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Household determinants of delayed MMR vaccination: longitudinal analysis using electronic health records

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Complete List of Authors:	Marszalek, Milena; Queen Mary University of London Firman, Nicola; Queen Mary University of London, Centre for Primary Care and Public Health Wilk, Marta; Queen Mary University of London Gutierrez, Ana; Queen Mary University of London, Centre for Clinical Effectiveness and Health Data Science Institute of Population Health Sciences Barts and the London School of Medicine and Dentistry Smith, Kelvin; Queen Mary University of London Dezateux, Carol; Queen Mary University of London, Centre for Primary Care
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ehold determinants of delayed MMR vaccination: longitudinal analysis using electronic
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a Marszalek ¹ , Nicola Firman ¹ , Marta Wilk ¹ , Ana Gutierrez ¹ , Kelvin Smith ¹ , Carol Dezateux ¹
re for Primary Care, Wolfson Institute of Population Health, Faculty of Medicine and Dentistry,
n Mary University of London, Yvonne Carter Building, 58 Turner Street, London, E1 2AB
sponding author: Milena Marszalek; Centre for Primary Care, Wolfson Institute of Population
h, Faculty of Medicine and Dentistry, Queen Mary University of London, Yvonne Carter Building,
irner Street, London, E1 2AB; m.marszalek@qmul.ac.uk; 0207 882 6806
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2	45	
4	15 16	Abstract
5 6	17 18	Background
7 8	19	There is a lack of information about household factors associated with delayed Measles Mumps and
9	20	Rubella (MMR) vaccination. We examined whether delay in first MMR (MMR1) receipt is associated
10 11	21	with sharing a household with an older child with delayed MMR1 receipt and whether this is
12 13	22	independent of household composition and number of children.
14 15	23	Methods
16 17	24	We conducted a longitudinal study using the primary care electronic health records of children
18 19	25	registered with general practices in north east London and eligible to receive MMR1 between 1 st
20 21	26	January 2020 and 28th February 2020. The primary outcome was MMR1 receipt – between age 12
22 23	27	and 24 months. The explanatory variable was non-receipt of MMR1 between age 12 and 24 months
24 25	28	in the oldest child sharing the same household. We used Poisson regression to calculate MMR1
26 27	29	prevalence ratios (PR) and 95% confidence intervals (CI) for index children sharing a household with
28 29	30	an older child with non-receipt of MMR1 before and after adjustment for individual-, household-, and
30 31	31	area-level covariates. We carried out a sensitivity analysis excluding households where the age
32	32	interval between oldest and youngest child was > five years.
33 34	33	Findings
35 36	34	The index cohort comprised 71,509 children (51.0% males), of whom 59,851 (83.6%) received MMR1
37 38	35	by age 24 months. MMR1 receipt was less likely in index cohort members sharing a household with
39 40	36	an older child with non-receipt of MMR1 by age 24 months: PR: 0.67 (95% CI: 0.66,0.68) in the fully
41 42	37	adjusted model. This association strengthened when households with an age interval > five years
43 44	38	were excluded: PR: 0.57 (0.57,0.58)
45 46	39	Interpretation
47 48	40	There is a strong concordance within households of delay in MMR1 receipt independent of household
49 50	41	size and composition. Lack of timely protection within households increases the risk of measles
50 51 52	42	outbreaks. There is a need for household-based interventions to improve MMR1 timeliness.
53	43	
54 55	44	Funding
56 57	45	National Institute of Health and Care Research; Barts Charity
58 59	46	
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1 2		
- 3 4	47	Strengths and limitations
5 6	48	• The strengths of our study include the use of a novel method to create households securely
7 8	49	while maintaining privacy, as well as having access to a large population with EHRs, for a
9 10	50	geographically contiguous area.
11	51	Additionally, we have access to high quality MMR data, that is recorded accurately in the
12 13	52	EHR through data recording templates. ⁽¹⁾ The codeset used to identify MMR1 in the EHR was
14 15	53	validated.
16 17	54	We used robust statistical methods to assess relationships between the exposure and
18 19	55	outcome variables, and we selected a time period before lockdowns due to the Coronavirus
20 21	56	pandemic disrupted access to health care in England (March 2020).
22 23	57	
24 25	58	We were not able to confirm whether the processes of decision-making about vaccines
26 27	59	differed between the linked index and older children.
28 29	60 61	A However, we were able to see a strengthening of appeciation between the vessingtion status
30 31	62	However, we were able to see a strengthening of association between the vaccination status
32 33	63	of a younger and linked older child in the sensitivity analyses when excluding children with an age gap of over 5 years. This finding will need to be explored further with research exploring
34 35	64	the decision-making around vaccination for multiple young children in a household.
36 37	65	the decision-making around vaccination for multiple young children in a household.
38 39	66	
40	67	Introduction
41 42	68	Childhood vaccinations form an essential part of public health interventions provided by primary
43 44	69	care. ⁽²⁾ In England and Wales, it is recommended that children receive a first dose of Measles,
45 46	70	Mumps and Rubella (MMR) vaccine by age 12 months ⁽³⁾ : currently only 89% receive a first dose by
47 48	71	age 24 months, and only 84% a second dose by age five years. ⁽⁴⁾ This countrywide statistic conceals
49 50	72	marked geographic inequalities linked to deprivation. The World Health Organization (WHO)
51 52	73	recommends that 95% of the population are given two MMR doses toachieve herd immunity and
53 54	74	eliminate measles. ⁽⁵⁾ The United Kingdom (UK) lost measles elimination status in 2018 and while this
55 56	75	was reinstated in 2021, measles outbreaks in areas with high measles susceptibility in young children
57 58	76	in England suggest that this will not be sustained. ⁽⁶⁾ Clusters of inequalities in MMR coverage
59 60	, 0	

