Original research

Epilepsy and education: a nationwide cohort study

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► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/jnnp-2026-338791).

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Received 13 March 2026
Accepted 12 July 2026

ABSTRACT

Background Childhood-onset epilepsy has been linked to poor school performance but limited evidence exists for long-term educational achievement. We examined educational achievement from adolescence into adulthood in individuals with childhood-onset epilepsy compared with the general population.

Methods In this nationwide population-based cohort study using Danish registers, we included 1 195 138 individuals born between 1987 and 2005 and followed through 2023. Epilepsy before age 15 years was identified from hospital diagnoses and antiseizure medication prescriptions (n=11 758). Individuals with epilepsy were matched on sex and age to reference individuals without epilepsy, with additional propensity score matching on perinatal and parental factors. Outcomes included completion of primary school, ninth grade mean grades and attainment of higher educational levels. Adjusted ORs (aORs), mean grade differences and adjusted incidence rate ratios were estimated using multivariable regression models. Educational trajectories were assessed from age 15 to 35 years.

Results Compared with reference individuals, those with epilepsy had higher odds of not completing primary school (aOR 3.0, 95% CI 2.8 to 3.1) and lower grades in mathematics (−0.9, 95% CI −0.9 to −0.8) and language (−0.6, 95% CI −0.6 to −0.5). Educational attainment rates were reduced by 50%–56% across all higher levels, and only 9.3% of individuals with epilepsy attained the highest educational level versus 19.5% of matched reference individuals by age 35 years.

Conclusions Childhood-onset epilepsy was associated with significantly lower primary school completion rates, grades and long-term educational attainment. Targeted assessment of academic capacity, interventions and support are needed to optimise outcomes for young people with epilepsy.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Childhood-onset epilepsy is associated with poorer school performance, particularly among children with complicated epilepsy or neurodevelopmental and psychiatric comorbidities.
⇒ Early educational achievement is a strong predictor of long-term academic performance and success.

WHAT THIS STUDY ADDS

⇒ People with childhood-onset epilepsy had consistently worse early academic performance and significantly lower long-term educational attainment compared with matched references without epilepsy.
⇒ The poorest outcomes were observed in people with very early-onset epilepsy, brain lesions and neurodevelopmental disorders, but also for children with epilepsy without these conditions, the long-term educational achievement was significantly reduced.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The results emphasise the importance of systematic academic assessment and tailored educational support to optimise outcomes for young people with epilepsy.

INTRODUCTION

Epilepsy affects approximately 0.5%–1% of children in high-income countries.[1–4] Epilepsy has a wide range of clinical manifestations and complex aetiologies,[5] and may be accompanied by neurodevelopmental comorbidities, such as autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), cerebral palsy and intellectual disability.[6 7] Further, cognitive challenges in children with epilepsy may include impaired attention and concentration.[8 9]

Previous studies have demonstrated poorer school performance in national tests during primary school[10] and loss of working years[11] in people with epilepsy compared with the general population. However, although epilepsy is among the most common neurological disorders in childhood, only few large-scale studies on long-term educational outcomes exist.[12 13] Importantly, the long-term impact of epilepsy, epilepsy subtypes and psychiatric comorbidities on educational trajectories remains insufficiently characterised.

This is a nationwide study of the association of childhood-onset epilepsy with educational performance and attainment up to 35 years of age. We quantified educational achievement from adolescence into adulthood and examined how epilepsy subtypes and psychiatric comorbidities influence long-term educational outcomes.

MATERIALS AND METHODS

Study design and data sources

In this register-based cohort study, we included all children born in Denmark between 1 January 1987 and 31 December 2005, who had known parents, and were residing in Denmark at age 15 years.

We retrieved information from Danish nationwide registers and linked this through the personal

Linked

► http://dx.doi.org/10.1136/jnnp-2026-339491

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To cite: Wimberley T, Trabjerg BB, Dreier JW, *et al*. *J Neurol Neurosurg Psychiatry* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/jnnp-2026-338791

identification number assigned to all Danish residents since 1968. Individual-level information on civil status, date of birth and death, emigration from Denmark and parental links were obtained from the Danish Civil Registration System.[14] Hospital diagnoses (main and secondary) relied on International Classification of Diseases (ICD) codes and were obtained from the Danish Psychiatric Research Register (since 1969)[15] and the Danish National Patient Register (since 1977),[16] with outpatient contacts since 1995. Prescription data were obtained from the Danish National Prescription Register since 1995.[17] Educational outcomes were obtained from the Population Education Registers.[18]

Epilepsy

Childhood-onset epilepsy was defined as epilepsy with onset before age 15 years (hereafter referred to simply as 'epilepsy'). A diagnosis of epilepsy was based on one of the two following register-based criteria: (1) ≥2 hospital-based inpatient or outpatient epilepsy diagnosis codes ≥7 days apart (ICD-8 code 345 (excluding 345.29); ICD-10 code G40); or (2) ≥1 epilepsy diagnosis code and ≥1 filled prescription for antiseizure medication (Anatomical Therapeutic Chemical codes N03A or N05BA09). Children were considered unaffected until meeting the full components of the criterion. On the date of first fulfilment of the diagnostic criteria, epilepsy cases were categorised, in line with previous register-based definitions of epilepsy subtypes as[10]: (1) early-onset epilepsy (onset <3 years); (2) complicated epilepsy (onset ≥3 years with pre-existing intellectual disability or any condition identified as a possible underlying cause: cerebral palsy, brain tumour, traumatic brain injury, stroke, selected malformations, infections or selected conditions originating in the perinatal period (ICD codes in online supplemental table 1); and (3) uncomplicated epilepsy (onset ≥3 years and no such conditions). Children with uncomplicated epilepsy were further divided, when possible, into focal epilepsy (ICD-8: 345.3, ICD-10 G40.0-2) and generalised epilepsy (ICD-8: 345.09–10, ICD-10: G40.3).

