"Do as I say!" : parenting and the biology of child self-regulation
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Parenting, corpus callosum, and executive function in preschool children

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Abstract

In this longitudinal population-based study ($N = 544$) we investigated whether early parenting and corpus callosum length predict child executive function (EF) abilities at 4 years of age. The length of the corpus callosum in infancy was measured using postnatal cranial ultrasounds at six weeks of age. At 3 years, two aspects of parenting were observed: maternal sensitivity during a teaching task and maternal discipline style during a discipline task. Parents rated EF problems at 4 years of age in five domains of inhibition, shifting, emotional control, working memory, and planning/organizing, using the Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF-P). Maternal sensitivity predicted less EF problems at preschool age. A significant interaction was found between corpus callosum length in infancy and maternal use of positive discipline to determine child inhibition problems: In children with a relatively shorter corpus callosum in infancy more positive discipline predicted lower levels of child inhibition problems. Our results point to the buffering potential of positive parenting for children with biological vulnerability.

Introduction

Executive function (EF) is an umbrella term for several higher-order, self-regulatory functions such as inhibitory control, working memory, planning ability, and attention shifting, which start to develop in the first five years of life (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Garon, Bryson, & Smith, 2008; Hughes & Ensor, 2009). Early variation in the development of EF has been found to predict social functioning (Spinrad et al., 2007) and school functioning (e.g., Monette, Bigras, & Guay, 2011) at a later age. Also, problems in the development of EF have been implicated in several types of developmental disorders and psychopathologies, such as autism, Attention-Deficit Hyperactivity Disorder (Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; for a review, see Pennington & Ozonoff, 1996), and depression (Maalouf et al., 2011). Prior studies on differences in EF development have mainly focused on the genetic component of EF (Friedman et al., 2008; Jester et al., 2009; Polderman et al., 2007) and its association with brain development (Ghassabian et al., 2012; Jacobs, Harvey, & Anderson, 2011; Skranes et al., 2009). Some recent studies assessed not only biological parameters but also environmental influences on EF development (e.g., Bernier et al., 2012; Carlson, 2009; Garon et al., 2008; Hughes, 2011). The current study examines whether early parenting influences child EF at preschool age independent of the impact of infant brain development as demonstrated in a previous study on the same sample (Ghassabian et al., 2012).

The complexity and diversity of EF has resulted in a multitude of definitions in empirical research (Jurado & Rosselli, 2007). Originally, EF has been described as a unitary construct but due to the complexity of the construct a multifactorial view of distinct but related EF domains seems more plausible (Garon et al., 2008; Jurado & Rosselli, 2007). EF develops over an extended period starting in infancy in which externalized monitoring is gradually replaced by internal regulation (Bernier et al., 2011), followed by a rapid development of functions during early childhood (Anderson, 2002) and further maturation of EF domains in adolescence (Crone, 2009). One focus of research in EF development has been its association with maturation or integrity of brain structures in children and adults. The prolonged developmental trajectory of EF domains during child development parallels the development of the prefrontal cortex (PFC), which makes this brain region a natural candidate to be involved in EF (Bernier et al., 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

A meta-analysis by Alvarez and Emory (2006), however, showed that empirical support is inconsistent for the association between EF and frontal lobe functioning. Their analysis of studies on adults with brain lesions resulted in the conclusion that both frontal and non-frontal brain regions are involved in EF. Similarly, Jacobs, Harvey, and Anderson (2011) compared children with frontal pathology to children with pathology in other brain areas and to control subjects on several EF domains. All children with brain pathology showed EF deficits irrespective of the site of the damage. Studies in children with very low birth weight demonstrated that the accompanying white matter abnormalities in the corpus callosum are related to their EF problems (e.g., Skranes et al., 2009; Woodward, 2011). Similarly, in the large population-based cohort study Generation R we found that children with a shorter corpus callosum in infancy showed more EF problems at preschool age (Ghassabian et al., 2012). In summary, most recent evidence indicates that EF skills not only rely on the integrity of the prefrontal cortex but also on the quality of the white matter connections between the frontal regions and other brain regions, such as the corpus callosum, and the integrity of those connected regions (Anderson, 2002; Jacobs et al., 2011; Skranes et al., 2009; Woodward, 2011).

Because EF has an extended postnatal developmental course, EF development is particularly sensitive to environmental influences (e.g., Bernier et al., 2012; Conway & Stifter, 2012). The potential short and long term effects of early caregiving on offspring development have been established in animal and human research (e.g., Champagne, Francis, Mar, & Meaney, 2003; Sroufe, Coffino, & Carlson, 2010). Recent studies focusing on the association between parenting quality and EF development in children also emphasize the importance of early experiences in the family environment. A study by Jennings and colleagues (2008) demonstrated that maternal warmth during teaching predicted greater inhibitory capacity in toddlers. In preschoolers, maternal scaffolding (support and guidance of goal-directed activities), maternal planning, and consistent parenting were each found to predict the development of EF (Hughes & Ensor, 2009). A study on the influence of parenting on EF subdomains showed that in early childhood maternal autonomy support was the strongest predictor of child working memory and set shifting abilities 3 to 14 months later but that no parenting factor predicted child impulse control (Bernier, Carlson, & Whipple, 2010).

