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Trajectories of attention problems in preschoolers born very preterm

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Background: Children born preterm are at heightened risk for neurodevelopmental impairment, including specific deficits in attention. Few studies have investigated change over time in attention problems prior to school entry. The current study aims to describe trajectories of attention problems from age 2 through 5 years in a cohort of children born <30 weeks of gestational age (GA), identify sociodemographic, medical, and neurobehavioral characteristics associated with attention trajectories, and test whether attention problem trajectories predict the risk of a reported attention-deficit/hyperactivity disorder (ADHD) diagnosis. **Methods:** We studied 608 infants from the Neonatal Neurobehavior and Outcomes in Very Preterm Infants (NOVI) Study, a prospective, multisite study of infants born <30 weeks of GA. Parents reported on child attention problems at ages 2, 3, 4, and 5 years using the Child Behavior Checklist and the Behavior Assessment System for Children. Sociodemographic and medical characteristics were assessed via maternal interview and medical record review. Neurobehavioral characteristics were determined using neonatal and 2-year assessments. Parent report of child ADHD diagnosis was obtained. We used latent growth curve (LGC) modeling to test our study aims. **Results:** A linear LGC model provided the best fit to the data. The average trajectory of attention problems evidenced low initial levels of symptoms and little change over time, yet there was significant heterogeneity in both initial levels and change over time. Individual differences in trajectory parameters were associated with sociodemographic, medical, environmental, and neurobehavioral characteristics. Children with higher initial levels of attention problems as well as steeper increases in attention problems over time were more likely to have a reported ADHD diagnosis. **Conclusions:** There is significant heterogeneity in trajectories of attention problems from age 2 to 5 in children born <30 weeks of GA and these differences have clinical relevance. These data could inform follow-up guidelines for preterm infants. **Keywords:** Attention problems; attention deficit hyperactivity disorder; preterm; preschool; trajectories.

Children born preterm are at heightened risk for a wide range of neurodevelopmental disorders (e.g., Song, 2023) including specific deficits in attention and executive function (Mulder, Pitchford, Hagger, & Marlow, 2009). These deficits cannot be attributed to general cognitive impairment, indicating that these neuropsychological domains constitute specific problem areas for preterm children. Deficits in attention associated with prematurity are of great clinical significance as attention-deficit/hyperactivity disorder (ADHD) is already one of the most prevalent mental health disorders of early childhood. Rates of ADHD in children born preterm are two to four times greater than in the general population (Anderson et al., 2011; Franz et al., 2018), with rates increasing with each declining week of gestation (Sucksdorff et al., 2015). Children with ADHD are at increased risk of poor long-term outcomes including academic underachievement and poor health outcomes (Nigg, 2013; Shaw et al., 2012), with a large economic impact (Doshi et al., 2012).

Multiple studies have investigated the prevalence of attention problems in children born preterm (Franz et al., 2018), yet few have assessed change over time in attention problems in this population, with the majority conducted with older children (Breeman, Jaekel, Baumann, Bartmann, & Wolke, 2016; Krasner et al., 2018; Linsell et al., 2019). Understanding trajectories of attention problems in preterm children prior to school entry could help identify preterm children at highest risk for later ADHD diagnosis and

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associated health and developmental difficulties. The dearth of research in younger children is notable, given that the latest version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5-TR) acknowledges that ADHD often manifests as early as preschool age (American Psychiatric Association, 2022). In addition, independent of average levels of attention problems, children with persistent or increasing attention problems over time have been shown to be uniquely at risk for poor academic outcomes (Krasner et al., 2018; Pingault et al., 2014), though again these findings are based on school-age children. Thus, the primary aim of this study is to describe trajectories of attention problems prior to school entry in children born <30 weeks of GA.

Among children born preterm, sociodemographic, medical, and neurobehavioral characteristics have been associated with attention problems (Downey et al., 2015; Doyle & Anderson, 2009; Linsell et al., 2019; Scott et al., 2017). Specifically, singleton birth, male sex, low socioeconomic status, maternal prepregnancy obesity, maternal tobacco use, and child neurodevelopmental impairment have been shown to be associated with increased attention problems in preterm children. Only one study to date has examined attention problems in preterm children prior to school entry (at age 2 years; Downey et al., 2015), and this study did not investigate change over time. Thus, the goal of the current study is twofold. First, we describe trajectories of attention problems from age 2 through 5 years in a cohort of children born <30 weeks of GA. We interpret the initial level of attention problems and rate of change in attention problems over time, and investigate whether there is significant heterogeneity in these trajectory parameters. Second, we investigate whether early life sociodemographic, medical, and neurobehavioral variables are associated with attention problem trajectories, to better understand risk stratification. To provide insight into the clinical relevance of early attention problem trajectories, we also test whether initial levels and rates of change in attention problems from age 2 to 5 predict the likelihood of ADHD diagnosis. We hypothesized that we would observe significant heterogeneity in attention problem trajectories and that these trajectories would be related to sociodemographic, medical, and neurobehavioral factors as well as likelihood of an ADHD diagnosis.