Comorbid psychiatric disorders

Epilepsy with psychiatric comorbidity[6 7] was defined hierarchically based on diagnoses given before 15 years of age into: (1) no epilepsy (reference), (2) epilepsy and intellectual disability, (3) epilepsy and ASD, (4) epilepsy and ADHD, (5) epilepsy and anxiety, (6) epilepsy and other psychiatric disorders and (7) epilepsy and no psychiatric disorders (ICD codes in online supplemental table 1).

Educational outcomes

First, we identified those who completed primary school (corresponding to primary and lower secondary education level or at least 10 years of compulsory schooling (preparatory school class through ninth grade) before their 17th birthday). Next, among those with registered final exam scores (ninth grade) in mathematics and language (Danish), we calculated weighted average scores for mathematics and for language, respectively.[19 20] Each test was graded on a 7-point scale (12, 10, 7, 4, 2, 0, −3) with European Credit Transfer System (ECTS) equivalents (A, B, C, D, E, Fx, F),[21] where a score of ≥2 indicates a passing result. Grades recorded before 2007 had a 13-point scale and were converted to the 7-point scale for consistency.[22] Mean grade scores were also converted to z-scores to represent performance on a standardised scale. Third, we defined longer-term educational outcomes by the registered date for the highest attained educational level at all ages from 15 to 35 years, registered annually on October 1. Education levels were categorised as attainment of (1) primary school; (2) high school or vocational training; (3) short-cycle or medium-cycle higher education (bachelor's); and (4) long-cycle higher education (master's degree) or PhD. Our classification aligns with previous categorisation of highest attained education in the Danish Population Education Registers,[18 23] as well as international classifications from the International Standard Classification of Education (ISCED)[24] and the Organization for Economic Co-operation and Development (OECD).[25]

Covariates

All analyses were adjusted for sex and birth year. Fully adjusted analyses additionally included the following factors (table 1): firstborn status, birth weight, Apgar score, gestational age at birth and parental factors at childbirth, including parental origin, maternal age, maternal and paternal education level, household income, parental epilepsy and parental psychiatric diagnoses. Missing data were minimal, occurring only for perinatal factors (1%) and were addressed by creating a separate category for missing values.

Statistical analysis

First, in the entire cohort, we used logistic regression to estimate adjusted ORs (aOR) for the association between epilepsy and completing primary school by age 17 years. Second, we used linear regression to estimate the adjusted mean differences (aDiff) in final exam grades for mathematics and language (ninth grade). To interpret associations on a common scale, we repeated the linear regression analysis using the standardised (z-scored) grades. Third, we defined a 1:1 age-matched and sex-matched reference cohort without epilepsy using exposure density sampling,[26] and a 1:1 propensity score (PS)-matched reference cohort without epilepsy to minimise confounding[27] based on logistic regression models with all the above-mentioned covariates, nearest-neighbour matching and with scores re-estimated within the matched sample to improve balance (*matchit* package in R).[28] To visualise the impact of epilepsy on education levels across age, we calculated proportions of highest attained education across ages 15–35 years for those with epilepsy and matched references. Individuals were followed until age 35 or end of study (31 December 2023), whichever comes first. Fourth, we calculated incidence rates for attainment of education levels beyond primary school, following individuals from their 15th birthday until death, emigration/disappearance, end of study or educational outcome, whichever came first. For the epilepsy cohort as well as the matched reference cohorts, incidence rates were calculated in intervals of 0.5 years from age 15 to age 36, and smoothed curves were drawn using penalised B-spline smoothing[29] with 100 knots and a smoothing parameter of 0.2. Additionally, we plotted incidence rates by time since the previous education level, with only individuals who attained that level contributing risk time, and rates calculated in one-year intervals before smoothing the curves. Finally, based on the entire cohort, adjusted incidence rate ratios (aIRRs) were estimated by Poisson regression models. Individuals were censored at first event of death, emigration, disappearance, or end of study or attainment of higher-ranked education level.

All analyses were run with basic adjusted (sex and birth year) and fully adjusted models, and estimates were accompanied by 95% CIs. Main analyses were repeated including interaction with sex in the models for sex-specific estimates and for the epilepsy exposure categorised into epilepsy subtypes and by psychiatric