In a follow-up study (Bernier et al., 2012) of the role of maternal and paternal parenting and child attachment security in the development of child working memory, set shifting, inhibitory control (summarized as conflict-EF), and impulse control parenting also did not predict impulse control. Attachment security appeared to be the only contributor to conflict-EF. Studies on the association between disciplinary strategies of parents and child EF or self-regulatory abilities have shown that physically punitive discipline can be detrimental for self-regulation (Colman, Hardy, Albert, Raffaelli, & Crockett, 2006) and that positive control strategies are associated with child compliance, a self-regulatory domain, though the overall effect size of this relation in a recent meta-analysis was small (Karreman, Van Tuijl, Van Aken, & Dekovic, 2006).

The aim of the present study was to combine the socialization perspective with the neuroscience perspective and to investigate in a large population-based cohort study whether early parenting predicts child EF abilities at a later age, independent of infant brain development. In a previous report on the current sample we found that the length of the corpus callosum in infancy was associated with EF at 4 years of age (Ghassabian et al., 2012). Here we examine whether independently or in interaction with corpus callosum length maternal sensitivity and maternal discipline style at child's age of 3 years predicted child EF problems at 4 years. We included two aspects of parenting, maternal sensitivity and maternal discipline, because previous studies have found differences in associations between various parenting aspects and EF abilities in children (e.g., Bernier et al., 2010; Hughes & Ensor, 2009; Karreman et al., 2006). We investigated the influence of parenting on multiple domains of EF problems in children: inhibition, shifting, planning, emotional control, and working memory, because EF is a complex construct which is difficult to capture in a unitary score (Anderson, 2002; Garon et al., 2008; Jurado & Rosselli, 2007; Schroeder & Kelly, 2010) and because not all EF domains might be equally influenced by early parenting (e.g., Bernier et al., 2010; Hughes & Ensor, 2009; Karreman et al., 2006; Schroeder & Kelly, 2010).

Method

Setting

The current investigation is embedded within the Generation R Study, a prospective cohort investigating growth, development, and health from fetal life onwards in Rotterdam, the Netherlands (Jaddoe et al., 2008, 2012). Detailed measurements were obtained in a subgroup of children of Dutch national origin, meaning that the children, their parents, and their grandparents were all born in the Netherlands to reduce confounding and effect modification (e.g., Luijk et al., 2010; Tharner et al., 2011). Children with a delivery date between February 2003 and August 2005 were enrolled. Data were collected with questionnaires and during visits to the research centre for behavioral assessments. All measures were approved by the Medical Ethics Committee of the Erasmus Medical Center, Rotterdam. Written informed consent was obtained from all adult participants.

Study population

In the current study postnatal cranial ultrasounds, questionnaire data, and observation data of the lab visit at 3 years are presented. A total of 904 neonates and their parents attended the lab visit for the postnatal cranial ultrasound. Because of potential differences in brain development of fetuses born to multiple and singleton pregnancies, we excluded 10 twin pairs. Eight mothers participated in the 3-year visit twice, with siblings. One child of each sibling pair was randomly selected for the analyses to avoid paired data. Of the remaining neonates ($n = 876$) we obtained 774 ultrasound images of corpus callosum length with sufficient quality. For 79% of these 774 eligible mother-child dyads observed maternal sensitivity and discipline at child age of 3 years were available. Reasons for missing observed parenting data were attrition, participation in the 3-year visit with father or grandparent, and technical or procedural difficulties during the mother-child interaction tasks. Of the remaining 613 mother-child dyads, parental report on child EF at 4 years was available for 544 children.

Non-response analyses were performed comparing these 544 mother-child dyads with the 230 mother-child dyads excluded from the analyses on predictors and background variables. Mothers excluded from the analyses were younger than mothers included in the sample, $t(367.97) = -3.02$, $p < .01$, and boys were more often excluded than girls, χ^2 $(1, 774) = 6.84$, $p < .01$. Children excluded from the analyses had a lower gestational age at birth than children included in the sample, $t(772) = -3.00$ $p < .01$. Children excluded from the analyses were 0.5 weeks older at the 6 weeks cranial ultrasound than children included in the sample, $t(383.70) = 2.31$, $p < .05$. Children excluded also had more emotional control problems around 4 years of age than children included in the sample, $t(648) = 2.90$, $p < .01$. All differences between the two groups were small (range of explained variance: 1%-2%).

