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What is the relationship between deprivation, modifiable factors and childhood deaths: a cohort study using the English National Child Mortality Database

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ABSTRACT

Objectives The aim of this analysis is to identify the patterns of social deprivation and childhood mortality; and identify potential points where public health, social and education interventions, or health policy may be best targeted.

Design Decile of deprivation and underlying population distribution was derived using Office for National Statistics data. The risk of death was then derived using a Poisson regression model, calculating the increasing risk of death for each increasing deprivation decile.

Setting England.

Participants 2688 deaths before 18 years of age reviewed between April 2019 and March 2020.

Main outcome measures The relationship between deprivation and risk of death; for deaths with, and without modifiable factors.

Results There was evidence of increasing mortality risk with increase in deprivation decile, with children in the least deprived areas having a mortality of 13.25 (11.78–14.86) per 100 000 person-years, compared with 31.14 (29.13–33.25) in the most deprived decile (RR 1.08 (95% CI 1.07 to 1.10)); with the gradient of risk stronger in children who died with modifiable factors than those without (RR 1.12 (95% CI 1.09 to 1.15)) vs (RR 1.07 (95% CI 1.05 to 1.08)). Deprivation subdomains of employment, adult education, barriers to housing and services, and indoor living environments appeared to be the most important predictors of child mortality

Conclusions There is a clear gradient of increasing child mortality across England as measures of deprivation increase; with a striking finding that this varied little by area, age or other demographic factor. Over one-fifth of all child deaths may be avoided if the most deprived half of the population had the same mortality as the least deprived. Children dying in more deprived areas may have a greater proportion of avoidable deaths. Adult employment, and improvements to housing, may be the most efficient place to target resources to reduce these inequalities.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Based on statutory death registrations.
⇒ High level of data completeness.
⇒ Detailed measures on all childhood deaths.
⇒ Limited precision due to small numbers of individual events.
⇒ Denominators based on population estimates.

BACKGROUND

The death of every child is a devastating loss that profoundly affects bereaved parents as well as siblings, grandparents, extended family members, friends and professionals. The evidence relating to social deprivation and death is strongest for infant mortality, however the effects appear measurable across the life course.[1] A systematic review examining the relationship between social factors and early childhood health and developmental outcomes provides strong evidence that factors such as neighbourhood deprivation, lower parental income, unemployment and educational attainment, lower occupational social class, heavy physical occupational demands, lack of housing tenure and material deprivation in the household are all independently associated with a wide range of adverse health outcomes.[2]

We know that early child development plays a major role in affecting future life chances and health throughout the life course[3] with adverse exposures having greater impacts on younger children.[4] While initiatives have been proposed to reduce the impact of deprivation on health[5]; babies, children and young people remain the most vulnerable in society. Currently, England has one of the highest infant mortality rates in Europe[6 7] and while much of the variation may be due to socioeconomic factors,[8] it is clear that since infant mortality among the most deprived groups continues to rise,[9] effective policies and other

Table 1 Characteristics of the populations of child deaths reviewed by CDOPs in England during 2019/2020

Measure	N	Child deaths reviewed 2019/2020
All Deaths	2688	–
Age of Death	2688	
<1 year		1675 (62.3%)
1–4 years		322 (12.0%)
5–9 years		211 (7.9%)
10–14 years		227 (8.4%)
15–17 years		253 (9.4%)
Sex	2670	
Male		1505 (56.4%)
Female		1165 (43.6%)
Area of residence	2688	
Rural		328 (12.2%)
Urban		2360 (87.8%)
Ethnicity	2390	
White		1554 (65.0%)
Asian or British Asian		427 (17.9%)
Black or British Black		188 (7.9%)
Mixed		136 (5.7%)
Other		85 (3.6%)
Region of residence	2688	
East Midlands		214 (8.0%)
East of England		211 (8.2%)
London		473 (17.6%)
North East		109 (4.1%)
North West		362 (13.5%)
South East		336 (12.5%)
South West		232 (8.6%)
West Midlands		400 (12.9%)
Yorkshire and the Humber		341 (12.7%)

CDOPs, child death overview panels.

interventions are either lacking or have not been successfully implemented. While the COVID-19 pandemic continues to impact delivery of social and healthcare programmes across the world, the longer-term impact on economies and social and healthcare budgets is likely to be substantial, and social inequalities even in developed nations, may worsen.

The National Child Mortality Database (NCMD) Programme was established in 2018 to collate and analyse data about all children in England who die before their 18th birthday, with statutory death notifications required within 48 hours.[10] The data are collated from the 58 Child Death Overview Panels (CDOPs) in England who carry out detailed analysis of the circumstances of death and identify the modifiable contributory factors relevant to the death as part of the child death review (CDR) process with the aim of identifying common themes to guide learning and inform actions to reduce future child deaths.[11] The CDR process is statutory, with the Children Act 2004 mandating the review and analysis of all child deaths so the circumstances of death that relate to the welfare of children locally and nationally, or to public health and safety, are identified and understood, and preventive actions established. This work is based on the NCMD Programme's first thematic report.[12]

Aims

The aim of this analysis is to identify and report the patterns of social deprivation, and modifiable factors in relation to childhood mortality, and identify potential intervention points and high-risk groups where public health, social and education, or health policy may be best targeted.

