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Differential effects of factors influencing cognitive development at the age of 5-to-6 years

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A B S T R A C T

This study aims to determine whether early predictors of cognitive development affect some cognitive functions more than others. Children (N = 1129) from the EDEN mother-child cohort were assessed at the age of 5-to-6 years using verbal and nonverbal cognitive tests. We used structural equation modeling to simultaneously examine the effects of a broad range of predictors on each cognitive dimension and to test to what extent each predictor differentially affected these dimensions. Effects of family stimulation, breastfeeding duration and number of older siblings were more strongly related to verbal than nonverbal cognitive measure. Our findings provide robust evidence that some modifiable aspects of the early environment are associated with children's cognitive development and may be more strongly associated with their verbal than nonverbal skills.

1. Introduction

Research on intelligence has established that performance in a wide variety of cognitive tasks is positively correlated (across individuals), such that it is possible to explain a substantial part of variance in all tests by one factor, called *g* for general intelligence (Spearman, 1904; Sternberg & Grigorenko, 2002). Several models have proposed breaking down intelligence into different dimensions such as the verbal/nonverbal model (Ramsden et al., 2011), the crystallized/fluid intelligence model (Cattell, 1971) or even more complex ones (*e.g.*, Carroll's three-stratum (Carroll, 1997) and the Cattell–Horn–Carroll models (Flanagan, Ortiz, & Alfonso, 2013) models). Although the effects of many environmental factors on general intelligence have been extensively studied (Belfort et al., 2013; W. Eriksen, Sundet, & Tambs, 2010; Poulsen et al., 2013; Tong,

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Baghurst, Vimpani, & McMichael, 2007), little attention has been paid to the role of specific environmental factors on different dimensions of intelligence.

Prior research suggests that many environmental factors, when examined independently, are associated with children's cognitive skills. The level of parental education, parental income and the home environment are strong contributors to children's cognitive development (Crosnoe, Leventhal, Wirth, Pierce, & Pianta, 2010; Tong et al., 2007). Preterm birth (gestational age (GA) < 37 weeks) (Poulsen et al., 2013) and/or low birth weight (<2.5 kg) (Elgen, Sommerfelt, & Ellertsen, 2003) also have deleterious cognitive effects, and even studies conducted among children with birth weight within the normal range have reported a significant association between birth weight corrected for GA and cognitive skills (Eriksen et al., 2010; W. Matte, Bresnahan, Begg, & Susser, 2001). Breastfeeding and its duration (Belfort et al., 2013; Bernard et al., 2013; Kramer et al., 2008; Leventakou et al., 2013; Tozzi et al., 2012), as well as birth rank (Kristensen & Bjerkedal, 2007) are also linked with cognitive skills in some studies, but not all (Der, Batty, & Deary, 2006; Jacobson, Chiodo, & Jacobson, 1999; Wichman, Rodgers, & Maccallum, 2007).

Because all these environmental factors seem to be very general, it may be expected that they have effects on all cognitive functions. A similar idea emerges from genetic research, with the generalist genes hypothesis (Kovas & Plomin, 2007). According to that hypothesis, most genes influencing one cognitive ability tend to influence other abilities as well. Interestingly, the same authors have also proposed that, while genes are generalists, environments may be specialists, *i.e.*, leading to greater differentiation among cognitive functions (Kovas & Plomin, 2007). However, this hypothesis concerns mostly nonshared environmental factors, *i.e.*, those that differentially affect one twin and not the other in behavior genetic studies. Such environmental factors are more likely to be factors outside the home environment, related to peers and schooling. Within that framework, the environmental factors mentioned above and usually recorded in epidemiological studies tend to be shared environmental factors, and are thus more likely to have general effects on cognition. Nonetheless, there are some suggestions from the literature that some of these may have more specific effects than expected (Belfort et al., 2013; Eriksen et al., 2010; Gustafsson, Duchén, Birberg, & Karlsson, 2004; Sommerfelt, Ellertsen, & Markestad, 1995; Taylor, Espy, & Anderson, 2009; Tozzi et al., 2012). In the present study, we aim to address the question whether certain general environmental factors have an influence that is *specific* to one or several cognitive functions (as opposed to all of them), or a *greater influence* on some cognitive functions than on others.

Results of epidemiological studies have suggested that the level of parental education and the amount of cognitive stimulation from parents have a greater influence on children's verbal than nonverbal skills (Eriksen et al., 2010; Sommerfelt et al., 1995). Some studies have suggested that preterm children (GA < 37 weeks) and/or those born with a low birth weight (<2.5 kg) may have particular problems with visual or spatial skills and mathematical skills (W. Klein, Hack, & Breslau, 1989; Rickards et al., 1993; Taylor et al., 2009), but most studies have argued for a generalized cognitive deficit (Breslau et al., 1994; Breslau, Chilcoat, DelDotto, Andreski, & Brown, 1996; Johnson et al., 2009; Wolke & Meyer, 1999). For example, Breslau et al. (1996) reported that the gradient relationship of birth weight with IQ applies equally to verbal and performance IQ. Contrariwise, findings from Sommerfelt et al. (Sommerfelt et al., 1995) suggested that performance IQ was more influenced by birth weight than verbal IQ. Some studies reported effects of breastfeeding on both verbal and performance IQ (Belfort et al., 2013; Kramer et al., 2008; Leventakou et al., 2013; Mortensen E, Michaelsen K, Sanders SA, & Reinisch J, 2002) whereas others have reported a significant association of breastfeeding (Tozzi et al., 2012) or breastfeeding duration (Gustafsson et al., 2004; Horwood, Darlow, & Mogridge, 2001; Oddy et al., 2003) solely with verbal IQ. Belfort et al. (2013) also reported that breastfeeding duration may not be associated with better visual memory skills. No differential effect on verbal and performance IQ has ever been reported concerning the 'birth order effect', which is known to be in favour of first-born siblings (Kristensen & Bjerkedal, 2007). Thus, some studies have suggested differential cognitive effects of some factors, but the literature remains largely inconsistent. Most importantly, none of these previous studies has tested this hypothesis in a statistically rigorous manner. Indeed, testing the difference between the regression parameters of a single determinant on two different cognitive measures raises methodological problems and cannot be performed by the statistical methods most widely used in epidemiology; for details see Supplementary methods).

