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Sex differences in psychomotor development during the preschool period: A longitudinal study of the effects of environmental factors and of emotional, behavioral, and social functioning

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ABSTRACT

We sought to determine the extent to which sex differences in psychomotor development during the preschool period can be explained by differential exposure to environmental factors and/or differences in emotional, behavioral, or social functioning. Children from the EDEN mother–child cohort were assessed for language, gross motor, and fine motor skills at 2, 3, and 5–6 years of age using parental questionnaires and neuropsychological tests. Structural equation models examining the associations between sex and language, gross motor, and fine motor skills at 2, 3, and 5–6 years were performed while adjusting for a broad range of pre- and postnatal environmental factors as well as emotional, behavioral and socialization difficulties. Girls ($n = 492$) showed better fine motor skills than boys ($n = 563$) at 2 years (Cohen's

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d = 0.67 in the fully adjusted models), at 3 years (d = 0.72), and to a lesser extent at 5–6 years (d = 0.29). Girls also showed better language skills at 2 years (d = 0.36) and 3 years (d = 0.37) but not at 5–6 years (d = 0.04). We found no significant differences between girls and boys in gross motor skills at 2, 3, or 5–6 years. Similar results were found in the models unadjusted and adjusted for pre- and postnatal environmental factors as well as emotional, behavioral, and socialization difficulties. Our findings are consistent with the idea that sex differences in fine motor and language skills at 2 and 3 years of age are not explained by differential exposure to environmental factors or by sex differences in emotional, behavioral, or social functioning.

Introduction

Prior research suggests significant sex differences in psychomotor development, albeit of small magnitude and with substantial heterogeneity (Halpern, 2013). Girls have earlier development (Eriksson et al., 2012) and better language skills than boys in most linguistic domains (phonology, lexicon, and syntax) that may disappear between 3 years (Toivainen, Papageorgiou, Tosto, & Kovas, 2017) and 5 years (Bornstein, Hahn, & Haynes, 2004) of age. Girls have also been found to display greater fine motor skills (Flatters, Hill, Williams, Barber, & Mon-Williams, 2014; Junaid & Fellowes, 2006)—that is, activities requiring a high degree of precision and typically involving manual manipulation of objects (Malina, Bouchard, & Bar-Or, 2004)—until 4 years of age (Toivainen et al., 2017) or even later (6–7 years in Flatters et al., 2014). No clear picture emerges from studies on sex differences in gross motor skills—that is, activities involving locomotion and movement of the torso (Malina et al., 2004)—during the preschool period (Nelson, Thomas, Nelson, & Abraham, 1986).

Based on the Twins Early Development Study (TEDS), Toivainen et al. (2017) argued that sex differences in language skills at 2–4 years of age may reflect sex differences in cognitive development, as indicated by measures in nonverbal domains using the Parental Report of Children's Ability that captures fine motor skills and other cognitive dimensions such as nonverbal intelligence (Saudino et al., 1998). Based on the same cohort, Galsworthy, Dionne, Dale, and Plomin (2000) reported that opposite-sex dizygotic (DZ) twins experienced larger differences in verbal skills than same-sex DZ twins, which was not observed for nonverbal skills. They concluded that individual differences in verbal ability partly depend on some sex-specific factors.

Three main hypotheses related to environmental, behavioral, and biological factors have been proposed to explain these early sex differences in psychomotor development. First, differential exposure to environmental factors known to influence psychomotor development may contribute to explain sex differences in psychomotor development (i.e., the *environmental* hypothesis). Differential exposures between boys and girls may include (a) life experiences in relation to gender role stereotypes (Bornstein, 2012; Leaper, Anderson, & Sanders, 1998; Suizzo & Bornstein, 2006) and (b) childbirth complications that are more prevalent in boys, possibly due to their greater body height and weight compared with girls (Eliot, 2010). Nevertheless, no study has fully explained sex differences in early psychomotor development during the preschool period by differential exposure to environmental factors. In a study conducted among 13,783 European children, Eriksson et al. (2012) reported that sex differences in language skills, assessed using the MacArthur–Bates Communicative Development Inventories, remained consistent in 10 non-English-language communities, suggesting that sex differences in cognitive development might not be explained by cultural factors. Finally, few longitudinal studies have used neuropsychological tests to examine sex differences in psychomotor skills (e.g., Bornstein et al., 2004; Lingam, Hunt, Golding, Jongmans, & Emond, 2009). This limitation is noteworthy because parents' responses to questionnaires may be influenced by gender stereotypes (Mondschein, Adolph, & Tamis-LeMonda, 2000).

Second, sex differences in emotional, behavioral, or social functioning might contribute to sex differences in psychomotor development during the preschool period (i.e., the *behavioral* hypothesis). Several studies consistently support sex differences in emotional, behavioral, or social functioning during childhood (Rutter, 2010). Boys exhibit more behavioral and social problems (Eliot, 2010; Gimpel, Peacock, & Holland, 2003), and neurodevelopmental disorders (autism spectrum disorder, attention deficit/hyperactivity disorder, intellectual disability, development coordination disorder, and other specific acquisition and learning disorders) are much more prevalent in boys than in girls (American Psychiatric Association, 2013). To date, no previous study has been able to conclusively support or reject the hypothesis that sex differences in emotional, behavioral, or social functioning could contribute to explain sex differences in early psychomotor development.

Third, biological differences might underlie the advantage in psychomotor skills observed in girls compared with boys during the preschool period such as the negative effect of testosterone on brain development (Knickmeyer & Baron-Cohen, 2006).