METHODS

Three external sources of data were linked to the CDR data using the smallest geographical level of the deprivation index (the Lower Super Output Area (LSOA)). The main measure of deprivation used here is derived from the Office for National Statistics (ONS) Index of Multiple Deprivation (IMD), which is a complex summary statistic,[13] then split into 10 equal sized (by people) deciles. In this work, a higher decile of deprivation represents a higher level of deprivation in the area where the child lived. The LSOA code also allowed further estimation of the population estimates of age and sex,[14] its rural (rural town and fringe, rural village) or urban (urban city and town, urban major conurbation) status[15] and its location in England (East Midlands, East of England, London, North East, North West, South East, South West, West Midlands, Yorkshire and the Humber).[16]

Exploratory variables

For the primary exploratory analysis, variables of interest were as follows:

- Age of death (age as a continuous measure) then coded for analysis and presentedn as<1 year, 1–4 years, 5–9 years, 10–14 years and 15–17 years).
- Sex (male, female or missing (including 'indeterminate', 'not known', 'N/A', 'NULL', etc)).
- Area of residence: urban versus rural.[15]
- Region of England.
- Ethnicity was coded as white, Asian or British Asian, black or British black, mixed or other.

Specific detailed data from CDR process

The CDOP is responsible for identifying any modifiable factors in relation to the child's death. Modifiable factors are those which may have contributed to the death of the child and which might, by means of a locally or nationally achievable intervention, be modified to reduce the

Table 2 Deaths and risk of death by deprivation decile, stratified by the category of death and patient characteristics of child deaths

Measure	Deprivation decile						
No of deaths	**1/2 (least deprived)**	**3/4**	**5/6**	**7/8**	**9/10 (most deprived)**		**P_{trend}**
	N (%)					**Median decile (IQR)**	
All deaths	293 (10.9%)	383 (14.2%)	476 (17.7%)	644 (24.0%)	892 (33.2%)	7 (4–9)	0.003
Category of death							
Acute medical and surgical	22 (12.9%)	30 (17.5%)	28 (16.4%)	46 (27.0%)	45 (26.3%)	7 (4–9)	0.017
Congenital anomalies	60 (9.0%)	71 (10.7%)	117 (17.6%)	147 (22.1%)	270 (40.6%)	7 (5–9)	0.003
Chronic medical	15 (11.2%)	16 (11.9%)	30 (22.4%)	31 (23.1%)	42 (31.3%)	7 (5–9)	0.006
Deliberately inflicted injury	8 (13.1%)	8 (13.1%)	8 (13.1%)	16 (26.2%)	21 (34.4%)	8 (4–9)	0.025
Infection	23 (13.4%)	15 (8.7%)	25 (14.5%)	54 (31.4%)	55 (32.0%)	7 (5–9)	0.021
Malignancy	38 (18.1%)	41 (19.5%)	42 (20.0%)	36 (17.1%)	53 (25.2%)	5 (3–8)	0.326
Perinatal	74 (8.8%)	128 (15.1%)	152 (18.0%)	223 (26.4%)	268 (31.7%)	7 (4–9)	0.006
SUDIC	17 (8.0%)	30 (14.2%)	44 (20.8%)	48 (22.6%)	73 (34.4%)	7 (4–9)	0.003
Suicide or deliberate self-inflicted harm	19 (18.6%)	20 (19.6%)	17 (16.7%)	18 (17.7%)	28 (27.5%)	6 (3–9)	0.296
Trauma	17 (14.7%)	24 (20.7%)	13 (11.2%)	25 (21.6%)	37 (31.9%)	7 (3–9)	0.038
	Risk (per 100 000 children) (95% CI)					**Overall risk (95% CI)**	
All deaths	13.25 (11.78 to 14.86)	17.78 (16.04 to 19.65)	21.10 (19.25 to 23.09)	26.01 (24.04 to 28.10)	31.14 (29.13 to 33.25)	26.01 (24.04 to 28.10)	<0.001
Category of death							
Acute medical and surgical	1.00 (0.62 to 1.51)	1.39 (0.94 to 1.99)	1.24 (0.82 to 1.79)	1.86 (1.36 to 2.48)	1.57 (1.15 to 2.10)	1.43 (1.22 to 1.66)	0.030
Congenital anomalies	2.71 (2.07 to 3.49)	3.30 (2.57 to 4.16)	5.19 (4.29 to 6.22)	5.94 (5.02 to 6.98)	9.43 (8.33 to 10.62)	5.56 (5.15 to 6.00)	<0.001
Chronic medical	0.68 (0.38 to 1.12)	0.75 (0.42 to 1.21)	1.33 (0.90 to 1.90)	1.25 (0.85 to 1.78)	1.47 (1.06 to 1.98)	1.12 (0.94 to 1.33)	0.004
Deliberately inflicted injury	0.13 (0.16 to 0.71)	0.37 (0.16 to 0.73)	0.35 (0.15 to 0.70)	0.65 (0.37 to 1.050)	0.73 (0.45 to 1.12)	0.51 (0.39 to 0.66)	0.009
Infection	1.04 (0.66 to 1.56)	0.70 (0.39 to 1.15)	1.11 (0.72 to 1.64)	2.18 (1.64 to 2.85)	1.92 (1.45 to 2.50)	1.44 (1.23 to 1.67)	<0.001
Malignancy	1.72 (1.22 to 2.36)	1.91 1.37 to 2.58)	1.86 (1.34 to 2.52)	1.45 (1.02 to 2.01)	1.85 (1.39 to 2.42)	1.76 (1.53 to 2.01)	0.868
Perinatal	3.35 (2.63 to 4.20)	5.94 (4.96 to 7.07)	6.74 (5.71 to 7.90)	9.01 (7.86 to 10.27)	9.36 (0.27 to 10.54)	7.06 (6.60 to 7.56)	<0.001
SUDIC	0.77 (0.45 to 1.23)	1.39 (0.94 to 1.99)	1.95 (1.42 to 2.62)	1.94 (1.43 to 2.57)	2.55 (2.00 to 3.20)	1.77 (1.54 to 2.03)	<0.001
Suicide or deliberate self-inflicted harm	0.86 (0.52 to 1.34)	0.93 (0.57 to 1.43)	0.75 (0.44 to 1.21)	0.73 (0.43 to 1.15)	0.98 (0.65 to 1.41)	0.85 (0.70 to 1.04)	0.831
Trauma	0.77 (0.45 to 1.23)	1.11 (0.71 to 1.66)	0.58 (0.31 to 0.99)	1.01 (0.65 to 1.49)	1.29 (0.91 to 1.78)	0.97 (0.80 to 1.16)	0.075