Our framework is based on a distinction between proximal and distal processes, a distinction that originates from ecological models of development (Bronfenbrenner, 1979, 1986). Distal factors includes aspects of the child's background that are correlated with developmental outcomes. Proximal factors can be thought of as mediating pathways, or interceding mechanisms through which the distal factor exerts an influence on the outcome. Proximal factors are closer to the lived experience of the child and impact directly on attainment, such as the nature of day-to-day parent-child interactions. For example, parental education can be considered as a distal factor influencing cognitive skills through a range of proximal factors such as the child's cognitive environment, breastfeeding duration or birth weight. Structural equation modeling (SEM) allows the estimation of the total effect of a distal factor on cognitive measure. This total effect can be then decomposed into an indirect effect (*i.e.*, effect that is mediated by more proximal factors) and a direct effect (*i.e.*, effect that is not mediated by other factors) (Kaplan, 2000).

This report aims at identifying specific effects of a broad range of factors on children's verbal and nonverbal skills, using SEM. As few studies have specifically examined this issue, our analyses were considered exploratory. Based on prior literature, we hypothesized that: 1) factors related to the child's cognitive environment are more strongly associated with verbal than with nonverbal skills and 2) birth weight is more strongly associated with nonverbal than with verbal skills. With respect to breastfeeding, given the conflicting results yielded by prior studies, our study also sought to determine whether its effects are global or restricted to language abilities. SEM provides a useful inference framework for the epidemiology of cognitive

Table 1
Characteristics of included and non-included participants.

	Sample of analysis N = 1129 Mean (SD) or%	Not included in the analysis N = 776 Mean (SD) or%	Comparison Wald Test [p value]
Factors			
Male (*vs.* female)	53.3	51.3	0.7 [0.3]
Birth weight (kg)	3.29 (0.51)	3.27 (0.51)	0.5 [0.5]
Score for cognitive stimulation at 5–6 years[a]	17.2 (2.3)	17.0 (2.1)	0.2 [0.7]
Breastfeeding duration (months)	3.3 (3.7)	3.1 (3.6)	1.5 [0.2]
Parental education (years)	13.5 (2.3)	13.0 (2.5)	**23.8 [<0.001]**
Household income (k€/months)	2.7 (1.0)	2.4 (1.1)	**30.6 [<0.001]**
Maternal age at birth of child (years)	29.6 (4.7)	28.2 (5.0)	**39.5 [<0.001]**
Gestational age (weeks)	39.3 (1.7)	39.2 (1.8)	1.2 [0.3]
Number of older siblings	0.8 (0.9)	0.9 (1.0)	2.4 [0.1]
Number of younger siblings	0.5 (0.6)	0.1 (0.4)	**175.1 [<0.001]**
Recruitment center (% Nancy)	43.4	61.2	**57.7 [<0.001]**
Age of the child at the time of testing (months)	67.9 (1.8)	N/A	N/A

In bold $p < 0.05$. N/A = Non Applicable.
[a] Minimum of the score for cognitive stimulation at 5–6 years = 5 and maximum = 32.

development because: (*i*) it simultaneously takes into account the causal and temporal relationships between all factors; (*ii*) it allows the estimation of the total effect, the indirect effect and direct effect of a given factor on each cognitive measure; and (*iii*) it allows the testing of the differential effects of a specific factor on different cognitive skills in a statistically rigorous manner.

2. Methods

2.1. Study design

Mother-child pairs were recruited as part of the EDEN prospective mother-child cohort study (Heude et al., 2015). Pregnant women seen during a prenatal visit at the departments of Obstetrics and Gynecology of the French University Hospitals of Nancy and Poitiers before their twenty-fourth week of amenorrhea were invited to participate. Exclusion criteria included a personal history of diabetes, twin pregnancy, intention to deliver outside the university hospital or to move out of the study region within the following 3 years, and inability to speak French. The participation rate among eligible women was 53%. Enrolment started in February 2003 in Poitiers and in September 2003 in Nancy and lasted for 27 months in each center and resulted in the inclusion of 2002 pregnant women. Compared to the national perinatal survey carried out on 14,482 women who delivered in France in 2003 (Blondel, Supernant, Du Mazaubrun, & Bréart, 2006), female participants in the EDEN study had similar sociodemographic characteristics except they had higher educational background and were more often employed (Heude et al., 2015). Detailed data on each child's environment and cognitive development were collected using obstetrical records, questionnaires and neuropsychological tests. The study was approved by the Ethical Research Committee (Comité consultatif de protection des personnes dans la recherche biomédicale) of Bicêtre Hospital and by the Data Protection Authority (Commission Nationale de l'Informatique et des Libertés). Informed written consents were obtained from parents for themselves at the time of enrollment and for the newborn after delivery.

