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ORIGINAL ARTICLE

Risk factors for executive function impairment in adolescence: an analysis of data from the 2004 Pelotas Birth Cohort study

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Objective: To investigate risk factors associated with impaired attention-related executive functions (EFs) at age 11 and working memory at age 15.
Methods: Data from participants of the population-based 2004 Pelotas Birth Cohort at ages 11 (n=3,582) and 15 (n=1,950) were analyzed. The study measured attentional control, cognitive flexibility, and selective attention using the Test of Everyday Attention for Children (TEA-Ch). Spatial working memory was assessed by the Cambridge Neuropsychological Test Automated Battery (CANTAB). Logistic regression was employed to explore the relationship between perinatal and childhood exposures and EF impairment.
Results: Low maternal education had a significant negative impact on EFs. At age 11, it was associated with decreased attentional control (OR = 3.04; 95%CI 2.09-4.43), and at age 15, it was linked to impaired spatial working memory (OR = 2.21; 95%CI 1.58-3.09). Additional risk factors included low household income, black or brown maternal skin color, high parity, prematurity, low birth weight, and multiple siblings. Breastfeeding, regardless of duration, was found to be a protective factor against impaired cognitive flexibility (OR = 0.38; 95%CI 0.22-0.65).
Conclusion: This study underscores the lasting impact of perinatal exposures on EF development. Policies that mitigate the negative effects of risk factors and promote EF development, especially among vulnerable populations, are needed.

Keywords: Birth cohort; attention; memory; adolescent

Introduction

Cognitive development in childhood and adolescence is influenced by several factors, including socioeconomic and birth conditions, family characteristics, and parenting practices.[1] Executive functions (EF)s play a critical role in healthy cognitive development, as they are responsible for controlling and executing mental, attentional, behavioral, and emotional processes in situations of conflict or distraction. According to Diamond,[2] EFs are a set of higher-order cognitive abilities consisting of at least three subcomponents: inhibition, working memory, and cognitive flexibility. Other cognitive processes, such as attentional functions, act as underlying factors that support engagement of the main EFs.[3]

Previous research has shown that healthy EF development is a hugely important predictor for later life outcomes such as subjective and physical well-being.[4] Children who experience adversity during childhood and adolescence are more likely to have impaired EFs, which affects both their quality of life and development over time.[5] In the medium and long term, EF deficits are associated with high-risk behaviors such as crime and violence, obesity, overeating, substance abuse, and marital problems.[6] Attention deficits and internalizing/externalizing problems are also associated with EF development disorders.[7]

The development of EFs involves several factors and is closely linked to the sensitive periods of brain maturation and the formation of neural circuits, particularly in the prefrontal cortex and limbic regions.[8] Some of these factors are inherent to individual neurobiological development, while others are environmental. It has been argued that adolescence constitute a sensitive period for a range of cognitive functions, including affect regulation and EFs.[9]

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Studies have described multiple risk factors associated with impaired executive functioning in adolescence, including prematurity, perinatal complications, childhood abuse and neglect, low socioeconomic status, and prolonged exposure to maternal depression.[10-13] These risk factors can disrupt the normal development of brain regions involved in EFs, such as the prefrontal cortex, leading to compromised cognitive abilities.[14] Additionally, they may contribute to increased stress levels and altered neurobiological processes, further impairing the functioning of executive processes in adolescence.

Research on risk factors associated with EF impairment has increased in the literature over the past 20 years.[15,16] However, studies have mainly focused on cohorts from high-income countries (HICs), leaving a significant gap in understanding the impact of risk factors on EF development in low- and middle-income countries (LMICs).[17] Generalization of results from HICs may lead to underestimation of the harmful effects of risk factors on populations in LMICs, including countries such as Brazil. This discrepancy arises from substantial disparities in the quality of life and socioeconomic conditions experienced by these populations. In LMICs, issues such as child poverty, low birth weight, and inadequate nutrition are more prevalent than in wealthier nations. As a consequence, the impact of these risk factors is expected to be significantly more pronounced in LMICs.[18] To address this knowledge gap, the present study aims to examine the factors associated with impaired EFs related to attentional control, selective attention, and cognitive flexibility (at age 11) and working memory (at age 15) among children and adolescents from the 2004 Pelotas Birth Cohort.

Methods

Participants

The 2004 Pelotas Birth Cohort is a population-based study that included children born in Pelotas, state of Rio Grande do Sul, Brazil, between January 1 and December 31, 2004. The original cohort comprised 4,231 newborns (99.2% of all births; 51.2% boys), who were followed throughout childhood and adolescence. The data included 3,491 participants who were followed up at 11 years old and 1,950 who were followed up at 15 years old. The sixth follow-up wave (at 11 years of age) was conducted between May and October 2015, with a follow-up rate of 87%. The seventh follow-up occurred between November 2019 and March 2020; however, only 46.1% of the original cohort was followed up before the start of the coronavirus disease 2019 (COVID-19) pandemic, which disrupted further data collection. The timeline of follow-up waves is described in Figure S1 (available as online-only supplementary material). Additional information about the methodology of the 2004 Cohort and the collected data can be found in previous studies.[19,20]

Measures

Executive functions

Attention-related EFs at age 11 were assessed by performing tasks contained in the Test of Everyday Attention for Children (TEA-Ch),[21] a neuropsychological test developed to assess the multidimensional nature of attention and related EFs in children and adolescents. The three attention-related EFs assessed were attentional control, cognitive flexibility, and selective attention. At the age of 15, spatial working memory was examined using a subtest of the Cambridge Neuropsychological Test Automated Battery (CANTAB).[22] The tasks are described in Table S1 (available as online-only supplementary material).

In the present study, attention-related EFs and spatial working memory were dichotomized to define a low-performance group. Categorization of attention-related EFs was done using a cutoff point of $<$ 10th percentile, indicating those children who took the longest to complete the task. Meanwhile, categorization of spatial working memory was based on the cutoff point for the 3rd tertile, identifying those with a greater number of errors.