Methods

Design

The Neonatal Neurobehavior and Outcomes in Very Preterm Infants (NOVI) Study is a prospective, longitudinal study of infants born <30 weeks of GA. Families were enrolled from nine neonatal intensive care units (NICUs) affiliated with six universities from April 2014 to June 2016. Inclusion criteria were birth <30 weeks of GA, parental ability to read and speak English or Spanish, and residence within 3 hr of the NICU and follow-up clinic. Exclusion criteria included major congenital anomalies, NICU death, maternal age <18 years, maternal cognitive impairment, or maternal death. Researchers explained the study procedure to eligible families and obtained informed consent in accordance with each institution's review board.

Baseline demographic and medical information were obtained from maternal interview and medical record review. Certified examiners conducted neurobehavioral assessments and administered maternal questionnaires at NICU discharge and at annual follow-up visits from ages 2 to 7 years.

Participants

Of the 704 children enrolled in NOVI, 608 (86%) completed at least one assessment of attention problems between ages 2 and 5 years and were included in this analysis (Figure 1). These 608 children were primarily singletons (n = 470; 77%) with a smaller number of twins (n = 120; 20%) and higher order multiples (n = 18; 3%). Children missing attention problem data were less likely to be born to mothers who self-identified as White (29% vs. 44%, p = .01), more likely to be born to mothers who did not report their race (18% vs. 8.8%, p = .01), and less likely to be born to mothers who were obese before pregnancy (BMI ≥30; 20% vs. 36%, p = .01; Table S1).

Measures

Attention problems. Attention problems were measured using the Child Behavior Checklist 1½–5 (CBCL1½–5; Achenbach & Rescorla, 2000) at ages 2 and 3 years and the Behavior Assessment System for Children, Third Edition (BASC-3; Reynolds & Kamphaus, 2015) at ages 4 and 5 years. The CBCL ADHD Problems subscale includes six items (e.g., 'can't concentrate') that are rated on a 3-point scale from 0 (*Not True*), 1 ('Somewhat or Sometimes True'), or 2 (*Very True or Often True*). The BASC-3 Attention Problems subscale includes seven items (e.g., 'has trouble concentrating') that are rated on a 4-point scale of 0 (*Never*), 1 (*Sometimes*), 2 (*Often*), or 3 (*Almost Always*). For both CBCL and BASC, raw scores are summed and converted to normalized *T*-scores. Unlike BASC, CBCL *T*-scores are truncated to a lower bound of 50 for subscale scores. To ensure compatibility of scores across CBCL and BASC, and consistent with our prior work (Camerota et al., 2024), we similarly truncated BASC *T*-scores to a lower bound of 50 for this analysis. In our prior work, we found that CBCL ADHD Problems and (truncated) BASC Attention Problems *T*-scores were highly correlated within children and showed no mean differences, on average (Camerota et al., 2024).

In addition to parent-reported attention problems measured via CBCL and BASC, parents completed a health history questionnaire at ages 5, 6, and 7 years. This questionnaire asked parents whether a doctor or other health care provider ever told them that their child had ADHD. If parents answered 'yes' to this question at either 5, 6, and/or 7, the child was considered to have an ADHD diagnosis.

Demographic and medical characteristics. Maternal demographic information (i.e., race, ethnicity, education, relationship status) was collected via maternal interview. Socioeconomic status (SES) was calculated using the Hollingshead index (Hollingshead, 1975); families with Hollingshead level V were categorized as low SES. Mothers also self-reported tobacco use during pregnancy and prepregnancy weight and height, which were used to calculate prepregnancy obesity status (BMI > 30). Maternal prenatal depression and anxiety were determined based on whether mothers reported diagnosis, treatment, or counseling for either condition during pregnancy.