2.2. Participants

Among the 2002 women included in the EDEN study, 1907 were still in the cohort at delivery. Some analyses of neuropsychological data collected at 2 and 3 years have previously been published (Bernard et al., 2013; Peyre et al., 2014). In this longitudinal study, the attrition rate was 39% at 5 years. At the age of 5-to-6 years, 1129 children have been assessed with at least one of the eleven neuropsychological tests described below. Compared to the 776 children who have not been assessed with neuropsychological tests at the age of 5-to-6 years, the children included in our analyses significantly differ in several potential determinants of cognitive development; notably, they had higher levels of parental education ($p < 0.001$) and income ($p < 0.001$) (Table 1).

2.3. Variables

2.3.1. Predictors of cognitive development

Sex, gestational age and birth weight were collected from obstetrical records. Mothers completed questionnaires on partial or exclusive breastfeeding duration (Bernard et al., 2013) and their date of birth. Both parents completed questionnaires on family income and education level. The average level of parental education and the household income (k€/months) were used in the analyses. The number of older and younger siblings were also assessed. At child's age 5–6, cognitive stimulation of the child at home was assessed by a psychologist using three subscales of the Home Observation for the Measurement of the Environment Scale: language stimulation, academic stimulation, and variety of experimentations (Caldwell & Bradley, 1984; Frankenburg & Coons, 1986). Higher scores represent greater cognitive stimulation and emotional support.

2.3.2. Neuropsychological measures

Trained psychologists in the two recruiting centers assessed each child's cognitive skills between 5 and 6 years (mean = 67.9 months; SD = 1.8) by using neuropsychological tests from the WPPSI-III (Wechsler, 1967) and NEPSY (Kemp, Kirk, & Korkman, 2001; Korkman Kirk & Kemp , 2003) batteries and the Peg-moving task (PMT-5) (Curt, De Agostini, Maccario, & Dellatolas, 1995; Nunes et al., 2008) and the Number Knowledge Test (Okamoto & Case, 1996).

Eleven tests were used (Table 1): (1) Nonword Repetition (NEPSY), scored as the number of syllables repeated correctly (out of 46 syllables in 13 nonwords (*e.g.*, [kiutsa], a nonword with two syllables). This test is designed to measure phonological processing and verbal short-term memory. (2) Sentence Repetition (NEPSY), scored as the number of sentences (17 items, *e.g.*, "dors bien" ["sleep well"]) repeated correctly. This test is designed to measure syntactic skills and verbal short-term memory. (3) Information (WPPSI-III), scored as the number of correct answers (verbally or by pointing) to questions that address a broad range of general knowledge topics (34 items). This test is designed to measure language comprehension, conceptual knowledge and verbal expressive ability. (4) Vocabulary (WPPSI-III), scored as the number of words correctly defined (25 items). This test is designed to measure receptive vocabulary, conceptual knowledge and verbal expressive ability. (5) Word Reasoning (WPPSI-III), scored as the number of concepts correctly identified from a series of clues (28 items). This test is designed to measure language comprehension, conceptual knowledge and general reasoning ability. (6) Block Design (WPPSI-III), scored as the number of correct designs recreated using blocks (20 items). This test is designed to measure nonverbal concept formation, visual perception and organization and visual-motor coordination. (7) Matrix Reasoning (WPPSI-III), scored as the number of matrices correctly completed (29 items). This test is designed to measure nonverbal concept formation and visual perception and organization. (8) Picture Concepts (WPPSI-III), scored as the number of correct selections of 2 or 3 pictures with common characteristics (28 items). This test is designed to measure abstract categorical reasoning ability. (9) Design Copying (NEPSY), scored as the number of figures correctly copied (18 items; each item rated from 0 to 4). This test is designed to measure visual perception and organization and visual-motor coordination. (10) Number Knowledge (NKT-1), scored as the number of correct answers to 13 calculation exercises (counting, adding, and subtracting); (11) Peg-moving task (PMT-5), for which children had to move five pegs, one by one, in a forward motion pattern, beginning with the peg at the side of each hand. The task started with the preferred hand and the subject had to perform three complete trials with each hand. This test is designed to measure visual-motor coordination.

The manual of WPPSI-III reports evidence of high subtest reliability (0.83 to 0.95), internal consistency, test-retest stability, and validity for all subtests (Wechsler, 1967). The nonword repetition, sentence repetition and design copying tests from the NEPSY had a high internal consistency (0.80, 0.81 and 0.79) in a population of 5 to 12 years children (Korkman et al., 2003). The PMT-5 has been widely used to study manual skill development and its relationship to cognitive development in children (Curt et al., 1995; Nunes et al., 2008). The Number Knowledge Test is amongst the most well-known informal measures of number sense and it has been used in many studies (Gersten, Jordan, & Flojo, 2005).