Perinatal exposures

Maternal, socioeconomic and pregnancy characteristics. Variables were collected in the perinatal interview and included household income (measured as a continuous variable and categorized into quintiles), maternal education (categorized into 0, 1-4, 5-8 and $\geqslant$ 9 years of formal education), self-reported maternal skin color (white, black, brown, yellow/indigenous), living arrangement (alone or with a partner), maternal age ($<$ 20, 20-34, and $\geqslant$ 35 years), and parity (defined as the number of previously born children and categorized as 1, 2, and $\geqslant$ 3). Smoking during pregnancy was assessed retrospectively at birth by maternal reporting; regular smokers were defined as women who smoked at least one cigarette per day in any trimester of pregnancy.

Birth characteristics and breastfeeding. The variables of the child at birth assessed were low birth weight ($<$ 2,500 g) and prematurity (gestational age $<$ 37 weeks). Duration of breastfeeding was assessed by maternal reporting at 24 months and categorized as $<$ 1, 1-3, 3-6, 6-12 or $\geqslant$ 12 months.

Childhood exposures

Environmental characteristics. Absence of father (social or biological father) was measured in the first 48 months of life (never absent, absent at 24 months, absent at 48 months, always absent). The number of older siblings (none, 1, $\geqslant$ 2) was reported by the mother in the perinatal interview.

Maternal depressive symptoms. The Edinburgh Postnatal Depression Scale (EPDS) was originally designed for the identification of postpartum depression disorders in clinical and research settings.[23] The EPDS is a self-administered scale consisting of 10 items evaluated on a 4-point scale (0-3), with a total minimum score of 0 and a maximum score of 30. The scale indicates the intensity of depressive symptoms in the 7 days preceding the interview. The validated version of the questionnaire was administered to the mothers of the 2004 Pelotas Cohort.[24] EPDS scores from the 3-month to the 11-year follow-ups were used to construct trajectories of maternal depressive symptoms through a semiparametric group-based modeling approach, a specialized form of finite mixture modeling.[25,26] Details of the steps and methods used to identify the trajectories of maternal depressive symptoms have been reported in previous studies.[27,28] Groups 1 (low depressive symptomatology trajectory, n=1,161) and 2 (moderately low trajectory, n=1,361) represented 75.7% of mothers, who had EPDS scores $<$ 10 points in all follow-ups. Group 3 (increasing depressive symptomatology trajectory) included 9% (n=300) of the women monitored, who had a consistent increase in depressive symptoms throughout the study period. Group 4 (descending trajectory) included 9.9% (n=329) of women and, unlike the previous group, these mothers had high EPDS scores during the first 2 years postpartum and a sharp decrease thereafter. Finally, group 5 (chronic-high trajectory) represented 5.4% of the population (n=181), and included mothers who had high EPDS scores throughout the study period.

Maltreatment. Adolescent maltreatment was evaluated at the 11-year follow-up. Caregivers, most of whom were mothers, were asked about parenting strategies using the Parent-Child Conflict Tactics Scale (CTSPC).[29] The Portuguese version of the CTSPC was adapted and validated cross-culturally for use in Brazil.[30-32] The CTSPC is a 22-item questionnaire that measures parental behavior toward the child in the preceding 12 months. The CTSPC evaluates behaviors related to nonviolent discipline (four items), psychological aggression (five items), and physical aggression, including corporal punishment (five items), physical abuse (four items), and severe physical abuse (four items; not administered in this study). All items were scored on a 3-point scale (0-2; never, once, or more than once), yielding a total score of 0 to 28. Higher scores indicate higher exposure to maltreatment. In this study, the total score on the CTSPC scale was categorized into tertiles.

Statistical analysis

Comparisons between socioeconomic, maternal, and birth characteristics among the participants of the 11-year (n=3,582) and 15-year (n=1,950) follow-ups in relation to the total number of participants at baseline (n=4,231) were performed using the chi-square test. The descriptive analysis was performed by calculating the absolute and relative frequencies of the variables of interest. Bivariate statistical analysis between each exposure and the study outcomes was performed by means of the chi-square test. To study the potential risk factors for impaired performance in EFs related to attentional control, cognitive flexibility, selective attention, and spatial working memory, logistic regression models were constructed for each EF analyzed and adjustment was performed using a hierarchical conceptual model for determining risk factors (Figure 1) with four levels: 1) level 1: adjustment for maternal, socioeconomic, and gestational characteristics; 2) level 2: adjustment for level 1 variables and environmental characteristics; 3) level 3: adjustment for level 2 variables and characteristics of birth and breastfeeding; 4) level 4: adjustment for level 3 variables and maltreatment in childhood. Odds ratios (OR) were used to assess the associations between variables. If the significance level was below 0.20, the variable remained in the model as a potential confounder for the next level.[33] An alpha level of 0.05 was considered to indicate an association. All analyses were conducted

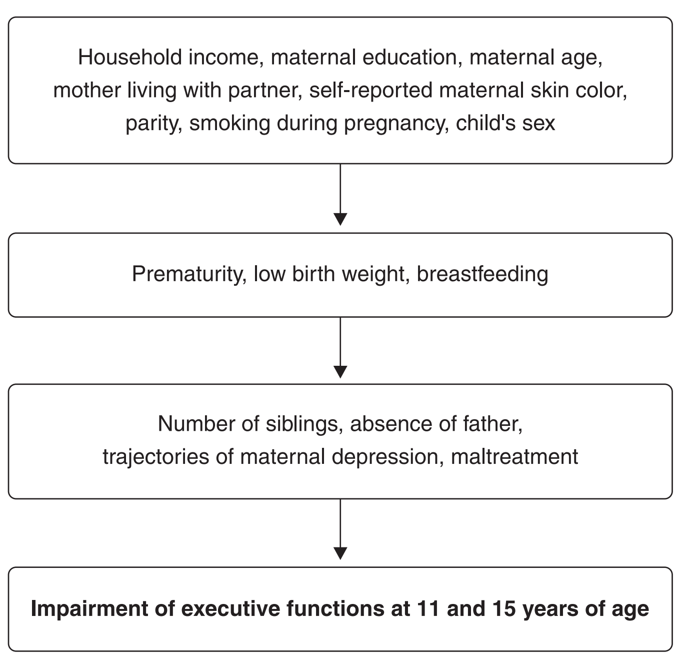

Figure 1 Conceptual model for determining risk factors associated with executive functions at 11 and 15 years of age in adolescents from the 2004 Pelotas Birth Cohort.

using Stata software, version 16.1. An additional analysis was conducted in which potential risk factors were modeled for two distinct groups: participants belonging to the lowest income quintile, representing the economically disadvantaged group; and the other participants belonging to the second to fifth income quintiles.

