Effect of socioeconomic deprivation on uptake of measles, mumps and rubella vaccination in Liverpool, UK over 16 years: a longitudinal ecological study

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SUMMARY

Suboptimal uptake of the measles, mumps and rubella (MMR) vaccine by certain socioeconomic groups may have contributed to recent large measles outbreaks in the UK. We investigated whether socioeconomic deprivation was associated with MMR vaccine uptake over 16 years. Using immunization data for 72 351 children born between 1995 and 2012 in Liverpool, UK, we examined trends in vaccination uptake. Generalized linear models were constructed to examine the relative effect of socioeconomic deprivation and year of birth on MMR uptake. Uptake of MMR1 by age 24 months ranged between 82·5% in 2003 [95% confidence interval (CI) 81·2–83·7] and 93·4% in 2012 (95% CI 92·7–94·2). Uptake of MMR2 by age 60 months ranged between 65·3% (95% CI 64·4–67·4) in 2006 and 90·3% (95% CI 89·4–91·2) in 2012. In analysis adjusted for year of birth and sex, children in the most deprived communities were at significantly greater risk of not receiving MMR1 [risk ratio (RR) 1·70, 95% CI 1·45–1·99] and MMR2 (RR 1·36, 95% CI 1·22–1·52). Higher unemployment and lower household income were significantly associated with low uptake. Contrary to concerns about lower MMR uptake in affluent families, over 16 years, children from the most socioeconomically deprived communities have consistently had the lowest MMR uptake. Targeted catch-up campaigns and strategies to improve routine immunization uptake in deprived areas are needed to minimize the risk of future measles outbreaks.

Key words: Analysis of data, epidemiology, measles (rubeola), MMR vaccination, public health.

INTRODUCTION

The combined measles, mumps and rubella (MMR) vaccination was introduced in the UK in 1988 [1].

The two-dose MMR vaccine schedule is offered as part of the routine childhood vaccination programme, with the first dose (MMR1) administered at age 13

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months, and the second dose (MMR2) at age 3 years 4 months [1]. Uptake of MMR1 in the UK reached as high as 92% in 1995 [2]. However, an MMR vaccine scare caused by the publication in 1998 of a high-profile but now discredited report linking autism and bowel disorders to MMR vaccination [3], caused substantial declines in UK MMR vaccine uptake, which dropped to 80% for MMR1 in 2003/2004 [2].

Large outbreaks of measles associated with low MMR coverage occurred in Yorkshire, Surrey, London and Cheshire between 2006 and 2008 [4–7]. Concerted public health efforts to improve coverage at a local and national level followed and in 2011/2012 [8], UK uptake of MMR1 and MMR2 had reached 91·2% and 86·0%, respectively, the highest levels since the MMR vaccine scare [2]. Despite these efforts, UK coverage of MMR, especially in older cohorts affected by the MMR vaccine scare, remains below levels required to ensure herd protection. During 2012/2013 there were 2534 notified reports of measles in Liverpool and the surrounding areas, of which 652 were laboratory confirmed [9].

Previous studies have shown conflicting data regarding the effect of deprivation on MMR uptake. In England, ecological studies examining associations at health administrative geographies and ward-level have suggested that uptake is lowest in the most deprived areas [10–12]. In contrast, a large UK cohort study found that measures of individual- and household-level deprivation such as income and education were not associated with lower uptake of MMR [13]. Moreover, following the MMR vaccine scare, MMR uptake in the early 2000s declined by the greatest amount in the most affluent UK areas [12]. Qualitative studies from the UK and USA have consistently highlighted the importance of concerns over the safety of the MMR vaccine in more affluent families as a contributing factor to low uptake [14]. Other factors shown to be associated with lower uptake of MMR vaccination in the UK include larger GP practice size, single parenthood, family size and higher birth order [10, 13, 15, 16].

The effect of socioeconomic deprivation on MMR uptake is therefore poorly understood, and a major barrier to improving vaccine uptake rates in the most at-risk groups. In this study, we describe trends in MMR uptake over 16 years and investigate the relative effects of socioeconomic deprivation and year of birth on uptake in Liverpool, UK.

METHODS

Setting

Liverpool, England, had an estimated population of 469 700 people (78 609 of whom were aged <16 years) in 2012 [17]. Over 65% of the population of Liverpool live in the most socioeconomically deprived national quintile (Fig. 1) [18].