2.4. Exploratory factor analysis (EFA) and structural equation modeling (SEM)

We used exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to identify the latent structure underlying the 11 neuropsychological scores and determine the different cognitive dimensions to be used as outcomes. For the EFA, analysis with oblique rotation was conducted, because it was not presumed that the underlying cognitive dimensions would be orthogonal to each other.

Next, we performed a structural equation model (SEM) to simultaneously examine the effect of each predictor on each cognitive dimension, while ensuring that postulated causal relationships respected obvious temporal relationships. Structural equation modeling allows to parse total effect of each determinant on each cognitive outcome into direct effect (effect of the predictor on the outcome that is independent of effects of other factors) and indirect effect (effect between one predictor and one outcome that is mediated by other predictors) (Bollen, 1989).

We used standardized data because they are less affected by the scales of measurement and can be used to evaluate the relative impact of each predictor (Kline, 2010). Non-significant ($p > 0.05$) paths were removed from the model. Modification indices (*i.e*. chi-square tests with 1 *df*) were examined to test if any residuals were significantly correlated. Significant residual correlations considered theoretically relevant to our model were included in the final model. Last, we used a robust difference test to compare the magnitude of regression coefficients of the associations of each predictor with the different cognitive dimensions (Wald test of parameter equalities).

Rates of missing data ranged from 0.6% to 3.6% (Sentence Repetition and Number Knowledge) for neuropsychological measures and from 0.0% to 3.5% (score for cognitive stimulation at 5 years) for determinants of cognitive development. Missing data were handled using the Maximum Likelihood (ML) method (Schafer, 1997). Excluding individuals with missing data from our analyses did not alter the significance of our results.

We examined measures of goodness-of-fit, including the comparative fit index (CFI), the Tucker–Lewis index (TLI), the root mean squared error of approximation (RMSEA) and the chi-square test of model fit. CFI and TLI values greater than

Table 2
Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) of the neuropsychological tests.

	N = 1129 Mean (SD)	2-factor solution (EFA/GEOMIN)	
Neuropsychological Tests		F-1	F-2
Exploratory Factor Analysis (EFA)			
Nonword Repetition (NEPSY)	28.0 (8.1)	**0.602**	−0.003
Sentence Repetition (NEPSY)	15.4 (4.1)	**0.793**	−0.059
Information (WPPSI-III)	25.0 (3.0)	**0.777**	0.054
Vocabulary (WPPSI-III)	23.6 (5.7)	**0.768**	−0.092
Word Reasoning (WPPSI-III)	16.1 (4.7)	**0.821**	0.028
Block Design (WPPSI-III)	28.1 (3.7)	0.078	**0.658**
Matrix Reasoning (WPPSI-III)	15.4 (3.9)	0.177	**0.397**
Picture Concepts (WPPSI-III)	14.3 (3.9)	**0.233**	**0.351**
Design Copying (NEPSY)	41.1 (7.6)	−0.013	**0.643**
Number Knowledge (NKT-1)	7.0 (3.4)	**0.514**	**0.207**
Peg Moving Task 5¥	−28.2 (5.2)	−0.043	**0.384**
Confirmatory Factor Analysis (CFA)			
Nonword Repetition (NEPSY)	28.0 (8.1)	**0.553**	
Sentence Repetition (NEPSY)	15.4 (4.1)	**0.695**	
Information (WPPSI-III)	25.0 (3.0)	**0.825**	
Vocabulary (WPPSI-III)	23.6 (5.7)	**0.702**	
Word Reasoning (WPPSI-III)	16.1 (4.7)	**0.852**	
Block Design (WPPSI-III)	28.1 (3.7)	–	**0.686**
Matrix Reasoning (WPPSI-III)	15.4 (3.9)	–	**0.573**
Picture Concepts (WPPSI-III)	14.3 (3.9)	–	**0.512**
Design Copying (NEPSY)	41.1 (7.6)	–	**0.569**
Number Knowledge (NKT-1)	7.0 (3.4)	–	–
Peg Moving Task 5¥	−28.2 (5.2)	–	**0.313**

Footnotes: N = 1129.
Eigenvalues of EFA: 4.521 (1); 1.357 (2); 1.048 (3); 0.759 (4).
Loadings > 0.20 in bold.
¥ The sign of the time measure has been reversed.
Fit indices of EFA: Chi-Square Test of Model Fit = 51.4 (DF = 36; p = 0.0465); RMSEA = 0.019; CFI = 0.997; TFI = 0.993.
Fit indices of CFA: Chi-Square Test of Model Fit = 74.3 (DF = 33; p < 0.0001); RMSEA = 0.033; CFI = 0.991; TFI = 0.981.

0.95 and values of RMSEA less than 0.06 are commonly used to indicate good model fit and were used as cut-offs (Hooper, Coughlan, & Mullen, 2008).

Because these analyses were considered exploratory, we did not correct for multiple comparisons and the traditional alpha level of 0.05 was retained for all statistical tests. All analyses were conducted in Mplus Version 7.1 (Muthen & Muthen, 1998).

3. Results

Characteristics of the study population are described in Table 1. Of the 1129 children included, 53.3% were male, mean (SD) birth weight was 3.3 (0.5) kg, and mean gestational age was 39.3 (1.7) weeks (Table 1). The mean (SD) breastfeeding duration was 3.3 (3.7) months, the mean maternal age at delivery was 29.7 (SD = 4.7) and the mean number of older and younger siblings were respectively 0.8 (0.9) and 0.5 (0.6).