Ethics statement

This study was approved by the Ethics Committee for the Analysis of Research Projects (CAPPESq) of Universidade de São Paulo and by the research ethics committee of Universidade Federal de Pelotas. At the sixth follow-up (at age 11), the study was also approved by CAPPESq. Written informed consent was obtained from the adolescents' mothers or guardians. At the sixth and seventh follow-up visits (at ages 11 and 15 years), the adolescents themselves signed an assent form.

Results

Attrition analysis

Participants who were followed up at 11 and 15 years had better socioeconomic indicators than the baseline sample as a whole, as shown in Table 1. Additionally, there were fewer cases of preterm birth and low birth weight among those followed up at 11 and 15 years compared to the baseline sample. At the 11-year follow-up, a higher proportion of mothers reported living with their partner, while at the 15-year follow-up, more participants had been born to mothers aged 35 or older. There were no differences in maternal skin color or child's sex between those reached at the 11- and 15-year follow-ups and the baseline sample.

Sample description

The majority of mothers of participants followed up at 11 and 15 years of age were white, aged 20 to 34, had at least 9 years of schooling, and had not smoked during pregnancy. The prevalence of boys was slightly higher at both the 11- and 15-year follow-ups. Most adolescents' fathers had been present during childhood. In addition, the majority of adolescents were breastfed for at least the 1st month of life. For more details on participant characteristics, see supplementary material (Table S2, available as online-only supplementary material).

Bivariate analysis

Lower household income, lower levels of maternal education, and greater number of siblings were associated with attention-related EFs at age 11 and spatial working memory impairment at age 15 (Table 2). Children of single mothers and of mothers who smoked during pregnancy performed comparatively poorly in attentional control. Other factors associated with lower performance in attentional control, selective attention, and spatial working memory were black or brown maternal skin color, parity of three or more children, and absence of father at 24 and 48 months. Additionally, prematurity and low birth weight were associated with lower performance of attention-related EFs at 11 years of age. Male adolescents presented lower performance in selective attention, while girls showed lower performance in spatial working memory more frequently. Furthermore, adolescents whose mothers had chronic and severe depressive symptoms when they were aged 3 months to 11 years had lower performance in attentional control, selective attention, and spatial working memory. Higher levels of maltreatment were associated with lower performance in cognitive flexibility. Lower performance in cognitive flexibility was also observed among children who were never breastfed.

Adjusted analysis

Several perinatal and childhood predictors were associated with impaired attention-related EFs and spatial working memory (Table 3). Low maternal education was a strong predictor of deficit in attention-related EFs and spatial working memory. This observation remained consistent even after stratifying by household income (Tables S3 and S4, available as online-only supplementary material). Moreover, lower household income was associated with higher odds of attentional control impairment. Notably, children of mothers who described their skin color as black performed worse than children of white mothers on attentional control, selective attention, and spatial working memory. This result persisted for selective attention impairment even when household income stratification was taken into account.

A greater number of siblings was associated with impaired attentional control and spatial working memory. Additionally, low birth weight was found to be related to poorer selective attention at 11 years of age. Moderate-low and decreasing maternal depression symptoms were linked to poorer spatial working memory at age 15. Stratification by household income revealed that within the lowest income quintile group, moderate-low and increasing maternal depression symptoms were associated with impaired attentional control.

In terms of sex differences, girls exhibited a reduced risk of selective attention impairment at the age of 11, while presenting poorer performance in spatial working memory at age 15.

Interestingly, breastfeeding reduced the odds of impaired cognitive flexibility, regardless of duration. In addition, a protective effect was observed in which children of mothers older than 35 years showed higher cognitive flexibility. Potential risk factors such as maternal age, whether the mother lived with a partner, absence of father, smoking during pregnancy, and maltreatment were not found to have any significant association with EFs.

Discussion

Using data from a population-based cohort study, the present study examined the impacts of socioeconomic, parental, and adolescent variables on the performance of attention-related EFs at the age of 11 and spatial working

Table 1 Maternal and adolescent characteristics among participants at follow-ups conducted at 11 and 15 years of age in relation to the baseline (perinatal) sample