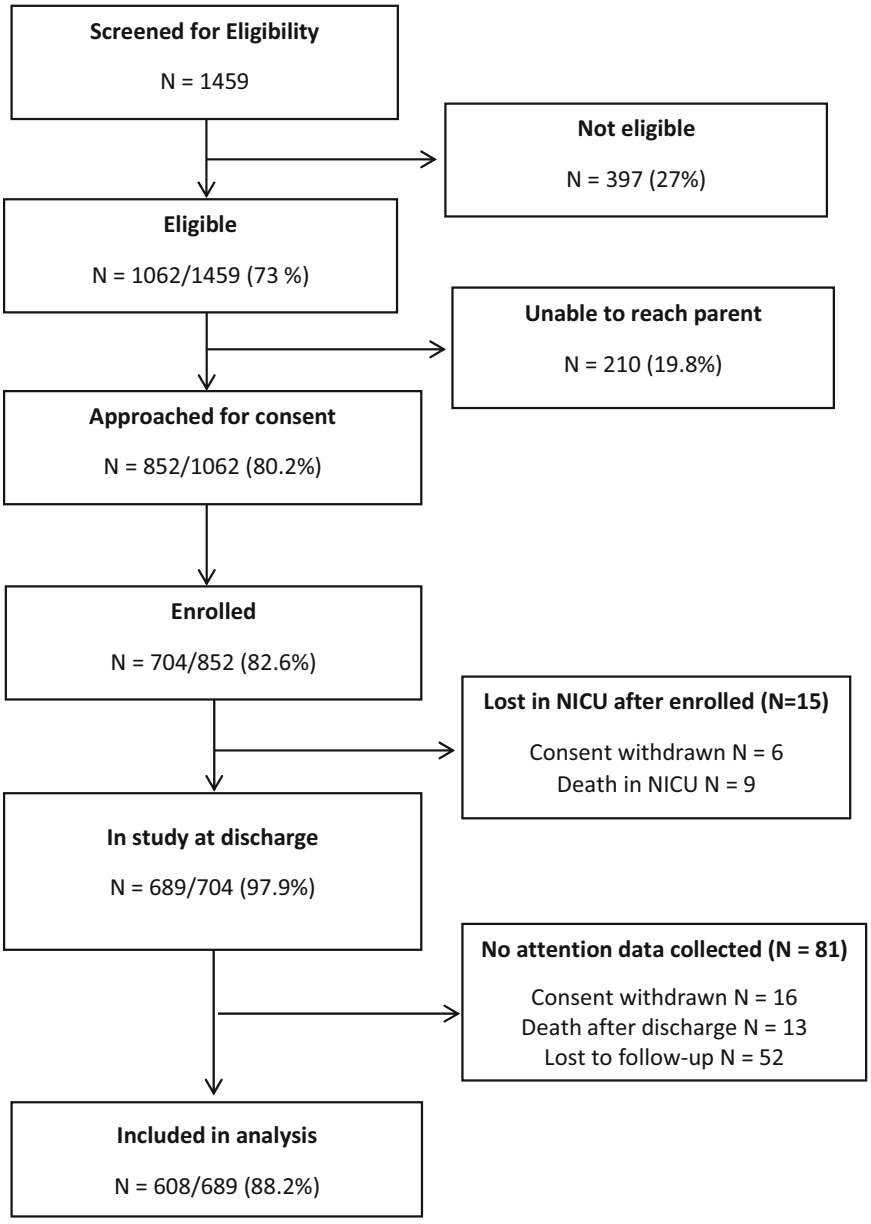

Figure 1 Study flowchart. NICU, neonatal intensive care unit

We created a cumulative postdischarge adversity index (i.e., discharge to 24 months) based on six risk factors: (a) limited socioeconomic resources, defined as household income <150% of the poverty line and/or Hollingshead level V; (b) limited child-care assistance, defined as no reported secondary caregiver; (c) caregiver psychiatric disorder, defined as primary caregiver scoring above the clinical cutoff for depression and/or anxiety (T-score ≥ 63) on the Brief Symptom Inventory (Derogatis & Melisaratos, 1983), in the mild to severe depression range (total score ≥ 6) on the Quick Inventory of Depressive Symptomology, or self-report of any diagnosis, treatment, or counseling for depression and/or anxiety; (d) family disruption/separation, defined as any reported Child Protective Services involvement; (e) high number of stressful life events, defined as the sum of stressful life events >1 *SD* above the sample mean; and (f) crowded household, defined as four or more children reported to be living in the household. A cumulative adversity index was constructed as the proportion of experienced risk factors (M = 0.24; SD = 0.20; range = 0.00–0.83).

Infant demographic and medical information were collected via maternal report and medical record review and included infant sex at birth, multiple gestation, GA at birth, birth weight, head circumference, GA at NICU discharge, and presence of neonatal medical morbidities. Medical morbidities included severe retinopathy of prematurity (stage 4 or 5 or surgery), necrotizing enterocolitis or culture-positive sepsis (early and late onset), bronchopulmonary dysplasia (requiring supplemental oxygen at 36 weeks of GA), and serious brain injury (periventricular leukomalacia, moderate to severe ventriculomegaly, or parenchymal echodensity with or without intraventricular hemorrhage). Consistent with prior work, we calculated a sum score of the four neonatal medical morbidities as an indicator of neonatal medical risk (Bassler et al., 2009; McGowan et al., 2022).

Neurobehavioral characteristics. Neonatal neurobehavior was assessed using the NICU Network Neurobehavioral Scale (NNNS), a standardized assessment of newborn muscle tone, reflexes, movement, attention, regulation, and signs of stress and abstinence (Lester & Tronick, 2004). The NNNS results in 12 summary scores. Previously, we applied latent profile analysis to NNNS summary scores to derive mutually exclusive groups of children with similar neurobehavioral

profiles (McGowan et al., 2020). Two of the six groups show evidence of neurobehavioral dysregulation: a hypo-aroused group (23%) with poor attention, low arousal, high lethargy, hypotonia, and nonoptimal reflexes, and a hyper-aroused group (7%) with poor attention, self-regulation, and quality of movement along with high arousal, excitability, hypertonia, and many stress signs.

At 2-year follow-up (mean corrected age = 25.3 months), certified examiners administered the Bayley Scales of Infant and Toddler Development, third Edition (Bayley-III; Bayley, 2006). The Bayley-III is a widely used developmental assessment that captures cognitive, fine and gross motor, and receptive and expressive language abilities. Our Bayley-III outcome measures are cognitive, motor, and language composite scores, which are norm-referenced with a mean of 100 and a standard deviation of 15 in typical populations. Scores <85 (1 *SD* below mean) indicate cognitive, motor, and/or language delay (Anderson & Burnett, 2017; Bayley, 2006; Johnson, Moore, & Marlow, 2014).

The CBCL was also administered at age 2. To understand whether other types of behavior problems were associated with attention problem trajectories, we investigated CBCL syndrome subscales of emotionally reactive, anxious/depressed, somatic complaints, withdrawn, sleep problems, and aggressive behavior. *T*-scores ≥65 were considered elevated (Achenbach & Rescorla, 2000).