3.1. Structure of neuropsychological scores

The exploratory factor analysis of the 11 neuropsychological scores returned three factors with eigenvalues greater than 1. However, in the scree plot, the elbow was at two factors and the third factor was difficult to interpret (the third factor had only one salient loading corresponding to Nonword Repetition (NEPSY)). Consequently, the 2-factor solution was selected (see Table 2). To ensure a better interpretation of the factors, we did not allow cross loadings and decided to withdraw the Number Knowledge (NKT-1) test from our final model (because we expect this test to preferentially load on the nonverbal factor). The first latent variable, measured by Nonword Repetition (NEPSY), Sentence Repetition (NEPSY), Information (WPPSI-III), Vocabulary (WPPSI-III) and Word Reasoning (WPPSI-III) was labeled "Verbal Skills". The second latent variable, measured by Block Design (WPPSI-III), Matrix Reasoning (WPPSI-III), Picture Concepts (WPPSI-III), Design Copying (NEPSY) and Peg-moving task (PMT) tests was named "Nonverbal Skills". The 2-factor CFA model provided a very good fit to the data: CFI = 0.991, TLI = 0.981, RMSEA = 0.033 (0.023, 0.043) and Chi-Square Test of Model Fit = 74.3 (df = 33; p < 0.001). In a supplementary model (see Supplementary Table S1 and Fig. S1 in the online version at DOI: 10.1016/j.cogdev.2016.10.001), we used all of the relevant information present at the manifest variable level in the 2-factor CFA model, we allowed cross loadings (loading > 0.20) and we did not exclude any neuropsychological test. Similar results were found in this supplementary model.

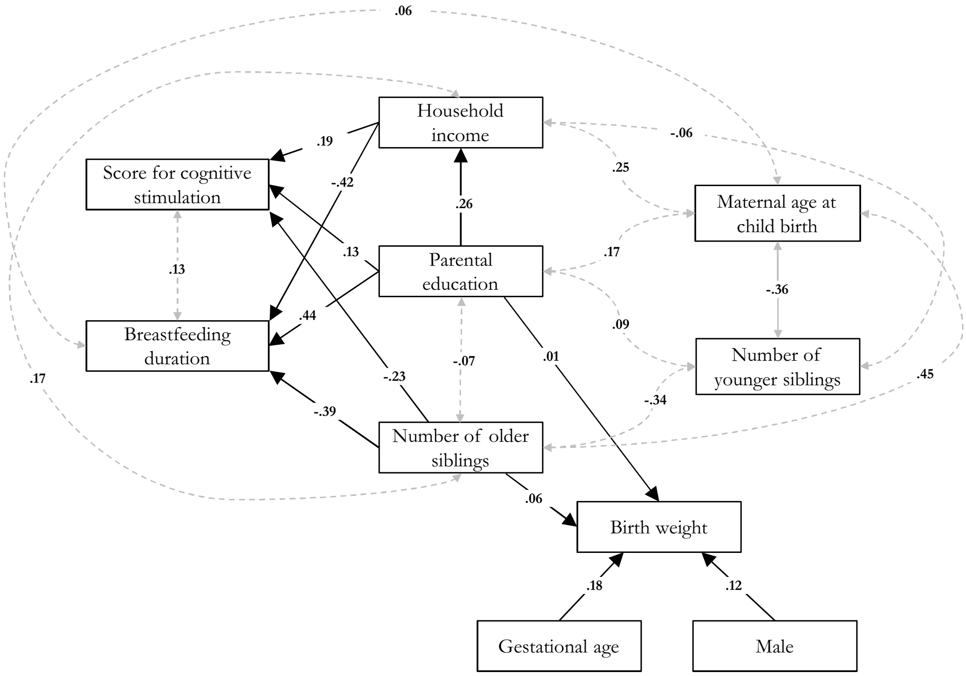

Fig. 1. The network of the relationships between all predictors. Single headed arrows represent direct effect (unstandardized coefficient are indicated). Double headed arrows indicate correlations. Figs. 1 and 2 *represent two parts of the same model.*

3.2. Structural equation model of verbal and nonverbal skills

As most neuropsychological measures were significantly associated with children's age at the time of testing and recruitment center (because of subtle differences in how tests were scored by the two psychologists), we adjusted for these variables in all analyses. Based on the examination of modification indices, we allowed a residual covariance between Nonword Repetition (NEPSY) and Sentence Repetition (NEPSY). This adjustment makes sense because both of these tests involved verbal short-term memory.

The network of the relationships between factors and the two cognitive dimension outcomes is shown in Figs. 1 and 2 (Figs. 1 and 2 and represent two parts of the same model). The final structural equation model shows a very good fit to the data: CFI = 0.972; TLI = 0.960; RMSEA = 0.032 (CI 95%: 0.028–0.037); Chi-Square Test of Model Fit = 327.3 (df = 150, $p < 0.001$) (Fig. 1 and 2). Our model explained respectively 19% and 13% of the variance of verbal and nonverbal skills respectively.