N.B. In this work, an increase in the deprivation decile indicates a higher level of local deprivation.
SUDIC, sudden unexplained death in childhood.

Table 3 Relative risk of death for increasing deprivation stratified by category of death, and testing for interactions by characteristics of the child deaths

	Unadjusted					Adjusted*			
Measure	**n**	**Risk per 10 000 children/year**	**RR95% CI**	**P value**		**n**	**RR 95% CI**	**P value**	
All deaths	2688	22.47 (21.63–23.34)	1.11 (1.09 to 1.12)	<0.001		2670	1.08 (1.07 to 1.10)	<0.001	
Acute medical and surgical	171	1.43 (1.22–1.66)	1.06 (1.01 to 1.12)	0.030		170	1.06 (1.00 to 1.12)	0.052	
Congenital anomalies	665	5.56 (5.15–6.00)	1.17 (1.14 to 1.21)	<0.001		658	1.13 (1.10 to 1.17)	<0.001	
Chronic medical	134	1.12 (0.94–1.33)	1.09 (1.03 to 1.16)	0.004		134	1.09 (1.02 to 1.17)	0.007	
Deliberately inflicted injury	61	0.51 (0.39–0.66)	1.13 (1.03 to 1.24)	0.009		61	1.11 (1.00 to 1.22)	0.040	
Infection	172	1.44 (1.23–1.67)	1.13 (1.07 to 1.19)	<0.001		172	1.11 (1.05 to 1.18)	<0.001	
Malignancy	210	1.76 (1.53–2.01)	1.00 (0.95 to 1.04)	0.868		210	1.00 (0.95 to 1.05)	0.979	
Perinatal	845	7.06 (6.60–7.56)	1.11 (1.09 to 1.14)	<0.001		836	1.07 (1.04 to 1.10)	<0.001	
SUDIC	212	1.77 (1.54–2.03)	1.13 (1.08 to 1.19)	<0.001		211	1.10 (1.05 to 1.16)	<0.001	
Suicide or deliberate self-inflicted harm	102	0.85 (0.70–1.04)	1.01 (0.94 to 1.08)	0.831		102	1.03 (0.96 to 1.10)	0.475	
Trauma and other external factors	116	0.97 (0.80–1.16)	1.06 (0.99 to 1.13)	0.075		116	1.05 (0.98 to 1.12)	0.174	
Interactions			**RR 95% CI**	**P value**	**$P_{interaction}$**		**RR 95% CI**	**P value**	**$P_{interaction}$**
Sex					0.227				0.196
Female	1165	19.98 (18.85–21.16)	1.11 (1.09 to 1.13)	<0.001		1165	1.07 (1.05 to 1.09)	<0.001	
Male	1505	24.55 (23.33–25.83)	1.10 (1.08 to 1.11)	<0.001		1505	1.09 (1.07 to 1.11)	<0.001	
Age					0.003				<0.001
<1 year	1675	261.81 (249.42–274.66)	1.11 (1.09 to 1.13)	<0.001		1659	1.10 (1.08 to 1.12)	<0.001	
1–4 years	322	11.88 (10.62–13.25)	1.10 (1.06 to 1.14)	<0.001		321	1.09 (1.05 to 1.13)	<0.001	
5–9 years	211	5.99 (5.21–6.85)	1.00 (0.96 to 1.05)	0.956		210	0.99 (0.95 to 1.04)	0.785	
10–14 years	227	6.93 (6.06–7.89)	1.07 (1.03 to 1.12)	0.002		227	1.07 (1.02 to 1.11)	0.006	
15–17 years	253	13.97 (12.30–15.80)	1.06 (1.01 to 1.10)	0.011		253	1.05 (1.01 to 1.09)	0.028	
Area					0.616				0.463
Urban	2360	23.30 (22.37–24.26)	1.10 (1.09 to 1.12)	<0.001		2342	1.08 (1.06 to 1.10)	<0.001	
Rural	328	17.89 (16.00–19.93)	1.12 (1.07 to 1.17)	<0.001		328	1.10 (1.05 to 1.16)	<0.001	
Region					0.074				0.165
East Midlands	214	21.47 (18.69–24.54)	1.07 (1.02 to 1.12)	0.004		214	1.06 (1.01 to 1.11)	0.023	
East of England	221	16.54 (14.43–18.87)	1.07 (1.02 to 1.13)	0.005		220	1.06 (1.01 to 1.11)	0.030	
London	473	23.38 (21.32–25.59)	1.06 (1.02 to 1.10)	0.003		464	1.06 (1.01 to 1.10)	0.007	
North East	109	20.56 (16.88–24.80)	1.06 (0.99 to 1.13)	0.098		109	1.04 (0.97 to 1.12)	0.233	
North West	362	23.29 (20.95–25.95)	1.10 (1.06 to 1.14)	<0.001		360	1.08 (1.04 to 1.12)	<0.001	
South East	336	17.16 (15.37–19.09)	1.11 (1.07 to 1.15)	<0.001		336	1.09 (1.05 to 1.14)	<0.001	