Variables	Perinatal (n=4,231)	Follow-ups 11 years (n=3,582)	Follow-ups 15 years (n=1,950)
Household income (quintiles)		p < 0.001	p = 0.001
5th (wealthiest)	830 (19.6)	693 (19.4)	362 (18.6)
4th	858 (20.3)	754 (21.1)	432 (22.2)
3rd	816 (19.3)	709 (19.9)	407 (20.9)
2nd	854 (20.2)	716 (20.1)	383 (19.7)
1st (poorest)	871 (20.6)	696 (19.5)	365 (18.7)
Maternal education (years)		p = 0.001	p = 0.021
⩾ 9	1,801 (43.0)	1,542 (43.7)	868 (44.9)
5-8	1,731 (41.4)	1,465 (41.5)	790 (40.8)
1-4	611 (14.6)	497 (14.1)	264 (13.6)
0	43 (1.0)	29 (0.8)	13 (0.7)
Self-reported maternal skin color		p = 0.142	p = 0.057
White	2,581 (61.7)	2,197 (62.3)	1,220 (63.4)
Black	689 (16.5)	584 (16.6)	316 (16.4)
Brown	868 (20.8)	711 (20.2)	375 (19.5)
Yellow/Indigenous	43 (1.0)	35 (1.00)	14 (0.7)
Maternal age at birth (years)		p = 0.079	p < 0.001
20-34	2,865 (67.8)	2,404 (67.4)	1,296 (66.5)
< 20	799 (18.9)	669 (18.8)	350 (18.0)
⩾ 35	563 (13.3)	493 (13.8)	303 (15.6)
Mother living with partner		p = 0.001	p = 0.062
Yes	3,536 (83.6)	3,013 (84.5)	1,652 (84.8)
No	693 (16.4)	555 (15.6)	297 (15.3)
Child's sex		p = 0.348	p = 0.350
Male	2,194 (51.8)	1,840 (51.6)	996 (51.1)
Female	2,035 (48.1)	1,728 (48.4)	953 (48.9)
Low birth weight		p < 0.001	p = 0.024
No	3,803 (90.0)	3,247 (91.0)	175 (91.1)
Yes	423 (10.0)	320 (9.0)	173 (8.9)
Preterm birth		p = 0.007	p = 0.025
No	3,603 (85.5)	3,068 (86.1)	1,689 (86.8)
Yes	612 (14.5)	495 (13.9)	257 (13.2)

Data presented as n (%).

memory at the age of 15 years. Among the perinatal exposures investigated, low maternal education was the risk factor that presented the greatest negative impact on attention-related EFs at 11 years and spatial working memory at 15 years. The results also indicated that breastfeeding (regardless of duration) and late maternity had a protective effect on the performance of attention-related EFs at age 11.

Low maternal education and low household income have been consistently identified as risk factors for EFs development, as shown in a meta-analysis by Lawson et al.[15] with 18 independent populations. Our results add to this literature by showing that the negative association of low family income is particularly strong in countries such as Brazil, where about 42% of children aged 0-14 years live in poverty.[34] Furthermore, our study revealed that low maternal education had a greater negative impact on EFs at 11 and 15 years of age than household income. Maternal education plays a critical role in child development, reflecting maternal characteristics that may influence the parent-child relationship, while income has a greater impact on children's exposure to environmental stressors.[35] Compared to countries in the Global North, countries in the South offer less social protection for children in terms of nutrition, health, and education. Thus, mothers and caregivers have a more central role in the child's development process. Mothers with higher levels of education have the potential to create healthier and more stimulating home environments for child development. This includes providing greater economic resources, enhanced information processing capacity, and increased access to better educational environments.[36] Higher levels of maternal education are associated with a decreased risk of maternal depressive symptoms, which in turn can have a great impact on the quality of the mother-child relationship.[37] Interestingly, the study also found that older maternal age served as a protective factor for executive functioning impairment, possibly due to greater maternal experience and stability.

The results of this study showed negative consequences of maternal characteristics on the development of executive functioning in late childhood and

Table 2 Frequency of impairment of EFs related to attention and spatial working memory according to maternal and adolescent characteristics

	EF impairment			
Variables	Attentional control (p10) at 11 years n=3,452	Cognitive flexibility (p10) at 11 years n=3,413	Selective attention (p10) at 11 years n=3,392	Spatial working memory (p3) at 15 years n=1,910
Household income (quintiles)	$p < 0.001$	$p = 0.001$	$p = 0.001$	$p < 0.001$
5th (wealthiest)	2 (0.3)	49 (7.4)	30 (4.6)	65 (18.3)
4th	45 (6.1)	54 (7.4)	57 (7.8)	92 (21.7)
3rd	71 (10.3)	77 (11.3)	74 (10.8)	108 (27.1)
2nd	91 (13.0)	9 (1.3)	92 (13.5)	110 (29.5)
1st (poorest)	110 (16.7)	82 (12.6)	86 (13.5)	132 (36.9)
Maternal education (years)	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
⩾ 9	72 (4.8)	106 (7.1)	85 (5.7)	162 (18.9)
5-8	159 (11.3)	166 (11.9)	158 (11.5)	235 (30.6)
1-4	105 (22.0)	64 (13.6)	87 (18.7)	100 (38.6)
0	7 (25.9)	4 (16.0)	9 (33.3)	7 (63.6)
Maternal age at birth (years)	$p = 0.009$	$p = 0.108$	$p = 0.006$	$p = 0.065$
20-34	221 (9.5)	219 (9.6)	239 (10.5)	332 (26.1)
< 20	84 (12.9)	79 (12.2)	66 (10.3)	106 (31.1)
⩾ 35	37 (7.8)	43 (9.1)	33 (7.0)	69 (23.2)
Mother living with partner	$p = 0.041$	$p = 0.907$	$p = 0.689$	$p = 0.167$
Yes	277 (9.5)	287 (10.0)	284 (9.9)	421 (26.0)
No	67 (12.4)	54 (10.1)	55 (10.5)	86 (29.9)
Self-reported maternal skin color	$p < 0.001$	$p = 0.169$	$p < 0.001$	$p < 0.001$
White	142 (6.7)	19 (0.9)	151 (7.2)	279 (23.3)
Black	96 (16.1)	69 (12.3)	99 (18.1)	113 (36.6)
Brown	93 (13.6)	67 (9.9)	80 (11.9)	106 (29.0)
Yellow/Indigenous	4 (11.8)	2 (5.9)	2 (5.9)	4 (28.4)
Parity	$p < 0.001$	$p = 0.063$	$p < 0.001$	$p = 0.009$
1	105 (7.7)	131 (9.7)	109 (8.1)	183 (25.1)
2	71 (7.6)	79 (8.5)	81 (8.8)	127 (23.4)
3+	168 (14.6)	131 (11.6)	149 (13.3)	197 (30.8)
Smoking during pregnancy	$p = 0.004$	$p = 0.788$	$p = 0.099$	$p = 0.470$
No	230 (9.1)	248 (9.9)	236 (9.5)	342 (24.2)
Yes	114 (12.4)	93 (10.2)	103 (11.4)	165 (33.3)
Absence of father	$p = 0.019$	$p = 0.841$	$p = 0.005$	$p < 0.001$
Never absent	176 (8.6)	196 (9.7)	173 (8.6)	302 (25.3)
Absent at 24 months	22 (10.1)	22 (10.1)	22 (10.4)	27 (26.5)
Absent at 48 months	47 (13.0)	37 (10.3)	51 (14.4)	50 (28.2)
Always absent	52 (12.1)	36 (8.6)	47 (11.4)	66 (30.0)
Low birth weight	$p = 0.004$	$p = 0.046$	$p < 0.001$	$p = 0.032$
No	300 (9.5)	309 (9.9)	290 (9.4)	1,292 (74.1)
Yes	44 (14.7)	32 (10.8)	49 (16.8)	111 (66.5)
Preterm birth	$p < 0.001$	$p = 0.046$	$p < 0.001$	$p = 0.334$
No	275 (9.2)	282 (9.6)	271 (9.2)	434 (26.2)
Yes	69 (14.7)	58 (12.6)	67 (14.6)	73 (29.1)
Child's sex	$p = 0.202$	$p = 0.710$	$p = 0.007$	$p < 0.001$
Male	188 (10.6)	178 (10.2)	197 (11.3)	201 (20.7)
Female	156 (9.3)	163 (9.8)	142 (8.6)	306 (32.7)
Maltreatment (CTSPC score) (tertile)	$p = 0.878$	$p = 0.022$	$p = 0.139$	$p = 0.435$
1st (lower)	113 (9.6)	120 (10.3)	107 (9.2)	156 (26.0)
2nd	131 (10.1)	107 (8.4)	117 (9.2)	177 (25.8)
3rd (highest)	95 (10.2)	110 (11.9)	106 (11.5)	152 (28.8)