Study population

Children born in Liverpool between 1 January 1995 and 31 December 2012 and who remained resident in the city were identified using the Child Health Information System (CHIS) [19]. The CHIS is administered by the UK National Health Service (NHS) and records a unique clinical record for each child resident within a defined population. Data from CHIS are used in routine practice to support a variety of community child health services, including immunization services [19, 20]. Records of doses of vaccinations given as part of the UK childhood vaccine schedule are recorded in CHIS for each child. The CHIS meets the NHS information governance requirements, which includes provision for the data to be used for monitoring child health activities and outcomes and has specification for secondary data use [19, 20].

We used codes in the CHIS dataset to exclude stillbirths, children who were born in Liverpool during the study period but subsequently moved out of the city and children who were born outside Liverpool but migrated in from the analysis.

Ethical approval

Ethical approval was not required for this study.

Uptake of MMR vaccination

Vaccine uptake for MMR1 by age 24 months and MMR2 by age 60 months were the main outcome measures for our analysis. We selected these outcome definitions to match measurements reported in the national Cover of Vaccination Evaluated Rapidly (COVER) programme [2]. Pseudo-anonymized data were extracted from the CHIS dataset for each child, including: unique identifier, year and month of birth; year and month of MMR1 and MMR2 vaccination; sex; and postcode of residence. Postcode data were
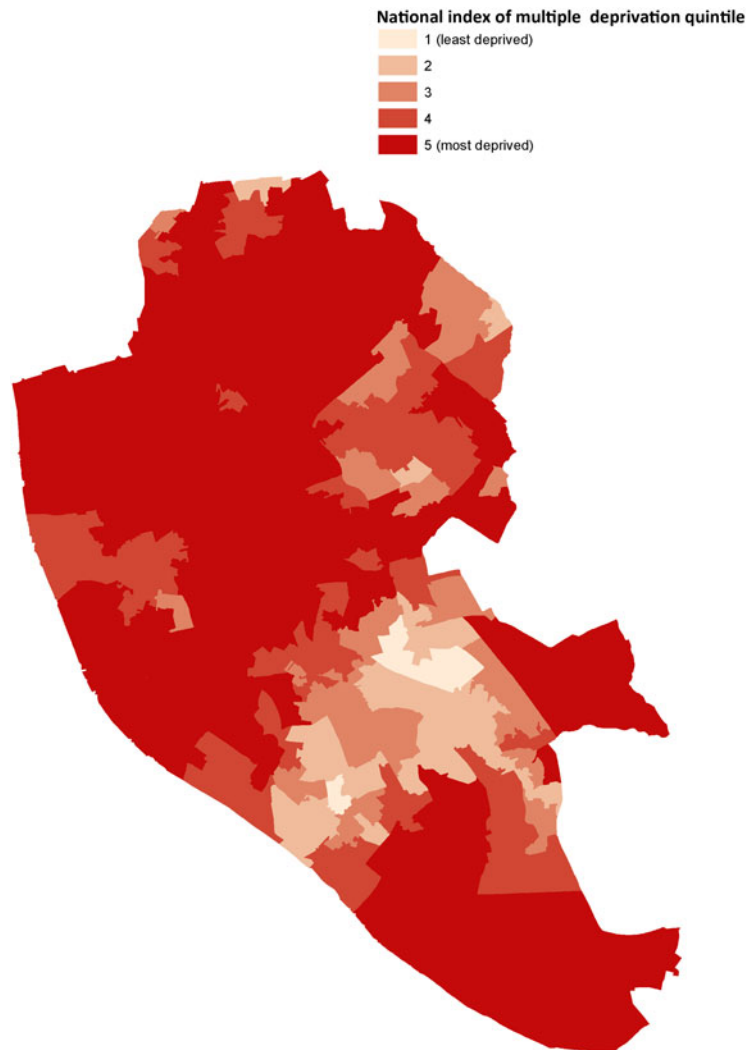
Fig. 1. Socioeconomic deprivation in Liverpool. Produced using the English indices of deprivation (2010), national quintiles for the index of multiple deprivation.

used to determine the Lower Super Output Area (LSOA) of residence.

Area of residence and socioeconomic deprivation

English LSOAs are small statistical boundaries consisting of about 1500 people, which were first defined following the 2001 census [21]. Our study used LSOAs from the 2001 census. The CHIS dataset does not hold historic address information and therefore each child's most recently recorded address was used to derive the LSOA of residence.