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exacerbate existing outbreaks - a large proportion have been in London, an area with both low and profoundly inequitable coverage.⁽⁴⁾

In light of these public health concerns, there has been increasing emphasis on the importance of timely receipt of MMR, with the first dose conferring 93% protection against infection.⁽⁷⁾ In the UK, national targets to ensure receipt of first MMR (MMR1) between 12 and 24 months of age have been recently replaced by a 12-18 month target reflecting this emphasis on timeliness.⁽⁸⁾

It is known that equity in vaccination coverage is impacted by social determinants such as deprivation, ethnicity and area-level variation in healthcare services.^(9, 10) There is strong evidence demonstrating that children from more deprived areas are less likely to receive MMR vaccination compared to those living in affluent areas.⁽¹¹⁾ We and others ⁽¹²⁾ have previously shown that family size is an important determinant of partial or non-immunisation with MMR, suggesting that access to services may play an important role.(13)(14)

Identifying factors at a household level can create actionable insights into how services might be tailored to improve receipt of vaccinations.⁽¹⁵⁾ We used electronic health records (EHRs) for an ethnically diverse and disadvantaged population, with among the lowest proportion of children receiving MMR1 by 24 months of age in the UK, to investigate whether non-receipt of MMR1 by 24 months of age is clustered in households. Specifically, we hypothesised that children with non-receipt of MMR1 by age 24 months were more likely to share a household with an older child with non-receipt of MMR1 by age 24 months, independently of the number of children in the household and household composition.

Methods

Study design and setting

We conducted a longitudinal study using primary care EHRs from 266 general practices in seven

North-East London (NEL) localities: Barking & Dagenham, City & Hackney, Havering, Newham,

Redbridge, Tower Hamlets, and Waltham Forest. Enseignement Superieur (ABES) . Protected by copyright, including for uses related to text and data mining, Al training, and similar technologies.