Continued on next page

Table 2 (*continued*)

Variables	EF impairment Attentional control (p10) at 11 years n=3,452	Cognitive flexibility (p10) at 11 years n=3,413	Selective attention (p10) at 11 years n=3,392	Spatial working memory (p3) at 15 years n=1,910
Number of siblings	$p < 0.001$	$p = 0.009$	$p < 0.001$	$p < 0.001$
0	80 (7.2)	94 (8.5)	83 (7.5)	133 (22.5)
1	92 (7.4)	120 (9.7)	118 (9.6)	177 (24.9)
⩾ 2	158 (16.3)	119 (12.6)	125 (13.4)	176 (34.2)
Trajectories of maternal depressive symptoms	$p = 0.001$	$p = 0.218$	$p = 0.040$	$p < 0.001$
Low	84 (7.7)	95 (8.7)	84 (7.7)	115 (19.6)
Moderate-low	137 (9.6)	144 (10.2)	141 (10.0)	223 (27.5)
Decreasing	48 (12.7)	43 (11.5)	46 (12.5)	65 (32.0)
Increasing	47 (15.3)	35 (11.6)	34 (11.4)	52 (31.0)
Chronic-high	17 (10.7)	21 (13.4)	19 (12.1)	33 (35.1)
Breastfeeding duration (months)	$p = 0.009$	$p = 0.000$	$p = 0.253$	$p = 0.047$
0	11 (12.1)	19 (21.6)	15 (16.7)	16 (27.6)
< 1	27 (10.3)	21 (8.1)	25 (9.8)	40 (30.8)
1-3	71 (13.9)	67 (13.4)	53 (10.7)	93 (33.2)
3-12	105 (8.32)	116 (9.3)	120 (9.6)	175 (25.1)
⩾ 12	128 (9.7)	11 (9.0)	122 (9.5)	182 (24.7)

Data presented as n (%).
p-values from a chi-square test.
CTSPC = Parent-Child Conflict Tactics Scale; EFs = executive functions; p10 = worst decile (adolescents who took the longest to complete the task); p3 = worst tertile (adolescents who made the highest number of mistakes in the task).

adolescence. Maternal skin color (black or brown) has been identified as a risk factor insofar as it reflects disparities in access to resources and opportunities, potentially influencing the development of offspring EF.[38] Multiparity, or having multiple children, has been linked to potential challenges in parenting practices that may negatively affect children's EFs. This association is particularly notable in families of low socioeconomic status, where the presence of multiple siblings can lead to competition for parents' time and attention.[39]

Exposures to maternal depressive symptoms and a high number of siblings in the 1st years of age were identified as potential risk factors for impairment of attention-related EFs and spatial working memory at ages 11 and 15. According to the theory of ecological development, stressors in the environment and the absence of complex stimuli can impair the development and regulation of cognitive processes linked to EFs.[40] Having a higher number of siblings can impair EFs due to factors such as reduced parental monitoring, limited practice in negotiation and conflict resolution, and increased social complexity.[39] This can result in reduced opportunities for one-on-one interactions and cognitive stimulation, which are important for the development of EFs. Meanwhile, maternal depressive symptoms have a persistent negative impact on executive functioning throughout child development due to a lack of essential environmental stimuli important for cognitive growth, including cognitive stimulation, communication, and positive emotions.[41]

In addition to maternal characteristics, birth characteristics such as prematurity and low birth weight were identified as risk factors for impaired EFs at age 11. Prematurity was associated with impaired attentional control, while low birth weight was associated with impaired selective attention. These results are in line with previous research that points to prematurity and low birth weight as risk factors for several long-term cognitive outcomes, including EFs impairment.[13,42] Although positive parenting and good parental mental health can minimize the negative effects of premature birth and positively influence neurodevelopment,[43] adverse effects of prematurity and complications related to the development of brain regions such as the prefrontal cortex may be associated with cognitive deficits throughout childhood, adolescence, and adulthood.[13]

In our study, we found sex differences in selective attention at age 11 and in spatial working memory at age 15. However, this result should be interpreted with caution. A recent literature review indicates that gender is not the main factor in individual differences in EF and cognitive performance.[44] The literature suggests that these differences are often due to minor changes in task design, suggesting that variations in strategic approaches and outcome preferences contribute to the observed effects on EF, rather than being due to inherent differences in ability between the sexes.