Table 1 Characteristics of children with and without epilepsy before age 15

		Epilepsy			
	No epilepsy	All	Early-onset*	Complicated†	Uncomplicated‡
Characteristics	N (%)	N (%)	N (%)	N (%)	N (%)
Total	1 183 380	11 758	2561	1767	7430
Sex					
Female	576 222 (48.7)	5507 (46.8)	1174 (45.8)	751 (42.5)	3582 (48.2)
Male	607 158 (51.3)	6251 (53.2)	1387 (54.2)	1016 (57.5)	3848 (51.8)
Birth year					
1987–1990	230 050 (19.4)	2213 (18.8)	333 (13.0)	377 (21.3)	1503 (20.2)
1991–1995	325 405 (27.5)	3236 (27.5)	707 (27.6)	508 (28.8)	2021 (27.2)
1996–2000	318 845 (26.9)	3274 (27.8)	803 (31.4)	485 (27.5)	1986 (26.7)
2001–2005	309 080 (26.1)	3035 (25.8)	718 (28.0)	397 (22.5)	1920 (25.8)
Firstborn, yes	522 452 (44.2)	5255 (44.7)	1200 (46.9)	797 (45.1)	3258 (43.9)
Birth weight, g					
<2500	56 907 (4.8)	1057 (9.0)	315 (12.3)	265 (15.0)	477 (6.4)
2500–2999	137 557 (11.6)	1616 (13.7)	382 (14.9)	268 (15.2)	966 (13.0)
3000–3999	764 078 (64.6)	7014 (59.7)	1446 (56.5)	984 (55.7)	4584 (61.7)
≥4000	214 648 (18.1)	1948 (16.6)	386 (15.1)	232 (13.1)	1330 (17.9)
Missing	10 190 (0.9)	123 (1.1)	32 (1.3)	18 (1.0)	73 (1.0)
Apgar score at 5 min					
10	1 084 116 (91.6)	10 210 (86.8)	2117 (82.7)	1414 (80.0)	6679 (89.9)
8–9	68 547 (5.8)	917 (7.8)	239 (9.3)	187 (10.6)	491 (6.6)
0–7	16 910 (1.4)	468 (4.0)	169 (6.6)	133 (7.5)	166 (2.2)
Missing	13 807 (1.2)	163 (1.4)	36 (1.4)	33 (1.9)	94 (1.3)
Gestational age at birth, weeks					
<37	69 100 (5.8)	1122 (9.5)	307 (12.0)	261 (14.8)	554 (7.5)
≥37	1 102 853 (93.2)	10 511 (89.4)	2229 (87.0)	1490 (84.3)	6792 (91.4)
Missing	11 427 (1.0)	125 (1.1)	25 (1.0)	16 (0.9)	84 (1.1)
Parental factors					
Parental origin					
Both Danish	1 000 412 (84.5)	10 019 (85.2)	2158 (84.3)	1484 (84.0)	6377 (85.8)
One Danish	99 658 (8.4)	915 (7.8)	217 (8.5)	142 (8.0)	556 (7.5)
Both foreigner or missing	83 310 (7.0)	824 (7.0)	186 (7.3)	141 (8.0)	497 (6.7)
Maternal age at birth, years					
<25	214 605 (18.1)	2431 (20.7)	550 (21.5)	389 (22.0)	1492 (20.1)
25–34	818 700 (69.2)	7828 (66.6)	1701 (66.4)	1144 (64.7)	4983 (67.1)
≥35	150 075 (12.7)	1499 (12.8)	310 (12.1)	234 (13.2)	955 (12.9)
Paternal age at birth, years					
<25	103 748 (8.8)	1195 (10.2)	261 (10.2)	190 (10.8)	744 (10.0)
25–34	758 088 (64.1)	7385 (62.8)	1586 (61.9)	1096 (62.0)	4703 (63.3)
≥35	321 544 (27.2)	3178 (27.0)	714 (27.9)	481 (27.2)	1983 (26.7)
Maternal education§					
Primary	308 752 (26.1)	3750 (31.9)	839 (32.8)	610 (34.5)	2301 (31.0)
High school or vocational	520 225 (44.0)	4928 (41.9)	1094 (42.7)	698 (39.5)	3136 (42.2)
Short-cycle or medium-cycle	261 192 (22.1)	2246 (19.1)	468 (18.3)	328 (18.6)	1450 (19.5)
Long-cycle or PhD	60 843 (5.1)	524 (4.5)	85 (3.3)	75 (4.2)	364 (4.9)
Missing	32 368 (2.7)	310 (2.6)	75 (2.9)	56 (3.2)	179 (2.4)
Paternal education§					
Primary	276 054 (23.3)	3199 (27.2)	715 (27.9)	498 (28.2)	1986 (26.7)
High school or vocational	583 934 (49.3)	5697 (48.5)	1255 (49.0)	861 (48.7)	3581 (48.2)
Short-cycle or medium-cycle	186 792 (15.8)	1610 (13.7)	347 (13.6)	239 (13.5)	1024 (13.8)
Long-cycle or PhD	93 537 (7.9)	800 (6.8)	149 (5.8)	96 (5.4)	555 (7.5)
Missing	43 063 (3.6)	452 (3.8)	95 (3.7)	73 (4.1)	284 (3.8)
Household income¶, quintiles					
Lowest	235 235 (19.9)	2698 (23.0)	600 (23.4)	450 (25.5)	1648 (22.2)
Second	235 402 (19.9)	2532 (21.5)	550 (21.5)	400 (22.6)	1582 (21.3)
Third	235 622 (19.9)	2312 (19.7)	473 (18.5)	333 (18.9)	1506 (20.3)

Continued

Table 1 Continued

Characteristics	No epilepsy	Epilepsy			
		All	Early-onset*	Complicated†	Uncomplicated‡
	N (%)	N (%)	N (%)	N (%)	N (%)
Fourth	235 785 (19.9)	2149 (18.3)	462 (18.0)	301 (17.0)	1386 (18.7)
Highest	235 910 (19.9)	2023 (17.2)	464 (18.1)	277 (15.7)	1282 (17.3)
Missing	5426 (0.5)	44 (0.4)	12 (0.5)	6 (0.3)	26 (0.4)
Parental epilepsy**, yes	16 158 (1.4)	537 (4.6)	102 (4.0)	69 (3.9)	366 (4.9)
Parental psychiatric disorders††, yes	58 906 (5.0)	785 (6.7)	202 (7.9)	127 (7.2)	456 (6.1)

