Household income and maternal education in early childhood and activity-limiting chronic health conditions in late childhood: findings from birth cohort studies from six countries

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ABSTRACT

Background We examined absolute and relative relationships between household income and maternal education during early childhood (<5 years) with activity-limiting chronic health conditions (ALCHC) during later childhood in six longitudinal, prospective cohorts from high-income countries (UK, Australia, Canada, Sweden, Netherlands, USA).

Methods Relative inequality (risk ratios, RR) and absolute inequality (Slope Index of Inequality) were estimated for ALCHC during later childhood by maternal education categories and household income quintiles in early childhood. Estimates were adjusted for mother ethnicity, maternal age at birth, child sex and multiple births, and were pooled using meta-regression.

Results Pooled estimates, with over 42 000 children, demonstrated social gradients in ALCHC for high maternal education versus low (RR 1.54, 95% CI 1.28 to 1.85) and middle education (RR 1.24, 95% CI 1.11 to 1.38); as well as for high household income versus lowest (RR 1.90, 95% CI 1.66 to 2.18) and middle quintiles (RR 1.34, 95% CI 1.17 to 1.54). Absolute inequality showed decreasing ALCHC in all cohorts from low to high education (range: −2.85% Sweden, −13.36% Canada) and income (range: −1.8% Sweden, −19.35% Netherlands).

Conclusion We found graded relative risk of ALCHC during later childhood by maternal education and household income during early childhood in all cohorts. Absolute differences in ALCHC were consistently observed between the highest and lowest maternal education and household income levels across cohort populations. Our results support a potential role for generous, universal financial and childcare policies for families during early childhood in reducing the prevalence of activity limiting chronic conditions in later childhood.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The association of activity limiting chronic conditions in childhood with low family socioeconomic status (SES) is well established.
⇒ The effect of exposure to low SES during early childhood on activity limiting chronic conditions in later childhood is under-researched.
⇒ Relative and absolute inequalities in activity limiting chronic conditions from prospective studies in child populations in different countries have not been reported.

WHAT THIS STUDY ADDS

⇒ High family SES, measured by either household income or maternal education in early childhood, is associated with lower relative risk of activity limiting chronic conditions in later childhood in all six high-income countries studied.
⇒ Absolute inequality in activity limiting chronic conditions by household income and maternal education is present across the child populations in all six countries showing the potential for reduction in prevalence associated with exposure to improved income and maternal education in early childhood.
⇒ The low absolute inequality by income and maternal education in the Swedish cohort supports a potential role for generous, universal financial and childcare policies for families during early childhood in reducing the prevalence of activity limiting chronic conditions in later childhood.

INTRODUCTION

Activity-limiting chronic health conditions (ALCHCs) in childhood are a heterogeneous group of conditions with diverse aetiologies and lifetime courses combining genetic, biological and social-environmental factors.[1] Individual activity-limiting chronic conditions, such as asthma[2] and cerebral palsy,[3] have internationally agreed diagnostic criteria, coded in the International Classification of Diseases (ICD). Standardised methods for studying aetiology, prevalence and risk factors can be derived based on the diagnostic criteria.[4 5] However, to study the prevalence and correlates of disabling conditions in child populations, a generic, all-cause measure encompassing many different conditions is required.[6] Halfon *et al*[7] propose using the activity-limitation measure definition

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study has implications for the six included countries as all demonstrate varying levels of inequality associated with early childhood income and maternal education.
⇒ The potential causal role of early SES in activity-limiting chronic health condition (ALCHC) during later childhood should include studies examining the effect of policy changes that improve financial or educational circumstances within populations on ALCHC.
⇒ Further research is needed to identify the mediating pathways between SES and ALCHC in different countries employing the most advanced effect decomposition analysis accounting for potential exposure-induced mediator outcome confounding.
⇒ Practitioners working with children with ALCHC should take account of the impact of low income and maternal education in their case management.
⇒ The study findings suggest a potential role for generous, universal financial and childcare policies for families during early childhood in reducing the prevalence of activity limiting chronic conditions in later childhood.

developed in the US National Health Interview Surveys that they characterise as 'an environmentally contextualised health-related limitation in a child's existing or emergent capacity to perform developmentally appropriate activities and participate, as desired, in society' (p.32).

The focus on function in the activity-limiting measure is consistent with the International Classification of Functioning, Disability and Health-Children and Youth Version, which moves the focus of childhood disability from medical diagnosis to a broader social and environmental context.[8] However, to operationalise the measure of all-cause ALCHC, the groups of conditions encompassed by the measure must be specified. Box 1 shows the groups of conditions specified by Halfon *et al*.[7] Conditions associated with episodic activity-limitation (eg, asthma) are included, along with those associated with more continuous limitation of normal age appropriate activity (eg, hearing and vision problems).

Box 1 Conditions associated with limitations in usual activities (activity limiting) derived from Halfon et al,[7] Table 3 (p.24); categories are not mutually exclusive; more than one condition could contribute to activity limitation

⇒ Speech problem
⇒ Learning disability
⇒ ADHD
⇒ Other mental, emotional or behavioural problem
⇒ Other developmental problem
⇒ Asthma/breathing problem
⇒ Birth defect
⇒ Bone/joint/muscle problem
⇒ Hearing problem
⇒ Vision problem
⇒ Mental retardation
⇒ Epilepsy/seizures
⇒ Injuries

ALCHCs impose a heavy burden on children, their families and society. Newacheck and Halfon[9] estimated that, in the USA, these conditions are responsible for 60 million restricted activity days, including 24 million days lost from school annually in the 1990s, 26 million physician contacts, and 5 million hospital days annually. Estimates of prevalence in the UK[10 11] and Australia[12] range between 7% and 10% of children and youth under 19 years of age.