Statistical analysis

First, we characterized trajectories of attention problems using latent growth curve (LGC) models. With four timepoints of data, we tested both linear and quadratic models, to understand the nature of change in attention problems from ages 2 to 5. For all models, the trajectory intercept refers to the level of attention problems at age 2 and the slope refers to the yearly change in attention problems from ages 2 to 5. We examined means of the latent intercept and slope terms to understand average levels and rates of change in attention problems across the entire sample. We examined variance in latent intercept and slope terms to understand whether there were individual differences in initial levels and rates of change in attention problems.

Using the LGC with the best fitting functional form (i.e., linear or quadratic), we tested pre-, peri-, and neonatal antecedents of attention problem trajectories. These models included maternal and infant demographic and medical characteristics, neonatal neurobehavior (NNNS hypo- and hyper-aroused profiles), and postdischarge environmental adversity. We tested each predictor's association with trajectory intercept and slope terms, first as individual predictors in unadjusted models (minimally controlling for study site) and then, for all predictors associated with either the intercept or slope term ($p < .15$), we estimated a single adjusted model. The adjusted model controlled for study site and birth GA as a priori covariates.

Separately, we investigated age 2 neurobehavioral correlates of attention problem trajectories. We first tested each correlate individually in models minimally adjusted for study site. Then, for each correlate that was associated with either the intercept or slope term ($p < .15$), we estimated a single adjusted model. The adjusted model controlled for study site and birth GA.

Finally, we extended the LGC model to test the association between attention problem trajectories and ADHD diagnosis by regressing the presence of parent-reported ADHD diagnosis on attention problem trajectory parameters. As in prior steps, we controlled for study site and birth GA. We additionally controlled for sex given well-documented sex differences in rates of ADHD diagnosis.

Data manipulation and descriptive statistics were performed using R (4.3) whereas all LGC models were estimated in Mplus (8.6). Missing data were handled using full information maximum likelihood. A robust maximum likelihood estimator was chosen to account for any deviations from normality in observed attention problem scores. All models accounted for nesting of children in families by incorporating cluster-robust standard errors.

Results

Sample description

The mean GA of children was 27 weeks (*SD* = 1.9 weeks) and 54% of children were male (Table 1). The distribution of maternal race was: <1% American Indian/Alaska Native, 4.1% Asian, 20% Black, <1% Native Hawaiian/Other Pacific Islander, 44% White, 22% Multiracial, and 8.8% unknown/not reported. In addition, 23% of mothers reported Hispanic/Latinx ethnicity. Of the 608 children with at least one assessment of attention problems between ages 2 and 5, ninety-four (15%) completed one assessment, 86 (14%) completed two, 158 (26%)

Table 1 Characteristics of the study sample

Maternal characteristics (*N* = 535)	*M* (*SD*) or % (*n*)
Minority race or ethnicity	56% (299/532)
American Indian/Alaska Native race	0.19% (1/535)
Asian race	4.1% (22/535)
Native Hawaiian/Other Pacific Islander race	0.93% (5/535)
Black or African American race	20% (105/535)
White race	44% (237/535)
More than one race	22% (118/535)
Unknown/Race not reported	8.8% (47/535)
Hispanic/Latino ethnicity	23% (124/535)
Low SES: Hollingshead level 5	9.2% (49/531)
Maternal education: <HS/GED	13% (69/530)
No partner	26% (136/531)
Pre-pregnancy obesity	36% (188/521)
Prenatal tobacco use	14% (76/531)
Prenatal depression	9% (47/521)
Prenatal anxiety	10% (53/521)
Neonatal characteristics (*N* = 608)	***M* (*SD*) or % (*n*)**
Multiple gestation	27% (163/607)
Vaginal delivery	30% (179/606)
Neonatal medical morbidities (count)	0.86 (0.87)
Severe retinopathy of prematurity	5.6% (34/607)
Necrotizing enterocolitis/sepsis	18% (109/607)
Bronchopulmonary dysplasia	50% (305/607)
Serious brain injury	12% (74/606)
Male sex	54% (330/608)
GA at birth (weeks)	27.0 (1.9)
Head circumference (cm)	24.5 (2.4)
GA at NICU discharge (weeks)	40.5 (5.4)
Length of NICU stay (days)	94.0 (43.9)
Birth weight (g)	949.5 (281)
Weight at discharge (g)	3,011 (904)

Minority race or ethnicity was defined as any non-White race (e.g., Black, Asian) or ethnicity (e.g., Hispanic and/or Latino/a). Serious brain injury included parenchymal echodensity, periventricular leukomalacia, or ventricular dilation diagnosed via cranial ultrasound. GA, gestational age; GED, General Equivalency Diploma; HS, high school; NICU, neonatal intensive care unit; SES, socioeconomic status.

completed three, and 270 (44%) completed all four. Between 10% and 11% of children had attention problem *T*-scores ≥65 at each time point, indexing clinically elevated problems. Approximately 15% of children had a reported ADHD diagnosis.