The main exposure variable examined in our analysis was socioeconomic deprivation, measured using English indices of deprivation at LSOA level. English indices of deprivation are constructed and quality checked nationally using census information

and other local administrative data [18]. They include 38 indicators in seven domains: Income, Employment, Health and Disability, Education Skills and Training, Barriers to Housing and Other Services, Crime, and Living Environment [18]. Weighted domain scores have been used to calculate an overall index of multiple deprivation score (IMD). We linked datasets containing the English indices of deprivation calculated in 2004, 2007 and 2010 to child LSOAs of residence in the CHIS dataset.

Statistical analysis

We used R version 3.1.0 to conduct all analysis [22]. We constructed socioeconomic deprivation groups for IMD and each of the seven indices of deprivation domains using quintiles of their score. As socioeconomic
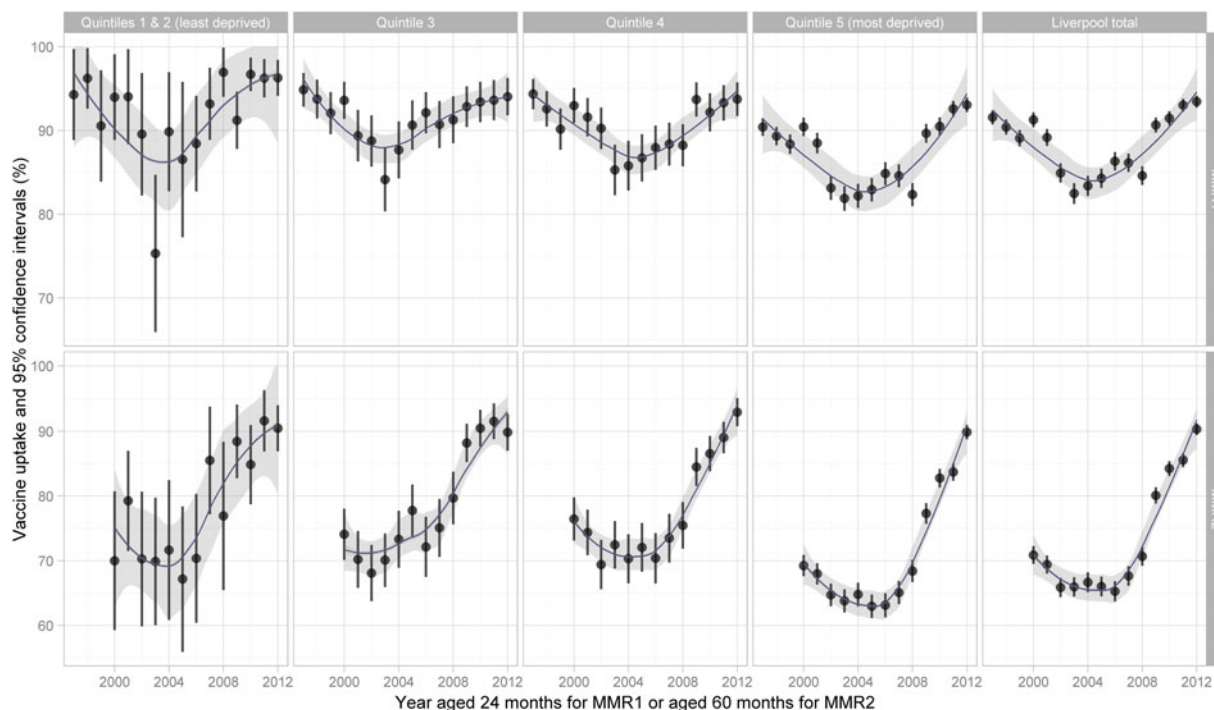
Fig. 2. Trends in MMR1 and MMR2 vaccination uptake (%) by year and socioeconomic deprivation group, Liverpool. MMR1 uptake by age 24 months, and MMR2 uptake by age 60 months. Showing a locally weighted scatterplot smoothing (LOESS) curve and 95% confidence intervals.

deprivation in Liverpool is skewed towards the most-deprived quintiles, we combined Liverpool LSOAs in quintiles 1 (least deprived) and 2. We constructed year-of-birth groups, consisting of 3- or 4-year bands.