The association of social disadvantage with ALCHC was examined in a systematic review and meta-analysis of studies in high-income countries between January 1991 and December 2013.[13] The pooled random effects ORs estimate for low socio-economic status (SES) by all-cause ALCHC was 1.72 (95% CI 1.48 to 2.01), based on 29 studies. Subsequent studies confirm this relationship.[1 14–17] Despite this body of evidence, there are gaps in the literature with few studies examining the associations of early childhood disadvantage with ALCHC during later childhood or adolescence.[1 18] Few studies have compared the association across child populations in different countries.[17]

The Elucidating Pathways Of Child Health inequalities (EPOCH) study draws on data from birth cohort studies across high-income countries to explore the pathways from early SES exposure to child health outcomes during later childhood. Outcomes investigated include Attention Deficit Hyperactivity Disorder (ADHD),[19] oral health[20] and obesity,[21] among others. This current project within the larger EPOCH study explores pathways to ALCHCs in six prospective cohort studies based in six countries.

METHODS

Data sources

Secondary data analysis was undertaken in six cohorts participating in the EPOCH study: UK Millennium Cohort Stud; Alla Barn i Sydöstra Sverige (All Babies in South-East Sweden); Longitudinal Study of Australian Children K-cohort; Generation R Rotterdam, the Netherlands; National Longitudinal Study of Children and Youth, Canada and National Longitudinal Survey of Youth Children and Young Adults, USA. One of the EPOCH study cohorts, the Quebec Longitudinal Study of Child Development, was not included in this paper as a comparable composite measure of ALCHC could not be derived from the cohort dataset. Cohort profiles and cohort technical report references are shown in table 1. All cohorts enrolled population-based samples of children at birth or within the first 4 years of life. The Swedish cohort, based on medical records, had the highest complete case rate (96.0%). Complete case rates for the remaining cohorts varied between 83.6% (Netherlands) and 60.9% (Canada). (Note, these complete case rates are intentionally overly conservative, reflecting complete cases for all variables included in current analyses.) Weights accounting for differential attrition and non-response were applied in all cohorts except the Swedish cohort.

Study variables

Activity-limiting chronic health conditions

ALCHC are chronic conditions that have lasted or are expected to last more than 4 months and limit the child's normal daily activities (eg, attend school, complete schoolwork, participate in physical activities). Data on ALCHC were collected from parents by questionnaire in five cohorts (UK, Australia, Canada, Netherlands, USA) and extracted from medical records (ICD codes) in the Swedish cohort. Data for ALCHC were collected at age 10/11 years in all cohorts, except for the Netherlands where activity limitation questions were asked at 5/6 years. Full details

Table 1 Cohort profiles*

Cohort country/region baseline year	Age at baseline and cohort follow-up†	Sampling methodology	Sample size (N) baseline and 10/11 years complete case rate‡ (%)	Weighting and imputation for attrition
MCS[38] UK 2000	Baseline (Sweep 1): 9 months Sweep 2: 3 years Sweep 3: 5 years Sweep 4: 7 years Sweep 5: 10/11 years	► All children born between 1 September 2000 and 31 August 2001 (for England and Wales), and between 24 November 2000 and 11 January 2002 (for Scotland and Northern Ireland), alive and living in UK at age 9 months, and eligible to receive child benefit at that age ► Eligibility based on government child benefit records (ie, nearly universal coverage); asylum seekers not eligible ► Subgroups intentionally oversampled (living in disadvantaged areas, ethnic minorities)	Baseline: 18 552 10/11 years (Sweep 5): 13 354 Complete Cases: 71.6%	► Weights applied ► Imputation for differential attrition
ABIS[39] Southeast Sweden 1997 to 1999	Baseline (Sweep 1): Birth Sweep 2: 1 year Sweep 3: 2.5 years Sweep 4: 5 years Sweep 5: 8 years Sweep 6: 10–12 years	► All children born between 1 October 1997 and 30 September 1999 in a defined region in southeast of Sweden were invited	Baseline: 17 055 Diagnoses available from Patient Register at age 11 years for 16 365 Complete Cases: 96.0%	► No weights applied ► No imputation
LSAC K[40] Australia 2004	Baseline (Wave 1): 4–5 years Wave 2: 6–7 years Wave 3: 8–9 years Wave 4: 10–11 years	► National sample using two-stage random sampling design: (1) random selection of 10% of postcodes, stratified by state and urban/rural locations, (2) random selection of in-age children within those postcodes from Medicare (universal healthcare) database ► Excluded remote postcodes and postcodes with <20 children (n=874 postcodes, 3.2% of population)	Baseline: 4983 10–11 years (Wave 4): 4164 Complete cases: 83.6%	► Weights applied to account for differential attrition ► No imputation
GenR[41] Rotterdam, The Netherlands 2002 to 2006	Baseline (Wave 1): Birth-4 years ('Preschool Period': 2 months, 6 monthss, 1 year, 1.5 years, 2 years, 3 years, 4 years) Wave 2: 5–6 years Wave 3: 9–10 years	► Pregnant women who expected to deliver between April 2002 and January 2006, living in Rotterdam, who visited a midwife or obstetrician were eligible for participation and contacted by GenR staff	Baseline: 9749 5–6 years (Wave 2): 8305 Complete cases: 85.2%	► Weights applied to account for differential attrition ► No imputation
NLSCY[42] Canada 2000–2004	Baseline: birth to 11 months Cycle 2: 2 years Cycle 3: 4 years Cycle 4: 6 years Cycle 5: 8 years Cycle 6: 10 years	► Sampling conducted in collaboration with Canada's Labour Force Survey and National Population Health Survey ► Sampling stratified by province to select a representative sample of children in Canada	Baseline: 2227 10 years (cycle 6): 1356 Complete cases: 60.9%	► Weights applied to account for differential attrition and to weight back to population ► No imputation
USNLSY[43] USA 1988 to 1996	Baseline: Birth Round 2: 2 years Round 3: 4 years Round 4: 6 years Round 5: 8 years Round 6: 10 years	► Original NLSY79 cohort was cross-sectional, population representative sample born between January 1958 and December 1964; subsamples intentionally included Hispanic or Latino, black, economically disadvantaged nonblack/non-Hispanic, and military personnel ► NLSY79 Child and Young Adult cohort follows offspring born to female respondents of the original NLSY79 cohort. Analytical sample for present study was limited to children born between 1988 and 1996.	Baseline: 3657 10 years (round 6): 2578 Complete cases: 70.5%	► Weights applied to account for differential attrition and to weight back to the population ► No imputation