Lower scores for cognitive stimulation at 5–6 years, household income, breastfeeding duration, parental education, number of older siblings and gestational age significantly decreased verbal skills, independently from the effects of other predictors (Table 3). Lower scores for cognitive stimulation at 5–6 years, birth weight household income, parental education and greater number of younger siblings significantly also decreased nonverbal skills independently from the effects of other predictors. Furthermore, scores for cognitive stimulation at 5–6 years (total and direct effects: p = 0.037), number of older siblings (p = 0.014; p = 0.024) and breastfeeding duration (total and direct effects: p = 0.049) were significantly more strongly related to verbal than nonverbal skills (p-values of Wald tests of parameter equalities). Each point of the score for cognitive stimulation at 5–6 years (range: 5–32) increased verbal skills by 0.076 (0.015) and nonverbal skills by 0.045 (0.017) standard deviations. The variables "Breastfeeding duration" and "Number of older siblings" were significantly associated with the latent variable verbal skills only (both total and direct effects). Each month of breastfeeding increased verbal skills by 0.019 (0.008) standard deviations and did not affect nonverbal skills. Each older sibling decreased verbal skills by 0.131 (0.036) standard deviations and did not affect nonverbal skills. Each year of parental education increased verbal skills by 0.154 (0.014) and nonverbal skills by 0.126 (0.016) standard deviations (p-values of Wald tests of parameter equalities = 0.059). No test for differential effects on children's verbal and nonverbal skills was significant for indirect effects.

4. Discussion

Using the EDEN prospective mother-child cohort, we identified a broad range of factors, each predicting a unique share of variance in verbal and/or nonverbal skills in children aged 5–6 years. They include cognitive stimulation at 5–6 years, parental education, breastfeeding duration, birth weight, household income and number of older and younger siblings, and are largely consistent with previous studies. Our structural equation modeling results also suggest that, while many factors (such as birth weight or household income) have similar effects on verbal and nonverbal skills, some of them seem to have

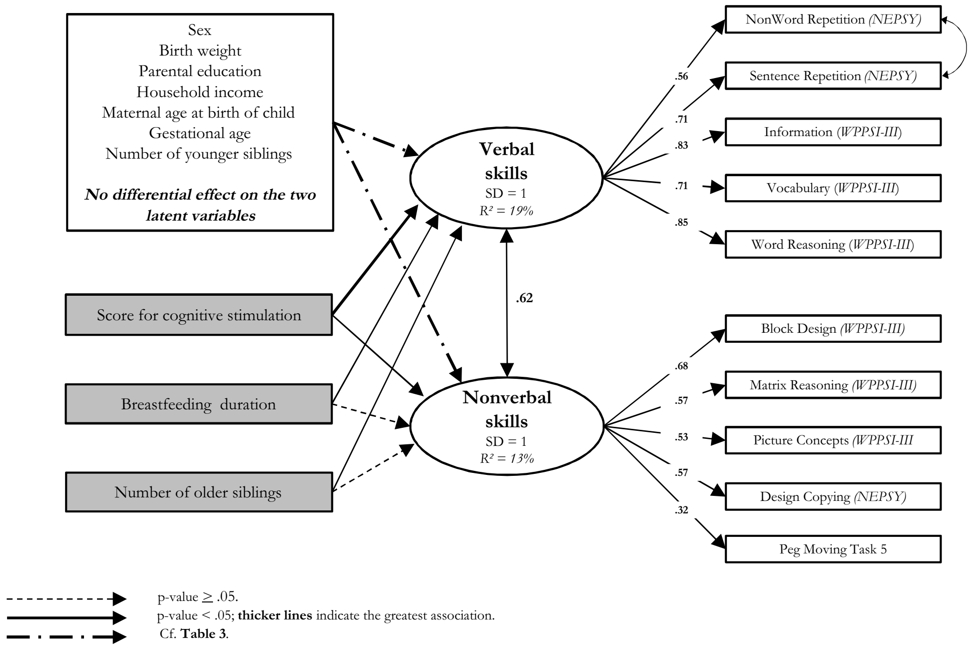

Fig. 2. Significant differential direct effects of predictors on latent variables representing verbal and nonverbal skills in a sample of 1126 children aged 5 to 6 years. Ellipses are used to denote latent constructs, rectangles are used to denote the observed variables. Variables in gray boxes have significant differential effects on the latent variables representing verbal and nonverbal skills. Figs. 1 and 2 *represent two parts of the same model.*

differential effects. Specifically, cognitive stimulation was significantly more strongly related to verbal than to nonverbal skills. Most strikingly, breastfeeding duration and the number of older siblings significantly influenced verbal skills only.

These results should be interpreted in the light of several limitations. First, although this study examined a wide range of predictors previously reported to be associated with cognitive ability in children, we did not have any estimate of genetic factors, and our coverage of environmental factors is of course incomplete, lacking in particular any information on cognitive stimulation outside the home. Nevertheless, our models explained respectively 19% and 13% of the variance in verbal and nonverbal skills, which is acceptable since the heritability of both verbal and nonverbal cognitive ability is thought to be 50% on average (Plomin & Deary, 2015), although this varies across levels of socioeconomic level (Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003). Second, our study examined predictors of verbal and nonverbal skills in children aged 5–6 years. The pattern of associations may of course differ for younger or older children. It is conceivable that more differential effects may emerge at later ages, together with greater expertise and specialization of cognitive functions. Conversely, it is also possible that fewer differential effects may be observed at later ages, if cognitive functions positively influence each other and therefore become more strongly correlated with each other through development (van der Maas et al., 2006). Similar investigations at later ages will be necessary to investigate these possibilities. Third, we focused on a limited number of robust cognitive constructs (verbal and nonverbal skills) rather than on very specific cognitive skills (such as visuospatial or memory skills). Future studies with larger test batteries should be able to test the differential effect question on a greater number of specific cognitive skills. Finally, neuropsychological tests load more strongly onto the verbal factor than the nonverbal factor, suggesting that the nonverbal factor may be less robust than the verbal factor. This may be true, however, this only affects the confidence intervals of the estimates of the regression parameters, not their magnitude. This generally reduces our statistical power to detect differential effects (which relies on the comparison of the estimates of regression parameter of verbal vs. nonverbal skills), but does not bias the outcome in favour of, say, verbal skills as opposed to nonverbal skills. Despite these limitations, our findings advance our knowledge of factors contributing to verbal and nonverbal skills in children.