*Early-onset epilepsy was defined as epilepsy at age <3 years, with epilepsy defined as in online supplemental table 1.
†Complicated epilepsy was defined as epilepsy onset age ≥3 years with pre-existing intellectual disability or any condition identified as a possible underlying cause: cerebral palsy, brain tumour, traumatic brain injury, stroke, selected malformations, infections or selected conditions originating in the perinatal period (ICD codes in online supplemental table 1).
‡Uncomplicated epilepsy was defined as onset age ≥3 years and no such conditions, and was further divided into focal epilepsy (ICD-8 code 345.3; ICD-10 codes G40.0-2),and generalised epilepsy (ICD-8 codes 345.09–10; ICD-10 code G40.3).
§Parental education was defined as the highest attained education level at time of birth of the index child.[18 23] Categories corresponded to those used as the child's outcome, with a separate category if the information was missing.
¶Household income was defined as the equivalised disposable household income after taxes and interest+imputed rental value of own housing at time of birth of the index child.[23 37] Categorised in quintiles if non-missing; separate category if missing.
**Parental epilepsy was defined as having a registered epilepsy diagnosis (ICD-8 code 345 (excl. 345.29); ICD.10 code G40) before the birth of the index child.
††Parental psychiatric disorders were defined as having a registered psychiatric disorder diagnosis (ICD-8codes 290–315; ICD-10codes F00-F99)before the birth of the indexchild.
ICD, International Classification of Diseases.

comorbidities. All analyses and plots were done in SAS V.9.4 or R V.4.4.1.

Patient and public involvement

Patients and the public were not directly involved in the design of this study, but the Danish Epilepsy Association supported the study. Unpublished findings have been presented at professional conferences for educators and social workers and shared with families affected by epilepsy through patient advocacy organisations.

RESULTS

A total of 1 195 138 15-year-olds (51.3% males) were included in the entire cohort of whom 11 758 (1.0%) were diagnosed with epilepsy (median age at onset 7.4 years (IQR 3.5–10.7 years; males 53.2%). Information on final exam grades in primary school was available for 1 092 980 individuals (91.5%; epilepsy 0.67%) for mathematics and for 1 083 374 individuals (90.6%; epilepsy 0.66%) for language. Children with epilepsy compared with children without epilepsy were more likely to have had adverse birth outcomes such as low birth weight, Apgar score and gestational age at birth, younger parents and lower parental education and income—most pronounced for children with complicated epilepsy (table 1). Similar differences were seen in the sex-matched and age-matched reference cohort, while differences were negligible to the PS-matched cohort, indicating successful matching (online supplemental table 2).

Primary school completion and final exam performance

Among 11 758 children with epilepsy, 1400 (11.9%) did not complete primary school before age 17 years compared with 45 451 (3.8%) of 1 183 380 children without epilepsy. In the fully adjusted model, epilepsy was associated with an increased likelihood of not completing primary school (aOR 3.0 (95% CI 2.8 to 3.1)). This association was more pronounced in females (aOR 3.8 (3.4 to 4.1)) than in males (aOR 2.5 (2.3 to 2.7)). Children with early-onset epilepsy (aOR 3.7 (3.3 to 4.1)) or complicated epilepsy (aOR 3.9 (3.4 to 4.4)) had higher relative risks of not completing primary school compared with uncomplicated epilepsy (aOR 2.5 (2.3 to 2.7)). Among children with uncomplicated epilepsy, there was no significant difference between generalised (aOR 2.6 (2.1 to 3.1)) and focal epilepsy (aOR 2.3 (1.9 to 2.6)). In those with psychiatric comorbidities, having intellectual disability (aOR 4.8 (4.3 to 5.4)) and ASD (aOR 5.3 (4.1 to 6.7)) was associated with the highest ORs of not completing primary school (figure 1A). Numbers, proportions and basic adjusted estimates are shown in online supplemental table 3.

Final exam grades in primary school were lower in children with epilepsy compared with children without epilepsy for both mathematics (mean 5.8 vs 6.7) and language (mean 6.3 vs 7.0) resulting in aDiff of −0.9 (95% CI −0.9 to −0.8) for mathematics and −0.6 (−0.6 to −0.5) for language. Sex-differences were observed for final exam grades in language with stronger associations for girls than for boys. Differences were significant even in uncomplicated epilepsy (mathematics: −0.8 (−0.9 to −0.8); language: −0.6 (−0.7 to −0.5)), with strongest association for generalised (vs focal) epilepsy. Lower mean scores were found in individuals with epilepsy without psychiatric comorbidity compared with individuals without epilepsy (mathematics: −0.8 (−0.8 to −0.7) and language: −0.5 (−0.6 to −0.5)), but not surprisingly it was more pronounced for epilepsy with severe psychiatric comorbidity such as intellectual disability (mathematics: −3.1 (−3.7 to −2.6), language: −1.9 (−2.4 to −1.4)) and ADHD (mathematics: −2.5 (−2.9 to −2.1), language: −1.5 (−1.8 to −1.1)) (figure 1B). Numbers, mean grades and basic adjusted estimates are shown in online supplemental table 4. Standardised mean differences of final exam grades were 0.3 and 0.2 SDs lower for children with epilepsy compared with children without epilepsy for mathematics and language, respectively, and particularly lower for epilepsy with comorbid intellectual disability; 1.0 SD for mathematics and 0.7 SD for language (online supplemental table 5).