We estimated the annual proportion of children born and resident in Liverpool between 1995 and 2012 who received MMR1 by age 24 months and MMR2 by age 60 months and stratified by socio-economic deprivation group, sex and year-of-birth group. As children born after 31 December 2010 would not have reached the age of 24 months by 31 December 2012, we excluded them from MMR1 analysis. For MMR2 analysis, we excluded children born after 31 December 2007, as they would not have reached age 60 months by 31 December 2012.

To investigate the effect of socioeconomic deprivation on MMR1 and MMR2 vaccine uptake, we constructed generalized linear models with logarithmic link functions to estimate risk ratios (RRs) and 95% confidence intervals (CIs). Our analysis was adjusted for year-of-birth group and sex according to our pre-specified statistical plan. We also examined associations between MMR uptake and each of the seven English indices of deprivation domains.

RESULTS

Between 1 January 1995 and 31 December 2012, 72 351 children born in Liverpool were recorded as being Liverpool residents in the CHIS dataset. Birth records show that between 1995 and 2012 there were 98 077 live births for residents of Liverpool [23], with CHIS and migration records indicating an efflux of about 30 000 people from Liverpool during this time period.

Annual trends in MMR1 uptake

In total, 62 689 children born between 1995 and 2010 were eligible for inclusion in analysis of MMR1 uptake by age 24 months. Overall trends in MMR 1 uptake between 1997 and 2012 followed a 'U-shaped' distribution (Fig. 2). Vaccine uptake declined from 91·6% (3816/4168, 95% CI 90·7–92·4%) in 1997 and reached a low of 82·5% (2940/3565, 95% CI 81·2–83·7%) in 2003. Subsequently, there was a steady increase in uptake to a peak of 93·4% (4170/4462, 95% CI 92·7–94·2%) in 2012.

Across each IMD group, similar bimodal U-shaped patterns of uptake by year occurred. However, an outlier from the trend was seen in the least deprived socio-economic group in 2003, contemporaneous with the

Table 1. *Univariate and multivariate associations with non-vaccination with MMR1 by age 24 months (n = 62 689)*

	No. (%) vaccinated with MMR1 by age 24 months	Univariate RR	95% CI	P value	Adjusted RR	95% CI	P value
Sex							
Female	25 902/29 254 (88·5)	1	–	–	1	–	–
Male	29 529/33 435 (88·3)	1·02	0·98–1·06	0·382	1·02	0·98–1·07	0·375
IMD quintiles[a]							
1 and 2 (least deprived)	2034/2180 (93·3)	1	–	–	−1	–	–
3 (average)	6049/6604 (91·6)	1·26	1·05–1·49	0·011	1·12	0·94–1·34	0·190
4	8174/9035 (90·5)	1·42	1·20–1·68	<0·001	1·26	1·06–1·49	0·008
5 (most deprived)	39 174/44 870 (87·3)	1·90	1·62–2·23	<0·001	1·70	1·45–1·99	<0·001
Year birth cohort aged 24 months*							
1997–2000	14 591/16 107 (90·6)	1	–	–	1	–	–
2001–2004	12 343/14 523 (85·0)	1·60	1·51–1·70	<0·001	1·59	1·49–1·69	<0·001
2005–2008	13 130/15 388 (85·3)	1·55	1·46–1·67	<0·001	1·57	1·47–1·67	<0·001
2009–2012	15 367/16 671 (92·2)	0·83	0·77–0·90	<0·001	0·84	0·78–0·9	<0·001

RR, Risk ratio; CI, confidence interval; IMD, index of multiple deprivation.

* Year birth cohort aged 24 months = year in which a child was 24 months old, to test vaccine uptake by 24 months.

UK MMR vaccination scare (61/81, 75·3%, 95% CI 65·9–84·7). Excluding this outlier, the nadir was among children in the most deprived socioeconomic group who were aged 24 months 2003 (2125/2595, 81·9%, 95% CI 80·4–83·4).

Annual trends in MMR2 uptake

A total of 50 018 children born between 1995 and 2007 were eligible for inclusion in analysis of MMR2 uptake by age 60 months. Overall trends in MMR2 uptake followed a 'J-shaped' distribution. Large increases in MMR2 uptake occurred between 2007 and 2012, following a period of low uptake. Uptake was 70·9% (2954/4168, 95% CI 69·5–72·3) in 2000 and declined to a low of 65·3% (2327/3565, 95% CI 64·4–67·4) in 2006. Uptake remained lower than the 2000 baseline until 2009 when it reached 80·1% (3010/3758, 95% CI 78·8–81·4). Uptake then rapidly increased to 90·3% (3613/4000, 95% CI 89·4–91·2) in 2012. Similar trends were seen across all socioeconomic deprivation groups, with the lowest uptake in the most deprived group in 2006 (1638/2595, 63·1% 95% CI 61·3–65·0).