*Factual content about Cohort Profiles is similarly provided across all EPOCH Collaborative Group publications.
†Follow-ups specific to timeframe of present analyses (birth to age 10); several cohorts are ongoing. Follow-up terminology preserved (eg, wave, sweep); when no term given, 'wave' was used for clarity.
‡Sample size at age 10 years was based on complete cases with all variables observed to yield conservative complete case rate estimate.
ABIS, All Babies in South-East Sweden; EPOCH, Elucidating Pathways Of Child Health inequalities; GenR, Generation R; LSAC K, Longitudinal Study of Australian Children K-cohort; MCS, Millennium Cohort Study; NLSCY, National Longitudinal Study of Children and Youth ; USNLSY, National Longitudinal Survey of Youth Children and Young Adults.

of questions and harmonised chronic health conditions across cohorts are shown in online supplemental tables S1 and S2.

Socioeconomic measures (main independent variables of interest)

Household income and maternal education are two of the most common measures of SES in observational studies.[22] Household income quintiles at birth or within early life with ranges in local currency and $purchasing power parity 2000 ($PPP) were obtained for each cohort (table 2). $PPP uses international currency rates to estimate equivalent relative costs of goods and services between countries and is adjusted annually (https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm). $PPP facilitates comparison of household income across international cohorts during years by yielding a harmonised metric

Table 2 Household income data Harmonisation and quintile ranges and means by cohort*

Cohort	Child age at income assessment	Annual income (Gross or Net)	Equivalised (Yes or No)	Annual household income range and mean (local currency) and $PPP (purchasing power parities)				
				Quintile 1 Richest	Quintile 2	Quintile 3	Quintile 4	Quintile 5 Poorest
MCS UK	nine mos	Net	Yes (OECD)	Range (£ Pound Sterling)				
				>£23 863 ($PPP>33 896)	£16 843–£23 862 ($PPP23 924–$PPP33 895)	£11 944–£16 842 ($PPP16 967–23 923)	£7167–£11 944 ($PPP10 178–$PPP16 966)	<£7166 ($PPP<10 178)
				Mean (£)				
				£34 008 ($PPP48 307)	£20 346 ($PPP29 028)	£14 434 ($PPP20 489)	£9568 ($PPP13 591)	£5148 ($PPP7313)
ABIS† Southeast Sweden	1–3 years	Net	No	Range (SEK Swedish Krona)				
				>SEK346 653 ($PPP>37 844)	SEK304 698–SEK3 46 653 ($PPP33 264–$PPP37 844)	SEK274 558–SEK304 698 ($PPP29 974–$PPP33 264)	SEK235 852–SEK274 559 ($PPP25 748–$PPP29 974)	<SEK235 852 ($PPP<25 748)
				Mean (SEK)				
				SEK479 075 ($PPP 52 301)	SEK23 268 ($PPP35 291)	SEK289 508 ($PPP31 606)	SEK256 949 ($PPP28 051)	SEK177 216 ($PPP19 347)
LSAC K Australia	4–5 years	Gross	No	Range ($A, Australian Dollar)				
				>$A94 524 ($PPP>69 197)	$A68 900–$A94 380 ($PPP50 439–$PPP69 092)	$A50 725–$A68 876 ($PPP 37 134–$PPP50 422)	$A33 411–$A50 700 ($PPP24 459–$PPP37 116)	<$A33 332 ($PPP<24 401)
				Mean ($A)				
				$A138 330 ($PPP101 267)	$A80 255 ($PPP58 752)	$A59 297 ($PPP43 409)	$A42 416 ($PPP31 051)	$A23 027 ($PPP16 857)
GenR‡ Rotterdam, Netherlands	5 years	Net	Yes	Range (€ Euro)				
				>€57 600 ($PPP>49 133)	€48 000–€57 600 ($PPP40 944–$PPP49 133)	€33 600–€48 000 ($PPP28 661–$PPP40 944)	€24 000–€33 600 ($PPP20 472–$PPP28 661)	<€24 000 (<$PPP20 472)
NLSCY§¶ Canada	0–11 mos	Gross	No	Range ($C, Canadian Dollar)				
				>$C80 000 (>$PPP66 225)	$C50 000–$C79 999 ($PPP41 391–$PPP66 224)	$C40 000–$C49 999 ($PPP33 113–$PPP41 390)	$C30 000–$C39 999 ($PPP 24 834–$PPP33 112)	<$C29 999 (<$PPP24 833)
USNLSY USA	0–2 years	Net	No	Range (US$)				
				>US$86 065	US$48 459–US$86 064	US$34 678–US$48 458	US$21 968–US$34 677	<US$21 967
				Mean (US$)				
				US$89 369	US$49 384	US$35 375	US$22 585	US$10 521

*Factual content about Cohort Profiles is similarly provided across all EPOCH Collaborative Group publications.
†PPP conversion rate year 2000 9.16 kr/dollar.
‡Means not calculable as income data not continuous.
§Average $PPP conversion of 1994 and 1995. Source: https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm.
¶NLSCY restricts data release; mean data cannot be released.
ABIS, All Babies in South-East Sweden; EPOCH, Elucidating Pathways Of Child Health inequalities; GenR, Generation R; LSAC K, Longitudinal Study of Australian Children K-cohort; MCS, Millennium Cohort Study; NLSCY, National Longitudinal Study of Children and Youth; OECD, Organisation for Economic Co-operation and Development; PPP, purchasing power parity; USNLSY, National Longitudinal Survey of Youth Children and Young Adults.

that provides a more accurate and interpretable estimate about a country's overall standard of living. Four cohorts (UK, Sweden, Netherlands, USA) collected household income net of tax and transfers and two (Australia, Canada) collected gross income. Two cohorts (UK, Netherlands) reported equalised income derived using the Organisation for Economic Co-operation and Development Equivalence Scales (www.oecd.org/els/soc/OECD-Note-EquivalenceScales.pdf).