Highest attained education level across age

Individuals with epilepsy on average reached lower levels of education throughout adolescence and young adulthood than the matched reference individuals without epilepsy. Proportions across ages are visualised in figure 2 and selected proportions are

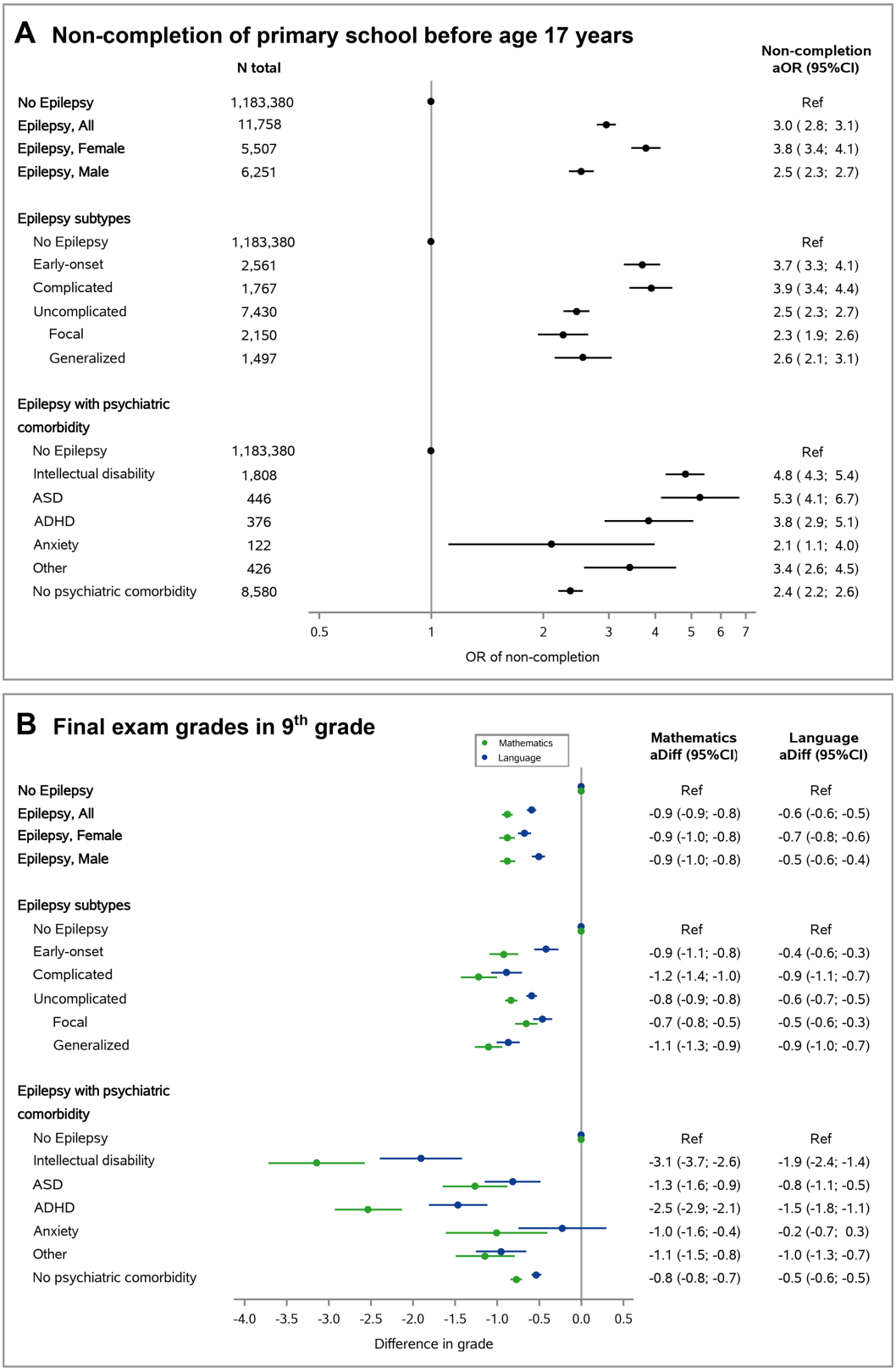

Figure 1 Associations of childhood-onset epilepsy with primary school non-completion and final exam grades. (A) Analyses were based on the entire cohort of 1 195 138 individuals. Among people with epilepsy, 11.9% did not complete primary school (females 10.4%; males 13.2%); among people without epilepsy, 3.8% did not complete primary school (females 2.7%; males 5.0%). (B) Information on final exam grades in primary school were available for 1 092 980 individuals (91.5%; epilepsy 0.7%) for mathematics and 1 083 374 individuals (90.6%; epilepsy 0.7%) for language. Numbers, proportions and mean grades across all subcategories are presented in online supplemental table 3 and online supplemental table 4. Estimates were adjusted for the following variables: sex, birth year, firstborn status, birth weight, Apgar score, gestational age at birth and parental factors at childbirth, including parental origin, maternal age, maternal and paternal education level, household income, parental epilepsy and parental psychiatric diagnoses. aDiff, adjusted mean difference; ADHD, attention-deficit/hyperactivity disorder; aOR, adjusted OR; ASD, autism spectrum disorder; Ref, reference group.