In the current study, we sought to determine the extent to which sex differences in psychomotor development during the preschool period can be explained by differential exposure to environmental factors (environmental hypothesis). We collected several environmental and perinatal factors such as child's cognitive stimulation at home, gestational age, and birth weight and other environmental predictors of psychomotor development that may differ between the sexes (e.g., smoking status and alcohol consumption during pregnancy, breastfeeding, etc.). We also aimed to determine whether sex differences in psychomotor development during the preschool period can be explained by sex differences in emotional, behavioral, or social functioning (behavioral hypothesis). The biological hypothesis could not be directly tested in our study and, therefore, was considered as an alternative hypothesis to the two other hypotheses. We used data from a large prospective mother–child cohort in which psychomotor development was assessed using both parental questionnaires and neuropsychological tests at 2, 3, and 5–6 years of age. Based on prior findings, we hypothesized that (a) girls might present with greater language and fine motor skills at 2 and 3 years, and to a lesser extent at 5–6 years, compared with boys and that (b) boys and girls may have similar performances in gross motor skills. Moreover, we hypothesized that (c) sex differences in exposure to environmental and perinatal factors, as well as sex differences in emotional, behavioral, or social functioning, might at least partly explain sex differences in psychomotor development during the preschool period.

Method

Study design

We used data from the EDEN mother–child cohort study (Heude et al., 2016), the primary aim of which is to identify prenatal and early postnatal nutritional, environmental and social determinants of children's health and development. Participants were recruited between 2003 and 2006 among pregnant women followed in Poitiers and Nancy university maternities in France. Exclusion criteria included history of diabetes, twin pregnancies, intention to deliver outside the university hospital or to move out of the study region within the next 3 years, and inability to speak French. Compared with the National Perinatal Survey (ENP) carried out among 14,482 women who delivered in France in 2003 (Blondel, Supernant, Du Mazaubrun, & Bréart, 2006), women participating in the EDEN study ($N = 2002$) had similar sociodemographic characteristics except for higher educational background (53.6% had a high school diploma vs. 42.6% in the ENP) and higher employment level (73.1% were employed during pregnancy vs. 66.0% in the ENP) (Drouillet et al., 2009; Heude et al., 2016). 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 newborns after delivery.

Participants

Among the 2002 pregnant women included in the EDEN study, 1907 children were born in the cohort, as described in detail elsewhere (Heude et al., 2016). The attrition rate of children at 5 years of age was 39%. At 2 years of age, 1772 children were assessed using parental questionnaires, the Brunet–Lezine Psychomotor Development Scale, and/or the MacArthur–Bates Communicative Development Inventory (CDI-2) (see flowchart in Fig. 1). Among these 1772 children, 1261 were assessed using the Ages and Stages Questionnaire (ASQ) and/or at least one neuropsychological test at 3 years of age and 1055 were assessed using the ASQ and/or at least one neuropsychological test at 5–6 years of age. Compared with children who were assessed at 2 years but not at 5–6 years ($n = 717$), the children included in our analyses significantly differed in predictors of psychomotor development (e.g., children included in our analyses had lower family income and level of parental education (both p values < .001) than those not included in our analyses), but not in terms of sex ($p = .40$). This differential attrition was found in both girls and boys.

Measures

Psychomotor development

At 2, 3, and 5–6 years of age, children were assessed with parental questionnaires and neuropsychological tests examining language, fine motor, and gross motor skills.

Age 2 years. Parental questionnaires. The main developmental milestones of language, fine motor, and gross motor skills at 2 years of age were assessed using a parental questionnaire derived from the Brunet–Lézine Psychomotor Development Scale (Josse, 1997). This scale is widely used in France by both clinicians and researchers (Fily et al., 2006; Peyre et al., 2017) to assess cognitive development during the first 2 years. It was validated on a sample of 1032 French children between 1994 and

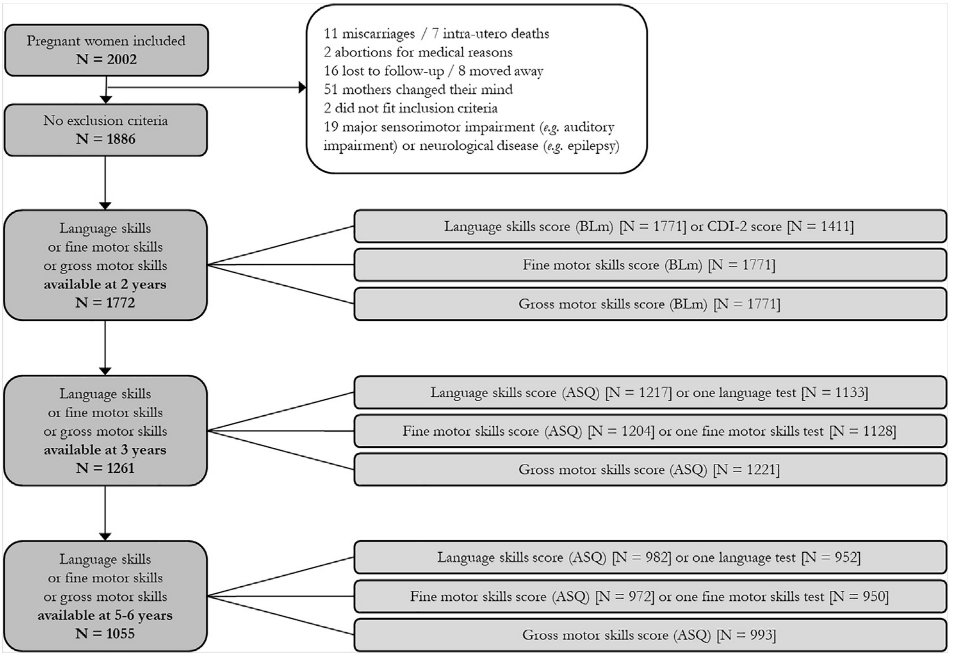


Fig. 1. Flowchart. CDI-2, MacArthur–Bates Communicative Development Inventory at 2 years; BLm, parental questionnaire derived from the Brunet–Lézine Psychomotor Development Scale; ASQ, Ages and Stages Questionnaire.