Maternal education at child's birth or within first year of life was harmonised to high, middle and low categories using the International Standard Classification of Education (ISCED): low education=ISCED I-II; middle education=ISCED III-IV; high education=ISCED V-VII.[23]

Baseline covariates and potential mediators

Cohort studies defined ethnicity using 'majority/minority' or 'born inside country/born outside country' designations; mother's ethnicity was dichotomised using these designations. Aboriginal mothers were classified as 'born in country' in the Australian cohort. Additional covariates were mother's age at child's birth, child's sex and multiple births. Mother's age at child's birth is associated with SES before conception and, as such, it could be a confounder but not a mediator of the pathway of interest. Data from the birth cohorts did not include SES before conception, which precluded our ability to test this. Potential mediators identified in published literature (smoking in pregnancy,[24] birth weight,[25] lone parenthood,[10] maternal chronic condition,[10] maternal depression[26]) that are plausibly on the SES-ALCHC pathway were excluded from the regression models to avoid blocking any of the pathway of interest and to avoid bias by conditioning on colliders.

Statistical analyses

We estimated unweighted frequencies for all variables. We estimated unadjusted and adjusted risk ratios (RRs) using a generalised linear model with a log link and robust variance estimation[27] (online supplemental file S1 includes details of data analyses in each cohort). In cohorts with lost to follow-up, either

censoring and/or sample weights were used to adjust for nonresponse and/or to make the sample comparable to its reference population. RRs were pooled using the Metafor package in R.[28] We estimated the I^2, which is the percentage heterogeneity in RRs among studies, relative to the total amount of variance. The Slope Index of Inequality (SII) was calculated for each cohort; the overall slope from data pooled across cohorts was plotted. SII represents the absolute difference in prevalence between the most advantaged and the least advantaged groups in a population. SIIs were calculated using regressions with weighted prevalence of ALCHC as the dependent variable and the cumulative midpoint of the three-category maternal educational level and household income quintiles as the predictors with the N in each category as the weight.[29] The SIIs were weighted to adjust for differential lost to follow-up in the Netherlands cohort and to weight back to the population in the Australian, Canadian, UK and USA cohorts. Whereas adjusting the RRs aimed to isolate the potential effect of income and maternal education taking covariates into consideration, unadjusted SIIs were used to reflect the absolute burden of risk across the populations

Ethics approval

Concordia University Human Research Ethics Committee certified the ethical acceptability for EPOCH's secondary data use (#2011028). Procedures of the original cohorts complied with the ethical standards of their relevant institutional and/or national committees and with the Helsinki Declaration of 1964, and its later amendments (see online supplemental file S2).

RESULTS

Sample characteristics

Samples for all cohorts were drawn from whole populations and were broadly representative of their target populations (table 1). Numbers of children with data on SES exposures in early childhood and ALCHC in later childhood and cohort sample

Table 3 Sample characteristics by cohort (unweighted frequencies)