Measures

Executive function problems

When the children were around 4 years of age ($M = 48.5$ months, $SD = 1.04$), the Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF-P) was used to measure EF problems (Gioia, Espy, & Isquith, 2003). The BRIEF-P is a parent-completed questionnaire to assess EF behaviors in a broad age range of preschoolers (2-5 years). It contains 63 items within five related but non-overlapping theoretically and empirically derived clinical scales that measure children's ability in different aspects of EF: *inhibition* (16 items), to stop his/her own behavior; *shifting* (10 items), to change focus from one mindset to another; *emotional control* (10 items), to modulate emotional responses; *working memory* (17 items), to hold information in mind for the purpose of completing a task; and *planning/organization* (10 items), to manage current and future-oriented task demands within the situational context. Parents were asked to rate how often a particular behavior was problematic in the preceding month on a 3-point scale (never, sometimes, often). A sum score (the Global Executive Composite) can be derived by adding the scores of the five domains. The clinical raw scores and the composite scores yield *T*-scores based on gender and age. Higher scores indicate more problems with EF.

The BRIEF-P measures EF in a naturalistic setting and does not have the limitations of performance-based tests and environmental effects during the administration. Correlations between the scales of the BRIEF-P and performance-based EF measures are positive and consistent though modest only (Mahone & Hoffman, 2007). The content validity and internal consistency of the BRIEF-P are adequate, and the subscales of the BRIEF-P and the Global Executive Composite show adequate to high test-retest reliability (Sherman & Brooks, 2010). The distributions of subscale *T*-scores and the Global Executive Composite *T*-score were skewed and therefore scores were transformed with natural logarithm to approach normality.

Cranial ultrasound measurements

Postnatal cranial ultrasounds were performed in infants at the age of 6.7 weeks ($SD = 1.7$) with a commercially available multifrequency electronic transducer (3.7-9.3 MHz) with a scan angle of 146°, usable for 3-dimensional volume acquisition (Voluson 730 Expert, GE Healthcare, Waukesha, WI, USA). The details of ultrasound measurements have been described previously (Herba et al., 2010; Roza et al., 2008). The probe was positioned on the anterior fontanel and a volume box was placed at the level of the foramen of Monro in a symmetrical coronal section. A pyramid-shaped volume of the brain tissue was scanned and the diameter of brain structures were measured offline. Two raters, trained by a neonatologist with expertise in neonatal cranial ultrasound imaging (P.G.), independently measured every image. Raters also coded the quality of the ultrasound image on a 3-point rating scale, based on the ability to clearly delineate the boundaries of the structures. We excluded images with a quality rating of "very poor" by both raters.

In the best mid-sagittal view, we defined the corpus callosum length as the largest diameter from rostrum to splenium (see Figure 1). Commonly, the thickness of corpus callosum, as measured by MRI, is used in neuroimaging studies (Stewart et al., 1999). However, with ultrasound techniques variations in the thickness of corpus callosum cannot be reliably measured (Anderson et al., 2004). Therefore, we used the measurement along the entire body of the corpus callosum and obtained an average corpus callosum length using measurements from the two raters. The interrater reliability of the corpus callosum length was good (Cronbach's $\alpha = .85$, intra-class correlation coefficient [ICC] = .85; Ghassabian et al., 2012).

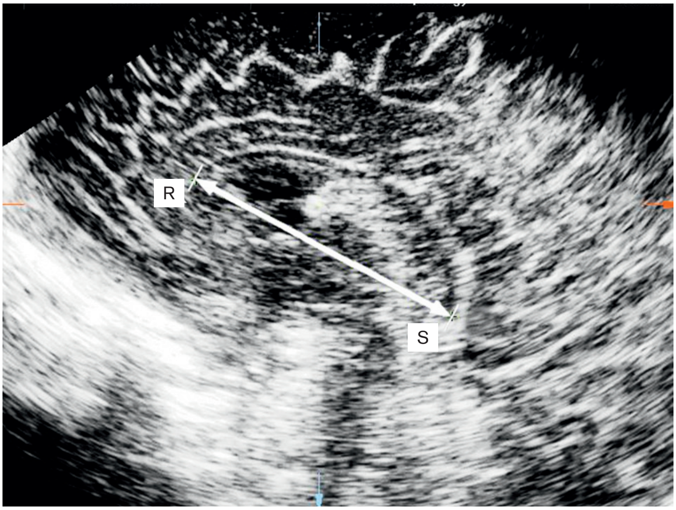

Figure 1. Corpus Callosum Length: largest diameter from rostum (R) to splenium (S).

Parenting

Sensitivity

At 3 years maternal sensitivity was observed when mother and child performed two tasks that were too difficult for the child: building a tower and an etch-a-sketch task. Mothers were instructed to help their child as usual. Maternal sensitivity was coded from DVD recordings with the revised Erickson 7-point rating scales for Supportive Presence and Intrusiveness (Egeland, Erickson, Clemenhagen, Hiester, & Korfmacher, 1990). The subscales Supportive Presence and Intrusiveness were coded for each task. An overall sensitivity score was created by reversing the Intrusiveness scales, standardizing all scores, and creating an average over both scales and both tasks. The two tasks were independently coded by 13 trained coders. Coders were unaware of other data concerning the mother-child dyad. Coders were extensively trained and regularly supervised. Reliability of the coders was assessed directly after the training and at the end of the coding process to detect possible rater drift. ICCs for the subscales were .75 on average for the tower task (range .73 - .77, $n = 53$) and .79 on average for the etch-a-sketch task (range .65 - .93, $n = 55$; Kok et al., 2012a).