Characterizing trajectories of attention problems from ages 2 to 5

First, we estimated an unconditional LGC model to characterize the change in attention problems from ages 2 to 5. A linear growth model fit the data well, $\chi^2(5) = 2.39$, $p = .79$, CFI = 1.00, RMSEA (90% confidence interval) = 0.00 (0.00 to 0.04), SRMR = 0.04. The intercept mean ($\mu_{INT} = 54.8$, $p < .001$) indicates that the mean attention problem *T*-score at age 2 was 54.8. The nonsignificant slope estimate ($\mu_{SLOPE} = 0.21$, $p = .08$) indicates that, on average, there was little to no yearly change in attention problems across ages 2–5. However, the variance of the intercept ($\varphi_{INT} = 29.78$, $p < .001$) and slope ($\varphi_{SLOPE} = 2.94$, $p < .001$) were both significant, indicating significant individual differences around the average trajectory. For example, even though the mean slope did not differ significantly from 0, children's individual slope estimates ranged from −3.38 to 4.48, indicating large individual differences in the rate of change in attention problems. Their latent intercept and slope were inversely correlated ($\varphi_{INT,SLOPE} = -0.36$, $p < .001$) indicating that, on average, children who had more attention problems at age 2 had a steeper decline in attention problems between ages 2 and 5.

We next tested whether a quadratic growth model fit better than the linear model. Though a quadratic model indicated adequate model fit [$\chi^2(1) = 1.68$, $p = .20$, CFI = 1.00, RMSEA (90% confidence interval) = 0.03 (0.00 to 0.12), SRMR = 0.01], the mean ($\mu_{QUAD} = -0.01$, $p = .95$) and variance ($\varphi_{QUAD} = 0.28$, $p = .74$) of the quadratic slope did not differ significantly from 0, indicating that a quadratic slope was not necessary to adequately characterize the trajectory shape. Thus, we determined the linear model provided the best fit to the data.

To visualize heterogeneity, we plotted model-implied attention problem trajectories for a random sample of 50 children (Figure 2). For descriptive purposes, we classified individuals as having stable (within 1 *SD* of the mean slope; blue line), increasing (>1 *SD* above the mean slope; green line), or decreasing (<1 *SD* below the mean slope; red line) trajectories. Of the 608 children, 467 (77%) had stable slopes, while 70 (11.5%) had increasing and 71 (11.7%) had decreasing slopes. Some trajectories of attention problems crossed into or out of the clinically elevated range ($T \geq 65$).

Pre-, peri-, and neonatal predictors of attention trajectories

Next, we examined the association of pre-, peri-, and neonatal predictors and attention problem trajectories using conditional LGC models (Table 2). In unadjusted models, lack of maternal relationship partner during pregnancy ($\beta = .28$, $p < .001$), multiple gestation ($\beta = -.17$, $p < .001$), maternal prepregnancy obesity ($\beta = .11$, $p < .05$), maternal prenatal tobacco use ($\beta = .14$, $p < .01$), and cumulative environmental adversity ($\beta = .37$, $p < .001$) were significantly associated with the latent intercept, whereas male sex ($\beta = -.19$, $p < .01$), birth head circumference ($\beta = -.17$, $p < .05$), and hyper-aroused NNNS profile ($\beta = -.13$, $p < .05$) were significantly associated with the latent slope.

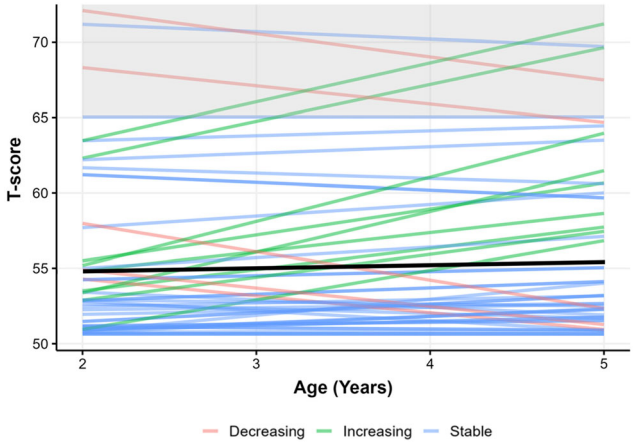

Figure 2 Model-implied trajectories. Model-implied trajectories are shown for a random sample of 50 participants, based on parameters from the linear latent growth curve model. For descriptive purposes, we classified individuals as having stable (within 1 *SD* of the mean slope; blue line), increasing (>1 *SD* above the mean slope; green line), or decreasing (<1 *SD* below the mean slope; red line) trajectories. The black line depicts the average trajectory across the entire sample ($N = 608$). The threshold for clinically elevated scores ($T \geq 65$) is shaded in gray

In the adjusted model (Table 2), multiple gestation ($\beta = -.12$, $p < .01$) was associated with lower intercepts (fewer attention problems at age 2) whereas lack of maternal relationship partner during pregnancy ($\beta = .16$, $p < .01$), maternal prepregnancy obesity ($\beta = .09$, $p < .05$), and higher levels of postdischarge environmental adversity ($\beta = .28$, $p < .001$) were all associated with higher intercepts (more attention problems at age 2). In the same model, male sex ($\beta = -.18$, $p < .05$) and birth head circumference ($\beta = -.24$, $p < .05$) were both inversely associated with slope, indicating that girls and infants with smaller head circumferences had greater increases in attention problems between ages 2 and 5. The adjusted model fit the data well [$\chi^2(41) = 45.1$, $p = .30$, CFI = 0.99, RMSEA (90% confidence interval) = 0.01 (0.00 to 0.03), SRMR = 0.02]. The proportion of variance (R^2) explained by the adjusted model was .24 ($p < .001$) for the latent intercept and .12 ($p = .02$) for the latent slope.