First, as expected, many factors were found to have similar effects on verbal and nonverbal skills at 5–6 years of age. These include male sex (negative), birth weight (positive), household income (positive), maternal age (positive), gestational age (positive), and the number of younger siblings (positive). These associations are consistent with previous studies (Crosnoe et al., 2010; Eriksen et al., 2010; Shenkin, Starr, & Deary, 2004; Tong et al., 2007, 2007; Wallentin, 2009), except the positive association with the number of younger siblings which had rarely been examined in previous studies.

4.1. Home cognitive stimulation

We found that home cognitive stimulation was more strongly associated with verbal than nonverbal skills. Previous studies had suggested similar results, but these studies had not tested these differential effects in a statistically rigorous

Table 3
Differential effects of factors on Verbal and Nonverbal skills latent dimensions at 5 years (N = 1129) (Fig. 1 and 2).

TOTAL EFFECTS	a. Verbal skills			b. Non-verbal skills			Wald tests of parameter equalities (df = 1) a = b.
	Estimates(a)	SD(a)	p-value	Estimates(b)	SD(b)	p-value	p-value
TOTAL EFFECTS							
Male gender (% female)	−0.059	0.058	0.315	−0.035	0.069	0.609	ns
Birth weight (kg)	0.093	0.073	0.204	**0.185**	**0.085**	**0.030**	ns
HOME score at 5 years	**0.076**	**0.015**	**0.000**	**0.045**	**0.017**	**0.009**	**0.0368**
Breastfeeding duration (months)	**0.019**	**0.008**	**0.024**	0.002	0.010	0.833	**0.0492**
Parental education (years)	**0.154**	**0.014**	**0.000**	**0.126**	**0.016**	**0.000**	0.0593
Household income (k€/months)	**0.094**	**0.040**	**0.018**	**0.146**	**0.046**	**0.002**	ns
Maternal age at birth of child (years)	0.012	0.007	0.097	0.003	0.009	0.690	ns
Gestational age (weeks)	**0.034**	**0.017**	**0.046**	0.036	0.020	0.068	ns
Number of older siblings	**−0.131**	**0.036**	**0.000**	−0.039	0.042	0.347	**0.0135**
Number of younger siblings	0.035	0.055	0.523	**0.133**	**0.064**	**0.041**	ns
DIRECT EFFECTS							
Male gender (% female)	−0.070	0.059	0.236	−0.058	0.068	0.405	ns
Birth weight (kg)	0.093	0.073	0.204	**0.185**	**0.085**	**0.030**	ns
HOME score at 5 years	**0.076**	**0.015**	**0.000**	**0.045**	**0.017**	**0.009**	**0.0368**
Breastfeeding duration (months)	**0.019**	**0.008**	**0.024**	0.002	0.010	0.833	**0.0492**
Parental education (years)	**0.110**	**0.017**	**0.000**	**0.080**	**0.016**	**0.000**	0.0787
Household income (k€/months)	**0.088**	**0.039**	**0.026**	**0.138**	**0.045**	**0.003**	ns
Maternal age at birth of child (years)	0.012	0.007	0.097	0.003	0.009	0.690	ns
Gestational age (weeks)	0.017	0.021	0.415	0.003	0.020	0.892	ns
Number of older siblings	**−0.126**	**0.037**	**0.001**	−0.042	0.042	0.328	**0.0241**
Number of younger siblings	0.035	0.055	0.523	**0.133**	**0.064**	**0.041**	ns
INDIRECT EFFECTS							
Male gender (% female)	0.011	0.009	0.218	**0.023**	**0.011**	**0.046**	ns
Birth weight (kg)	0.000	N/A	N/A	0.000	N/A	N/A	ns
HOME score at 5 years	0.000	N/A	N/A	0.000	N/A	N/A	ns
Breastfeeding duration (months)	0.000	N/A	N/A	0.000	N/A	N/A	ns
Parental education (years)	**0.045**	**0.011**	**0.000**	**0.047**	**0.013**	**0.000**	ns
Household income (k€/months)	0.006	0.009	0.466	0.008	0.007	0.261	ns
Maternal age at birth of child (years)	0.000	N/A	N/A	0.000	N/A	N/A	ns
Gestational age (weeks)	0.017	0.013	0.205	**0.033**	**0.015**	**0.031**	ns
Number of older siblings	−0.004	0.009	0.644	0.002	0.009	0.796	ns
Number of younger siblings	0.000	N/A	N/A	0.000	N/A	N/A	ns