Discipline style

Maternal discipline was observed at 3 years in a disciplinary context. In this task of 2 minutes the parent prohibited the child to touch or play with a set of attractive toys that were displayed before the child. Coding procedures were based on Kuczynski, Kochanska, Radke-Yarrow, and Girnius-Brown (1987) and Van der Mark, Van IJzendoorn, and Bakermans-Kranenburg (2002). Maternal verbal and physical discipline strategies were observed and coded in different categories: Commands, Support, and Physical obstruction or interference (micro coded); and with the revised Erickson 7-point rating scale for Supportive Presence (macro coded; Egeland et al., 1990). Both micro- and macro coding strategies were used because they represent two different types of parental behavior: planned and intuitive behaviors, probably reflecting two dimensions of the same underlying construct (Mesman, 2010). To create a comprehensive picture of positive and negative strategies, micro codes and macro codes were combined. Commands were coded when mothers prohibited their child to touch or play with toys in an authoritarian manner. Support involved all maternal remarks that helped the child to comply, such as distracting the child from the toys and responding to what the child said. Physical obstruction or interference was coded when mothers used physical force to keep the child from touching the toys. The mother's supportiveness toward her child during the discipline task was coded with the Supportive Presence scale, which refers to the level of positive regard and emotional support the mother shows toward the child. A supportive mother is a reassuring, calm, and affectively positive secure base for the child. Support and Supportive Presence represent a maternal positive discipline style. Commands and Physical obstruction are indicators of maternal negative discipline style.

Maternal behavior was coded by five trained coders. Coders were unaware of other data concerning the mother-child dyad. Coders were extensively trained and regularly supervised. Reliability of the coders was assessed directly after the training and at the end of the coding process to detect possible rater drift. The number of times a specific behavior was coded was divided by the total number of codings to create a relative score for each behavioral category. This resulted in scores for each category that were independent of the number of maternal messages. Intercoder reliability was adequate (ICC for Commands was .85, for Support .85, for Physical Interference .90, and for Supportive Presence .79, $n = 57$; Kok et al., 2012b). A principal components analysis on z-standardized discipline components was conducted. The first component explained 53.5% of the variance, and factor scores were extracted by regression method. Higher scores on the overall maternal discipline composite indicate a more positive discipline style and lower scores indicate a more negative discipline style. The overall maternal discipline composite was square root transformed to normality.

Covariates

Maternal depressive symptoms

Maternal depressive symptoms at 20 weeks of gestation and at child's age of 3 years were assessed by postal questionnaires with the 6-item depression scale of the Dutch version (De Beurs, 2004) of the Brief Symptom Inventory (Derogatis, 1993; Derogatis & Melisaratos, 1983), a validated self-report questionnaire of 53 items which is widely used to assess psychological distress. Sum scores were divided by the number of endorsed items with a maximum of one missing item allowed. The internal consistency of the depression scale in the current study was $\alpha = .73$ during pregnancy and $\alpha = .78$ at child's age of 3 years. Scores were transformed inversely to approach a normal distribution and reversed for interpretation purposes.

Background variables

Gestational age at birth was obtained from community midwife and hospital registries at birth. We adjusted the analyses for gestational age at birth as an indicator of the biological risk of developmental delays (MacKay, Smith, Dobbie, & Pell, 2010; Yang, Platt, & Kramer, 2010). The age of the child in weeks and the head circumference were registered at the time of the cranial ultrasound measurement. We adjusted all analyses for head circumference and age of the child at the time of ultrasound to ensure that the effects did not reflect the association with head size or with maturity. The age of the mother and her educational level were reported at the intake of the Generation R Study. Educational level was dichotomized as 'high' (at least higher vocational training or a bachelor's degree, $n = 370$) or 'low/medium' ($n = 168$). Information on maternal smoking during pregnancy was obtained by repeated self-reports in the first, second, and third trimester of pregnancy. Based on this information mothers were divided into two groups: mothers that never smoked in pregnancy ($n = 403$) versus mothers that smoked until pregnancy was known or continued smoking during pregnancy ($n = 95$).

Statistical analyses

Because of missing data on maternal educational level (1.1%), maternal smoking during pregnancy (8.5%), child age (0.4%) and head circumference at the postnatal cranial ultrasound (3.7%), and maternal depressive symptoms during pregnancy (5.3%) and at child's age of 3 years (4.8%) we generated five imputed data sets. Missing data were imputed with the predictive mean matching method in IBM SPSS Statistics, version 19.0.1 for Windows (Meulman, Heiser, & SPSS, 2010). Data were analyzed in separate data sets and subsequently pooled to obtain an overall result based on five imputations. Analyses conducted with the imputed data set ($N = 544$) yielded similar (significant) results compared to analyses with the complete data set ($N = 432$). Results of the imputed data set are presented unless otherwise indicated.