1996 (Josse, 1997). Questions were in the form of “Does your child do X?” with only yes/no responses (e.g., “Does your child eat independently with a spoon?”). In total, 36 questions were completed by parents at 2 years with regard to gross motor skills (8 questions), fine motor skills (14 questions), and language skills (14 questions). Scores were calculated as the sum of all questions from each cognitive domain.

At 2 years of age, parents completed the short French version of the CDI-2 (Kern, 2003; Kern, Langue, Zesiger, & Bovet, 2010; Peyre et al., 2014). Parents were asked to indicate which words from a list of 100 words their children could say spontaneously (expressive vocabulary). A child’s score was the sum of the words produced by him or her. Psychometric properties of the CDI-2 have been examined by Kern et al. (2010), showing high test–retest reliability and strong associations with the corresponding scores from the complete version (Kern et al., 2010).

Ages 3 and 5–6 years. Parental questionnaire. Development was investigated at 3 and 5–6 years of age with the second French edition of the ASQ (Squires & Bricker, 2009). This is a parent-completed assessment that includes five domains of development (communication, gross motor, fine motor, problem solving, and personal–social), with six questions in each domain. For each question, there is a choice of three responses—“yes,” “sometimes,” and “not yet”—that are scored as 10, 5, and 0, respectively. Although the ASQ is a screening tool created to diagnose developmental delays, its use as a continuous score has been considered in epidemiological studies (Troude, Squires, L’Hélias, Bouyer, & de La Rochebrochard, 2011).

Neuropsychological tests. Trained psychologists in the two recruiting centers assessed each child’s cognitive skills at 3 years of age (M = 38.0 months, SD = 0.8) and at 5–6 years of age (M = 67.8 months, SD = 1.8).

Regarding language skills, the following were used to assess children at 3 years of age:

- *Semantic fluency* (from the ELOLA [*Evaluation du Langage Oral de L’enfant Aphasique*] battery; De Agostini et al., 1998), scored as the sum of the number of animals named in 1 min plus the number of objects named in 1 min. This test is designed to measure expressive vocabulary and lexical retrieval.
- *Word and nonword repetition* (ELOLA), scored as the number of words (6 items) and nonwords (6 items) repeated correctly. This test is designed to measure phonological processing and verbal short-term memory.
- *Sentence repetition* (from the NEPSY [NEuroPSYchological assessment] battery; Kemp, Kirk, & Korkman, 2001; Korkman, Kirk, & Kemp, 2003), scored as the number of sentences of increasing complexity and length repeated correctly (17 items; e.g., “dors bien” [sleep well]). This test is designed to measure verbal short-term memory and syntactic skills.
- *Picture naming* (ELOLA), scored as the number of pictures named correctly (10 items; e.g., “cheval” [horse]). This test is designed to measure expressive vocabulary.
- *Comprehension of instructions* (NEPSY), a sentence comprehension task scored as the number of correct answers by pointing at one of eight pictures (13 items; e.g., “Montre-moi un grand lapin” [Show me a large rabbit]). This subtest is designed to assess the ability to receive, process, and execute oral instructions of increasing syntactic complexity.

Regarding language skills, the following were used to assess children at 5–6 years of age:

- *Nonword repetition* (NEPSY), scored as the number of syllables repeated correctly (out of 46 in 13 nonwords; e.g., [kiutsa], a nonword with two syllables). This test is designed to measure phonological processing and verbal short-term memory.
- *Sentence repetition* (NEPSY), scored as the number of sentences repeated correctly (17 items; e.g., “dors bien” [sleep well]). This test is designed to measure syntactic skills and verbal short-term memory.

- *Information* (from the Wechsler Preschool and Primary Scale of Intelligence–Third Edition [WPPSI-III] battery; Peyre, Bernard, et al., 2016; Wechsler, 2002), 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.
- *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.
- *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.
- *Full scale IQ* (FSIQ) (WPPSI-III).

Regarding fine motor skills, the following were used to assess children at 3 and 5–6 years of age:

- *Peg-moving task* (PMT-5) has been widely used to study hand skills and visual–motor coordination (Annett, 1985; Curt, De Agostini, Maccario, & Dellatolas, 1995; Nunes et al., 2008). After a demonstration by the examiner, children needed to move five pegs, one by one, to the hole in the opposite row. Each hand performed two trials, one trial from the nearest row to the farthest one and one trial from the farthest row to the nearest one. The task started with the preferred hand, then the participant needed to perform two trials with the nonpreferred hand, and the task finished with a trial with the preferred hand. The peg-moving task was scored as the total time for the two trials for each hand.
- *Design-copying task* (NEPSY) (Kemp et al., 2001; Korkman et al., 2003), scored as the number of designs correctly copied (18 items; each item rated from 0 to 4). The designs progressively increase in complexity (vertical line, horizontal line, circle, etc.).

Environmental predictors of psychomotor development

Sex, gestational age and birth weight were collected from obstetrical records.

At child's ages 2 and 3 years, maternal cognitive stimulation of the child at home was assessed by a questionnaire completed by the mother and evaluating the weekly frequency of eight activities (e.g., storytelling, singing, drawing). At child's age 5–6 years, 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 (HOME) scale: language stimulation, academic stimulation, and variety of experimentations (Caldwell & Bradley, 1984; Frankenburg & Coons, 1986). Higher scores represent greater cognitive stimulation and emotional support.

Other environmental predictors of psychomotor development that may differ between sexes were also collected. Smoking status and alcohol consumption during pregnancy (units/week) were determined from the questionnaires completed by the mother during pregnancy and at delivery. Mothers completed questionnaires on partial or exclusive breastfeeding (breastfeeding initiation) (Bernard et al., 2017). Both parents completed questionnaires on their age at child's birth, family income, and education level. The average level of parental education and the household income (thousands of euros [k€]/month) were used in the analyses. The number of older siblings and the age at school entry were also retrieved. We assessed maternal depression after birth with the Edinburgh Postnatal Depression Scale at 4, 8, and 12 months (a cutoff of 13 was used to define depression; Adouard, Glangeaud-Freudenthal, & Golse, 2005; Teissedre & Chabrol, 2004) and with the Center for Epidemiologic Studies–Depression (CES-D) scale at 3 and 5 years of age following delivery (a cutoff of 16 was used to define depression; Hann, Winter, & Jacobsen, 1999; Morin et al., 2011). Mothers and fathers completed questionnaires (one about language delay and the other about expressive language impairment during childhood) on history of speech and language delay.