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3 4	107	Data Sources
5 6	108	Pseudonymised data were provided from the NEL Discovery Data Service (DDS), which receives
7 8	109	primary care EHR data in near-real time for all general practices (GPs) in NEL. (16) Unique Property
9 10	110	Reference Numbers (UPRNs) are allocated to all GP-recorded patient addresses in DDS using a
11	111	quality-assured and validated address-matching algorithm. ⁽¹⁷⁾ UPRNs are pseudonymised into
12 13	112	Residential Anonymous Linking Fields (RALF) ⁽¹⁸⁾ using a study-specific encryption key. We used
14 15	113	RALFs to link children in households for address records and registrations from 2014 onwards, when
16 17	114	data flow for address registrations into NEL DDS commenced. Data were extracted on 23rd November
18 19	115	2021.
20 21	116	
22 23	117	Study population
24 25	118	The study population comprised 159,300 children registered with a NEL GP at the time of their
26 27	119	second birthday and eligible to receive MMR1 between 1 st January 2014 and 28 th February 2020. We
28 29	120	excluded 17,038 children without a RALF, with a non-residential RALF, with a poor-quality RALF
30 31	121	match, or with more than one RALF at time of MMR1 or second birthday, leaving 142,262 children
32 33	122	eligible for inclusion (see flow chart S1).
34	123	
35 36	124	Identifying children sharing a household
37 38	125	We identified older children sharing a household with the 142,262 index children at the index child's
39 40	126	MMR1 date or 24 months of age, whichever is the earliest. Index and older children sharing a RALF
41 42	127	at index child's MMR1 date, or at the index child's second birthday were considered to share a
43 44	128	household. We identified all children in DDS based on the index children's RALFs and excluded
45 46	129	52,693 children without an older child in the household, and 15,516 older children who were already
47 48	130	included as index children, leaving 71,509 index children with at least one older child sharing their
49 50	131	household at the index child's MMR1 date or second birthday (see flow chart S2). These 71,509
51 52	132	children are henceforth referred to as the "linked index cohort" and the older children with whom they
53	133	share a household as the "linked older children's cohort".
54 55	134	
56 57	135	The study methodology has been reported against both the STrengthening the Reporting of
58 59 60	136	OBservational studies in Epidemiology (STROBE) and the REporting of studies Conducted using

1 2		
3 4	137	Observational Routinely-collected health Data (RECORD) statement (see supplementary files S3 &
5 6	138	S4). ^(19, 20)
7 8	139	
9 10	140	Primary outcome
11 12	141	The primary outcome is receipt of MMR1 between 12 and 24 months of age, which is consistent with
13 14 15	142	the Cover of Vaccination Evaluated Rapidly (COVER) measures in place during the study period. ⁽²¹⁾
16 17	143	We extracted sociodemographic and area-level data for the linked index and linked older child
18 19	144	cohorts, together with all clinical events relating to MMR1 procedures (see Table S1s). We derived a
20 21	145	proxy date of birth from calendar week, month and year of birth by combining the date of the first day
22 23	146	of the week of the calendar week of birth with month and year of birth. We excluded duplicated
24 25	147	events, and events without correct clinical codes. We assumed MMR1 was not given if there was no
26	148	record of MMR1 being given in the primary care EHR. If a child did not have a record of a MMR1
27 28	149	vaccination, they were linked to a RALF at the time of their second birthday, and were defined as
29 30	150	children with non-receipt of MMR1.
31 32 33 34	151	Explanatory variable
35 36	152	The main explanatory variable was non-receipt of MMR1 in the linked older child defined as no record
37 38	153	of MMR1 given between 12 and 24 months of age.
39 40 41	154	Covariates
42 43 44	155	Individual-level
45	156	Individual-level covariates were sex and ethnic group. We categorised ethnic group of the index
46 47	157	children using the NHS 5+1 classification using information recorded in the EHR. ⁽²²⁾ We created five
48 49	158	mutually exclusive ethnic groups: white ('white British', 'white Irish' or 'any other white background');
50 51	159	black ('black African', 'black Caribbean' or 'any other black background'); South Asian ('Indian',
52 53	160	'Pakistani', 'Bangladeshi' or 'Sri Lankan'); mixed/other ('any other ethnic background', 'mixed
54 55	161	ethnicity', 'Chinese' or 'Asian other'); and missing category (ethnicity code in the primary care record
56 57	162	missing or 'not stated' category selected).
58 59	163	Household-level