Continued

Table 3 Continued

Measure	Unadjusted				Adjusted*		
	n	Risk per 10 000 children/year	RR95% CI	P value	n	RR 95% CI	P value
South West	232	21.03 (18.41–23.92)	1.10 (1.05 to 1.16)	<0.001	232	1.09 (1.03 to 1.14)	0.001
West Midlands	400	30.93 (27.98–34.12)	1.16 (1.11 to 1.20)	<0.001	395	1.14 (1.09 to 1.19)	<0.001
Yorkshire and the Humber	341	29.24 (26.22–32.51)	1.10 (1.06 to 1.14)	<0.001	340	1.09 (1.05 to 1.13)	<0.001

N.B. In this work, an increase in the deprivation decile indicates a higher level of local deprivation.
*Adjusted for age, sex, region and rural/urban area.
RR, Relative Risk; SUDIC, sudden unexplained death in childhood.

risk of future deaths. Factors identified by the CDOP were further classified as (aligning with the statutory CDR categories) as follows:

- ► Characteristics of the child (eg, loss of key relationships, risk taking behaviour, comorbidity, prematurity, congenital anomaly, learning disability, eating disorder, suicidal ideation or previous suicide attempt).
- ► Social environment (eg, abuse, parenting, consanguinity, financial pressures/hardship).
- ► Physical environment (eg, animal attack, homicide, vehicle-related deaths, safety within the home, unsafe infant sleeping practices and public equipment).
- ► Service provision (eg, gaps in service provision, failure to follow guidelines, poor communication, staffing issues and bed occupancy).

Category of death was allocated by the CDOP while reviewing the case and was categorised as: acute medical and surgical, congenital anomalies, chronic medical, deliberately inflicted injury, infection, malignancy, perinatal, sudden unexplained death in childhood (SUDIC), suicide or deliberate self-inflicted harm or Ttrauma.

Analysis

Initially, the characteristics of all child deaths reviewed between April 2019 and March 2020 were derived, stratified by the available covariates (listed above). Next, we derived the proportion of deaths in each deprivation decile. Evidence of any trend in proportions by increasing deprivation decile were tested using a non-parametric test for trend across ordered groups.[17] This was then repeated for each category of death.

Second, to assess any association between deprivation and the risk of death, the population distribution was derived using ONS data for each LSOA producing a dataset with the predicted numbers of children of each age, sex, rural/urban status and region. The risk of death was then derived using a Poisson regression model, calculating the increasing risk of death for each increasing deprivation decile, with the model then adjusted for the other known underlying population characteristics or possible confounders (sex, age, rural/urban area and region). Lastly both the unadjusted and adjusted model were repeated for each reported category of death and tested (using the likelihood ratio test) to assess if the association between deprivation measures and overall mortality was modified by sex, age category, region, rural/urban status or local population density (total population per 100 m^2). Finally for overall mortality a separate model was derived for those children in the lowest five versus the highest five deciles of deprivation, and used to estimate the population attributable risk fraction for those children living the in the most deprived five deciles.

Next, to interrogate the possible causes, we initially derived the number, proportion and evidence of trend of modifiable factors identified at the CDOP review across each deprivation decile. We then calculated the increasing risk of death for each increasing deprivation