Emotional and behavioral problems assessment

The Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997; Peyre, Ramus, et al., 2016; Shojaei, Wazana, Pitrou, & Kovess, 2009) was used to measure emotional and behavioral problems when children were 3 and 5–6 years of age. The SDQ is a 25-item scale comprising five scores covering emotional problems (fears, worries, misery, nervousness, and somatic symptoms), conduct problems (tantrums, obedience, fighting, lying, and stealing), inattention/hyperactivity symptoms (restlessness, fidgeting, ability to concentrate, distractibility, and impulsivity), peer relationships (popularity, victimization, isolation, friendship, and ability to relate to children as compared with adults), and prosocial behavior (consideration of others, ability to share, kindness to younger children, helpfulness to other children when distressed, and willingness to comfort others). Answer options for each item are "not true," "somewhat true," and "very true"—scored 0, 1, and 2, respectively, yielding a total score ranging from 0 to 10 for each subscale. Higher scores represent worse functioning problems except for prosocial behavior. The five-factor structure of the SDQ at 3 and 5–6 years has been supported by some studies (Croft, Stride, Maughan, & Rowe, 2015) but not all studies (Stochl, Prady, Andrews, Pickett, & Croudace, 2016). In the current data, Cronbach's alphas for each SDQ scale at 3 and 5–6 years, respectively, were as follows: .55 and .60 for emotional symptoms, .69 and .73 for conduct problems, .70 and .76 for inattention/hyperactivity symptoms, .48 and .54 for peer relationship problems, and .60 and .69 for prosocial behavior. These reliability estimates were similar to those found in a representative sample of 1348 French children aged 6–11 years (Shojaei et al., 2009).

Statistical analysis

We performed structural equation models (SEMs) to test our main hypotheses. SEMs offer the double advantage of summarizing multiple correlations across predictors and representing broad pathways underlying the associations between environmental and behavioral factors and psychomotor development.

We used confirmatory factor analysis (CFA) to determine whether a single-factor structure for each of the two cognitive domains, language skills and fine motor skills, fit the underlying structure of positively correlated individual measures of language skills and fine motor skills, respectively, in both sexes and at each time point (i.e., at 2, 3, and 5–6 years). 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 .95 and RMSEA values less than .06 are commonly used to indicate good model fit (Muthén & Muthén, 2012).

Next, we used longitudinal SEMs to determine whether there are sex differences in the scores of the three cognitive domains (i.e., language, fine motor, and gross motor skills) across the three time points (i.e., at 2, 3, and 5–6 years). The effect sizes of the association of sex with each cognitive domain (at each time point) were estimated using Cohen's *d* (Cohen, 2013). For each SEM, we used successively three sets of adjustments. First, measures of psychomotor development at 2, 3, and 5–6 years were adjusted for child's age at examination and the study center. Second, measures of psychomotor development were also adjusted for the pre- and postnatal environmental factors: alcohol and tobacco during pregnancy, birth weight and gestational age, maternal and paternal age at childbirth, parental education, household income, birth rank, breastfeeding initiation (i.e., ever breastfed; Girard et al., 2016), age of schooling, frequency of maternal stimulation at 2 and 3 years and HOME score at 5–6 years, maternal depression at 4, 8, and 12 months and at 3 and 5–6 years, and family history of language delay. Third, we also adjusted for the five SDQ subscores at 3 years (for the measures of psychomotor skills at 3 years) and 5–6 years (for the measures of psychomotor skills at 5–6 years): SDQ emotional symptoms, SDQ conduct problems, SDQ inattention/hyperactivity symptoms, SDQ peer relationship problems, and SDQ prosocial behavior. In all models, environmental factors were included as adjustment variables only if they occur before the measure of psychomotor skills (e.g., language skills at 2 years were not adjusted for variables measuring the frequency of maternal stimulation at 3 years) to respect the prospective design.

There were few missing data on parental questionnaires and neuropsychological tests (8.8%, *SD* = 6.0) and on predictors of psychomotor development (3.6%, *SD* = 5.7). Missing data were imputed using multiple imputation (Donders, van der Heijden, Stijnen, & Moons, 2006; Peyre, Leplège, & Coste, 2011) in SEMs.

Because of the relatively large sample size, and to reduce Type 1 error inflation due to multiple testing (we planned to perform 24 tests: 6 at 2 years, 9 at 3 years, and 9 at 5–6 years), we a priori set the alpha threshold at .001. Under these conditions, the sample under study provided power of 78% to detect an effect size of .25. All analyses that included latent variables (CFA and SEM) were conducted in Mplus Version 7.2 with the maximum likelihood estimator (Muthén & Muthén, 2007). All other analyses were performed using SAS 9.4 software (SAS Institute, Cary, NC, USA).

Complementary analyses

To examine the robustness of our results, we performed SEM analyses on children with FSIQs $\geq$ 85 (by excluding children with FSIQs < 85, who may be at risk for neurodevelopmental disorder).

Results

About 43% of the children were male ($n = 563$). Among the pre- and postnatal environmental factors, only birth weight significantly differed by sex (boys: 3.36 kg, $SD = 0.50$; girls: 3.23 kg, $SD = 0.49$) (Table 1). Compared with boys, girls had a lower SDQ conduct problems score (Cohen's d [girls – boys] = −0.13) and SDQ inattention/hyperactivity symptoms score ($d = -0.10$) at 5–6 years but had a higher SDQ emotional symptoms score ($d = 0.16$) at 3 years and a higher SDQ prosocial behavior score ($d = 0.17$) at 5–6 years (Table 2).

