: AGS Publishers; 1997.
- Dunn, LM.; Dunn, DM. *Peabody Picture Vocabulary Test*. 4th ed.. Bloomington, MN: NCS Pearson, Inc; 2007.
- Eyberg, SM.; Robinson, EA. *Dyadic Parent–Child Interaction Coding System*. Seattle, WA, USA: University of Washington, The Parenting Clinic; 1981.
- Espy KA, McDiarmid MM, Cwik MF, Stalets MM, Hamby A, Senn TE. The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology*. 2004; 26:465–486. [PubMed: 15276905]
- Fan J, McCandliss BD, Sommer T, Raz A, Posner MW. Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*. 2002; 14:340–347. [PubMed: 11970796]
- Fenson, L.; Dale, PS.; Reznick, JS.; Thal, D.; Bates, E.; Hartung, JP., et al. *MacArthur Communicative Development Inventories*. Baltimore, MD: Paul H. Brookes; 1992.
- Friedman NP, Miyake A, Young SE, DeFries JC, Corley RP, Hewitt JK. Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General*. 2008; 137:201–225. [PubMed: 18473654]

- Gerstadt CL, Hong YJ, Diamond A. The relationship between cognition and action: Performance of children 3 ½ –7 years old on a Stroop-like day-night test. *Cognition*. 1994; 53:129–153. [PubMed: 7805351]
- Gonzales A, Jenkins JM, Steiner M, Fleming AS. Maternal early life experiences and parenting: The mediating role of cortisol and executive function. *Journal of the American Academy of Child & Adolescent Psychiatry*. 2012; 51:673–682. <http://dx.doi.org/10.1016/j.jaac.2012.04.003>. [PubMed: 22721590]
- Hays, WL. *Statistics*. 4th ed. Forth Worth, TX: Holt, Rinehart, & Winston, Inc; 1988.
- Heaton, RK. PAR Staff. Wisconsin Card Sorting Test: Computer version 4. Odessa, FL: Psychological Assessment Resources, Inc; 2003.
- Hughes C. Changes and challenges in 20 years of research into the development of executive functions. *Infant and Child Development*. 2011; 20:251–271.
- Hughes, CH.; Ensor, RA. How do families help or hinder the emergence of early executive function?. In: Lewis, C.; Carpendale, JIM., editors. *New Directions in Child and Adolescent Development*. Vol. 123. 2009. p. 35-50. Social interaction and the development of executive function
- Huttenlocher PR, Dabholkar AS. Regional differences in synaptogenesis in human cerebral cortex. *The Journal of Comparative Neurology*. 1997; 387:167–178. [PubMed: 9336221]
- Jensen Pena CL, Champagne FA. Epigenetic and neurodevelopmental perspectives on variation in parenting behavior. *Parenting: Science and Practice*. 2012; 12:202–211.
- Jester JM, Nigg JT, Puttler LI, Long JC, Fitzgerald HE, Zucker RA. Intergenerational transmission of neuropsychological executive functioning. *Brain and Cognition*. 2009; 70:145–153. [PubMed: 19243871]
- Kaler SR, Kopp CB. Compliance and comprehension in very young toddlers. *Child Development*. 1990; 61:1997–2003.
- Kane MJ, Engle RW. The role of the prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*. 2002; 9:637–671. [PubMed: 12613671]
- Kochanska G, Knaack A. Effortful control as a personality characteristic of young children: Antecedents, correlates, and consequences. *Journal of Personality*. 2003; 71:1087–1112. [PubMed: 14633059]
- Kochanska G, Murray K, Harlan ET. Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology*. 2000; 36:220–232. [PubMed: 10749079]
- Kraybill JH, Bell MA. Infancy predictors of preschool and post-kindergarten executive function. *Developmental Psychobiology*. in press.
- Lemery KS, Essex MJ, Smider NA. Revealing the relation between temperament and behavior problem symptoms by eliminating measurement confounding: expert ratings and factor analyses. *Child Development*. 2002; 73:867–882. [PubMed: 12038557]
- Leve LD, DeGarmo DS, Bridgett JM, Neiderhiser JM, Shaw DS, Harold GT, Reiss D. Using an adoption design to separate genetic, prenatal, and temperament influences on toddler executive function. *Developmental Psychology*. in press.
- Mazzocco MMM, Kover ST. A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*. 2007; 13:18–45. [PubMed: 17364562]
- Mills-Koonce WR, Propper C, Garipey J-L, Barnett M, Moore GA, Calkins S, Cox MJ. Psychophysiological correlates of parenting behavior in mothers of young children. *Developmental Psychobiology*. 2009; 51:650–661. [PubMed: 19739135]
- Mizoguchi K, Ishige A, Takeda S, Aburada M, Tabira T. Endogenous glucocorticoids are essential for maintaining prefrontal cortical cognitive function. *Journal of Neuroscience*. 2004; 24:5492–5499. [PubMed: 15201321]
- Moffitt TE, Arseneault L, Belsky D, Dickson N, Hancox RJ, Harrington H, Caspi A. A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences, USA*. 2011; 108:2693–2698.