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3 4	164	All household members sharing a household at the index child's MMR1 date were identified. We
5 6	165	excluded households with more than ten members, only one child, or no adults aged ≥18.0 years.
7	166	Household information was available for 65,308 households containing index and linked older
8 9 10	167	children.
11 12	168	We categorised household composition using an adapted Harper and Mayhew method ⁽²³⁾ into one of
13 14	169	three mutually exclusive categories: working-age adults (aged 18-64 years) with children; single
15 16	170	working-age adult with children, or at least one working-age and one older adult (aged >65 years)
17 18	171	with children (three-generation household). We included households with at least one older adult with
19 20	172	children but no working-age adult (skipped generation households) in the three-generation household
21 22	173	group.
23 24	174	We calculated the total number of household members, as well as the number of children within a
25 26 27	175	household at the index child's MMR1 date or 24 months of age for those with no MMR1 date.
27 28 29	176	Area-level
30 31	177	We merged 2019 Index of Multiple Deprivation (IMD) decile ⁽²⁴⁾ into the datafile using the 2011 Lower
32 33	178	layer Super Output Area (LSOA), an area with an average population of 1,500 people or 650
34 35	179	households, as the linkage field. IMD deciles were concatenated into quintiles from most (1) to least
36 37 38	180	deprived (5).
39 40	181	We compared the linked index cohort ($n=71,509$) with the cohort of eligible children ($n=70,753$) not
41	182	linked to another older child (Table S2). The linked sample had a lower proportion with receipt of
42 43	183	MMR1 by 24 months of age, were less likely to be from a white ethnic background, from smaller
44 45 46	184	households, or from households with two or more working age adults.
40 47 48	185	
49	186	Statistical Methods
50 51 52	187	We calculated the proportion of the index and linked older child cohorts receiving MMR1 by 24
52 53	188	months of age. We examined variation in MMR1 receipt in the index cohort by individual-, household-,
54 55 56	189	and area-level characteristics, as well as by MMR1 receipt in the linked older children's cohort.
56 57 58 59 60	190	

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191 We estimated the likelihood of MMR1 vaccination by 24 months in the index cohort using Poisson 192 regression and calculated prevalence ratios (PR) and 95% confidence intervals (CI) for those sharing 193 a household with a linked older child with non-receipt of MMR1 by 24 months of age, before and after 194 adjustment for individual-, household-, and area-level covariates. Covariates with of p < 0.1 in the 195 univariable Poisson regressions were included in a multivariable Poisson regression model following 196 a step-wise model selection strategy. Variables were retained in the final multivariable model 197 if *p*≤0.05.

199 We performed three sensitivity analyses. In the first, we changed the definition of the primary outcome 200 to receipt of MMR1 between 12 and 18 months of age in line with the recently introduced Quality and 201 Outcomes Framework targets introduced in 2021.⁽²⁵⁾ In the second, we excluded households 202 containing index and linked older children with an age gap of more than five years. In the third, we 203 extended the age range for MMR1 receipt in the index children from 12-24 months to 11-25 months to 204 allow for potential misclassification of ages related to method for assigning date of birth. We 205 performed post-hoc power calculations to determine an appropriate sample size to power our study 206 for the primary outcome. All analyses were conducted using R Studio.⁽²⁶⁾

208 Patient and public involvement

209 We involved patients and the public in the communication of study results and dissemination within 210 the local community, using accepted principles from the UK Standards for Public Involvement.⁽²⁷⁾ The 211 aim was to raise awareness of the importance of inequalities in timely childhood vaccinations. We 212 established a patient advisory group, comprising six parents, to co-produce dissemination materials. 213 The patient and public involvement group reflected on vaccination inequalities, the study design and 214 how results were delivered. Participants expressed reservations about the categorisation of ethnic 215 group and whether more granular categories could be used in future research. They discussed 216 communication and visualisation of results. The results have been disseminated in the form of a short 217 film, informed by advice about accessing seldom-heard as well as and existing community groups. 218 219 220 Results

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The index cohort comprised 71,509 children (51% males) of whom 11,658 (16.4%) had not received MMR1 vaccine by 24 months of age. Children in the index cohort who did not receive MMR1 by 24 months of age were more likely to live with a linked older child who similarly had not received MMR1 by 24 months of age (Table 1). Index children receiving MMR1 by 24 months of age were more likely to be from South Asian ethnic groups, and living in households with fewer adults and fewer children, and in households with two or more working age adults or three generation households. Children in single adult households or in households with a larger number of children were less likely to receive MMR1 by 24 months. There was a marked gradient in MMR1 receipt by IMD guintile with an absolute difference of 7.3% in MMR1 receipt by 24 months between the least and most deprived quintiles. In the unadjusted model, MMR1 receipt by 24 months of age was less likely in the index cohort sharing a household with a linked older child with no MMR1 receipt by 24 months of age (PR: 0.66, 95% CI: 0.65,0.67). The PR did not change after stepwise introduction of individual-, household-, and area-level covariates resulting in a PR of 0.67 (0.66,0.68) in the fully adjusted model (Figure 1; Table S2). The proportion of index children with MMR1 receipt by age 18 months was, as expected, lower than the proportion with MMR1 receipt by age 24 months: 79.2%, 95% CI: 78.9,79.5. Sensitivity analyses using this measure as the primary outcome did not alter PR estimates (PR: 0.67; 0.66,0.68). Exclusion of households containing index children and linked older cohort children with an age gap of more than five years strengthened the association: PR: 0.57 (0.57, 0.58). Extension of the age range for MMR1 receipt from 12-24 months to 11-25 months did not change the main findings: PR: 0.67 (0.66,0.68) (Figure 2, supplementary file Tables S4-S7). While our study focussed on MMR1 receipt within the UK recommended age range at the time of the study, it is possible that children were vaccinated at older ages. We searched for MMR1 dates for those with no MMR1 date within the 12-24 month age range. Of the 11.658 index children with no MMR1 receipt by 24 months, 516 (4.4%) had a MMR1 record before 12 months, 2,893 (24.8%) had received MMR1 vaccination by 40 months or 3 years and 4 months (when children become eligible for the second dose), 749 (6.4%) received MMR1 after 40 months of age, and 7,500 (64.3%) had no