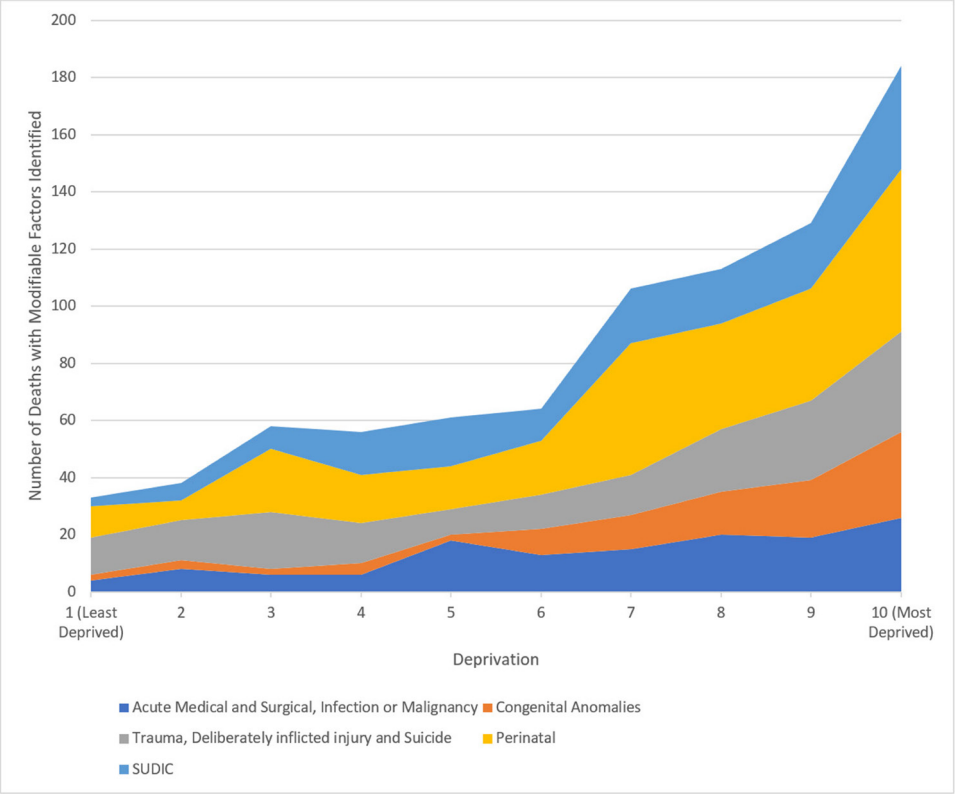

Figure 1 Number of deaths with modifiable factors identified at review, split by measure of local deprivation. SUDIC, sudden unexplained death in childhood.

decile separately for those deaths with, or without, modifiable factors identified. The analyses were repeated, stratified by the subcategories of modifiable factors, and by the category of death.

Patient and public involvement

Parent and public involvement is at the heart of the NCMD programme. We are indebted to Charlotte Bevan (Sands—Stillbirth and Neonatal Death Charity), Therese McAlorum (Child Bereavement UK) and Jenny Ward (Lullaby Trust), who represent bereaved families on the NCMD programme steering group.

RESULTS

A total of 2688 childhood deaths were reviewed by CDOPs between April 2019 and March 2020 and linked to deprivation measures (table 1).

The most common age at death was less than 1 year (62.3%) and more boys than girls died (56.5 vs 43.6% respectively). The majority lived in areas defined as urban (87.8%) and most were of a white ethnic background (65.0%). The number of deaths (p_{trend}=0.003), and the risk of death (p_{trend}<0.001) was more common for children in the most deprived deciles (table 2). Children in the least deprived two deciles had a mortality risk of 13.25 (95% CI 11.78 to 14.86) per 100 00 person-years, compared with 31.14 (95% CI 29.13 to 33.25) in the most deprived 2 deciles.

When looking at the categories of death, deaths due to acute medical or surgical disease (p_{trend}=0.017), congenital anomalies (p_{trend}=0.003), chronic medical (p_{trend}=0.006), deliberate inflicted injury (p_{trend}=0.025), infection (p_{trend}=0.021), perinatal (p_{trend}=0.006), SUDIC (p_{trend}=0.003) and trauma (p_{trend}=0.038) appeared to be associated with increasing deprivation. There was little evidence of an association between increasing deprivation and deaths from malignancy (p_{trend}=0.326) or suicide or deliberate self-inflicted harm (p_{trend}=0.296).

Overall, child mortality was estimated at 22.47 (95% CI 21.63 to 23.34) per 100 000 children/year (table 3). When estimating the relative risk of death using an unadjusted Poisson model, there was an increasing risk of all-cause mortality as measures of deprivation increased (Relative Risk (RR) 1.11 (95% CI 1.09 to 1.12), p<0.001); but also for death categorised as acute medical or surgical (RR 1.06 (95% CI 1.01 to 1.12), p=0.030), congenital anomalies (RR 1.17 (95% CI 1.14 to 1.21),p<0.001), chronic medical (RR 1.09 (95% CI 1.03 to 1.16), p=0.004), deliberately inflicted injury (RR 1.13 (95% CI 1.03 to 1.24), p=0.009), infection (RR 1.13 (95% CI 1.07 to 1.19), p<0.001), perinatal (RR 1.11 (95% CI 1.09 to 1.14),p<0.001) and SUDIC (RR 1.13 (95% CI 1.08 to 1.19), p<0.001) (table 3). After adjusting for age, sex, region and rural status, the association with all-cause mortality (RR 1.08 (95% CI 1.07 to 1.10), p<0.001) and for congenital anomalies (RR 1.13 (95% CI 1.10 to 1.17), p<0.001), chronic medical (RR

Table 4 The number of deaths, in each deprivation decile with identified modifiable factors; and the relative risk of death for each increasing deprivation decile with, or without them; split by category of death