- Morasch KC, Bell MA. The role of inhibitory control in behavioral and physiological expressions of toddler executive function. *Journal of Experimental Child Psychology*. 2011; 108:593–606. [PubMed: 20719337]
- Nigg JT, Casey BJ. An integrative theory of attention-deficit/hyperactivity disorder on the cognitive and affective neurosciences. *Developmental Psychopathology*. 2005; 17:785–806.
- Osaka M, Osaka N, Kondo H, Morishita M, Fukuyama H, Aso T, Shibasaki H. The neural basis of individual differences in working memory capacity: An fMRI study. *NeuroImage*. 2003; 18:789–797. [PubMed: 12667855]
- Polderman TJC, Gosso MF, Posthuma D, van Beusterveldt TCEM, Heutink P, Verhulst FC, Boomsma DI. A longitudinal twin study on IQ, executive functioning, and attention problems during childhood and early adolescence. *Acta Neurologica Belgica*. 2006; 106:191–207. [PubMed: 17323837]
- Posner MI, Rothbart MK. Research on attention networks as a model for the integration of psychological science. *Annual Review of Psychology*. 2007; 58:1–23.
- Preacher KJ, Hayes AF. SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers*. 2004; 36:717–731.
- Preacher KJ, Hayes AF. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*. 2008; 40:879–891. [PubMed: 18697684]
- Pungello EP, Iruka IU, Dotterer AM, Mills-Koonce R, Reznick JS. The effects of socioeconomic status, race, and parenting on language development in early childhood. *Developmental Psychology*. 2009; 45:544–557. [PubMed: 19271838]
- Rhoades BL, Greenberg MT, Lanza ST, Blair C. Demographic and familial predictors of early executive function development: Contribution of a person-centered perspective. *Journal of Experimental Child Psychology*. 2011; 108:638–662. [PubMed: 20828709]
- Rueda, MR.; Posner, MI.; Rothbart, MK. Attentional control and self-regulation. In: Baumeister, RF.; Vohs, KD., editors. *Handbook of self-regulation: Research, theory, and applications*. New York: Guilford Press; 2004. p. 283-300.
- Rushton JP, Brainerd CJ, Pressley M. Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin*. 1983; 94:18–38.
- Semrud-Clikeman M, Walkowiak J, Wilkinson A, Butcher B. Executive functioning in children with Asperger syndrome, ADHD-combined type, and ADHD-predominately inattentive type, and controls. *Journal of Autism and Developmental Disorders*. 2010; 40:1017–1027. [PubMed: 20140638]
- Smith CL, Calkins SD, Keane SP, Anastopoulos AD, Shelton TL. Predicting stability and change in toddler behavior problems: Contributions of maternal behavior and child gender. *Developmental Psychology*. 2004; 40:29–42. [PubMed: 14700462]
- St Clair-Thompson HL, Gathercole SE. Executive functions and achievement in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology*. 2006; 59:745–759. [PubMed: 16707360]
- Stroop JR. Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*. 1935; 18:643–662.
- Szyf M, Bick J. DNA methylation: A mechanism for embedding early life experiences in the genome. *Child Development*. 2013; 84:49–57. [PubMed: 22880724]
- Thompson, RA. Early sociopersonality development. In: Damon, W.; Eisenberg, N., editors. *Handbook of child psychology: Social, emotional, and personality development*. 5th ed.. Vol. Vol 3. Hoboken, NJ: Wiley; 1998. p. 25-104.
- Tsekhmistrenko TA, Vasil'eva VA, Shumeiko NS, Vologirov AS. Quantitative changes in the fibroarchitectonics of the human cortex from birth to the age of 12 years. *Neuroscience and Behavioral Physiology*. 2004; 34:983–988. [PubMed: 15686144]
- Wang Z, Deater-Deckard K, Cutting L, Thompson LA, Petrill SA. Working memory and parent-rate components of attention in middle childhood: A behavioral genetic study. *Behavior Genetics*. 2012; 42:199–208. [PubMed: 21948215]