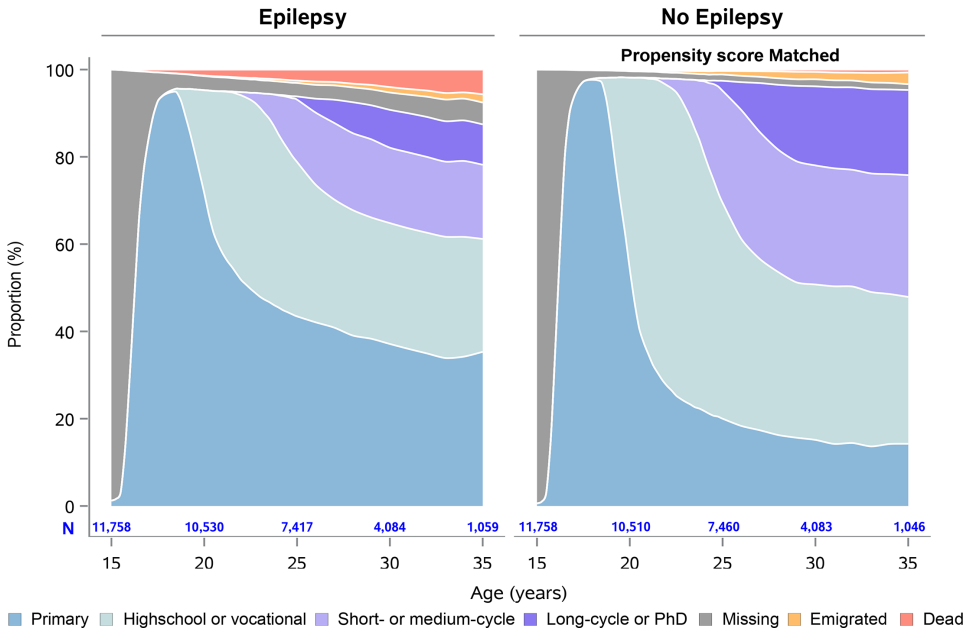

Figure 2 Proportion of highest attained education level by age in people with childhood-onset epilepsy and matched reference cohort. Numbers on the horizontal axis (denominator for proportions) correspond to the total number of individuals available in the register with the given age, who have not yet reached the maximum follow-up, 31 December 2023. Primary education levels include primary and lower secondary levels. Short-cycle or medium-cycle education includes bachelor's degrees and education of <5 years in standard nominal duration. Long-cycle and PhD include master's degree or education of at least 5 years in standard nominal duration. The propensity score matching included the following variables: sex, birth year, firstborn status, birth weight, Apgar score, gestational age at birth and parental factors at childbirth, including parental origin, maternal age, maternal and paternal education level, household income, parental epilepsy and parental psychiatric diagnoses.

presented in online supplemental table 6. For example, among those aged 30 years, 37.1% of individuals with epilepsy did not reach higher educational levels than primary school, compared with 15.1% in the PS-matched cohort. Among those aged 35 years, 9.3% of the epilepsy cohort had completed a long-term education compared with 19.5% in the PS-matched cohort. Importantly, mortality was substantially higher among those with epilepsy; 5.7% of individuals with epilepsy died before age 35 compared with 0.7% in the PS-matched cohort (figure 2). The corresponding results for the age-matched and sex-matched reference cohort are presented in online supplemental figure 1 and online supplemental table 6.

Rates of educational attainment across age

Rates of completing higher educational levels beyond primary school were significantly lower for those with epilepsy compared with those in the PS-matched cohort without epilepsy (figure 3 and online supplemental table 7). Adjustment for a range of baseline characteristics using PS-matching or covariate adjustment accounted for more than age and sex alone but did not explain the observed differences in rates (online supplemental figure 2). Multivariable time-to-event analyses confirmed this association across all three education levels, indicating approximately twofold lower completion rates among those with epilepsy compared with those without epilepsy (high school or vocational training: aIRR=0.44, 95% CI 0.43 to 0.45; short or medium-cycle education: aIRR=0.50, 95% CI 0.48 to 0.52; and long-cycle or PhD education: aIRR=0.47, 95% CI 0.43 to 0.51) (figure 4 and online supplemental table 8). Effect sizes for early-onset epilepsy and complicated epilepsy represented a stronger negative association compared with uncomplicated epilepsy for all educational outcomes. Stronger associations were observed for generalised epilepsy than for focal epilepsy, particularly for education levels beyond high school. Psychiatric comorbidities were associated with significantly lower completion rates (figure 4, online supplemental tables 7 and 8).

Among individuals who completed primary school, the median age at completion was 16.2 years (IQR: 15.9–16.6) in those with epilepsy and 16.1 years (IQR: 15.9–16.4) in PS-matched reference individuals. A similar and only slight upward shift in age distribution among individuals with epilepsy was observed for age at completion of higher educational levels (figure 3). After resetting the time from 'age' to 'time since lower education level', the difference in attainment rates in individuals with and without epilepsy was diminished, indicating that among those with epilepsy who successfully complete an education level, the association of epilepsy with progressing to the next educational level was attenuated (online supplemental figure 3).

DISCUSSION

In this large nationwide cohort, children with epilepsy had threefold higher odds of not completing primary school and lower final exam grades compared with peers without epilepsy. Young people with childhood-onset epilepsy were also less likely to achieve higher educational levels; among those aged 35 years, more than one third had not completed any education beyond primary school, compared with 12%–14% in the reference cohorts. Mortality accounted for an important proportion of this underachievement with nearly 6% of individuals with epilepsy dying before age 35 years. There was significant heterogeneity in the underachievement of individuals with epilepsy, and among those completing high school level, rates of attaining higher educational levels approached those of their matched peers without epilepsy. A schematic summary of the key findings is provided in online supplemental figure 4.