	Percentage of deaths with modifiable factors							Relative risk of death for increasing deprivation decile*	
		Split by deprivation decile							
Category of death	All deciles	1/2 N (%) (least deprived)	3/4 N (%)	5/6 N (%)	7/8 N (%)	9/10 N (%) (most deprived)	P_{trend}	Death without modifiable factors	Deaths with modifiable factors
All deaths	842 (31.3%)	71 (24.2%)	114 (29.8%)	125 (26.3%)	219 (34.0%)	313 (35.1%)	<0.001	1.07 (1.05–1.08)	1.12 (1.09–1.15)
Split by type of modifiable factors									
Characteristics of the child	70 (2.6%)	9 (3.1%)	14 (3.7%)	6 (1.3%)	15 (2.3%)	26 (2.9%)	0.797	1.08 (1.07–1.10)	1.10 (1.01–1.21)
Physical environment	185 (6.9%)	18 (6.1%)	30 (7.8%)	29 (6.1%)	41 (6.4%)	67 (7.5%)	0.764	1.08 (1.07–1.10)	1.08 (1.02–1.14)
Service provision	243 (7.9%)	26 (8.9%)	43 (11.2%)	47 (9.9%)	57 (8.9%)	70 (7.9%)	0.131	1.08 (1.07–1.10)	1.07 (1.02–1.12)
Social environment	416 (15.5%)	29 (9.9%)	46 (12.0%)	51 (10.7%)	106 (16.5%)	184 (20.6%)	<0.001	1.07 (1.05–1.09)	1.15 (1.11–1.20)
Split by category of death									
Acute medical and surgical	42 (24.6%)	5 (22.7%)	8 (26.7%)	7 (25.0%)	9 (20.0%)	13 (29.0%)	0.815	1.05 (0.98–1.12)	1.10 (0.98–1.24)
Congenital anomalies	99 (14.9%)	5 (8.3%)	6 (8.5%)	11 (9.4%)	27 (18.4%)	50 (18.5%)	0.001	1.11 (1.07–1.15)	1.27 (1.16–1.40)
Chronic medical	21 (15.7%)	1 (6.7%)	2 (12.5%)	6 (20.0%)	4 (12.9%)	8 (19.1%)	0.597	1.09 (1.01–1.17)	1.14 (0.96–1.35)
Deliberately inflicted injury	43 (70.5%)	4 (50.0%)	7 (87.5%)	6 (75.0%)	12 (75.0%)	14 (66.7%)	0.911	1.08 (0.90–1.29)	1.12 (0.99–1.26)
Infection	61 (35.5%)	6 (26.1%)	1 (6.7%)	13 (52.0%)	20 (37.0%)	21 (38.2%)	0.126	1.07 (1.00–1.15)	1.20 (1.07–1.33)
Malignancy	11 (5.2%)	0 (0.0%)	1 (2.4%0	5 (11.9%)	2 (5.6%)	3 (5.7%)	0.181	0.99 (0.94–1.05)	1.15 (0.91–1.46)
Perinatal	270 (32.0%)	18 (24.3%)	39 (30.5%)	34 (22.4%)	83 (37.2%)	96 (35.8%)	0.015	1.06 (1.03–1.10)	1.09 (1.04–1.14)
SUDIC	157 (75.1%)	9 (52.9%)	23 (76.7%)	28 (63.6%)	38 (79.2%)	59 (80.8%)	0.045	1.02 (0.92–1.12)	1.14 (1.07–1.21)
Suicide	59 (57.8%)	12 (63.2%)	9 (45.0%)	8 (47.1%)	9 (50.00%)	21 (75.0%)	0.317	1.01 (0.90–1.12)	1.04 (0.95–1.14)
Trauma	79 (68.1%)	11 (64.7%)	18 (75.0%)	7 (53.9%)	15 (60.0%)	28 (75.7%)	0.743	1.00 (0.89–1.12)	1.07 (0.99–1.17)

N.B. In this work, an increase in the deprivation decile indicates a higher level of local deprivation.
*Adjusted for age, sex, region and rural/urban area.
SUDIC, sudden unexplained death in childhood.

1.09 (95% CI 1.02 to 1.17), p=0.007), deliberately inflicted injury (RR 1.11 (95% CI 1.00 to 1.22), p=0.040), infection (RR 1.11 (95% CI 1.05 to 1.18), p<0.001), perinatal (RR 1.07 (95% CI 1.04 to 1.10), p<0.001) and SUDIC (RR 1.10 (95% CI 1.05 to 1.16), p<0.001) remained. However, in the adjusted analysis, the association between death in the acute medical or surgical category with increasing measures of deprivation weakened slightly (RR 1.06 (95% CI 1.00 to 1.12), p=0.052). There was little evidence to suggest an association with malignancy (RR 1.00 (95% CI 0.95 to 1.05), p=0.979), suicide or deliberate self-inflicted harm (RR 1.03 (95% CI 0.96 to 1.10), p=0.475) or trauma (RR 1.05 (95% CI 0.98 to 1.12), p=0.174) in the adjusted (or unadjusted) analyses (table 3).

There was strong evidence that the association between number of deaths and the deprivation index was modified by age (fully adjusted; $p_{interaction}$<0.001), but not sex (fully adjusted; $p_{interaction}$=0.196) or rural/urban status (fully adjusted; $p_{interaction}$=0.463). In the unadjusted model there was some weak evidence that the relationship may be modified by the region of England ($p_{interaction}$=0.0743) and population density ($p_{interaction}$=0.022) although both measures weakened in the adjusted model further (Region; $p_{interaction}$=0.165, Population Density; $p_{interaction}$=0.281).

In the final, adjusted, regression model, estimating the risk of death (adjusted for age, sex and rural/urban area), comparing the risk of death in the most deprived five deciles with the least deprived five deciles, gave compatible results to those from the main analysis (RR 1.47 (95% CI 1.35 to 1.60), p<0.001), and a population attributable risk fraction of 21.2% (95% CI 16.7% to 25.4%).