		MCS	ABIS	LSAC K	GenR	NLSCY	USNLSY
		UK	Sweden	Australia	Netherlands	Canada	USA
Variables		(n=13 354)	(n=16 365)	(n=4164)	(n=8305)	(n=1356)	(n=3657)
Child sex (n, %)	Male	6589 (50.0)	8485 (51.9)	2034 (48.8)	4188 (50.4)	687 (51)	1881 (51.4)
	Female	6601 (50.0)	7880 (48.1)	2130 (51.2)	4117 (49.6)	669 (49)	1776 (48.6)
Mother age at child birth* (n, %)	<20	925 (6.9)	218 (1.3)	91 (2.2)	274 (3.3)	310 (22.9)	0
	20–29	5809 (43.5)	8722 (53.7)	1763 (42.3)	3339 (40.2)	451 (33.2)	1767 (48.3)
	30–39	5849 (43.8)	6996 (43.1)	2144 (51.5)	4503 (54.2)	435 (32.1)	1887 (51.6)
	40+	293 (2.2)	307 (1.9)	140 (3.4)	186 (2.2)	144 (10.6)	0
	Missing	478 (3.6)	122 (0.01)	26 (0.6)	3 (0.1)	16 (1.2)	3 (0.1)
Mother ethnicity	Terminology	Majority/minority	Majority/minority	Born in country/ born outside	Majority/minority	Born in country/born outside	Majority/minority
	Ethnic majority/ born in country	10 919 (81.8)	14 960 (91.4)	2632 (63.2)	4234 (51.0%)	1232 (91.0%)	2050 (56.1%)
	Ethnic minority/ born outside country	1623 (14.4)	1062 (6.6)	1500 (36.0)	3722 (44.8)	123 (9.0)	1607 (43.9%)
	Missing	504 (3.8)	343 (2.0)	32 (0.8)	349 (4.2)	1 (0)	0
Multiple births (n, %)	Yes	343 (2.6)	380 (2.3)	114 (2.7)	208 (2.5)	36 (3.0)	91 (2.5)
	No	12 534 (93.9)	15 985 (97.7)	4049 (97.2%)	8097 (97.5)	1283 (95.0)	3566 (97.5)
	Missing	477 (3.6)	0	1 (0.0)	0 (0)	37 (3.0)	0
Outcome: ALCHC by late childhood (n, %)	Yes	1011 (7.6)	943 (5.8)	194 (4.7)	980 (11.8)	170 (13.0)	220 (6.0)
	No	12 343 (92.4)	15 451 (94.2)	3970 (95.3)	4283 (51.6)	1137 (84.0)	2869 (78.5)
	Missing	0 (0)	0 (0)	0 (0)	3042 (36.6)	49 (4.0)	568 (15.5)
Child age at ALCHC assessment†‡§ (mean, SD)	Years	11.2 (0.48)	11.0 (na§)	10.3 (0.50)	6.18 (0.49)	10.8 (0.30)	10.5 (0.74)
Exposure: income in early childhood (n, %; by quintile)	Q1 (richest)	2299 (17.2)	3259 (19.9)	903 (21.7)	1340 (16.1)	365 (26.9)	570 (15.6)
	Q2	2483 (18.6)	3251 (19.9)	889 (21.3)	682 (8.2)	396 (29.2)	570 (15.6)
	Q3	2483 (18.6)	3250 (19.9)	849 (20.4)	1581 (19.0)	219 (16.1)	559 (15.3)
	Q4	2748 (20.6)	3251 (19.9)	806 (19.4)	904 (10.9)	259 (19.1)	452 (12.4)
	Q5 (poorest)	2829 (21.2)	3242 (19.8)	717 (17.2)	1386 (16.7)	117 (8.6)	825 (22.6)
	Missing	512 (3.8)	112 (0.7)	0 (0)	2412 (29.0)	0 (0)	681 (18.6)
Exposure: Maternal education at baseline (n, %; by three categories)	High	4176 (31.3)	5068 (31.0)	1287 (30.9)	3374 (40.6)	567 (42.0)	1073 (29.3)
	Middle	5544 (41.5)	9525 (58.2)	2296 (55.1)	2257 (27.2)	568 (42.0)	1922 (52.6)
	Low	2782 (20.8)	1379 (8.4)	555 (13.3)	1832 (22.1)	187 (14.0)	657 (18.0)
	Missing	852 (6.4)	393 (2.4)	26 (0.6)	842 (10.1)	34 (3.0)	5 (0.1)

*Mother age at child birth categories differed for NLSCY (Canada): 15–24, 25–29, 30–34, 35+, Missing. Sample size may differ from baseline N reported in table 1 due to missing data for SES exposure in early childhood or ALCHC in late childhood, or cohort attrition.
†ALCHC measured at age 10–11 years in LSAC K.
‡ALCHC measured at age 6 years in GenR.
§SD not measurable in ABIS as diagnoses made at >11 years were excluded.
ABIS, All Babies in South-East Sweden; ALCHC, activity-limiting chronic health conditions; GenR, Generation R; LSAC K, Longitudinal Study of Australian Children K-cohort; MCS, Millennium Cohort Study; NLSCY, National Longitudinal Study of Children and Youth; SES, socioeconomic status; USNLSY, National Longitudinal Survey of Youth Children and Young Adults.

Table 4 Risk ratios for ALCHC in late childhood by income and maternal education at baseline using adjusted multivariate regression

		MCS	ABIS	LSAC K	GenR	NLSCY	USNLSY
		(UK)	(Sweden)	(Australia)	(Netherlands)	(Canada)	(USA)
Exposure		Risk ratio (95% CI)					
Household Income		(n=12 648)	(n=15 902)	(n=4129)	(n=5505)	(n=1271)	(n=2578)
	Q1 (richest) (Ref)	Reference	Reference	Reference	Reference	Reference	Reference
	Q2	1.05 (0.80 to 1.39)	0.78 (0.46 to 1.33)	0.85 (0.50 to 1.43)	1.08 (0.84 to 1.39)	1.36 (0.77 to 2.4)	1.13 (0.65 to 1.95)
	Q3	1.50 (1.15 to 1.95)	0.99 (0.58 to 1.69)	1.10 (0.65 to 1.85)	1.33 (1.09 to 1.62)	1.78 (0.87 to 3.65)	1.26 (0.72 to 2.21)
	Q4	1.59 (1.22 to 2.07)	1.02 (0.59 to 1.77)	1.18 (0.70 to 2.01)	1.71 (1.39 to 2.12)	1.39 (0.71 to 2.69)	1.53 (0.87 to 2.69)
	Q5 (poorest)	1.98 (1.51 to 2.59)		1.69 (1.04 to 2.74)		3.45 (1.74 to 6.83)	2.08 (1.23 to 3.50)
Maternal education		(n=12 661)	(n=15 894)	(n=4127)	(n=5500)	(n=1261)	(n=3085)
	High (ref)	Reference	Reference	Reference	Reference	Reference	Reference
	Middle	1.33 (1.11 to 1.59)	1.08 (0.94 to 1.26)	1.34 (0.90 to 1.99)	1.22 (1.02 to 1.46)	1.64 (1.0 to 2.7)	1.38 (0.97 to 1.97)
	Low	1.62 (1.30 to 2.01)	1.61 (1.29 to 2.00)	1.92 (1.15 to 3.20)	1.18 (1.02 to 1.36)	2.19 (1.23 to 3.92)	1.62 (1.00 to 2.61)

Risk ratios adjusted for child sex, maternal ethnicity, maternal age at birth, multiple births for all cohorts. Also see online supplemental table S3. Sample sizes differ from baseline N reported in table 1 due to missing data for SES exposure in early childhood or ALCHC in late childhood or cohort attritio.
ABIS, All Babies in South-East Sweden; ALCHC, activity-limiting chronic health conditions; GenR, Generation R; LSAC K, Longitudinal Study of Australian Children K-cohort; MCS, Millennium Cohort Study; NLSCY, National Longitudinal Study of Children and Youth; SES, socioeconomic status; SES, socioeconomic status; USNLSY, National Longitudinal Survey of Youth Children and Young Adults.

characteristics by unweighted frequencies are shown in table 3. Pooled estimates relate to a total of over 42 000 children in later childhood. The prevalence of ALCHC ranged from 4.7% in the Australian cohort to 13.0% in the Canadian cohort.