First, the bivariate associations among covariates, maternal parenting, corpus callosum length, and maternal parenting were determined. Second, linear regression analyses were performed to test whether maternal parenting at 3 years of age explained additional variance of child EF problems at 4 years of age above covariates and child brain development. In the regression equations we included covariates in the first step, followed by corpus callosum length, followed by maternal parenting, followed by interactions between corpus callosum length and maternal parenting (discipline and sensitivity). Interaction terms were computed after centering of the constituent variables. Non-significant interaction terms were removed from the model before interpreting the main effects. If interaction effects were significant, the sample was stratified by corpus callosum length based on a median split to investigate the associations between maternal parenting and child EF problems per subgroup.

Results

Sample characteristics are presented in Table 1. First, we studied gender differences on the main variables. The average corpus callosum length was larger in girls than in boys, $p < .01$. Mothers used more positive discipline behavior towards girls than towards boys, $p < .01$. Next, we studied differences on main variables by maternal educational level. Highly educated mothers demonstrated more positive discipline behavior than mothers with a lower educational level, $p < .05$, and demonstrated more sensitive behavior than mothers with a lower educational level, $p < .01$. Children of mothers with a higher educational level had a longer corpus callosum at 6 weeks of age than children of mothers with a lower educational level, $p < .05$. Mothers with a higher educational level reported lower levels of child inhibition problems at 4 years than mothers with a lower educational level, $p < .05$, lower levels of child working memory problems than mothers with a lower educational level, $p < .05$, and lower levels of child planning problems than mothers with a lower educational level, $p < .01$. Finally, mothers who smoked during pregnancy showed less sensitive behavior at 3 years of child's age than mothers who did not smoke during pregnancy, $p < .05$. Also, mothers who smoked during pregnancy reported higher levels of child working memory problems at 4 years than mothers who did not smoke during pregnancy, $p < .01$, and higher levels of child inhibition problems at 4 years, $p < .05$.

Table 1. *Sample characteristics.*

Child Characteristics		Maternal Characteristics	
Child gender, % female	52.0	Age at intake in years	32.11 (3.7)
Parity, % firstborn	63.9	Educational level, % high	68.5
Birth weight in grams	3516.56 (521.8)	Smoking during pregnancy, % yes	19.1
Gestational age in weeks	40.12 (1.6)	Positive Discipline	0.00 (1.0)
Corpus Callosum length in centimeter	4.63 (0.3)	Sensitivity	0.02 (0.7)
Inhibition Problem *T*-scores	47.67 (8.6)		
Shifting Problem *T*-scores	48.25 (8.3)		
Emotional Control Problem *T*-scores	47.98 (10.4)		
Working Memory Problem *T*-scores	47.08 (9.5)		
Planning Problem *T*-scores	45.56 (8.9)		
Global Executive Composite *T*-scores	46.60 (9.4)		

Note. Values are untransformed. Unless otherwise indicated, values are mean (*SD*).

The bivariate correlations among the main variables are presented in Table 2. A shorter corpus callosum at 6 weeks of age was correlated with higher levels of inhibition problems, emotional control problems, working memory problems, planning problems, and total EF problems at 4 years of age. Higher levels of maternal sensitivity were correlated with more positive maternal discipline. Higher levels of maternal sensitivity were associated with lower levels of inhibition problems, working memory problems, planning problems, and total EF problems one year later. More positive maternal discipline was also associated with lower levels of inhibition problems, working memory problems, and planning problems one year later. Correlations between the subdomains of EF problems were moderate to high.

Table 2. *Correlations between corpus callosum, maternal parenting, and child executive function problem T-scores.*

	Corpus Callosum	Sensitivity	Positive Discipline	Inhibition Pr.	Shifting Pr.	Emot. Contr. Pr.	Work. Mem. Pr.	Planning Pr.	Total EF Pr.
Head Circumference	.31**	.01	-.06	-.07	.06	-.05	-.12**	-.09*	-.07
Corpus Callosum		.02	-.03	-.12**	-.05	-.11*	-.10*	-.09*	-.13**
Sensitivity			.26**	-.18**	-.03	-.06	-.21**	-.17**	-.18**
Positive Discipline				-.09*	-.01	-.02	-.09*	-.09*	-.08
Inhibition Pr.					.33**	.58**	.70**	.64**	.86**
Shifting Pr.						.58**	.37**	.34**	.63**
Emot. Contr. Pr.							.47**	.48**	.78**
Work. Mem. Pr.								.74**	.85**
Planning Pr.									.80**
Total EF Pr.									