The absolute number of deaths where modifiable factors were identified increased as measures of deprivation increased (figure 1), with additional strong evidence that the proportion of deaths with modifiable contributory factors identified at the CDOP review increased with increasing measures of deprivation, with 24.2% of deaths in the least deprived, compared with 35.1% of deaths in the most (p_{trend}<0.001) (table 4).

Children who died with modifiable factors showed a stronger gradient with increasing deprivation (RR 1.12 (95% CI 1.09 to 1.15)) compared with those who died without (RR 1.07 (95% CI 1.05 to 1.08)). Individually, only those modifiable factors relating to social environment appeared to show this gradient (p_{trend}<0.001), with less evidence (but small numbers) for those factors around the child, services or their physical environment. When stratifying by the category of death there was evidence that modifiable factors were more commonly identified in deaths in areas of greater deprivation for congenital anomalies (p_{trend}=0.001), perinatal (p_{trend}=0.045) and SUDIC (p_{trend}=0.045) deaths; with corresponding greater relative risks with deprivation compared with deaths

Table 5 Subdomain measures identified as stongest associations with childhood death

IMD subdecile	Category of death										
	All deaths	Acute medical and surgical	Congenital anomalies	Chronic medical	Deliberately inflicted injury	Infection	Malignancy	Perinatal	Sudic	Suicide or deliberate self-harm	Trauma
Income											
Employment	1.04 (1.01–1.07)							1.04 (1.01–1.07)		1.12 (1.02–1.23)	
Child education						1.11 (1.05–1.18)					
Adult education	1.03 (1.00–1.05)		1.12 (1.08–1.16)								
Health		1.07 (1.01–1.14)		1.13 (1.05–1.21)							
Crime	0.97 (0.95–0.99)		0.95 (0.91–0.99)							0.90 (0.82–0.99)	
Geographic Barriers											
Wider barriers	1.06 (1.03–1.08)		1.07 (1.02–1.12)					1.06 (1.02–1.11)			
Outdoor living environment			1.04 (1.01–1.07)								
Indoor living environment	1.03 (1.01–1.05)		1.05 (1.01–1.09)								

Red boxes show measures where increase in deprivation measures are associated with high risks of death. Green boxes show measures where increase in deprivation measures are associated with lower risks of death.
*Adjusted for age, sex, region and rural/urban area.[13]
IMD, Index of Multiple Deprivation.

without modifiable factors identified (eg, relative risk of death from a congenital abnormality with increasing deprivation was 1.11 (95% CI 1.07 to 1.15) for deaths without modifiable factors, and 1.27 (95% CI 1.16 to 1.40) for those with).

When analysing the associations between the risk of childhood death and the deprivation subdomains (online supplemental appendix 1), many of the components of the IMD appeared to be closely correlated, with Income and Employment the highest correlation of 0.939 (online supplemental appendix 2). The subdomains selected by the adaptive model, as the strongest associations with childhood deaths (and each categories of death), are shown in table 5.

Measures of deprivation in the domains of employment, adult education, wider barriers (includes issues relating to housing such as affordability and homelessness) and indoor living environments were identified as most correlated with all-cause mortality. Crime also appeared correlated, but in the opposite direction to the others (ie, increasing measures of deprivation was associated with lower mortality). There was no clear association of any subdomain and death by malignancy or deliberately inflicted injury; while in contrast the model for perinatal deaths (the single most common category of death) identified measures of employment and wider Barriers as possible predictors. Due to the unexpected association between measures of crime and reductions in risk of death in the adaptive models, a post hoc analysis was performed to assess the association between this measure and overall mortality. In this model (without the other subdomain measures of deprivation), increases in measures of deprivation related to crime were associated with increased child mortality (RR 1.06 (95% CI 1.03 to 1.09), p<0.001).

Repeating the main analysis but using the Income Deprivation Affecting Children Index, a metric for the proportion of all children (aged 0–15) living in income deprived families, gave similar results to the main analysis (unadjusted RR 1.10 (95% CI 1.09 to 1.12), p<0.001)); fully adjusted RR 1.08 (95% CI 1.06 to 1.09), p<0.001).

DISCUSSION

Key findings

Over one-fifth of all child deaths may be avoided if the most deprived half of the population had the same mortality as the least deprived, alongside pervasive evidence of a clear gradient of increasing childhood mortality across England as measures of deprivation increase; with a striking finding that this varied little by area, age or other demographic factors. While we acknowledge this gradient is not new,[9] the magnitude of the associations is sobering and this study adds detail around the social patterning of potentially modifiable factors. The proportion of modifiable factors increased with increasing deprivation; and this appeared to be restricted to social factors such as financial difficulties, homelessness or poor maternal nutrition. In this detailed analysis, an association was seen in most of the categories of death (including the largest category, perinatal), with only causation of death

by malignancies, suicide or deliberate self-inflicted harm, and trauma not having clear evidence of an association.