- Wolfe CD, Bell MA. Source variability in working memory during early childhood: A consideration of age, temperament, language, and brain electrical activity. *Cognitive Development*. 2007; 22:431–455.
- Zelazo PD, Frye D, Rapus T. An age-related dissociation between knowing rules and using them. *Cognitive Development*. 1996; 11:37–63.

Table 1

Descriptive Statistics for Child and Maternal Measures of Executive Function.

Measure	Mean	Min	Max	SD	N
24months					
A-not-B	0.69	0.29	1.00	0.21	62
Crayon delay	2.87	0.00	5.00	2.19	61
36 months					
Tongue task	0.65	0.00	1.00	0.39	58
Simon-says	0.78	0.50	1.00	0.22	29
Day-Night	0.44	0.00	1.00	0.31	53
48 months					
DCCS	0.74	0.00	1.00	0.42	57
Simon-says	0.97	0.50	1.00	0.09	51
Yes-No	0.76	0.00	1.00	0.25	53
Mother					
WCST	54.66	1.00	99.00	26.64	61
Stroop color-word task	95.39	64.00	100.00	8.45	59
ANT	148.92	68.00	291.00	55.33	62
Backward digit span	5.40	2.00	9.00	1.57	47 ^a

^a Note. Task was not initially in experimental protocol.

Table 2

Correlations Between Child EF and Maternal EF and Caregiving.

	Maternal EF composite	Maternal negative caregiving composite ^a
24-month EF composite	.22*	-.06
36-month EF composite	.35**	-.37**
48-month EF composite	.32**	-.51***
Child EF composite	.41***	-.35**

Note: One-tailed *p*-values:

p < .001

**
p < .01,

*
p < .05.

^aThe caregiving composite includes 10- and 24-month behaviors for all analyses. The 36- and 48-month analyses also include 36-month caregiving behaviors.

Results of Hierarchical Regression Analysis Predicting 36-Month EF From Maternal Education, Maternal EF, Maternal Caregiving, and 36-Month Verbal Ability.

Table 3

	R	R ²	R ² Δ	FΔ	F	β	t	sr	sr ²
Dependent variable: 36-month EF									
Step 1	.30	.09			2.84				
Verbal Ability (36 months)						-.13	-.90	-.12	.01
Maternal Education						.34	2.38*	.30	.09
Step 2	.50	.25	.16	5.64**	4.47**				
Verbal Ability (36 months)						-.14	-1.07	-.13	.02
Maternal Education						.25	1.80*	.21	.05
Maternal EF						.27	2.13*	.25	.06
Maternal Caregiving Composite (10, 24, 36 months)						-.24	-1.79*	-.21	.04

Note: One-tailed *p*-values for *t*-tests and two-tailed *p*-values for *F*-tests.

**
p < .01;

*
p < .05, *n* = 59.

Results of Hierarchical Regression Analysis Predicting 36-Month EF From 24-Month EF, Maternal Education, Maternal EF, Maternal Caregiving, and 36-Month Verbal Ability.