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

Pr. = problems; Emot. Contr. = Emotional Control; Work. Mem. = Working Memory

Parenting and executive function problems

We tested whether variation in the quality of parenting at 3 years contributed to differences in EF problems at 4 years of age, independent or in interaction with infant corpus callosum length. A hierarchical regression analysis was performed for the total scale of EF problems (Global Executive Composite). Interaction terms were not significant and therefore excluded from the analysis. The final regression model is presented in Table 3. Maternal depressive symptoms during pregnancy ($\beta = .10$, $p < .05$) and at 3 years of child's age ($\beta = .20$, $p < .01$) predicted higher levels of child EF problems. A shorter corpus callosum at 6 weeks of age predicted higher levels of child EF problems at 4 years of age ($\beta = -.12$, $p < .01$). After controlling for the other predictors and covariates, higher levels of maternal sensitivity at 3 years predicted lower levels of child EF problems at 4 years of age ($\beta = -.14$, $p < .01$). Maternal discipline was not independently associated with child EF problems.

Table 3. *Predictors of child executive function problem T-scores (N = 544).*

	Child Executive Function Problems				
	β^a	*T*	*p*	R^{2a}	R^2change[a]
Step 1:				.09	.09
Gestational age at birth	-.07	-1.48	.14		
Age child at ultrasound (weeks)	.03	0.78	.43		
Head circumference 6w	-.02	-0.39	.70		
Maternal age at intake	-.03	-0.75	.45		
Maternal educational level	-.01	-0.18	.86		
Maternal smoking during pregnancy	.05	1.13	.26		
Maternal depression during pregnancy	.10*	2.30	<.05		
Maternal depression at child's age 36m	.20**	4.62	<.01		
Step 2:				.10	.01
Corpus Callosum Length 6w	-.12**	-2.72	<.01		
Step 3:				.13	.02
Maternal Positive Discipline 36m	-.03	-0.70	.48		
Maternal Sensitivity 36m	-.14**	-3.33	<.01		

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

[a] averages taken from the final regression models of the 5 imputed datasets.
Note. Betas are taken from the final models.

Executive function subdomains

To specify which specific EF domains accounted for the association with maternal parenting, the hierarchical regression analysis was repeated for the subscales of EF. Again, interaction terms remained in the analyses only if significant. Final regression models are presented in Table 4.

Table 4 shows that a shorter corpus callosum at 6 weeks of age predicted higher levels of inhibition problems at 4 years of age ($\beta = -.11$, $p < .01$). Maternal sensitivity at 3 years of age predicted lower levels of inhibition problems at 4 years of age ($\beta = -.14$, $p < .01$) but maternal discipline was not associated with the level of inhibition problems. A significant interaction was found between corpus callosum length at 6 weeks of age and maternal positive discipline at 3 years of child's age on the child's level of inhibition problems ($\beta = .09$, $p < .05$, R^2change = .01). The moderating effect of corpus callosum length was examined by comparing the association between discipline and inhibition problems in children with a relatively long corpus callosum ($n = 272$) versus children with a relatively short corpus callosum at 6 weeks postnatal ($n = 272$). The association between discipline and inhibition problems was stronger for the children with a short corpus callosum at 6 weeks postnatal ($r[270] = -.19$, $p < .01$) than for children with a long corpus callosum ($r[270] = .04$, $p = .48$). The bivariate associations between maternal discipline and child inhibition problems per group are displayed in Figure 2.

Table 4. *Predictors of child executive function problems subdomain T-scores (N = 544).*

	Inhibition Problems		Shifting Problems		Emotional Control Problems		Working Memory Problems		Planning Problems	
	β[a]	R^{2a}	β[a]	R^{2a}	β[a]	R^{2a}	β[a]	R^{2a}	β[a]	R^{2a}
Step 1:		.08		.07		.06		.08		.05
Gestational age at birth	-.06		-.09		-.05		-.03		-.03	
Age child at ultrasound (w)	.04		.00		.05		.02		.04	
Head circumference (6w)	-.02		.12*		-.01		-.09		-.07	
Maternal age at intake	-.03		.02		-.03		-.04		-.01	
Maternal educational level	-.03		.03		.08		-.03		-.07	
Maternal smoking (during pregnancy)	.07		.00		.01		.10*		-.01	
Maternal depression (during pregnancy)	.07		.05		.10*		.09*		.11*	
Maternal depression (3y)	.18**		.22**		.18**		.15**		.09*	
Step 2:		.09		.07		.08		.09		.06
Corpus Callosum Length (6w)	-.11**		-.09*		-.12**		-.06		-.07	
Step 3:		.11		.07		.08		.12		.08
Maternal Discipline (3y)	-.04		.01		.00		-.03		-.04	
Maternal Sensitivity (3y)	-.14**		-.02		-.05		-.17**		-.13**	
Step 4:		.12		--		--		--		--
Corpus Callosum * Maternal Discipline	.09*									

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

[a] averages taken from the final regression models of the 5 imputed datasets.
Note. Betas are taken from the final models.