$PPP for the highest (richest) income quintiles ranged from >33 896 (net, equivalised) in the UK cohort to >86 065 in the US cohort (net, non-equivalised) (table 2). In the poorest income quintiles, $PPP ranged from <10 178 in the UK cohort to <25 748 in the Swedish cohort (net, non-equivalised). Mean $PPP values by quintile were available for all cohorts except the Netherlands and Canadian cohorts (due to data release restrictions to protect participant confidentiality). Mean $PPP in the richest quintile ranged from 48 307 in the UK cohort to 101 267 in Australia (gross, non-equivalised). Mean $PPP in the poorest quintiles ranged from 7313 in the UK to 19 347 in Sweden.

The proportion of mothers with low education was highest in the Netherlands (22.1%) and UK (20.8%) cohorts and lowest in Sweden (8.4%) and Australia (13.3%). The proportion of mothers with high education was highest in Canada (42.0%) and the Netherlands (40.6%); the remaining cohorts had similar proportions (~30%). The proportion of mothers from ethnic minority groups or born outside the cohort country was highest in the Netherlands (44.8%) and lowest in Sweden (6.6%).

RRs for ALCHC

Unadjusted, bivariate RRs of ALCHC by income quintiles, maternal education categories, and all baseline confounding variables are shown in online supplemental table S3). Adjusted RRs, adjusting for all covariates, are shown in table 4. For household income quintiles, social gradients were present in all cohorts. Although the trend of increasing adjusted RRs with decreasing income was apparent in all cohorts, confidence intervals crossed unity for selected quintiles. For maternal education categories, social gradients were present in all cohorts. Unique to the Netherlands cohort, the adjusted RR for the middle education category was higher than the low education category.

Pooled estimates of the adjusted RRs are depicted in figure 1. For household income, the risk of ALCHC decreased with every incremental quintile, relative to the highest (richest) quintile; heterogeneity estimates were negligible ($Q<7$; $I^2=0\%$). For maternal education, the risk of ALCHC similarly decreased with each category, relative to the high education (ISCED V-VII) category; heterogeneity estimates were small to moderate ($Q<13$; $I^2=57.7\%$ and 24.0%, respectively).

Absolute inequality in ALCHC during later childhood confirms the advantage for children in high income households or those with more highly educated mothers in all cohorts (figure 2A,B). The steeper overall absolute inequality slope for income compared with education (figure 2A,B) is parallel with the findings of a higher pooled relative risk estimate for income than for education (figure 1). In contrast to relative inequality, absolute inequality is affected by prevalence rate of the outcome in the population. The higher prevalence of ALCHC in the Netherlands cohort accounts for the marked difference in absolute inequality by income in that cohort (−19.35%), compared with the UK and US cohorts (−6.32% and −5.94%, respectively) despite the relative risks for the lowest vs highest income quintiles being quite similar (1.92, 1.98, and 2.08, respectively; adjusted RRs in table 4). It should also be noted that while relative risks were adjusted for covariates, the SIIs were not.

Discussion

To our knowledge, this is the first published paper examining social gradients in ALCHC during later childhood, using relative and absolute measures of inequality, by household income and maternal education during early childhood in cohort studies from different high-income countries. The findings show that low household income and low maternal education in early childhood are associated with increased relative and absolute risk of ALCHC later in childhood in all cohorts. The pooled estimates showed a 90% increased risk of ALCHC in the lowest income quintile and a 54% increased risk in the low maternal education category, relative to the highest corresponding SES levels.

The pooled estimates for ALCHC by low household income (1.90, 95% CI 1.66 to 2.18) and low maternal education (1.54, 95% CI 1.28 to 1.85) observed in our study are consistent with the previously reported pooled estimate of 1.72 (95% CI 1.48 to 2.01) for all-cause chronic disabling conditions by low SES in 2015 systematic review.[13] Our study, based on comparable longitudinal data, adds to the mainly cross-sectional studies in the systematic review providing methodologically robust evidence of the association of between low SES in early childhood and greater risk for ALCHC later in the lifecourse.

Few longitudinal studies examining the association of ALCHC in later childhood with household income or maternal education measured in early childhood have been