Associations between socioeconomic deprivation and MMR uptake

Over the full study period MMR1 uptake was 93·3% (2034/2180, 95% CI 92·3–94·3) in the least socioeconomically deprived groups but six percentage points lower in the most socioeconomically deprived group (87·3%, 39 174/44870, 95% CI 87·0–87·6). By univariate analysis, children in the most socioeconomically deprived IMD group (RR 1·90, 95% CI 1·62–2·23) were significantly more likely not to have received MMR1 by age 24 months compared to children in the least deprived group (Table 1). The risk of not receiving MMR1 increased in a linear fashion as socioeconomic deprivation increased. Compared to the 1997–2000 baseline, the risk of not receiving MMR1 was significantly higher during 2001–2004 (RR 1·60, 95% CI 1·51–1·71) and 2005–2008 (RR 1·55, 95% CI 1·46–1·67). During 2009–2012, the risk of non-vaccination with MMR1 was significantly reduced (RR 0·83, 95% CI 0·77–0·90). There was no significant association between child's sex and uptake of MMR1 (RR 1·02, 95% CI 0·98–1·06).

In the MMR2 cohort uptake was 81·2% (1068/1315, 95% CI 79·1–83·3) in the least socioeconomically deprived groups and 71·1% (25 546/35933, 95% CI 70·6–71·6) in the most socioeconomically deprived group. By univariate analysis children in the most deprived IMD quintile were significantly more likely not to have received MMR2 by age 60 months compared to children in the least deprived group (RR 1·54, 95% CI 1·38–1·72) (Table 2). Compared to the 2000–2003, the risk of not receiving MMR2 was significantly higher during 2004–2006 (RR 1·09, 95% CI

Table 2. *Univariate and multivariate associations with non-vaccination with MMR2 by age 60 months (n = 50 018)*

	No. (%) vaccinated with MMR2 by age 60 months	Univariate RR	95% CI	*P* value	Adjusted RR	95% CI	*P* value
Sex							
Female	17 113/23 269 (73·5)	1	–	–	1	–	–
Male	19 462/26 749 (72·8)	1·03	1·00–1·06	0·048	1·02	0·99–1·05	0·119
IMD quintiles							
1 and 2 (least deprived)	1068/1315 (81·2)	1	–	–	1	–	–
3 (average)	4212/5367 (78·5)	1·15	1·01–1·30	0·031	1·02	0·90–1·15	0·808
4	5749/7403 (77·7)	1·19	1·05–1·34	0·005	1·06	0·94–1·19	0·342
5 (most deprived)	25 546/35 933 (71·1)	1·54	1·38–1·72	<0·001	1·36	1·22–1·52	<0·001
Year birth cohort aged 60 months*							
2000–2003	8429/12 257 (68·8)	1	–	–	1	–	–
2004–2006	9709/14 713 (66·0)	1·09	1·05–1·13	<0·001	1·09	1·06–1·13	<0·001
2007–2009	8154/11 193 (72·8)	0·87	0·84–0·90	<0·001	0·87	0·84–0·91	<0·001
2010–2012	10 283/11 855 (86·7)	0·42	0·4–0·45	<0·001	0·43	0·41–0·45	<0·001

RR, Risk ratio; CI, confidence interval; IMD, index of multiple deprivation.
* Year birth cohort aged 60 months = year in which a child was 60 months old, to test vaccine uptake by 60 months.

1·05–1·13). During 2007–2009, the risk of non-vaccination with MMR2 was significantly reduced (RR 0·87, 95% CI 0·84–0·90) and further reduced during 2010–2012 (RR 0·42, 95% CI 0·40–0·45). There was a weak significant association between sex and uptake of MMR2, with boys more likely to not receive MMR2 by age 60 months (RR 1·03, 95% CI 1·00–1·06).

Adjusting for the effect of year-of-birth group and sex had little impact on the significant association between increased deprivation and not receiving MMR1 [adjusted risk ratio (aRR) for most deprived *vs.* least deprived group: 1·70, 95% CI 1·45–1·99; Table 1], or MMR2 (aRR for most deprived *vs.* least deprived group: 1·36, 95% CI 1·22–1·52; Table 2). There was no association between child's sex and uptake of MMR1 (aRR 1·02, 95% CI 0·98–1·06) or MMR2 (aRR 1·02, 95% CI 0·99–1·05).