Age 2 neurobehavioral correlates of attention trajectories

We next investigated whether age 2 Bayley and CBCL scores were associated with attention problem

Table 2 Association between pre-, peri-, and neonatal predictors and attention problem trajectories

Independent variable	Intercept (age 2)		Slope (ages 2–5 years)	
	Unadj β (95% CI)	Adj β (95% CI)	Unadj β (*SE*)	Adj β (*SE*)
GA at birth (weeks)	−.049 (−.148 to .050)	.031 (−.122 to .183)	−.104 (−.244, .036)	.063 (−.158 to .284)
Low SES (NICU discharge)	.050 (−.059 to .160)		−.007 (−.159 to .146)	
<High school degree	.059 (−.046 to .164)		.084 (−.076 to .245)	
No relationship partner	.278 (.168 to .389)***	.163 (.041 to .284)**	−.026 (−.194 to .141)	−.030 (−.207 to .147)
Male sex	.037 (−.063 to .137)	.060 (−.035 to .154)	−.194 (−.336 to −.051)**	−.176 (−.317 to −.034)*
Multiple gestation	−.168 (−.258 to −.078)***	−.119 (−.208 to −.030)**	−.001 (−.121 to .119)	.020 (−.111 to .151)
Neonatal medical morbidities	−.021 (−.123 to .082)	−.075 (−.180 to .029)	.136 (−.016 to .289)$^{+}$	.098 (−.066 to .262)
Head circumference (birth)	−.074 (−.168 to .021)$^{+}$	−.057 (−.240 to .126)	−.172 (−.310 to −.034)*	−.240 (−.460 to −.019)*
Birth weight	−.052 (−.151 to .048)	−.027 (−.195 to .141)	−.132 (−.272 to .008)$^{+}$	.077 (−.153 to .307)
GA at NICU discharge	−.044 (−.136 to .047)		.115 (−.057 to .287)	
Prepregnancy obesity	.114 (.010 to .218)*	.094 (.000 to .189)*	−.084 (−.226 to .059)	−.070 (−.208 to .069)
Prenatal tobacco use	.144 (.035 to .252)**	.078 (−.023 to .180)	−.049 (−.215 to .118)	−.019 (−.180 to .142)
Prenatal depression	.105 (−.016 to .226)$^{+}$	.057 (−.051 to .165)	−.063 (−.237 to .112)	−.032 (−.195 to .131)
Prenatal anxiety	.011 (−.091 to .113)		−.045 (−.195 to .106)	
NNNS, Hypo-aroused	.095 (−.012 to .202)	.064 (−.035 to .163)	.115 (−.043 to .273)$^{+}$	.101 (−.053 to .255)
NNNS, Hyper-aroused	.040 (−.081 to .162)	.031 (−.083 to .145)	−.130 (−.250 to −.011)*	−.109 (−.233 to .015)$^{+}$
Postdischarge adversity (0–2 years)	.371 (.274 to .468)***	.279 (.172 to .387)***	−.100 (−.258 to .058)	−.101 (−.257 to .056)

Unadjusted models investigated single predictors in association with trajectory parameters and only controlled for study site. Adjusted models additionally included a priori covariates (i.e., GA at birth) and all variables associated with trajectory parameters ($p < .15$) in unadjusted models. All models accounted for nesting of children within families. Minority race or ethnicity was defined as any non-White race (e.g., Black, Asian) or ethnicity (e.g., Hispanic and/or Latino/a). Neonatal medical morbidities is a count variable indicating presence of severe retinopathy of prematurity, necrotizing enterocolitis/sepsis, bronchopulmonary dysplasia, and/or serious brain injury. GA, gestational age; NICU, neonatal intensive care unit; NNNS, NICU Network Neurobehavioral Scale; SES, socioeconomic status. $^{+}p < .15$, $*p < .05$, $**p < .01$, $***p < .001$.

trajectories (Table 3). In unadjusted models, Bayley cognitive, language, and motor delay (β = .17 to .33, all $p < .01$) and elevated CBCL *T*-scores for all subscales (β = .24 to .66, all $p < .001$) were positively associated with the latent intercept, whereas Bayley motor delay (β = .24, $p < .01$) and elevated CBCL emotionally reactive, anxious/depressed, withdrawn, sleep problems, and aggressive behavior *T*-scores (β = −.18 to −.33, all $p < .05$) were associated with the latent slope.

In the adjusted model (Table 3), Bayley language delay (β = .16, $p < .01$) and elevated CBCL emotionally reactive, sleep problems, and aggressive behavior *T*-scores (β = .18 to .44, all $p < .05$) were associated with higher intercepts (more attention problems at age 2). In the same model, Bayley motor delay (β = .27, $p < .01$) predicted higher slope (greater increases in attention problems from ages 2 to 5) and elevated CBCL anxious/depressed and aggressive behavior *T*-scores (β = −.19 to −.22, all $p < .05$) predicted lower slope (less increase or greater decrease in attention problems from age 2 to 5). The adjusted model fit the data well [$\chi^2(35) = 54.6$, $p = .02$, CFI = 0.97, RMSEA (90% confidence interval) = 0.03 (0.01 to 0.05), SRMR = 0.03]. The adjusted model R^2 was .59 ($p < .001$) for the latent intercept and .30 ($p < .01$) for the latent slope.