1 2		
2 3 4	251	record of MMR1 receipt in the EHR by November 2021 when data were extracted (Table 2). This
5	252	suggests that just over one third of index children did eventually receive MMR1 but significantly later
6 7	253	than the recommended age. Almost half (47%) of the linked older children without MMR1 receipt
8 9	254	between 12 and 24 months of age also eventually received MMR1 and this was also significantly later
10 11	255	than the recommended age.
12 13	256	
14 15	257	Post-hoc power calculations demonstrated that a sample size of 52,000 in the index cohort would
16 17	258	provide 90% power to detect a 2 percentage point difference significant at the 1% level in MMR1
18 19	259	receipt by 24 months of age in the index child between those with and without a linked older child with
20 21	260	no MMR1 receipt by 24 months.
 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 		no MMR1 receipt by 24 months.
49 50 51 52 53		
54 55 56 57 58 59 60		

Table 1: MMR1 receipt in linked index children by individual, household and area-level characteristics	Table 1: MMR1 rece	ipt in linked index children	by individual, hous	sehold and area-level	characteristics
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	children by individual, ho					/bmjopen-2024-097559 4 by copyright, includir			
	Vaccinated			Non- Vaco	cinated		All Inde	x cohort	
	N=59,851 (84.	1%)		N = 11,658	8 (15.9%)	on 2 N ig for L	N=71,50)9	
	Received first	MMR betwe	en 12 and	Did not red	ceive first	May 202 Enseiç <i>MMR</i> s re			
	24 months of a	ge		between 1	2 and 24	montascor			
				age		Downloaded from the ement Supprieur (AE to text, and data in 95%) and data in 95% and data in 95% and the ext, and the ext			
	N	%	95% CI	n	%	95% Of dec	n	%	95% CI
MMR1 Status of Oldest Child						l from d data			
Vaccinated	53198	88.4	88.1, 88.6	6987	11.6	11.32,500 11.32,500 nir	60185	84.2	83.9 , 84.4
Non-vaccinated	6653	58.8	57.8, 59.7	4671	41.2	40.%, 422	11324	15.8	15.6, 16.1
Individual covariates			9/			open.bmj. I training,			
Ethnic Background				97.		pen.bmj.co training, ar			
South Asian	16963	88.0	87.6, 88.5	2305	12.0	11.5 12.4	19268	25.5	25.1, 25.8
White	16625	83.8	83.3, 84.3	3219	16.2	15.2,16=7	19844	28.3	27.9-28.6
Black or Black British	5703	82.2	81.2,83.1	1238	17.8	16.94,18,57	6941	10.0	9.8,10.2
Mixed and Other	4847	78.8	77.8,79.8	1303	21.2	20 8 ,2232	6150	8.5	8.3,8.7
Missing**	15713	81.4	80.8,81.9	3593	18.6	<u>₹</u> <u></u> 18.1,19 2 2	19306	27.7	27.4,28.1
Sex						gence			
Female	29399	84.0	83.6,84.3	5614	16.0	e Bib4 15.6,164 ographique de l	35013	3 48.9	48.5,49.3