Uptake of MMR and domains of socioeconomic deprivation

Five of the seven domains comprising the English indices of deprivation (Income, Employment, Education Skills and Training, Crime, and Living Environment) showed significant associations between non-vaccination with MMR1 and MMR2 and socioeconomic deprivation groups, with children in the most socioeconomically deprived group at greatest risk of not receiving vaccination (Tables 3 and 4). These associations remained significant after adjustment for year-of-birth group and sex.

The Barriers to Housing and Other Services domain had an inverse relationship with low MMR uptake, with uptake significantly higher in the most deprived group for MMR1 (aRR for most deprived *vs.* least deprived group: 0·66, 95% CI 0·55–0·81) and MMR2 (aRR for most deprived *vs.* least deprived group: 0·68 95% CI 0·58–0·79). In the Health and Disability domain, children in socioeconomic deprivation group 3 (aRR for most deprived *vs.* least deprived group: 0·26, 95% CI 0·08–0·84) and group 4 (aRR for most deprived *vs.* least deprived group: 0·31, 95% CI 0·10–0·98) had significantly higher uptake of MMR2 at age 60 months.

DISCUSSION

The main findings of this study were that uptake of MMR vaccination declined substantially in Liverpool between 2000 and 2008, but was followed by impressive improvements, with overall uptake in Liverpool in 2012 reaching 93·4% for MMR1 by 24 months. Over the 16 years studied, higher levels of socioeconomic deprivation were consistently and strongly associated with lower uptake of both MMR1 and MMR2. Poorer educational attainment, lower levels of employment, and lower household income were also significantly associated with lower uptake of both MMR1 and MMR2.

Very few studies have investigated variation in MMR uptake in relation to population socioeconomic deprivation. Our analysis is the first to show a strong

Table 3. *Univariate and multivariate associations with non-vaccination with MMR1 by age 24 months*

Socioeconomic deprivation group	Education, skills, and training		Employment		Income		Living environment		Crime		Barriers to housing and other services		Health and disability	
	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR
1 and 2 (least deprived) (referent)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 (average)	1·34*** (1·21–1·46)	1·32*** (1·20–1·45)	0·89 (0·75–1·06)	0·84* (0·70–1·00)	1·09 (0·98–1·22)	1·11 (0·99–1·23)	1·03 (0·90–1·17)	0·99 (0·88–1·13)	0·98 (0·85–1·13)	0·90 (0·77–1·03)	0·92** (0·88–0·97)	1·04 (0·99–1·09)	0·46 (0·18–1·21)	0·40 (0·15–1·05)
4	1·43*** (1·31–1·57)	1·42*** (1·31–1·55)	0·90 (0·76–1·05)	0·83* (0·70–0·97)	1·26*** (1·14–1·38)	1·26*** (1·14–1·39)	1·04 (0·93–1·15)	1·03 (0·92–1·14)	1·22** (1·06–1·39)	1·06 (0·92–1·21)	0·76*** (0·71–0·82)	0·90** (0·84–0·97)	0·73 (0·29–1·86)	0·52 (0·20–1·31)
5 (most deprived)	1·68*** (1·57–1·80)	1·67*** (1·55–1·79)	1·31** (1·13–1·54)	1·21* (1·03–1·4)	1·55*** (1·43-1·7)	1·55*** (1·43–1·7)	1·20*** (1·09–1·32)	1·16** (1·05–1·27)	1·51*** (1·32–1·70)	1·25** (1·09–1·42)	0·55*** (0·45–0·67)	0·66*** (0·55–0·81)	1·16 (0·46–2·94)	0·80 (0·32–2·03)

RR, Risk ratio.
Adjusted risk ratios are adjusted for sex and year-of-birth group.
* $P < 0.05$,** $P < 0.01$,*** $P < 0.001$.