Fit indices: RMSEA = 0.032 (IC 95%: 0.028–0.037); CFI = 0.972; TLI = 0.960; Chi-Square Test of Model Fit = 327.3 (*df* = 150).
In bold $p < 0.05$. ns = non significant at $p < 0.05$. N/A = Non Applicable.
All regression coefficients are standardized and adjusted for recruiting center and child's age.

manner (Eriksen et al., 2013; Sommerfelt et al., 1995). The differential effect found in our study now establishes with much greater confidence the greater impact of the child's cognitive environment on verbal than on nonverbal skills. During the developmental period, language may be the cognitive function which is the most sensitive to the cognitive stimulation in the home. Parent's language complexity (total number of words spoken in the home, phonological and syntactic skills) is a well-known predictor of children's verbal skills (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010). The development of non-verbal skills (i.e., nonverbal concept formation, visual perception and organization, visual-motor coordination) is also influenced by home cognitive stimulation but to a lesser extended than for verbal skills, probably because children rely less on their parents to develop their nonverbal skills (in activities such as playing with dolls, cars, puzzles) than their verbal skills."

4.2. Breastfeeding duration

Some earlier studies reported a significant association of breastfeeding duration with verbal IQ only (Gustafsson et al., 2004; Horwood et al., 2001; Oddy et al., 2003). We also found an association between breastfeeding duration exclusively with verbal skills, and breastfeeding duration was significantly more associated with verbal than nonverbal skills. The interpretation of the effects of breastfeeding on cognitive development remains debated. Interpretations implicate nutritional mechanisms, but also social/affective mechanisms (Doyle, Rickards, Kelly, Ford, & Callanan, 1992). No component of human milk known to be involved in the brain's maturation has been reported to specifically promote language-related brain areas (e.g., long-chain poly-unsaturated fatty acids are ubiquitous components of neuron's membranes; German, 2011). Thus, our finding of a selective effect on verbal skills seems more compatible with a social/affective mediation of that effect (such as a greater availability of the mother for his/her child among mothers who breastfed for longer duration; Murtagh & Moulton, 2011). This issue nevertheless remains to be further explored, as well as the potential mediating factors.

4.3. Number of older siblings

This study is the first to our knowledge to show that the number of older siblings is more strongly negatively associated with verbal than with nonverbal skills. The study of Kristensen et al. (Kristensen & Bjerkedal, 2007) provided evidence that the relation between birth order and IQ scores is dependent on the actual rank in the family and not on birth order per se. The fact that older siblings seem to have a negative effect on the younger sibling's language development runs against the belief that older siblings increase the cognitive stimulation of the child. However, the key mechanism may be that, the greater the number of older siblings, the less undivided attention of the parents the child receives in the first years. Thus, the cognitive environment provided by the parents may be again one mediating mechanism of the older sibling effect (as suggested by the negative association between the two variables, cf. Fig. 1).

The relationships between the number of older siblings and verbal skills as well as between breastfeeding duration and verbal skills may actually be mediated by aspects of the child's cognitive environment that were not otherwise captured by the proximal variables included in our model (in particular, our measure of cognitive stimulation) (Walfisch, Sermer, Cressman, & Koren, 2013). This hypothesis is supported by the fact that the direction of the differential effects (a greater association with verbal than with nonverbal skills) of breastfeeding duration and the number of older siblings were similar to the direction of the differential effects of factors shown to influence the cognitive environment of the child (*i.e.*, the score for cognitive stimulation). Future studies comparing siblings brought up in the same family may be useful for controlling for the cognitive environment of the child and address this issue.

4.4. Parental education

Parental education tended to be more strongly associated with verbal than nonverbal. These effects are relatively straightforward to interpret, parental education being a distal factor influencing a range of proximal factors, such that the child's learning environment, which is likely to be predominantly mediated verbally by parents. The fact that parental education has a direct effect on cognitive skills that is not captured by the proximal factors already in the model suggests again that the measure of cognitive stimulation, as well as other proximal measures in this study, do not exhaust all the relevant aspects of the cognitive environment.

4.5. Birth weight

Against previous findings by Sommerfelt et al. (1995), we found that birth weight was not significantly more associated with nonverbal than with verbal skills, although birth weight was significantly associated to the latent variable nonverbal skills only. Our study may have lacked power to detect this differential effect; indeed, the ratio of the two regression parameters was relatively high (nonverbal/verbal = 2.0), suggesting a substantial differential effect. By what mechanism might birth weight have differential cognitive effects? One possibility is for instance that neurotrophic stress may primarily affect later maturing brain regions (*e.g.* the frontal lobes). However, it is also important to consider that birth weight may not have a causal effect on cognitive measures and may rather be considered as a proxy for other factors such as nicotine consumption during pregnancy or maternal nutrition during pregnancy. Future studies conducted on larger samples likely to include greater number of children with low birth weight (solely 5.5% of the children had a low birth weight (< 2.5 kg) in our study) are needed to confirm our findings and determine how birth weight may impact differentially verbal and nonverbal skills.

In conclusion, by using a latent variable approach which allows testing for differential effect of specific factor on specific cognitive skills in a large mother-child cohort, we have provided evidence that, although many broad environmental factors exert broad effects on both verbal and nonverbal skills in children aged 5–6 years, some factors (home cognitive stimulation, breastfeeding duration, and number of older siblings) show differential effects, *i.e.*, greater effects on verbal than on nonverbal skills.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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