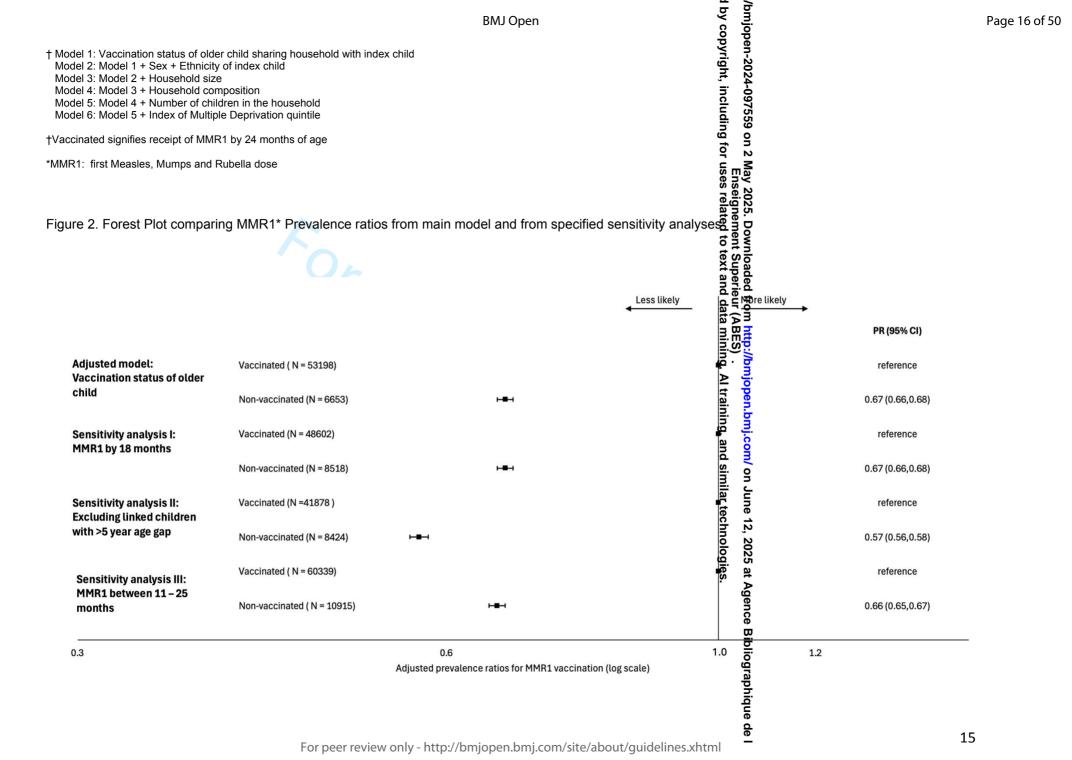
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Male	30452	83.4	83,83.8	6044	16.6	16,16,9 16,16,9	36496	51.1	50.7,51.
Household-level covariates						24-097: It, inclu			
Household size						559 udin			
3-4	18695	86.1	85.7-86.6	2976	13.9	13. द्र ,14 , 3	21671	30.3	30 ,30
5 to 7	26867	84.0	83.6,84.4	5097	16.0	<u>и ма</u> 15.68,956.4	31964	44.8	44.4,45
8 to 10	9397	80.6	79.9,81.3	2264	19.4	18 relation 18 relation 18 recently and the second	11661	16.3	16,16
Missing**	4881	78.7	77.7,79.7	1320	21.3	20.05 x 20.05	6201	8.6	8.4,8
Household Composition	0					Superie text and			
Two working age adults with childre	en 42380	84.6	84.3,84.9	7713	15.4	15.557 15.557 5.75	50093	76.7	76.4,7
Single working age adult with childre	ren 7699	81.5	80.7,82.3	1747	18.5	17. 3 .0003	9446	14.5	14.2,14
Three-generational household	4891	84.8	83.8, 85.7	878	15.5	14.5,164	5769	8.8	8.6
Missing**	4881	78.7	77.7,79.7	1320	21.3	20.4.223	6201	8.6	8.4,8
No. of children in the household						ing, a			
2 to 3	43968	85.4	85.0,85.7	7527	14.6	14.33,14-9	51495	72	71.7,72
4 to 6	10669	80.2	79.5,80.8	2629	19.8	19.84,2055	13298	18.7	18.4,1
7 to 9	333	64.7	60.4,68.8	182	35.3	31. 2 ,39.6	515	0.7	0.6,0
Missing**	4881	78.7	77.7,79.7	1320	21.3	2000,2223	6201	8.6	8.4,8
Area level covariates						at Agen es.			
Index of Multiple Deprivation Qui	ntile					nce B			
	23861	83.9	83.5,84.3	4587	16.1	15.7,16 5 5	28448	40	39.7,40