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Table 4. *Univariate and multivariate associations with non-vaccination with MMR2 by age 60 months*

Socioeconomic deprivation group	Education, skills and training		Employment		Income		Living environment		Crime		Barriers to housing and other services		Health and disability	
	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR	Univariate RR	Adjusted RR
1 and 2 (least deprived) (referent)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 (average)	1·07* (1·01–1·13)	1·02 (0·96–1·08)	0·89* (0·78–1·00)	0·86* (0·76–0·97)	0·89** (0·83–0·96)	0·90** (0·84–0·97)	1·06 (0·97–1·16)	1·11* (1·01–1·21)	1·03 (0·93–1·14)	0·95 (0·86–1·05)	0·94 (0·90–0·97)	1·05** (1·02–1·09)	0·30* (0·09–0·98)	0·26* (0·08–0·84)
4	1·20*** (1·14–1·26)	1·14*** (1·07–1·2)	0·87* (0·77–0·98)	0·81*** (0·72–0·9)	1·08* (1·02–1·15)	1·09** (1·03–1·16)	1·06 (0·99–1·15)	1·07 (1·00–1·16)	1·11* (1·01–1·22)	1·07 (0·97–1·17)	0·82*** (0·77–0·86)	0·98 (0·92–1·03)	0·61 (0·19–1·88)	0·31* (0·10–0·98)
5 (most deprived)	1·35*** (1·30–1·40)	1·32*** (1·27–1·38)	1·17** (1·05–1·31)	1·09** (0·98–1·22)	1·30*** (1·23–1·36)	1·30*** (1·23–1·36)	1·25*** (1·17–1·34)	1·22*** (1·15–1·31)	1·21*** (1·09–1·32)	1·21*** (1·11–1·32)	0·61*** (0·52–0·70)	0·68*** (0·58–0·79)	0·84 (0·27–2·59)	0·42 (0·14–1·3)

RR, Risk ratio.
Adjusted risk ratios are adjusted for sex and year-of-birth group.
* $P < 0.05$,** $P < 0.01$,*** $P < 0.001$.

association between socioeconomic deprivation and low MMR uptake at a local neighbourhood level over time in England. Previous studies have reported conflicting findings regarding MMR uptake and socioeconomic deprivation. Indeed, two small cross-sectional studies in Northern England conducted in 1991 and 2002–2004 that also used immunization records showed no significant association between MMR uptake and socioeconomic deprivation [16, 24]. Ecological studies of MMR uptake at larger geographical areas in England found an association between socioeconomic deprivation and lower MMR uptake [10–12]. One of these studies, using a sample of English health authorities found that the trend in MMR uptake was consistently lower in the most deprived areas [11]. Our study found that low employment was associated with lower MMR uptake, consistent with findings of a large UK cohort study [13]. In contrast to our findings, however, a number of studies have found a significant association between higher parental educational attainment and reduced MMR uptake [12, 13, 25].

Our analysis supports the hypothesis that the MMR safety scare reduced population-level MMR uptake. Trends in MMR1 and MMR2 uptake for Liverpool are similar to those observed for the whole of England over the same time period [2]. There was a fall in MMR1 uptake from 92% in the late 1990s in Liverpool and England, reaching a low of 80·0% in England and 82·5% in Liverpool in 2003 [2]. Our analysis also suggests that the drop in MMR1 uptake during the scare was more substantial in the least socioeconomically deprived population with a relative drop of 20% compared to 9% in the most socioeconomically deprived. However, MMR1 uptake rates recovered to within 1% point of pre-scare levels in 2007 in the least deprived areas but took a further 2 years in the most deprived populations. Subsequently, uptake of MMR1 and MMR2 have surpassed pre-MMR safety scare levels. Liverpool now has uptake rates for MMR1 and MMR2 which are higher than the national average [2]. The increase in MMR1 and MMR2 uptake from 2008 onwards followed outbreaks of measles in different parts of the UK [4–7], raising the profile of MMR and resulting in an MMR vaccine promotion and catch-up campaign in 2008 targeting all children aged <18 years [8].

Policy implications

Consistently lower levels of MMR1 and MMR2 uptake will result in a substantial increase in the proportion of people susceptible to infection over time. Our analysis has shown that the lowest uptake levels are consistently seen in the most deprived areas. These areas will likely have the highest population densities and crowding, greatest numbers of population with poor health and highest rates of disability [18]. Together, these factors create conditions conducive to higher measles transmission, as well as risk of more severe illness among individuals who are infected. The measles outbreak in Liverpool during 2012/13 had a disproportionately higher number of cases in the most socioeconomically deprived areas of the city [9]. This imbalance was likely driven by the high number of unvaccinated children from previous cohorts, mostly from socioeconomically deprived areas [26, 27].