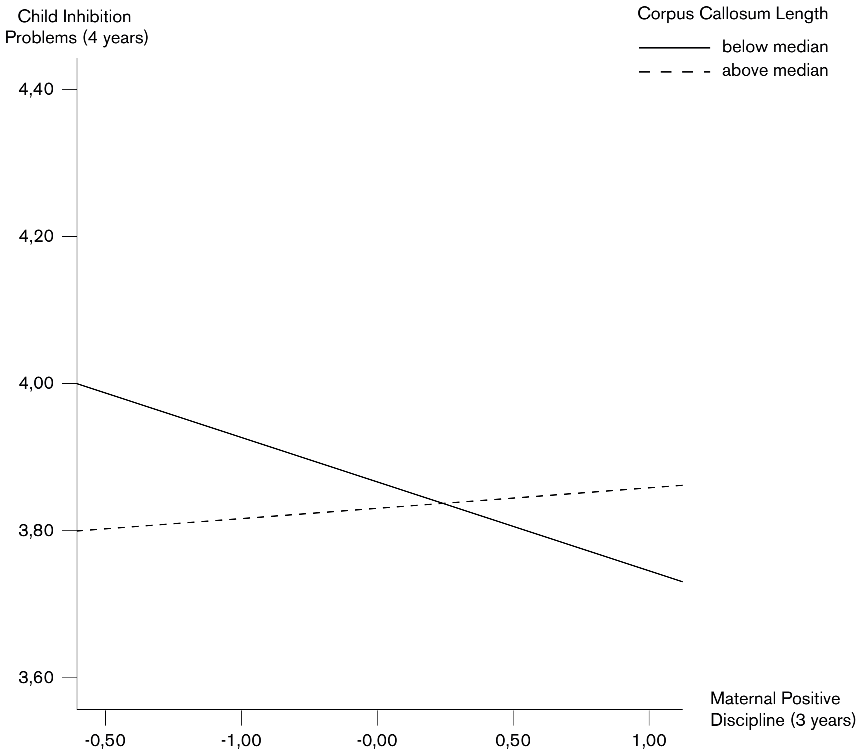

Figure 2. Interaction between corpus callosum length and maternal discipline predicting child inhibition problem T-scores.

As shown in Table 4 a shorter corpus callosum in infancy was associated with higher levels of shifting problems and emotional control problems at 4 years of age ($\beta = -.09$, $p < .05$; $\beta = -.12$, $p < .01$), but not related to working memory problems or planning problems. Maternal sensitivity and maternal discipline were not associated with shifting problems or emotional control problems. However, maternal sensitivity at 3 years was associated with lower levels of working memory problems ($\beta = -.17$, $p < .01$) and lower levels of planning problems one year later ($\beta = -.13$, $p < .01$).

Discussion

In this study we examined whether maternal sensitivity and maternal positive discipline were related to child EF problems one year later, independently or in interaction with corpus callosum length in infancy. In addition to the association of corpus callosum length in infancy with EF development (Ghassabian et al., 2012), we found that higher levels of maternal sensitivity at 3 years were associated with lower levels of EF problems at 4 years. Further analyses indicated that high levels of maternal sensitivity were associated with lower inhibition problem scores, working memory problem scores, and planning problem scores in preschoolers, but not lower emotional control problem scores or shifting problem scores. A significant interaction was found between the length of the corpus callosum in infancy and maternal discipline in association with child inhibition problem scores at preschool age. The beneficial effect of maternal positive discipline on child inhibition problem scores was stronger for children with a relatively short corpus callosum in infancy than for children with a relatively long corpus callosum.

The fact that maternal sensitivity was associated with lower levels of child EF problems one year later underlines the importance of parenting in the development of EF. The association of maternal sensitivity with child EF was independent of a marker of early brain maturation, maternal psychopathology, and background variables related to EF development. The exact mechanisms behind the influence of parenting on child EF remain unknown. A common explanation is that positive parenting can foster the development of regulatory skills by modeling appropriate behavior and by providing the child with a safe and encouraging environment in which it can practice self-regulation (e.g., Bernier et al., 2010; Perez & Gauvain, 2010). An alternative mechanism is that positive parenting may directly impact on child brain development and thus influence child EF. The notion that early brain development is under constant influence of the environment, in particular early caregiving experiences, has become widely accepted (Belsky & De Haan, 2011; Cicchetti, 2002; Glaser, 2000). Most studies have, however, focused on the influence of extreme rearing conditions, such as child abuse and neglect. Experience of neglect, child physical abuse, and child sexual abuse were all found to be associated with a reduced corpus callosum size (for a review, see Belsky & De Haan, 2011). It seems plausible that normal variation in parenting quality can also affect the development of the brain (Belsky & de Haan, 2011; Glaser, 2000). A randomized controlled trial in which maternal sensitivity towards preterm infants was enhanced found promising short-term benefits for the infants' brain development that might result in better cognitive development at a later age (Milgrom et al., 2010). An alternative explanation for the association between maternal sensitivity and child EF is that children with lower levels of EF problems might elicit a more positive response in their parents and thus increase maternal sensitivity (Bernier et al., 2010). In our research design bidirectional influences cannot be ruled out.