Attention trajectories from age 2 to 5 in relation to childhood ADHD diagnosis

Finally, we tested whether attention trajectories from ages 2 to 5 were associated with parent-reported ADHD diagnosis. In the adjusted model, there was a significant, positive association between the latent intercept (β = .40, $p < .001$) and slope (β = .48, $p < .001$) and likelihood of an ADHD diagnosis. For every 1-*SD* increase in latent intercept, the odds ratio for an ADHD diagnosis increased by 1.50 (95% CI = 1.25 to 1.79). For every 1 − *SD* increase in latent slope, the odds ratio for an ADHD diagnosis increased by 1.62 (95% CI = 1.32 to 1.98). In the adjusted model, there was no significant association between GA at birth and likelihood of an ADHD diagnosis (β = .04, p = .61) but

Table 3 Associations between age 2 neurobehavioral correlates and attention problem trajectories

	Intercept (age 2)		Slope (ages 2–5 years)	
	Unadj β (95% CI)	Adj β (95% CI)	Unadj β (*SE*)	Adj β (*SE*)
Bayley-III, cognitive composite <85	.243 (.133 to .353)***	.032 (−.058 to .122)	.102 (−.066 to .270)	.115 (−.059 to .288)
Bayley-III, language composite <85	.333 (.231 to .435)***	.157 (.059 to .255)**	−.073 (−.231 to .085)	−.119 (−.285 to .047)
Bayley-III, Motor composite <85	.166 (.056 to .276)**	−.018 (−.103 to .067)	.239 (.070 to .408)**	.273 (.099 to .448)**
CBCL emotionally reactive $T \geq 65$	.506 (.391 to .620)***	.181 (.052 to .311)**	−.290 (−.466 to −.113)**	−.138 (−.342 to .066)
CBCL anxious/ Depressed $T \geq 65$	.380 (.243 to .518)***	.048 (−.042 to .137)	−.317 (−.505 to −.129)**	−.191 (−.380 to −.002)*
CBCL somatic complaints $T \geq 65$	.238 (.112 to .363)***	−.004 (−.081 to .072)	−.032 (−.219 to .156)	.086 (−.087 to .259)
CBCL withdrawn $T \geq 65$	.452 (.336 to .568)***	.061 (−.059 to .182)	−.213 (−.390 to −.036)*	−.075 (−.262 to .111)
CBCL sleep problems $T \geq 65$	.421 (.292 to .550)***	.204 (.109 to .299)***	−.177 (−.336 to −.017)*	−.044 (−.185 to .098)
CBCL aggressive behaviors $T \geq 65$	.656 (.561 to .752)***	.441 (.315 to .568)***	−.333 (−.495 to −.171)***	−.216 (−.424 to −.007)*

Unadjusted models investigated single predictors in association with trajectory parameters and only controlled for study site. Adjusted models additionally included a priori covariates (i.e., GA at birth) and all variables associated with trajectory parameters ($p < .15$) in unadjusted models. All models accounted for nesting of children within families. Bayley-III, Bayley Scales of Infant and Toddler Development (third edition); CBCL, Child Behavior Checklist 1½–5. $^{+}p < .15$, $*p < .05$, $**p < .01$, $***p < .001$.

there was a significantly elevated likelihood of ADHD diagnosis among boys compared to girls (OR = 2.71, 95% CI = 1.33 to 5.50).

Given the increased odds of ADHD diagnosis in boys in the sample, we explored whether the association between attention trajectories and ADHD diagnosis differed by child sex. There were no significant interactions between trajectory parameters and child sex predicting the likelihood of ADHD diagnosis ($\beta = -.05$ to $-.09$, $p \geq .44$), suggesting that these associations do not differ for boys versus girls.

Discussion

We characterized trajectories of attention problems among children born <30 weeks of GA from age 2 to 5 years and identified associated demographic, medical, and neurobehavioral characteristics. We also explored the clinical relevance of preschool attention problem trajectories by testing whether trajectory parameters predicted likelihood of an ADHD diagnosis. The average trajectory of attention problems evidenced low initial *T*-scores at 2 years (significant intercept of 54.8) as well as relative stability in scores from ages 2 to 5 (nonsignificant slope of 0.21), albeit with substantial interindividual variability. Individual differences in the intercept and slope of attention problems were associated with sociodemographic, medical, environmental, and neurobehavioral variables, and children with higher initial levels of attention problems as well as steeper increases in attention problems over time were more likely to have an ADHD diagnosis. These findings shed light on the development of attention problems in children born <30 weeks of GA and may help us understand the risk for ADHD in this population.

There are no prior studies investigating trajectories of attention problems in very preterm children during the preschool years. However, our prevalence of clinically elevated ($T \geq 65$) attention problems at age 2 (10%) is consistent with a prior study of children born <28 weeks of GA (Downey et al., 2015) which reported 8%–11% prevalence. The prevalence of reported ADHD diagnosis in our sample (15%) is also consistent with studies reporting 12%–22% prevalence in children born very preterm (e.g., Breeman et al., 2016; Johnson et al., 2010). Thus, while the average level of attention problems was low, a sizable proportion of children in our sample had clinically elevated symptoms, as evidenced both by parent rating scales as well as reported diagnoses. Regarding change in attention problems from ages 2 to 5, we found overall stability in symptoms (average slope was not significantly different from 0). Others have shown decreases in attention problems over time for children born preterm (Breeman et al., 2016; Linsell et al., 2019) and at term (Faraone, Biederman, & Mick, 2006), although those prior studies were conducted with samples spanning childhood, adolescence, and early adulthood. Our greater stability may be due to the narrower developmental period we studied compared to prior studies.