Furthermore, breastfeeding was identified as a protective factor for cognitive flexibility at age 11 years, regardless of its duration. Our findings not only emphasize the influence of breastfeeding on children's cognitive development but also align with longitudinal observations from the 1982 Pelotas Birth Cohort study.[45] This study highlights the association between breastfeeding and improved performance on intelligence tests even after 3 decades. Importantly, despite growing recognition of breastfeeding's positive effects on child cognitive development, there is limited evidence associating it to EF,

Table 3 Logistic regression models for impairment in performance of attentional control, cognitive flexibility, and selective attention at age 11 and spatial working memory at age 15

	Attentional control		Cognitive flexibility		Selective attention		Spatial working memory	
Variables	Crude	Adjusted†	Crude	Adjusted†	Crude	Adjusted†	Crude	Adjusted†
Household income (quintiles)	$p < 0.001$	$p = 0.029$	$p = 0.001$	$p = 0.247$	$p < 0.001$	$p = 0.241$	$p < 0.001$	$p = 0.064$
5th (wealthiest)	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	-	1 (ref)	1 (ref)
4th	1.55 (0.94-2.52)	1.14 (0.69-1.89)	1.00 (0.67-1.49)	-	1.78 (1.13-2.80)	-	1.24 (0.87-1.77)	1.08 (0.75-1.57)
3rd	2.72 (1.72-4.30)	1.60 (0.98-2.60)	1.59 (1.10-2.32)	-	2.54 (1.64-3.94)	-	1.66 (1.17-2.35)	1.24 (0.85-1.80)
2nd	3.55 (2.28-5.54)	1.60 (0.98-2.60)	1.62 (1.12-2.35)	-	3.27 (2.13-5.01)	-	1.87 (1.32-2.65)	1.20 (0.81-1.78)
1st (poorest)	4.76 (3.08-7.36)	1.95 (1.20-3.17)	1.81 (1.25-2.62)	-	3.27 (2.12-5.03)	-	2.61 (1.85-3.69)	1.66 (1.13-2.45)
Maternal education (years)	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
⩾ 9	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
5-8	2.53 (1.90-3.38)	1.55 (1.12-2.15)	1.77 (1.37 -2.28)	1.77 (1.37 -2.98)	2.14 (1.63-2.82)	1.80 (1.33-2.42)	1.89 (1.51-2.38)	1.51 (1.17-1.95)
1-4	5.60 (4.07-7.72)	3.04 (2.09-4.43)	2.06 (1.48-2.86)	2.06 (1.48-2.86)	3.81 (2.77-5.24)	3.06 (2.15-4.36)	2.70 (2.00-3.66)	2.21 (1.58-3.09)
0	6.97 (2.85-17.01)	4.10 (1.53-10.95)	2.49 (0.84-7.39)	2.49 (0.84-7.39)	8.27 (3.61-18.96)	9.15 (3.82-21.96)	7.52 (2.17-25.99)	4.98 (1.41-17.62)
Maternal age at birth (years)	$p = 0.010$	$p = 0.003$	$p = 0.109$	$p = 0.218$	$p = 0.069$	$p = 0.014$	$p = 0.065$	$p = 0.338$
20-34	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	-
< 20	1.41 (1.07-1.84)	1.56 (1.11-2.19)	1.31 (1.00-1.73)	-	0.98 (0.74-1.31)	1.00 (0.70-1.41)	1.28 (0.98-1.66)	-
⩾ 35	0.80 (0.56-1.15)	0.67 (0.45-0.99)	0.95 (0.6-1.33)	-	0.64 (0.44-0.94)	0.55 (0.37-0.82)	0.85 (0.63-1.15)	-
Self-reported maternal skin color	$p < 0.001$	$p < 0.001$	$p = 0.173$	$p = 0.430$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.036$
White	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Black	2.83 (2.15-3.74)	2.14 (1.60-2.87)	1.36 (1.02-1.83)	-	2.86 (2.18-3.76)	2.47 (1.86-3.27)	1.90 (1.45-2.48)	1.52 (1.15-2.02)
Brown	2.19 (1.66-2.89)	1.66 (1.24-2.22)	1.06 (0.79-1.42)	-	1.74 (1.31-2.32)	1.45 (1.08-1.95)	1.34 (1.03-1.75)	1.11 (0.85-1.47)
Yellow/Indigenous	1.86 (0.65-5.36)	1.87 (0.64-5.46)	0.61 (0.14-2.54)	-	0.81 (0.19-3.40)	0.83 (0.20-3.53)	1.32 (0.41-4.23)	1.07 (0.33-3.51)
Parity	$p < 0.001$	$p < 0.001$	$p = 0.064$	$p = 0.287$	$p < 0.001$	$p = 0.116$	$p = 0.100$	$p = 0.251$
1	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	-
2	0.99 (0.72-1.35)	1.13 (0.80-1.61)	0.87 (0.65-1.17)	-	1.10 (0.82-1.49)	1.03 (0.74-1.44)	0.91 (0.70-1.18)	-
⩾ 3	2.05 (1.59-2.66)	1.93 (1.36-2.74)	1.23 (0.95-1.58)	-	1.74 (1.34-2.27)	1.36 (0.98-1.90)	1.32 (1.04-1.68)	-
Smoking during pregnancy	$p = 0.004$	$p = 0.738$	$p = 0.788$	$p = 0.264$	$p = 0.099$	$p = 0.471$	$p < 0.001$	$p = 0.063$
No	1 (ref)	-	1 (ref)	-	1 (ref)	-	1 (ref)	1 (ref)
Yes	1.41 (1.11-1.80)	-	1.04 (0.80-1.33)	-	1.23 (0.96-1.57)	-	1.57 (1.26-1.96)	1.26 (0.99-1.60)
Mother living with partner	$p = 0.041$	$p = 0.309$	$p = 0.907$	$p = 0.608$	$p = 0.689$	$p = 0.699$	$p = 0.167$	$p = 0.684$
Yes	1 (ref)	-	1 (ref)	-	1 (ref)	-	1 (ref)	-
No	1.34 (1.01-1.79)	-	1.02 (0.74-1.38)	-	1.06 (0.78-1.44)	-	1.21 (0.92-1.60)	-
Child's sex	$p = 0.203$	$p = 0.085$	$p = 0.710$	$p = 0.689$	$p = 0.007$	$p = 0.005$	$p < 0.001$	$p < 0.001$
Female	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Male	1.16 (0.92-1.45)	1.23 (0.97-1.56)	1.04 (0.83-1.31)	-	1.36 (1.08-1.71)	1.41 (1.11-1.78)	0.54 (0.43-0.66)	0.54 (0.44-0.67)
Preterm birth	$p < 0.001$	$p = 0.026$	$p = 0.047$	$p = 0.162$	$p = 0.047$	$p = 0.249$	$p = 0.334$	$p = 0.597$
No	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	-
Yes	1.69 (1.27-2.25)	1.42 (1.04-1.93)	1.36 (1.00-1.84)	1.24 (0.92-1.69)	1.36 (1.00-1.84)	-	1.16 (0.86-1.55)	-