The models (CFA) of the factor structures of language skills (CFI = .92, TLI = .90, RMSEA = .062) and fine motor skills (CFI = .97, TLI = .94, RMSEA = .034) provided an acceptable fit to the data in both sexes and at each time point (see Supplementary Figs. 1 and 2 in online supplementary material).

SEMs also showed a good fit to the data (SEM adjusted only for age at examination and center: CFI = .93, TLI = .90, RMSEA = .048; SEM adjusted for pre- and postnatal environmental factors, SDQ scores, age at examination, and center: CFI = .99, TLI = .99, RMSEA = .039).

In the SEM adjusted only for age at examination and center, girls ($n = 492$) showed significantly greater fine motor skills than boys at 2 and 3 years of age ($ds = 0.66$ and 0.70, respectively,

Table 1
Summary statistics of pre- and postnatal environmental factors by sex in participants from the EDEN cohort.

	Boys ($n = 563$)	Girls ($n = 492$)	p value
Alcohol during pregnancy (units/week)	0.51 (1.11)	0.56 (1.72)	.521
Tobacco during pregnancy, %	20.3	18.9	.584
Birth weight (kg)	3.36 (0.50)	3.23 (0.49)	<.001
Gestational age (weeks)	39.3 (1.7)	39.2 (1.7)	.783
Maternal age at birth of child (years)	29.6 (4.5)	29.7 (4.7)	.951
Paternal age at birth of child (years)	32.1 (5.4)	32.5 (5.7)	.270
Parental education (years)	13.8 (2.3)	13.7 (2.3)	.553
First-born, %	53.7	49.7	.191
Household income (k€/month)	2.86 (0.98)	2.77 (0.98)	.833
Ever breastfed, %	71.6	72.6	.724
Age of schooling (months)	36.4 (5.2)	36.4 (5.0)	.917
Frequency of maternal stimulation at 2 years[a]	3.32 (0.51)	3.33 (0.46)	.756
Frequency of maternal stimulation at 3 years[a]	2.71 (0.61)	2.75 (0.60)	.301
HOME score at 5–6 years	17.3 (2.2)	17.3 (2.3)	.886
HOME language stimulation	6.4 (0.8)	6.3 (0.8)	.420
HOME academic stimulation	3.4 (1.2)	3.5 (1.2)	.335
HOME variety of experimentations	7.5 (1.2)	7.5 (1.2)	.870
Maternal depression at 4 months, %	7.1	7.6	.790
Maternal depression at 8 months, %	6.9	8.1	.470
Maternal depression at 12 months, %	6.1	9.2	.065
Maternal depression at 3 years, %	16.0	20.3	.071
Maternal depression at 5–6 years, %	13.6	14.6	.648
Family history of language delay, %	12.4	11.2	.531
Study center (Poitiers), %	58.3	50.6	.013

Note. Values are means (and standard deviations) except percentages (%). k€, thousands of euros; HOME, Home Observation for the Measurement of the Environment.

[a] On a scale of 1 (*shared activities less than once per week*) to 5 (*shared activities nearly every day*).

Table 2
Summary statistics of cognitive development by sex in children from the EDEN cohort.

Cognitive variables	Boys (*n* = 563)	Girls (*n* = 492)	Girls – Boys Cohen's *d*	*p* value
Parental questionnaires				
2 years				
Language skills (BLm)	0.73 (0.22)	0.80 (0.19)	0.31 (0.06)	<.001
Fine motor skills (BLm)	0.67 (0.10)	0.75 (0.11)	0.65 (0.07)	<.001
Gross motor skills (BLm)	0.78 (0.15)	0.78 (0.15)	0.05 (0.07)	.395
CDI-2	57.4 (30.1)	66.5 (28.0)	0.31 (0.06)	<.001
3 years				
Language skills (ASQ)	55.7 (7.5)	56.9 (5.6)	0.20 (0.07)	.005
Fine motor skills (ASQ)	49.6 (12.8)	54.6 (8.8)	0.55 (0.08)	<.001
Gross motor skills (ASQ)	55.3 (7.4)	55.1 (7.6)	−0.02 (0.06)	.734
Emotional symptoms score (SDQ)	6.59 (1.54)	7.00 (1.66)	0.16 (0.04)	<.001
Conduct problems score (SDQ)	6.31 (2.08)	5.98 (1.94)	−0.09 (0.03)	.007
Inattention/hyperactivity symptoms score (SDQ)	4.58 (2.27)	4.22 (2.23)	−0.07 (0.03)	.009
Peer relationship problems score (SDQ)	2.48 (1.53)	2.41 (1.41)	−0.03 (0.04)	.483
Prosocial behavior score (SDQ)	12.59 (1.68)	12.85 (1.63)	0.09 (0.04)	.023
5–6 years				
Language skills (ASQ)	54.9 (7.0)	56.3 (5.5)	0.26 (0.07)	<.001
Fine motor skills (ASQ)	57.5 (4.7)	58.0 (3.9)	0.16 (0.07)	.033
Gross motor skills (ASQ)	57.4 (5.4)	57.7 (4.7)	0.08 (0.07)	.236
Emotional symptoms score (SDQ)	7.09 (1.88)	7.20 (1.87)	0.05 (0.03)	.188
Conduct problems score (SDQ)	5.57 (2.13)	5.08 (1.92)	−0.13 (0.03)	<.001
Inattention/hyperactivity symptoms score (SDQ)	4.34 (2.51)	3.74 (2.28)	−0.10 (0.03)	<.001
Peer relationship problems score (SDQ)	2.23 (1.46)	2.12 (1.22)	−0.07 (0.05)	.171
Prosocial behavior score (SDQ)	13.15 (1.78)	13.6 (1.53)	0.17 (0.04)	<.001
Neuropsychological tests				
3 years				
Semantic fluency (ELOLA)[a]	−0.09 (0.80)	0.07 (0.86)	0.19 (0.07)	.006
Word and nonword repetition (ELOLA)[a]	−0.06 (0.97)	0.09 (0.91)	0.17 (0.07)	.016
Sentence repetition (NEPSY)	6.80 (3.41)	7.62 (3.30)	0.24 (0.07)	<.001
Picture naming (ELOLA)	6.69 (1.95)	7.32 (1.84)	0.34 (0.07)	<.001
Comprehension of instructions (NEPSY)	8.14 (3.01)	9.00 (2.88)	0.29 (0.07)	<.001
Design-copying task (NEPSY)	9.17 (2.44)	10.1 (2.0)	0.45 (0.08)	<.001
Peg-moving task (s)	46.2 (10.6)	43.3 (10.4)	−0.29 (0.07)	<.001
5–6 years				
Nonwords repetition (NEPSY)	20.8 (5.1)	21.1 (4.8)	0.08 (0.07)	.248
Sentence repetition (NEPSY)	15.2 (3.9)	15.8 (4.2)	0.13 (0.07)	.056
Information (WPPSI-III)	24.9 (3.0)	25.3 (2.8)	0.14 (0.07)	.030
Vocabulary (WPPSI-III)	24.1 (5.6)	23.2 (5.7)	−0.19 (0.07)	.004
Word reasoning (WPPSI-III)	16.3 (4.7)	16.1 (4.6)	−0.07 (0.07)	.293
Design-copying task (NEPSY)	16.8 (2.9)	17.4 (2.8)	0.22 (0.07)	.002
Peg-moving task (s)	28.3 (5.3)	28.1 (5.1)	−0.15 (0.08)	.055
Total IQ (WPPSI-III)	103.4 (13.6)	103.6 (12.9)	−0.01 (0.07)	.836