Strengths and limitations

Chance and statistical power are always potential limitations in any statistical analysis, although results in this work were relatively precise. NCMD data are likely to have captured the vast majority of deaths, as child death notifications in England to the NCMD are a statutory requirement, and comparisons with ONS child mortality data for 0–15 years old in England in 2020, show that there were 1% more deaths reported in NCMD.[18] However, we acknowledge that some deaths may not have been reported. In addition, postcode data may not have been the child's only residence; so other influences, unmeasured in this work, may have also impacted on their outcome. However, this seems unlikely to have introduced significant bias, and the population nature of the index may be more likely to reduce any direct effect of inequalities than introduce a false association at the individual level. It is important to note that measures of deprivation are derived from neighbourhood measures, and even if directly relevant to the child, assumptions of causality are complex. In contrast, the relative increase in reported modifiable factors, as the index of deprivation increases does suggest that some of the excess mortality estimated here maybe avoidable. This work is novel, with the ability to report and review an individual/record level cohort of childhood mortality, alongside the detailed information obtained at the multi-agency review of every death.

Results in context

The population attributable risk (of 20%) identified here is crude, but a worrying estimate of the impact of deprivation in child mortality in England; and would equate to over 700 excess deaths a year in England. It highlights the importance of future work to identify the causal pathways involved and to develop interventions that effectively address the causes and improve survival. While some areas appear relatively unrelated to deprivation (eg, malignancy) most of these represent relatively uncommon categories of death. Perinatal events, which was the most prevalent, were strongly associated with deprivation and modifiable factors. We did identify some levels of variation of this association across some measures available to us, but overall the increasing risk with deprivation and child mortality was seen across the whole of England, in all age groups, and communities. Children under 1 living in areas of greater deprivation did appear to have the highest risk of death and this needs further analysis and exploration of potential causal mechanisms but may be due to different disease processes affecting children at different ages, or the differential impact of deprivation at critical periods of the children's lives. This finding is consistent with the findings from the national perinatal mortality surveillance data, which reported that women living in the most deprived areas are at an 80% higher risk of stillbirth and neonatal death compared with women living in the least deprived areas.[19] Given that death caused by perinatal events also represents the biggest number of childhood deaths in England,[20] these findings provide further evidence for the importance of prioritising interventions around pregnancy and the start of life, when parents are especially open to support, and targeting families at higher risk.[1] The Marmot review and subsequent reviews recommend that equity be placed at the heart of national decisions about education policy and funding.[1] This study provides further evidence for continued investment in current policies such as the National Healthy Child Programme which are based in the concept of proportionate universalism and designed to address health inequalities for children aged 0–19.[21]

Like the wider association with all deaths, the mechanisms are likely to be highly complex, and a combination of the intergenerational impact of poverty on family health and lifestyle choices such as maternal diet and family nutrition,[22] parental smoking,[23] as well as the environmental impacts of deprivation, such as housing quality, road traffic pollution and access to health and social care services which create intersectional disadvantage. Further evaluation of community-level interventions is needed, for example, there is an evidence that programmes such as Sure Start reduced the likelihood of hospitalisation among children of primary school age with greater impact on children living in the most deprived areas.[24]

Wider implications

Reviewing the components which make up the deprivation index, it should be noted that many of the measures remain very inter-dependent (eg, income and education) and interpretation should be cautious. Despite universal healthcare, employment was a key association for several of the cause of death categories, and access to care is likely to be an important mediating factor that is amenable to change.[25] A strong association between child mortality and income inequality has been reported among the wealthier OECD countries,[26] and the UK has among the highest levels of income inequality in Europe.[27] The highest reported measure of income inequality in the UK over the last decade was in the period April 2019 to March 2020[28] and impacts from the COVID-19 pandemic are likely to have worsened this trend. It is notable that employment, adult education, wider barriers and indoor living environments appear important predictors of child mortality suggesting that adult employment and education opportunities, and access and improvements to housing, may be the most efficient place to target resources in order to reduce these inequalities. This triangulates with qualitative work which identified the lack of cleanliness, unsuitable accommodation (eg, overcrowding or damp/mould) and financial issues being commonly reported modifiable factors after a child dies.[12] Some component of reverse causality is possible, with households moving to more deprived areas due to family impact of childhood ill health and disability; although children with chronic health conditions may find accessing services or housing/

financial support more difficult than others.[12] The unexpected association, in the multivariable model, was that of an inverse relationship (compared with the other data) with measures of crime. While it should be noted that before adjusting for other, correlated, measures of deprivation, increasing measures of crime remained associated with increased risk of childhood death; the finding is interesting, and some component measured in the crime metric provides additional and novel information in this area.

Currently, the CDR data collection form contains a free text area where social deprivation-related factors are noted if considered relevant by the CDOP review panel. The form does not include specific and prompting questions for possible factors relating to social deprivation, and improvements in collecting these data in a standardised format would assist in more detailed analysis of future deaths; and comparisons with control population would be vital in placing future work in context. Any future analyses should explore the information collected about the circumstances of death and modifiable factors in greater detail while analyses following on from this will also need to interpret the results in the context of the economic and social impact of the COVID-19 pandemic.

CONCLUSION

There is evidence of a clear gradient of increasing child mortality across England as measures of deprivation increase, with a striking finding that this varied little by area, age or other demographic factor. Over one-fifth of all child deaths may be avoided if the most deprived half of the population had the same mortality as the least deprived. Children dying in more deprived areas may have a greater proportion of avoidable deaths, while adult employment and education opportunities, and access and improvements to housing, may be the most efficient place to target resources in order to reduce these inequalities.

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