Continued on next page

Table 3 (*continued*)

Variables	Attentional control Crude	Attentional control Adjusted†	Cognitive flexibility Crude	Cognitive flexibility Adjusted†	Selective attention Crude	Selective attention Adjusted†	Spatial working memory Crude	Spatial working memory Adjusted†
Low birth weight	p = 0.005	p = 0.258	p = 0.623	p = 0.516	p = 0.623	p < 0.001	p = 0.033	p = 0.136
No	1 (ref)	-	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Yes	1.63 (1.16-2.29)	-	1.10 (0.75-1.62)	-	1.10 (0.75-1.62)	1.98 (1.40-2.79)	1.45 (1.03-2.03)	1.31 (0.92-1.88)
Breastfeeding duration (months)	p = 0.010	p = 0.160	p < 0.001	p = 0.001	p = 0.267	p = 0.618	p = 0.048	p = 0.135
0	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	1 (ref)
< 1	0.84 (0.40-1.77)	1.02 (0.46-2.27)	0.32 (0.16-0.63)	0.32 (0.16-0.64)	0.32 (0.16-0.63)	-	0.15 (-0.53-0.84)	1.41 (0.68-2.91)
1-3	1.18 (0.60-2.32)	1.33 (0.65-2.75)	0.56 (0.32-0.99)	0.56 (0.31-0.99)	0.56 (0.32-0.99)	-	0.27 (-0.36-0.89)	1.42 (0.73-2.75)
3-12	0.66 (0.34-1.28)	0.87 (0.43-1.75)	0.37 (0.22-0.64)	0.40 (0.23-0.70)	0.37 (0.22-0.64)	-	-0.13 (-0.73-0.47)	1.05 (0.56-1.99)
⩾ 12	0.78 (0.40-1.51)	0.94 (0.47-1.90)	0.36 (0.21-0.62)	0.38 (0.22-0.65)	0.36 (0.21-0.62)	-	-0.15 (-0.75-0.45)	0.98 (0.52-1.85)
Number of siblings	p < 0.001	p = 0.015	p = 0.009	p = 0.358	p < 0.001	p = 0.294	p < 0.001	p = 0.042
0	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	-	1 (ref)	1 (ref)
1	1.04 (0.76-1.41)	1.05 (0.73-1.48)	1.15 (0.87-1.53)	-	1.30 (0.97-1.74)	-	1.15 (0.89-1.48)	0.96 (0.72-1.27)
⩾ 2	1.53 (1.90-3.36)	1.60 (1.10-2.33)	1.53 (1.15-2.04)	-	1.89 (1.41-2.53)	-	1.79 (1.37-2.34)	1.34 (1.00-1.81)
Absence of father	p = 0.020	p = 0.394	p = 0.842	p = 0.717	p = 0.005	p = 0.074	p = 0.471	p = 0.986
Never absent	1 (ref)	-	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	-
Absent at 24 months	1.19 (0.74-1.89)	-	1.05 (0.66-1.66)	-	1.04 (0.66-1.66)	0.93 (0.57-1.53)	1.06 (0.67-1.68)	-
Absent at 48 months	1.58 (1.12-2.23)	-	1.07 (0.74-1.54)	-	1.07 (0.74-1.54)	1.58 (1.11-2.24)	1.16 (0.82-1.65)	-
Always absent	1.46 (1.05-2.02)	-	0.87 (0.60-1.26)	-	0.87 (0.60-1.26)	1.09 (0.76-1.56)	1.27 (0.92-1.74)	-
Trajectories of maternal depressive symptoms (3 months to 11 years)	p = 0.001	p = 0.209	p = 0.221	p = 0.819	p = 0.042	p = 0.995	p < 0.001	p = 0.013
Low	1 (ref)	-	1 (ref)	-	1 (ref)	-	1 (ref)	1 (ref)
Moderate-low	1.28 (0.96-1.70)	-	1.19 (0.91-1.56)	-	1.19 (0.91-1.56)	-	1.65 (1.29-2.14)	1.61 (1.23-2.12)
Decreasing	1.76 (1.21-2.56)	-	1.36 0.93-1.99)	-	1.36 (0.93-1.99)	-	1.93 (1.35-2.77)	1.52 (1.02-2.25)
Increasing	2.18 (1.49-3.20)	-	1.38 (0.92-2.08)	-	1.38 (0.92-2.08)	-	1.84 (1.25-2.70)	1.44 (0.95-2.20)
Chronic-high	1.45 (0.83-2.50)	-	1.62 (0.98-2.69)	-	1.62 (0.98-2.69)	-	2.22 (1.39-3.55)	1.69 (1.00-2.83)
Maltreatment (CTSPC score) (tertile)	p = 0.878	p = 0.964	p = 0.023	p = 0.051	p = 0.140	p = 0.517	p = 0.574	p = 0.753
3rd (highest)	1 (ref)	-	1 (ref)	1 (ref)	1 (ref)	-	1 (ref)	-
2nd	1.06 (0.81-1.38)	-	0.80 (0.61-1.05)	0.82 (0.62-1.08)	0.80 (0.61-1.05)	-	0.99 (0.77-1.27)	-
1st (lower)	1.07 (0.80-1.43)	-	1.18 (0.89-1.55)	1.16 (0.88-1.54)	1.18 (0.89-1.55)	-	1.15 (0.89-1.50)	-