Note. Values in first two columns are means and standard deviations. Standard deviations are in parentheses. BLm, parental questionnaire derived from the Brunet–Lézine Psychomotor Development Scale; CDI-2, MacArthur–Bates Communicative Development Inventory at 2 years; ASQ, Ages and Stages Questionnaire; SDQ, Strengths and Difficulties Questionnaire; ELOLA, Evaluation du Langage Oral de L'enfant Aphasique battery; NEPSY, NEuroPSYchological assessment battery; WPPSI-III, Wechsler Preschool and Primary Scale of Intelligence–Third Edition.
[a] *Z* scores

p values < .001) and to a lesser extent at 5–6 years of age (d = 0.26, p value < .001) (Fig. 3). Girls also showed significantly better language skills than boys at 2 and 3 years (Cohen's ds = 0.36 and 0.36, respectively, p values < .001), but not at 5–6 years (d = 0.04, p value = .50). No significant differences between girls and boys were found at 2, 3, and 5–6 years for gross motor skills (ds = 0.04, −0.05, and 0.05, respectively). Correlations between cognitive domains at each time point are presented separately for girls and boys in Fig. 2.

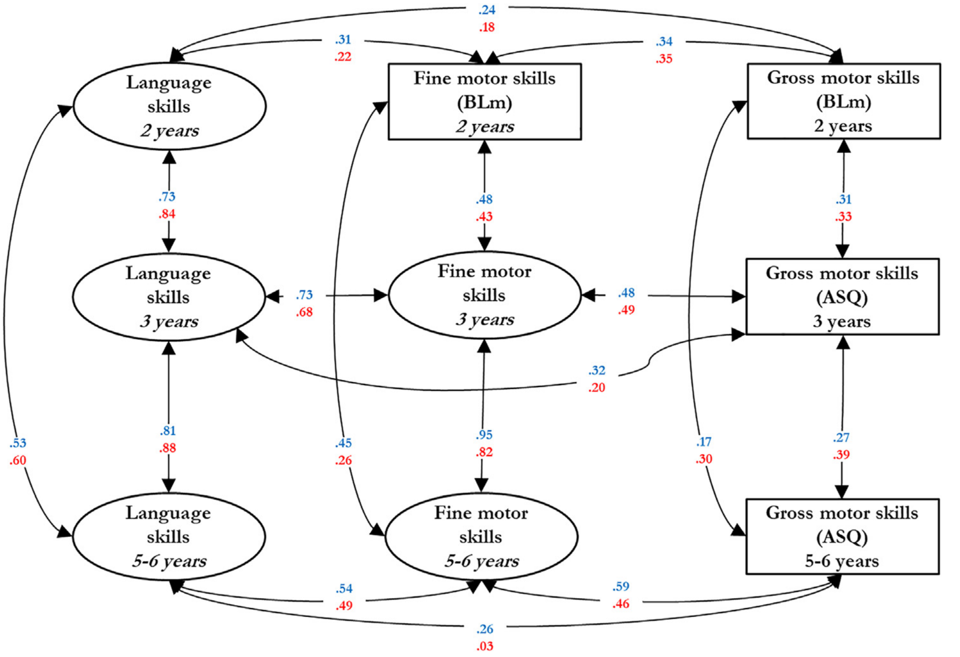
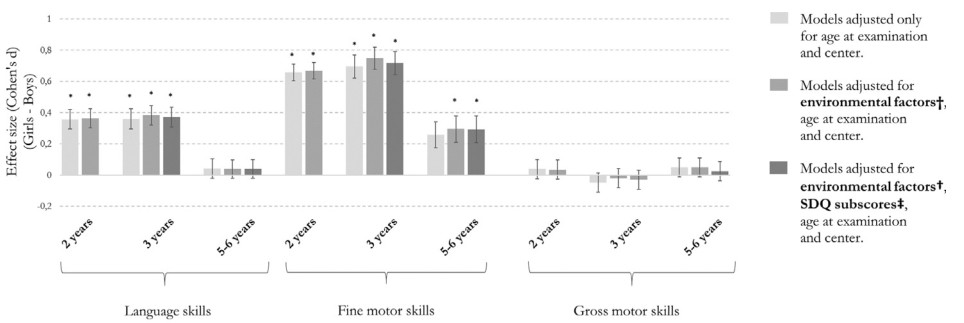