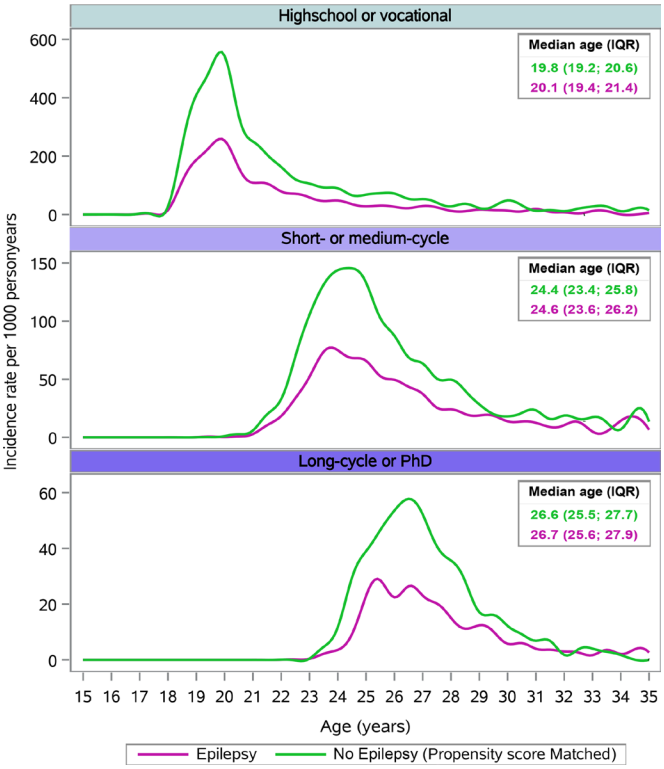

Figure 3 Incidence rates of attained education by age in people with childhood-onset epilepsy and matched reference cohort. Incidence rates were calculated by age 15– 35 years in 0.5 year intervals for the epilepsy cohort (pink, solid line), and the propensity score-matched cohort (light green, solid line), both based on 11 758 individuals at age 15 years. Curves were smoothed using penalised B-spline smoothing.[29] Median age with IQR were calculated among those attaining the education level. The propensity score-matching included the following variables: sex, birth year, firstborn status, birth weight, Apgar score, gestational age at birth and parental factors at childbirth, including parental origin, maternal age, maternal and paternal education level, household income, parental epilepsy and parental psychiatric diagnoses. Incidence rates with the time scale reset to time since the last attained education level are shown in online supplemental figure 3.

Our findings align with previous studies, including Danish,[12] Australian,[13] Finnish[30] and Canadian[31] cohorts showing reduced educational attainment in persons with epilepsy. However, this study extends existing evidence by examining both academic performance and long-term educational attainment in over one million young individuals, considering sex, age at onset, epilepsy subtype and psychiatric comorbidities. Using PS matching and multivariable modelling, we demonstrated that associations between epilepsy and various educational outcomes persisted after accounting for multiple confounding factors.

Comorbidity is common in children with epilepsy, particularly cognitive, psychiatric and behavioural problems,[3 6 32] and was strongly associated with worse educational outcomes in this study. As expected, academic achievement was lowest in children with complicated epilepsy (ie, presumed underlying brain pathology) or psychiatric comorbidities, particularly intellectual disability, ASD or ADHD. However, importantly, we found that even children with uncomplicated epilepsy, particularly generalised epilepsy, performed significantly worse than children without epilepsy, indicating that educational disadvantage is not limited to the most severely affected subgroups with epilepsy. Importantly, the attenuated differences in long-term education completion rates observed after conditioning on completion of prior educational levels suggest that a substantial subgroup of individuals with epilepsy may maintain educational trajectories comparable to peers without epilepsy. Future studies should investigate factors associated with preserved educational trajectories and resilience among young people with epilepsy.

Early-onset epilepsy was associated with poorer educational outcomes in the present study, consistent with previous studies on special educational needs,[33] school performance[10] and long-term educational attainment.[12] This likely reflects substantial comorbidity in children with neonatal or infantile-onset epilepsy,[34] many of whom have an underlying structural brain lesion or genetic cause.[5 35] Sex-differences were observed in the present study, with stronger associations between epilepsy and poor educational outcomes in girls, despite boys having higher rates of early-onset and complicated epilepsy. This suggests that epilepsy severity alone is unlikely to explain the observed educational disadvantage. The stronger association in girls may partly reflect lower baseline grades among boys and higher psychiatric comorbidity rates among boys in the general population, while boys with the most severe epilepsy were more likely to attend special needs schools, and therefore excluded from analyses. Nevertheless, the mechanisms underlying these sex differences remain uncertain and warrant further investigation.[13]

Strengths and limitations of this study

Important strengths include the population-based cohort design with prospectively collected information, which minimises risks of selection and information bias. Long-term follow-up and linkage across health and education registers enabled detailed subgroup analyses by epilepsy subtypes[4] and psychiatric comorbidity,[3] and the consistency of results across multivariable adjustment and PS matching supports their validity.

Several limitations should be considered. First, our study did not include information on seizure frequency, seizure control and antiseizure medication adherence, which may influence academic performance.[10] Second, analyses of the final grades in primary school were limited to students who completed the exams, likely excluding many children attending special needs schools or who were exempted from exam, which may lead to conservative estimates and limit generalisability to all children with epilepsy. However, we identified epilepsy in 0.67% of the entire population suggesting that we may capture a high proportion of the entire population with epilepsy.[4] Third, psychiatric comorbidity was based on hospital diagnoses, capturing mainly the most severe cases.[36] Fourth, our study is based on the Danish system, where education and healthcare are universally free, potentially limiting generalisability, though population-based registers and broad education measures reduce selection bias and improve comparability across high-income countries. Our supplementary analysis using standardised z-scores also improves the study's relevance for educational achievement internationally. The education system has changed over time,[23] and with follow-up spanning 2002–2023, residual time trends may remain, as older participants were born in earlier years. Conversion from the 13-point to 7-point grading scale in 2007 may also have reduced precision slightly.[22] Finally, HRs should be interpreted as conditional on survival. However, our descriptive analyses include death as a separate outcome category, providing observed proportions across educational and mortality trajectories rather than treating death as loss to follow-up.