Data presented as odds ratio (95%CI).
CTSPC = Parent-Child Conflict Tactics Scale.
† For attentional control, smoking during pregnancy (p = 0.738), low birth weight (p = 0.258), absence of father (p = 0.394), trajectories of maternal depression (p = 0.209), and maltreatment (p = 0.964) were excluded from the final model. For cognitive flexibility, household income (p = 0.247), maternal age at birth (p = 0.218), self-reported maternal skin color (p = 0.430), parity (p = 0.287), smoking during pregnancy (p = 0.264), child's sex (p = 0.689), mother living with partner (p = 0.608), low birth weight (p = 0.516), number of siblings (p = 0.358), trajectories of maternal depression symptoms (p = 0.819), and absence of father (p = 0.717) were excluded from the final model. For selective attention, income (p = 0.241), mother living with partner (p = 0.699), smoking during pregnancy (p = 0.471), preterm birth (p = 0.249), number of siblings (p = 0.294), trajectories of maternal depression symptoms (p = 0.995), breastfeeding duration (p = 0.618), and maltreatment (p = 0.517) were excluded from the final model. For working memory, maternal age at birth (p = 0.338), parity (p = 0.251), mother living with partner (p = 0.684), preterm birth (p = 0.597), absence of father (p = 0.986), and maltreatment (p = 0.753) were excluded from the final model.

as emphasized by a recent review.[46] In addition to the scarcity of studies in this field, breastfeeding duration is a complex behavior that is influenced by several factors, including the duration and exclusivity of breastfeeding pattern, maternal health, and other infant feeding practices, such as age at introduction of complementary feeding. These factors may vary across studies, leading to inconsistent results. Lastly, the long-term effects of breastfeeding on EF and cognitive development are not fully understood, and further research is needed to investigate the underlying physiological and behavioral mechanisms that may explain the observed associations.

Our study highlights the association between several perinatal, maternal, and environmental characteristics and impaired executive functioning in late childhood and adolescence. This multifaceted nature suggests that impaired EF results from the convergence of multiple environmental influences, rather than single exposures. One plausible mechanism for these impairments is toxic stress, a manifestation of chronic, uncontrollable exposure to stressors. When experienced without the support of caring adults, these stressors tend to trigger toxic stress responses in children.[47] Children exposed to prolonged adverse poverty and a buildup of unfavorable conditions (such as maternal depression, overcrowding, substandard housing, and family turbulence) often display elevated stress hormone levels.[48] Children with toxic stress exhibit higher cortisol levels, which could potentially mediate the link between these environmental factors and EF impairment. Toxic stress impacts brain architecture, particularly in regions rich in glucocorticoid receptors such as the amygdala, hippocampus, and prefrontal cortex. This leads to discernible differences in learning, memory, and EFs.[49] Caregivers, whether parents or providers, play a critical role in modulating stress hormone production during a child's formative years. Their empathetic and attentive support acts as a protective barrier against exposure to stress hormones. These practices hold special significance for vulnerable children by preventing activation of the stress system. Inappropriate parenting practices could potentially mediate the connection between risk factors and EF impairments.

When considering future public policies that could improve the development of EFs in children, particularly those exposed to negative events or insecure environments in LMICs, it becomes imperative to underscore the role of positive influences in their early life experiences. A recent meta-analysis of 102 randomized controlled trials demonstrated the impact of parenting interventions in this context, revealing more pronounced effects on child cognitive development in LMICs when compared to HICs.[50] Notably, this meta-analysis highlighted the effectiveness of interventions that prioritize parental sensitivity and responsiveness, and showed that their impact on cognitive development was three times greater in LMICs. Interventions which included parenting practices, child cognitive development, parental knowledge, and parent-child interactions were more effective than interventions lacking such content. This suggests that fostering a supportive and nurturing caregiving environment through targeted interventions can play an important role in mitigating the impact of negative events or insecure surroundings on children's EF development in LMICs.

The present study broadens our understanding of the risk factors associated with impaired EFs in adolescence. The data used were obtained from a large, unselected Brazilian population and acquired through the use of standardized instruments applied by trained field workers. However, it is important to consider some limitations. Disruption of the 15-year follow-up by the COVID-19 pandemic resulted in the loss of approximately 50% of the original cohort. Analysis of these losses to follow-up revealed that participants evaluated at age 15 had more favorable socioeconomic conditions in relation to the original (perinatal) sample. Thus, our analyses may be subjected to selection bias. If the sample had not suffered losses, the association found between maternal education and EF impairment might have been even stronger than that found in the present study. Finally, regarding the generalizability of our findings, it is important to note that our sample has particular demographic characteristics which should be considered when extending our results to other populations from different LMICs.

This study examined risk and protective factors related to impaired EFs in adolescence. The findings highlighted several significant predictors, with low maternal education showing the most detrimental effect on attention-related EFs at age 11 and spatial working memory at age 15. Perinatal exposures associated with maternal and birth characteristics, such as maternal black or brown skin color, low birth weight, and prematurity, were also identified as relevant risk factors. On the other hand, breastfeeding emerged as a protective factor for cognitive flexibility. These results provide evidence regarding the long-term impact of perinatal exposures on the development of EFs and can inform future public policies aiming to mitigate the negative effects of risk factors and enhance EF development, particularly among vulnerable populations.

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Disclosure

The authors report no conflicts of interest.

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