The average trajectory we describe (low initial levels of symptoms and little change over time) masks significant heterogeneity in trajectories, which others have similarly observed (e.g., Krasner et al., 2018). The significant variability in latent slopes means that some preterm children experience large decreases in attention problems across this time period, while others experience substantial increases, and these changes sometimes cross the threshold of clinical concern ($T \geq 65$). Increases in attention problems over time

were clinically relevant, predicting increased risk of ADHD diagnosis. These associations show the importance of tracking both initial levels and rates of change in attention problems across the preschool period to better predict which preterm children are at highest risk for ADHD and associated functional challenges (e.g., academic performance, well-being; Krasner et al., 2018). This information could be used to inform NICU follow-up program guidelines regarding optimal length of follow-up (up to school age; DeMauro et al., 2022) and frequency of behavioral assessments (repeated as opposed to single assessments).

Our investigation of predictors of attention problem trajectories confirmed some previously implicated risk factors and raised some novel factors for future study. A prior study similarly found that multiple gestation was associated with fewer attention problems in extremely preterm children (Downey et al., 2015), though the reason for this is unclear. Some have hypothesized that the greater social interaction afforded by same-age siblings confers developmental benefits for multiples (Lutz et al., 2012). Our identification of maternal prepregnancy obesity as a risk factor is also consistent with prior studies in both term (Sanchez et al., 2017) and preterm children (Dow et al., 2022). Finally, numerous studies report links between markers of socioeconomic status and/or environmental adversity and childhood attention problems in primarily term samples (e.g., Banerjee, Middleton, & Faraone, 2007; Chen et al., 2020) and our results are broadly consistent with this body of work. It is notable that we did not observe associations between prenatal tobacco use and attention trajectories, as tobacco use is one of the most commonly reported prenatal risk factors for ADHD (Langley, Rice, van den Bree, & Thapar, 2005; Thapar, Cooper, Eyre, & Langley, 2013). However, most prior studies have been conducted with children born at term, and genetically informed designs call into question whether these associations are causal or due to genetic confounding (Thapar et al., 2009).

Interestingly, we found that children born with smaller head circumferences had greater *increases* in attention problems, a novel finding that supports the link between small head circumference and ADHD in normative and at-risk infants (Aagaard, Bach, Henriksen, Larsen, & Matthiesen, 2018; Peterson, Taylor, Minich, Klein, & Hack, 2006). We also found that girls had greater increases in attention problems compared to boys, a counterintuitive finding given that boys tend to have more attention problems than girls in the general population (Willcutt, 2012). Whether these sex differences hold true in children born <30 weeks is less clear (Johnson et al., 2010) and worthy of future study.

Finally, we found associations between age 2 neurobehavioral characteristics and attention problem trajectories, with language and motor delay predicting more attention problems at age 2, and greater increases in attention problems from ages 2 to 5, respectively. These results are consistent with prior studies in preterm children showing that neurobehavioral deficits predict greater persistence of attention problems across childhood and adolescence (Krasner et al., 2018; Linsell et al., 2019). The associations between other CBCL subscales (e.g., emotional reactivity, sleep problems, and aggressive behaviors) and attention problem trajectories also speak to potential comorbid externalizing symptoms at age 2.

Study strengths include our relatively large, well-characterized cohort of children followed since birth and our focus on an understudied yet critical period of development during which attention problems begin to manifest. This study also has limitations. Attention problems reported by one parent may not be as reliable as multiple informant report (e.g., teacher- and parent-report) and/or expert clinician judgment (Peterson et al., 2024). Similarly, parent report of ADHD diagnosis may not be as reliable as direct clinical assessment or medical record abstraction, as parents may misremember or misinterpret medical information from their child's provider. Shared method variance may artificially enhance the association between attention problem trajectories and reported diagnosis as both were based on parental report. While alternative measures were not available during this developmental period, our study is ongoing, and objective assessments will be available at later timepoints.

Conclusion

There is significant heterogeneity in trajectories of attention problems from ages 2 to 5 in children born <30 weeks of GA. Sociodemographic, medical, environmental, and neurobehavioral variables are related to attention problem trajectories. Our findings shed light on the development of attention problems in preterm children during an understudied yet critical period preceding the transition to formal schooling. Clinicians should consider monitoring *changes* in attention problems across time, in addition to single timepoint elevations, as these could help pinpoint preterm children at highest risk for ADHD.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Table S1. Characteristics of participants included and excluded from the attention trajectory analysis.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical considerations

All study procedures complied with relevant ethical standards and the Helsinki Declaration. The Institutional Review Boards at each site approved the study protocol. Informed consent was obtained from all participants.

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Key points

- Children born <30 weeks of gestational age (GA) are at heightened risk for attention problems yet trajectories of attention problems in preschoolers born <30 weeks of GA have not yet been studied.
- We report significant heterogeneity in trajectories of attention problems from ages 2 to 5.
- Sociodemographic, medical, environmental, and neurobehavioral variables distinguish children with different attention trajectories.
- Children with elevated attention problems at age 2 and increases in attention problems from 2 to 5 are at increased risk of ADHD diagnosis.
- These findings have relevance for NICU follow-up procedures for preterm infants, especially regarding the need to track changes in attention problems over time.

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