Fig. 2. Correlations across cognitive domains at 2, 3, and 5–6 years of age in the structural equation model (SEM) adjusted for environmental factors, SDQ subscores, age at examination, and center. SEM was performed separately on girls and boys. Ellipses are used to denote latent constructs, and rectangles are used to denote the observed variables measuring or interacting with these constructs. Standardized correlation estimates are in red for girls and in blue for boys. BLm, parental questionnaire derived from the Brunet–Lézine Psychomotor Development Scale; ASQ, Ages and Stages Questionnaire. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)



† **Environmental factors**: alcohol and tobacco during pregnancy, birth weight and gestational age, maternal and paternal age at childbirth, parental education, household income, birth rank, breastfeeding initiation, age of school entry, frequency of maternal stimulation at 2 and 3 years and HOME score at 5-6 years, maternal depression at 4, 8 and 12 months and 3 and 5-6 years postpartum, and family history of language delay.
‡ **SDQ subscores**: SDQ Emotional symptoms, SDQ Conduct problems, SDQ Hyperactivity/inattention symptoms, SDQ Peer relationship problems and SDQ Prosocial behavior.
* p-values < 0.001. Vertical error bars correspond to 95% confidence intervals of the mean effect sizes.

Fig. 3. Sex differences in language, fine and gross motor skills at 2, 3 and 5–6 years in the EDEN cohort (structural equation models).

Adjustments for pre- and postnatal environmental factors as well as SDQ scores did not alter the significance of the observed sex differences in psychomotor skills. Although not statistically significant, girls' advantage in fine motor skills at 2, 3, and 5–6 years of age and in language skills at 2 and 3 years tended to increase numerically when adjusting for pre- and postnatal environmental factors, whereas it tended to decrease numerically when also adjusting for SDQ scores.

Complementary analyses

Similar effect sizes for sex difference in language, fine motor, and gross motor skills were found when reproducing the three SEMs (SEM adjusted only for age at examination and center, SEM also adjusted for pre- and postnatal environmental factors, and SEM also adjusted for SDQ scores) in a subsample of children with FSIQs $\geq$ 85 (n = 987; 41 boys and 27 girls with IQs < 85).

Discussion

Main findings

In the current study, we sought to determine the extent to which sex differences in psychomotor development during the preschool period could be explained by sex differences in exposure to environmental factors and/or in emotional, behavioral, or social functioning. Our results suggest significant and substantial sex differences in early psychomotor development, with girls displaying better fine motor and language skills at 2 and 3 years of age. These differences tended to diminish or disappear at 5–6 years of age. Our findings also suggest that sex differences in fine motor and language skills at 2 and 3 years were not explained by sex differences in exposure to environmental factors or in emotional, behavioral, or social functioning. No sex differences were found in gross motor skills at any age.

In line with previous studies (Toivainen et al., 2017), we found that language skills were significantly better in girls than in boys at 2 and 3 years of age but not at 5–6 years of age (Bornstein et al., 2004; Toivainen et al., 2017). Our results extend prior studies suggesting that these early sex differences are not only significant but also substantial. For example, we found that 64.1% of boys at 2 years of age and 64.4% of boys at 3 years of age had language skills below girls' mean (in the absence of sex difference, one would expect 50%); however this was the case for only 51.6% of boys at 5–6 years of age.

Concerning motor skills, our results are consistent with those of prior studies (Flatters et al., 2014; Toivainen et al., 2017) and suggest that girls may have greater fine motor skills at 2 and 3 years of age and that this difference may be of smaller magnitude at 5–6 years of age. In particular, 74.9% of boys at 2 years, 76.4% at 3 years, but only 64.1% at 5–6 years had fine motor skills below girls' mean. In addition, we found no significant differences in gross motor skills during the preschool period.

Overall, we found that sex differences in language and fine motor skills tended to decrease throughout the preschool period and were even negligible for language skills at 5–6 years of age. Our results are consistent with prior findings (Bornstein et al., 2004; Flatters et al., 2014; Toivainen et al., 2017) suggesting that these sex differences in early psychomotor development may be more a matter of developmental pattern than of permanent and fixed differences. It remains an open question whether these early sex differences, despite being transitory, might have longer term effects on development. For instance, is the early female advantage in language abilities associated with the later female advantage in reading ability and with the higher male prevalence of dyslexia? In that case, it could be that 3-year-old language measures, being taken during a more sensitive period, might have greater prognostic value for some purposes than 5-year-old measures despite being more distant from the outcomes. The current study was not suited to answer such questions. However, later waves of data collection of the EDEN cohort, as well as other studies, might be able to shed more light on them.

Our findings indicate that sex differences in exposure to environmental factors may play a lesser role in psychomotor development during the preschool period than previously thought (Bornstein, 2012; Eliot, 2010; Leaper et al., 1998; Suizzo & Bornstein, 2006). In particular, there were no significant sex differences in all pre- and postnatal environmental factors known to influence psychomotor development, with the only exception being birth weight, and there were no significant variations of the magnitude of sex differences in psychomotor skills before and after adjusting for a broad range of pre- and postnatal environmental factors. In addition, our results did not support the hypothesis that sex differences in psychomotor development during the preschool period result from sex differences in emotional, behavioral, or social functioning. In particular, despite several sex differences in emotional, behavioral, or social functioning, we did not find any significant variation of sex differences in psychomotor skills before and after adjusting for these factors, and sensitivity analyses excluding children with a high risk of neurodevelopmental disorders (i.e., FSIQ < 85) yielded similar results. Although the current study does not provide any direct evidence in this respect, our findings are consistent with the idea that early biological factors (such as the effects of sex chromosomes and hormones) may play a substantial role in the greater verbal and fine motor abilities observed in girls (Christiansen & Knussmann, 1987; Kung, Browne, Constantinescu, Noorderhaven, & Hines, 2016; Lutchmaya, Baron-Cohen, & Raggatt, 2001; Peper, Brouwer, Boomsma, Kahn, & Hulshoff Pol, 2007; Wallen & Hassett, 2009). Prior work has hypothesized that the brain may mature faster in girls than in boys (Lim, Han, Uhlhaas, & Kaiser, 2015). For example, neuroimaging studies have reported differential patterns of lateralization of function in girls and boys (Crow, 1998; Geschwind & Galaburda, 2003; Guadalupe et al., 2015, 2017; Preis, Jancke, Schmitz-Hillebrecht, & Steinmetz, 1999; Shaywitz et al., 1995). However, these sex differences in brain development do not explain why sex differences in language and fine motor skills decrease (or disappear) at the end of the preschool period.