The relation between maternal sensitivity and child EF was specific for child working memory, inhibition, and planning. We did not find an association between maternal sensitivity and shifting problems or emotional control problems. Working memory skills and inhibition skills are usually referred to as basic EF skills that develop earlier in life than more complex EF skills such as set shifting (Garon et al., 2008). This may be an explanation for our finding that shifting abilities were less influenced by maternal sensitivity than the EF subdomains that were already more mature at 4 years of age. The fact that we did not find an association between maternal sensitivity and child emotional control problems a year later was unexpected. Previous studies suggest that in an environment of sensitive and responsive care the child gradually learns how to regulate his behavior and emotions, resulting in higher levels of behavioral and emotional control (e.g., Fox & Calkins, 2003; Kochanska & Aksan, 1995; Morris, Silk, Steinberg, Myers, & Robinson, 2007). Overall our findings seem to imply that shifting and emotional control abilities follow a different developmental pattern than inhibition, planning, and working memory abilities.

An interaction effect between maternal discipline and infant corpus callosum length to determine child inhibition problems at the age of 4 years was found. In children with a relatively short corpus callosum at 6 weeks postnatal more maternal positive discipline predicted lower levels of child inhibition problems. The length of the corpus callosum is thought to be associated with the number of axons and the degree of myelination (Anderson, Laurent, Woodward, & Inder, 2006), and the integrity of this structure predicts the efficiency of interhemispheric connectivity (Keshavan et al., 2002). Corpus callosum abnormalities are indicative of less connectivity between the hemispheres and are often found in children born preterm (Woodward et al., 2011). Though in our sample most children were born a term (only 3.3% under 37 weeks) a relatively short corpus callosum might be an indicator of suboptimal white matter development and higher risk of EF problems. The fact that the level of maternal positive discipline was associated with child inhibition problems in the children with a small corpus callosum indicates that positive parenting might act as a buffer in children at risk. Similarly, a study comparing the influence of maternal sensitive responsiveness on child psychopathology in children with low birth weight versus normal weight demonstrated that sensitive responsiveness had a protective effect in the development of internalizing problems and ADHD symptoms in very low birth weight children (Laucht, Esser, & Schmidt, 2001).

Despite our study's strength such as the use of an observational paradigm in measuring different aspects of parenting, the longitudinal nature of our data, and the large number of participants, its results must be interpreted within the context of a number of methodological limitations. Firstly, we measured corpus callosum length using cranial ultrasound which does not provide detailed images of specific substructures in the brain. Although cranial ultrasound in neonates has limited value in reflecting variations in the brain structures as compared to MRI (Anderson et al., 2004), it is a reliable, non-invasive, and cost-effective technique to image very young children and can be used in follow-up studies of healthy infants (Riccabona, 2005). In a prospective study including neonates ultrasound measures are therefore the preferred choice. Secondly, whereas the corpus callosum area may be a better indicator of its size, we measured the corpus callosum across the entire length because the corpus callosum area cannot be measured reliably by cranial ultrasound. However, studies have reported strong correlations between the corpus callosum length and thinness (Anderson et al., 2006). Thirdly, we used parental report of child EF problems which might have introduced bias (Seifer, 2003). However, given that preschoolers have difficulty staying on task for longer periods of time and that parents are able to provide a picture of the everyday functioning of children on EF domains (Sherman & Brooks, 2010), maternal report is appropriate to assess EF problems. Also, observational measures were used to assess maternal sensitivity and maternal discipline which reduces the risk of bias in the association between parenting and EF problems. Fourthly, in the current study design we cannot rule out bidirectional effects between parenting and EF problems or the possibility that there is an underlying cause for both parenting and EF problems that might explain the association we found.

It is important to emphasize that the variation in corpus callosum length in the infants in our study was within the normal range. A relatively short corpus callosum length should not be interpreted as an indication of white matter or brain development abnormality. Furthermore, we do not know whether the reduction in length of the corpus callosum is due to a smaller number of axons or due to reduced degree of myelination and whether there might be a neuronal problem underlying the short length. Future research in high risk populations of children with white matter abnormalities is needed to investigate whether maternal sensitivity can contribute to EF development in this group of children and whether positive maternal discipline can act as a buffer for the development of inhibition problems. Moreover, although the buffering potential of positive discipline was congruent with some findings of earlier studies, the interaction effect accounted for only a small part of the variance in inhibition problems. We therefore have to be cautious in interpreting this interaction and the results should be considered hypothesis generating. This finding needs to be replicated in future research, including high-risk populations. Also, future research should focus on the mechanisms behind the influence of parenting on EF. It would be interesting to follow the children in the current study with new measures of brain development and EF to investigate whether the association between parenting and child brain development increases over time and alters the course of EF problems. We intend to measure final callosal size by structural magnetic resonance imaging in these children in the future. Furthermore, future studies should investigate the influence of both fathers' and mothers' parenting on child EF development as the role of the father in research on child development is often neglected.

The current study provides evidence for the importance of maternal sensitive parenting in the development of EF in preschoolers. The use of positive discipline strategies by mothers was associated with lower levels of inhibition problems in children with reduced corpus callosum length in infancy, which points to the buffering potential of positive parenting in children with biological risk.

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