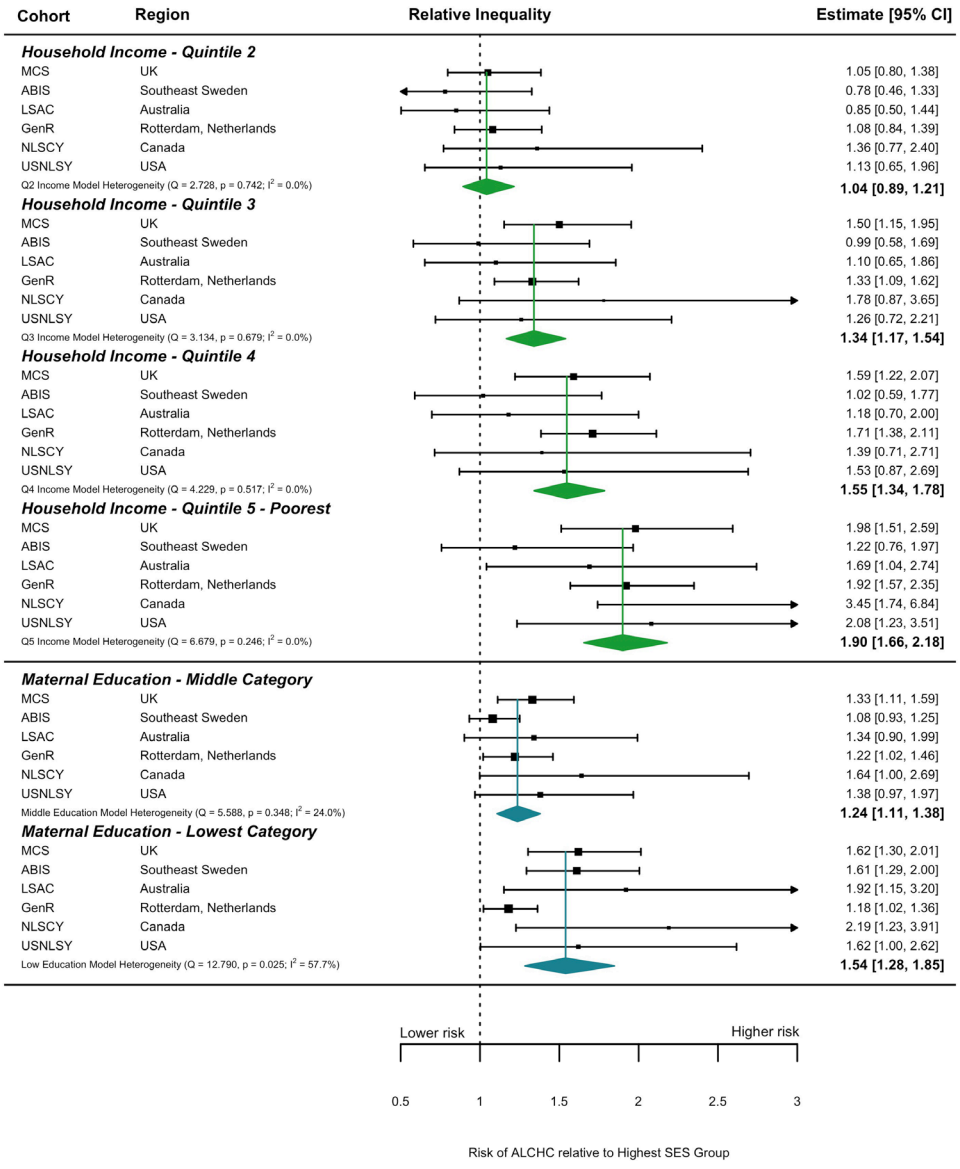

Figure 1 Forest plots by household income and maternal education (relative inequality). ABIS, All Babies in South-East Sweden; ALCHC, activity-limiting chronic health conditions; GenR, Generation R; LSAC, Longitudinal Study of Australian Children; MCS, Millennium Cohort Study; NLSCY, National Longitudinal Study of Children and Youth; SES, socioeconomic status; USNLSY, National Longitudinal Survey of Youth Children and Young Adults.

published, limiting comparison with our findings.[30] Bor *et al*[18] reported increasing likelihood of a child experiencing an activity limiting illness (chronicity not specified) if they experienced extended periods of low income in childhood. Similarly, Nikiéma *et al*[17] reported children in the UK and Quebec had an increased risk of limiting longstanding illness associated with cumulative experience of poverty in the first 4 years of life.

Interpretation

Low household income and low maternal education in a child's early years were associated with increased adjusted relative and unadjusted absolute risk of ALCHC in later childhood in all six countries. In contrast to relative inequality, absolute inequality is affected by prevalence rate of the outcome in the population. The higher prevalence of ALCHC in the Netherlands cohort accounts for the marked difference in absolute inequality by income in that cohort (−19.35%), compared with the UK and US cohorts (−6.32% and −5.94%, respectively) despite the relative risks for the lowest versus highest income quintiles being quite similar (1.92, 1.98, and 2.08, respectively; adjusted RRs in table 4).

Adjusted relative risk in the poorest income quintile varied from 3.45 (95% CI 1.74 to 6.84) in the Canadian cohort to 1.22 (95% CI 0.76 to 1.97) in the Swedish cohort. Absolute risk by income was highest in the Netherlands (−19.35%) and lowest in Sweden (−1.8%). The low relative and absolute risks in Sweden may be explained by the country having the lowest level of income inequality, as measured by the Gini Coefficient, among the six countries in 2000.[31] Consistent with this explanation, the ratio of the mean $PPP in the highest to lowest income quintile in the Swedish cohort (2.7:1) is low compared with the USA (8.5:1), Australian (6.0:1) and UK (6.6:1) cohorts. By maternal education, the relative risks in the Swedish, USA and UK cohorts were nearly identical (1.61, 1.62, 1.62, respectively) but the absolute risk in Sweden was