Table 4

	R	R ²	R ² Δ	FΔ	F	β	t	sr	sr ²
Dependent variable: 36-month EF									
<i>Step 1</i>	.30	.09			2.84				
Verbal Ability (36 months)						-.13	-0.90	-.11	.01
Maternal Education						.34	2.38*	.30	.09
<i>Step 2</i>	.41	.17	.08	4.97*	3.68*				
Verbal Ability (36 months)						-.15	-1.10	-.14	.02
Maternal Education						.29	2.05*	.25	.06
24-month EF						.28	2.23*	.27	.08
<i>Step 3</i>	.54	.30	.13	4.80*	4.43**				
Verbal Ability (36 months)						-.17	-1.28	-.15	.02
Maternal Education						.21	1.52	.18	.03
24-month EF						.23	1.86*	.21	.05
Maternal EF						.22	1.74*	.20	.04
Maternal Caregiving Composite (10, 24, 36 months)						-.25	-1.88*	-.22	.05

Note: One-tailed *p*-values for *t*-tests and two-tailed *p*-values for *F*-tests.

**
p < .01;

*
p < .05, *n* = 59.

Results of Hierarchical Regression Analysis Predicting 48-Month EF From Maternal Education, Maternal EF, Maternal Caregiving, and 48-Month Verbal Ability.

Table 5

	R	R ²	R ² Δ	FΔ	F	β	t	sr	sr ²
<i>Dependent variable: 48-month EF</i>									
<i>Step 1</i>	.45	.21			7.01***				
Verbal Ability (48 months)						.35	2.64**	.32	.10
Maternal Education						.18	1.39	.17	.03
<i>Step 2</i>	.62	.38	.18	7.46***	8.07***				
Verbal Ability (48 months)						.28	2.32*	.25	.06
Maternal Education						.06	0.49	.05	
Maternal EF						.19	1.68*	.18	.03
Maternal Caregiving Composite (10, 24, 36 months)						-.36	-2.88**	-.31	.10

Note: One-tailed *p*-values for *t*-tests and two-tailed *p*-values for *F*-tests.

p < .001;
**
p < .01;
*
p < .05.

Only *sr*²-values > .01 are reported. *n* = 57.

Table 6

Results of Hierarchical Regression Analysis Predicting 48-Month EF From 36-Month EF, Maternal Education, Maternal EF, Maternal Caregiving, and 48-Month Verbal Ability.

	R	R ²	R ² Δ	FΔ	F	β	t	sr	sr ²
Dependent variable: 48-month EF									
Step 1	.54	.30			10.88***				
Verbal Ability (48 months)						.44	3.46***	.40	.16
Maternal Education						.19	1.50	.17	.03
Step 2	.59	.34	.05	3.79	8.90***				
Verbal Ability (48 months)						.42	3.34***	.38	.14
Maternal Education						.13	1.01	.11	.01
36-month EF						.23	1.95*	.22	.05
Step 3	.73	.53	.19	9.85***	11.14***				
Verbal Ability (48 months)						.36	3.35***	.33	.11
Maternal Education						.00	-0.01	.00	
36-month EF						.10	0.89	.09	
Maternal EF						.07	0.62	.06	
Maternal Caregiving Composite (10, 24, 36 months)						-.47	-4.12***	-.40	.16

Note: One-tailed *p*-values for *t*-tests and two-tailed *p*-values for *F*-tests.

p < .001;

*
p < .05. Only *sr*² values > .01 are reported. *n* = 55.

Results of Hierarchical Regression Analysis Predicting Child EF (A Composite of 24, 36, and 48-Month Assessments) From Maternal Education, Maternal EF, and Maternal Caregiving.

Table 7

	R	R ²	R ² Δ	FΔ	F	β	t	sr	sr ²
<i>Dependent variable: Child EF Composite (24, 36, 48 months; controlling for verbal ability at each age)</i>									
Step 1	.25	.06			3.86				
Maternal Education						.25	1.96*	.25	.06
Step 2	.53	.29	.23	9.12***	7.72***				
Maternal Education						.16	1.38	.15	.02
Maternal EF						.38	3.35***	.37	.14
Maternal Caregiving Composite (10, 24 months)						-.24	-2.01*	-.22	.05

Note: One-tailed *p*-values for *t*-tests and two-tailed *p*-values for *F*-tests.

p < .001;

*
p < .05, *n* = 62.