Addressing the incorrect information generated during the MMR safety scare has been a public health priority in the UK and in other countries. Messages have been frequently targeted towards more affluent parents who declined MMR vaccine for their children. However, our findings show that children living in the most deprived areas of Liverpool were consistently at substantially greater risk of not receiving MMR vaccination compared to children in more affluent areas. Guidelines from the National Institute for Health and Clinical Excellence (NICE) for improving uptake of immunizations recommend that groups that are not fully vaccinated should be routinely identified and targeted with additional interventions [28]. However, no specific recommendations for deprived communities are made. Untargeted efforts to improve population uptake of vaccination may result in overall improvements, but do not reduce the inequalities in uptake that disproportionately affect deprived communities, and may in fact widen inequality gaps [29]. Our finding also indicate that recovery in uptake rates may have been slower post-MMR scare in the most deprived areas of Liverpool, suggesting that efforts to change attitudes and behaviours towards vaccination following the MMR safety scare may have been least effective in the most socioeconomically deprived populations.

The increasing availability of robust local monitoring data that is often available in near real-time (as was used in this study) can guide effective targeting of interventions, as well as allowing assessment of impact over time. Previous targeted interventions to improve access to immunization services in the most socioeconomically deprived neighbourhoods have included flexible service provision (e.g. expanded GP opening hours, outreach vaccination clinics in non-medical settings, child friendly clinics, and domiciliary vaccination programmes), checking vaccination status

at every clinical contact and during school registration, and providing an individually tailored vaccination service [28]. The CHIS has also been shown to be effective in increasing uptake if used by GPs as a recall system [10]. Unitization of targeted interventions such as these in socioeconomically deprived areas should help to ensure greater equity of vaccine uptake.

Nevertheless, in order to implement the best policies and practices to improve not only MMR uptake but all childhood immunisations, further evidence is needed on the pathways which lead to failure to immunise children, particularly those from the most socioeconomically deprived backgrounds. A number of factors which possibly influence the likelihood of parents vaccinating their children have previously been described, for example: time and money pressures (e.g time off work); access to clinic-based vaccination programmes; perceptions of disease severity and susceptibility; and information on vaccine safety [28]. However, specifically accessing the views of parents/carers and healthcare providers in the most deprived areas through high-quality qualitative research will be critical to further understand the mechanisms behind low vaccine uptake and would provide a forum for public involvement in the design of any future interventions.

Strengths and limitations

Our analysis benefited from using a large, well-defined population with records drawn from a robust data source, which allowed neighbourhood-level socioeconomic deprivation measures to be linked to individual-level records of vaccine uptake. Furthermore, the 16-year time period has allowed analysis of the effect of socioeconomic deprivation on MMR uptake over time, and consequently on consecutive child cohorts, analysis which has not previously been undertaken at the LSOA level. However, there were several limitations. The ecological study design means that inferring causation is difficult: we cannot determine associations at the individual level and consequently the study may be subject to the ecological fallacy. There may have been confounding at a neighbourhood level from unmeasured factors such as access to GP services, and at the individual level from factors such as family size. Nonetheless, these confounders are likely to be partially captured at a neighbourhood level by the English indices of deprivation.

Within our study it was not possible to account for intra-city migration, as CHIS records hold only the most recent known residence of the child. However, recent studies have shown that the UK has low levels of social mobility, meaning that intra-city migration is likely to occur within similar areas [30, 31]. The setting for analysis was Liverpool, a city that has high levels of socioeconomic deprivation compared to most other cities in the UK and for that reason our findings may not be generalizable to all populations and should be interpreted with caution.

Finally, our analysis measured uptake of MMR vaccination. Although uptake of vaccinations may be the most convenient measure of population protection it is more important for screening and immunization services to measure vaccination coverage in local area populations. Importantly for local screening and immunization services the CHIS dataset could be utilized to measure local vaccination coverage in the child population.

CONCLUSION

Declines in MMR uptake in Liverpool between 2000 and 2008 have been followed by improvements, with uptake of MMR in 2012 close to the levels required to ensure herd protection. Contrary to previous concerns about low MMR uptake by affluent UK families, over the past 16 years, children in the most deprived group in Liverpool have consistently had the lowest uptake of MMR immunization. Uptake rates also took more time to recover from the MMR safety scare in the most deprived group. Additional targeted strategies to improve immunization uptake in deprived areas, as well as catch-up campaigns are needed in order to prevent or minimize the risk of future outbreaks of measles.

DECLARATION OF INTEREST

None.

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