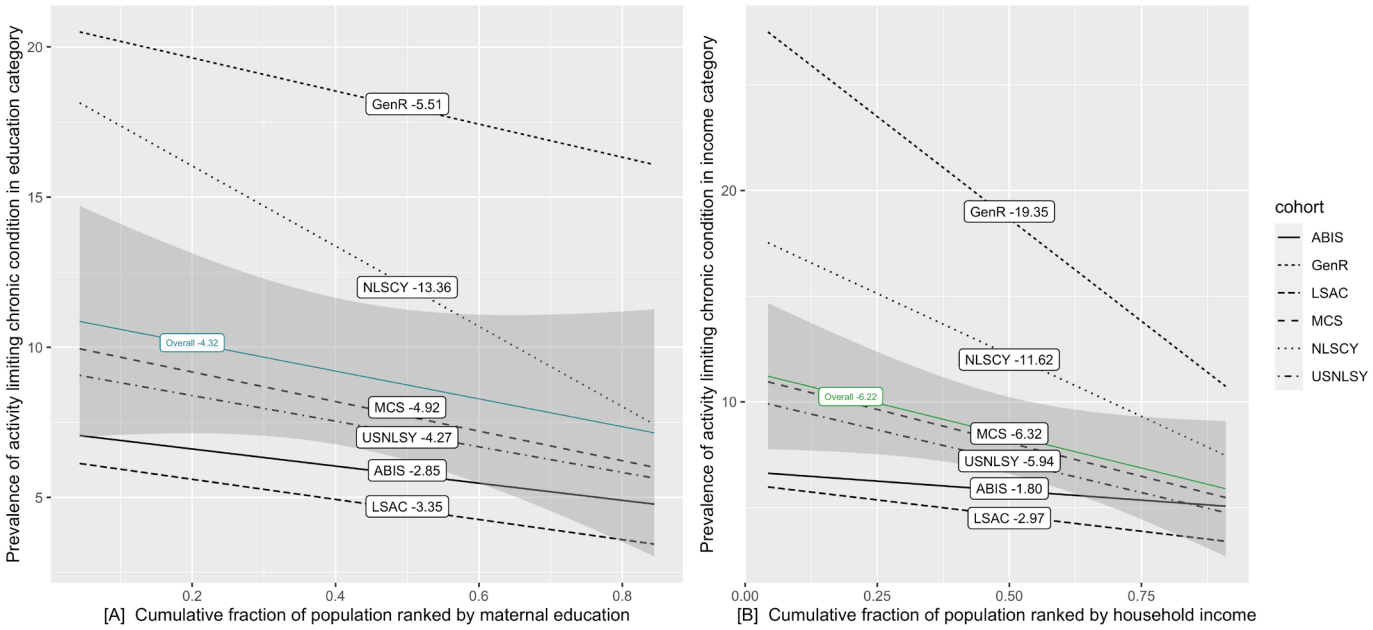

Figure 2 (A, B) Slope index of inequalities plots by household income and maternal education (absolute inequality). ABIS, All Babies in South-East Sweden; GenR, Generation R; LSAC, Longitudinal Study of Australian Children; MCS, Millennium Cohort Study; NLSCY, National Longitudinal Study of Children and Youth; USNLSY, National Longitudinal Survey of Youth Children and Young Adults.

the lowest (−2.85%) likely due to the low prevalence (8.5%) of low maternal education.

Pooled relative and absolute risks of ALCHC by income are raised more than those by maternal education suggesting income may exert a stronger influence than maternal education on ALCHC in later childhood and the mechanisms by which they exert their influence may differ. However, this interpretation is uncertain as the observed risk differences are relatively small and may reflect biases in the analysis.

Strengths and limitations

The study has several strengths. The longitudinal, prospective design using harmonised measures of income and maternal education in six cohorts enabled robust analysis of the association of early childhood SES with ALCHC in later childhood. Estimation of absolute inequality in addition to relative inequality provided a more complete account of the SES-ALCHC association.[29] Analysis of exposure to income and education in separate regression models reduced the potential for overcontrolling for SES[32] as did the exclusion of potential mediators from the regression analyses.[33]

The study also has noted limitations that should be considered when interpreting results. ALCHC were assessed via parent report in five cohorts introducing the potential for reporting bias. Despite harmonisation procedures, the inevitable variation of conditions categorised as ALCHC and differing definitions of chronicity (see online supplemental tables S1 and S2) may explain the observed variation in prevalence rates and, in addition, may have biased the associations with SES. Chronicity defined as 4 months or longer may partly explain the high prevalence in the Netherlands cohort. The Australian and Netherlands cohorts collected household income exposure data in the child's fifth year of life compared with the remaining cohorts that collected data at birth or in the first year of life. Raising a child with ALCHC has been shown to reduce household income[1] and reverse causation, due to this reduction among households with children with ALCHC during the first 5 years, may partly explain the relationship between household income and ALCHC in these two cohorts. We excluded SES-related risk factors from the regression analysis as potential mediators of the SES-ALCHC pathway; however, as distinguishing mediators and confounders is not straightforward, it is possible that we have omitted potential confounding variables.

Causal inference, policy and research implications

Income and maternal education in early childhood are likely to exert their effect on health outcomes in later childhood, such as ALCHC, through complex pathways involving inter-related risk and mediating factors acting over the early lifecourse. Our study findings and methodological design fulfil some of Bradford Hill's classical criteria for inferring causality: strength and consistency of the SES-ALCHC relationship; temporality - exposure collected up to 10 years before the outcome; biological gradient—dose–response relationship to both SES measures.[34] While the determination of causal effects is important, it is more pragmatic from a policy perspective to think of these effects as resulting from interventions.[35] If we were to give causal interpretation to policy differences of countries in which our cohorts are located (ie, that these policies are responsible for ameliorating observed differences in risk according to income and maternal education) then recommended interventions would include generous, universal financial and childcare policies for families in early childhood, which protect and enhance family incomes.[36] These might include policies to enhance women's participation in the workforce, extended parental leave for both parents paid at 80% of their normal pay and affordable universal childcare provision.[36] If a causal interpretation can be applied to the absolute risk estimates, the largest potential reduction in ALCHC prevalence due to increased maternal education levels would be observed in the Canadian and Netherlands cohorts (reduction in ALCHC: −13.36% and −5.51%, respectively); while improvement in household income would lead to the largest reductions in the same two cohorts, Netherlands and Canada (reduction in

ALCHC: −19.35% and −11.62%, respectively). Further investigation of the potential causal role of early SES in ALCHC during later childhood should include studies examining the effect of policy changes that improve financial or educational circumstances within populations on ALCHC as well as research to identify the mediating pathways between SES and ALCHC employing the most advanced effect decomposition analysis accounting for potential exposure-induced mediator outcome confounding.[37]

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