One limitation of many previous studies on sex differences in psychomotor development was the exclusive reliance on parental questionnaires, the responses of which may be biased by parents' stereotypes on gender. In the current study, we had results from both parental questionnaires and neuropsychological tests, for fine motor and language skills, at 3 and 5–6 years of age. Overall, results were consistent, with sex differences in the same direction with both sets of instruments (see Table 2). Discrepancies were nonetheless observed between few effect sizes, with the sex difference in fine motor skills at 3 years being larger using the ASQ questionnaire ($d = 0.55$) than using neuropsychological tests (mean $d = 0.37$). No such difference was observed at 5–6 years. Concerning language skills at 3 years, the sex difference was slightly smaller using the ASQ questionnaire ($d = 0.20$) than using language tests (mean $d = 0.25$). However, the pattern reversed at 5–6 years, with a greater sex difference on questionnaires ($d = 0.26$) than on tests (mean $d = 0.02$), where the sex difference even reversed (in favor of boys) on some tests. Overall, no consistent pattern of over- or underestimation of sex differences in parental responses seems to emerge. Differences in the estimation of effect sizes are more likely attributable to methodological differences in the instruments and perhaps to differences in the specific abilities that were evaluated in questionnaires and tests.

Strengths and limitations

Strengths of this study include the large sample size ($N = 1055$), the wide range of measures derived from questionnaires as well as neuropsychological tests for assessing psychomotor skills, and the possibility to take into account numerous confounding factors such as the level of parental cognitive stimulation of children.

Our study has several limitations. First, the measures used to evaluate children's cognitive stimulation at home were validated measures of good quality (such as the HOME questionnaire); however, they were isolated measures at three time points (at 2, 3, and 5–6 years of age) and did not cover all the potential factors that might differ between boys and girls or that might affect boys and girls differentially. A recent study directly measuring parents' attitude toward gender suggested that they may have an impact on infants' early cognitive abilities (Constantinescu, Moore, Johnson, & Hines, 2018). In contrast, we lacked information on important factors such as gender-typed toys (Bornstein, 2012), exploratory versus symbolic play (Suizzo & Bornstein, 2006), parents' language to their children (Leaper et al., 1998), and parents' attitude toward gender stereotypes. Therefore, our conclusion that environmental factors did not contribute to the observed sex differences is limited to the particular environmental factors that were measured in the current study and might not generalize if a broader range of relevant factors were measured. Second, gross motor skills at 2, 3, and 5–6 years of age were assessed only using parental self-administered questionnaires (and with fewer questions [8 items] on this cognitive domain than on language skills [14 items] and fine motor skills [14 items] at 2 years), and not using neuropsychological tests such as the Movement Assessment Battery for Children (Brown & Lalor, 2009). Third, the missing data may have induced a selection bias. We found that children whose data on psychomotor skills were available at 5–6 years significantly differed from those with missing data in several predictors of cognitive development (e.g., family income and level of parental education; these variables were associated with most psychomotor skills at 2, 3, and 5–6 years). However, this selective attrition concerned both sexes to a similar extent. The main consequence of this selective attrition was to reduce the variance of environmental conditions and potentially many other variables, thereby decreasing statistical power. Fourth, the environmental and behavioral hypotheses were tested considering unidirectional relationships (i.e., environmental and behavioral factors may explain psychomotor development); however, bidirectional relationships (or unidirectional relationships in the opposite direction) cannot be ruled out. The study of these complex relationships is an important direction for future research. Fifth, some questionnaires and neuropsychological tests were repeated (e.g., peg-moving task at 3 and 5–6 years), whereas others were not (e.g., vocabulary at 5–6 years only). We assumed that the latent variables at each time point (i.e., at 2, 3, and 5–6 years) captured the same underlying cognitive construct even with different measurements (parental questionnaires and neuropsychological tests). If this assumption was wrong, this could be an alternative explanation for the change in sex differences between two ages. However, we observed such changes only for language and fine motor skills between 3 and 5–6 years. For fine motor skills, the same measures (peg-moving task, design-copying task, and ASQ language skills score) were used at both ages, thereby avoiding this limitation. For language skills, tests differed, but the latent variables were still highly correlated (.81 [male] and .88 [female]) between 3 and 5–6 years, which does suggest that the same construct is being tapped. Finally, the available data did not allow us to examine the contribution of biological mechanisms such as hormonal differences and/or other factors associated with brain development to sex differences in psychomotor development. Future research would benefit from taking such biological factors into account.

Conclusion

Our results suggest that girls may have better fine motor and language skills than boys at 2 and 3 years of age. At 5–6 years of age, differences in fine motor skills were of a smaller magnitude and those in language skills were no longer significant. Our results indicate no significant sex differences in gross motor skills at 2, 3, and 5–6 years. We also found that sex differences in fine motor and language skills at 2 and 3 years were not explained by differential exposure to environmental factors or by differences in emotional, behavioral, or social functioning. Our findings are consistent with the idea that sex differences in biological factors may play a substantial role in the greater verbal and fine motor abilities observed in girls during the preschool period.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2018.09.002.

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