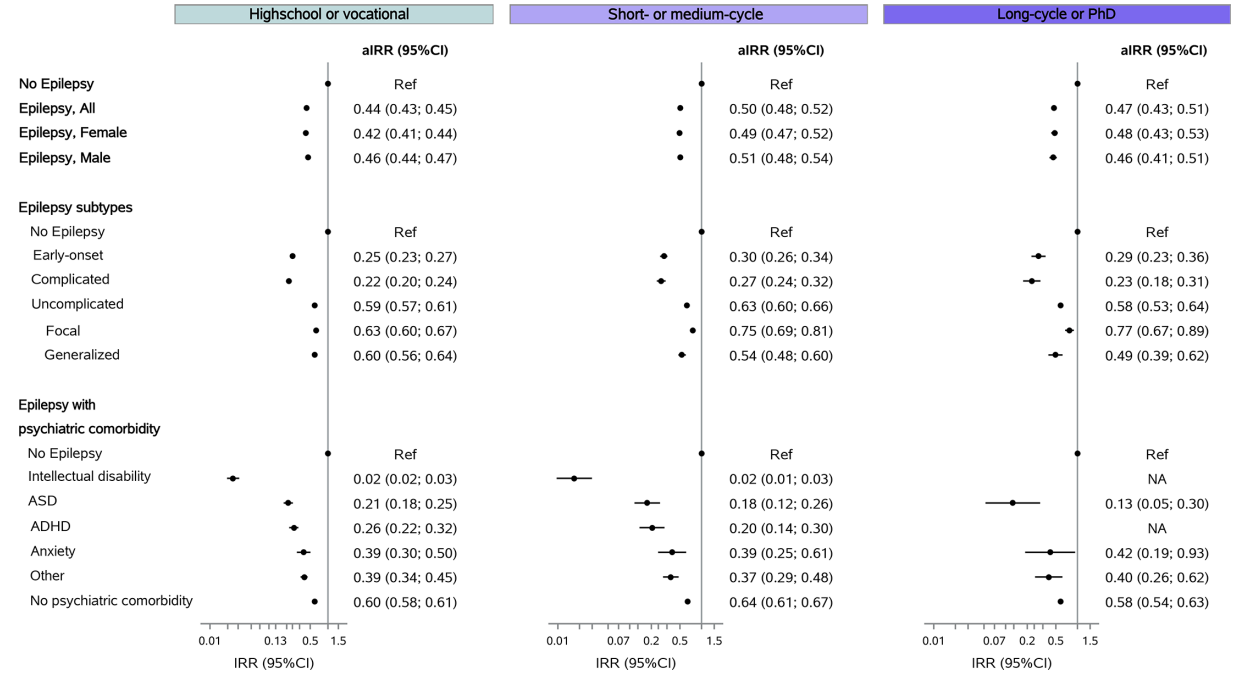

Figure 4 Associations between childhood-onset epilepsy and attained education levels. Incidence rate ratios were calculated in the entire study population of 1 195 138 individuals regardless of whether they attained the entrance-qualifying education or not. Estimates were adjusted for the following variables: sex, birth year, firstborn status, birth weight, Apgar score, gestational age at birth and parental factors at childbirth, including parental origin, maternal age, maternal and paternal education level, household income, parental epilepsy and parental psychiatric diagnoses. An aIRR below 1 corresponds to a decreased rate of educational attainment in individuals with childhood-onset epilepsy. Number of cases attaining each education level, total person-years and crude incidence rates are shown in online supplemental table 7 and basic aIRRs are shown in online supplemental table 8. ADHD, attention-deficit/hyperactivity disorder; aIRR, adjusted incidence rate ratio; ASD, autism spectrum disorder; NA, not applicable; Ref, reference group.

CONCLUSIONS

Our findings underscore the need for assessment of academic capacity as well as targeted intervention, integrating educational and psychosocial support to optimise the educational potential for young people with childhood-onset epilepsy. Future research should examine mechanisms underlying educational under-achievement, including seizure frequency and seizure control, use of antiseizure medication, underlying genetic causes and school-based interventions.

Contributors TW, BBT, JWD and JC all played a major role in the concept and design of the study. TW drafted the first version of the manuscript. BBT performed the statistical analyses. JWD, BBT and JC provided administrative, technical or material support. JC obtained funding. JWD and JC supervised the study. All authors contributed to the acquisition, analysis or interpretation of data and critically revised the manuscript for important intellectual content. The corresponding author (TW) attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. TW is the guarantor. The authors used ChatGPT (OpenAI, version GPT-5, accessed February 2026) for language editing. All scientific content, interpretations and conclusions were developed by the authors, who critically reviewed and approved the final manuscript and accepted full responsibility for the final content.

Funding The study was supported by Savværksejer Jeppe Juhl og hustru Ovita Juhls Mindelegat, the Novo Nordisk Foundation (NNF16OC0019126 and NNF22OC0075033), the Lundbeck Foundation (R400-2022-1205) and The Independent Research Fund Denmark (4253-00007B and 5336-00100B). Researchers were independent from funders.

Disclaimer The guarantor (TW) affirms that the manuscript is an honest, accurate and transparent account of the study being reported; that no important aspects of the study have been omitted, and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Competing interests JC received honoraria from serving on the Scientific Advisory Board of UCB Nordic and Eisai AB, honoraria from giving lectures from UCB Nordic and Eisai AB and funding for a trip from UCB Nordic.

Patient consent for publication Not applicable.

Ethics approval The study was approved by The Danish Data Protection Agency, Statistics Denmark and The Danish Health Data Authority. According to Danish legislation, informed consent is not required for registry linkage studies. All data were deidentified and could not be used to identify individuals.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. This study used data from Danish national registers. Due to legal and privacy regulations, individual-level data cannot be shared. Summary statistics beyond those presented in the Results section and Supplementary Material may be available upon reasonable request. Access to the original data requires application to the relevant Danish authorities in accordance with national protection legislation.

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