		E	3MJ Open			/bmjope I by cop			
2	23512	82.3	81.7,82.8	5052	17.7	17.31,18-1 17.39 18-0	28564	39.8	39.5,40.1
3	7600	83.9	83.2,84.7	1454	16.1	15. 3 ,168	9054	12.6	12.4,12.8
4	3345	88.9	87.9,89.9	417	11.1	10.5 10.5 0 0 0	3762	5.2	5,5.4
5 (least deprived)	1533	91.2	89.7,92.5	148	8.8	7.97,10,2 use пау	1681	2.3	2.2,2.4
* Children that could not be linked to othe /lissing' able 2. MMR1 receipt in Index and Older						ownloaded t nent Superie d to text and			אין
Non-vaccinated groups	Index	k Child (N =	= 11658)	%	0		=11324)	%	7
MMR1 receipt <12 months of age	516		6	4.4	99	<u>, <u></u>, <u></u>, <u></u>, <u>,</u></u>		8.8	-

			- 4 @	
Non-vaccinated groups	Index Child (N = 11658)	%	Older Children N=11324)	%
MMR1 receipt <12 months of age	516	4.4	993 (g. 0 ▶ jo	8.8
MMR1 receipt between 24 and 2y40 months of age	2893	24.8	2642 rainir	23.3
MMR1 receipt > 40 months of age	749	6.4	1689 (G	14.9
No record of MMR1 receipt in period of follow-up	7500	64.3		53.0
Total	11658	100.0	11324 ar une	100.0

chnologies.

e 15 of 50			BMJ Open		/bmjop I by co	
Figure 1. Forest Plot of	f MMR1* Vaccinat	ion Prevalence Ratios	by 24 months of age usi	ing stepwise Poisson	Regression	
			Less likely	More likely	Regrupping version of the second seco	
					din 59 PR (95% Cl) 9 on	
Unadjusted model: Vaccination status of	Vaccinated				for uses	
older child	Non-vaccinated	⊢ ∎-1			religner loo25. [7)
+ Demographics: Model 2 †	Vaccinated			ł	d to tex.	
	Non-vaccinated	⊦∎⊣			tand 0.66 (0.65,0.6 and fr	7)
+ Household Size : Model 3 †	Vaccinated			ł	darr om reference reference mirt BEC	
	Non-vaccinated	⊨∎⊣			0.66 (0.65,0.6	7)
+ Household Composition:	Vaccinated			ł	L reference	
Model 4 †	Non-vaccinated	⊢ ∎-1			ig, nj. 0.67 (0.66,0.6) and off	8)
+ No. of Children in Household:	Vaccinated			ł	similar	
Model 5 †	Non-vaccinated	HEH			• ne 0.67 (0.66,0.64 hechr 2,	8)
+ IMD Quintile: Model 6 †	Vaccinated			ł	ologies reference	
	Non-vaccinated	H H H			A 0.67 (0.66,0.6	8)
0.4		Adjusted	0.8 prevalence ratios for MMR1 vacc	1.0 ination (log scale)		
			•		graphi	
					Bibliographique de l	
		For peer review only -	http://bmjopen.bmj.com	/site/about/guidelines	.xhtml	



†Vaccinated signifies receipt of MMR1 by 24 months of age

*MMR1: first Measles, Mumps and Rubella dose J from http://bmippen.bmj.com/ on Ju. and data min/ng, Al training, and similar tec.

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261 Discussion

We have shown that 16% of children from an English urban, disadvantaged, and multi-ethnic population with low MMR1 coverage do not receive MMR1 by age 24 months, and that they are less likely to do so if they share a household with an older child who did not receive MMR1 by age 24 months. This association was independent of ethnic group, number of children in the household, household composition, and area-level deprivation, and was strengthened when analyses were confined to household children with an age gap of less than five years. We also found that children in single adult households or in households with a larger number of children are less likely to receive MMR1, confirming findings from previous studies reporting household characteristics of children with delayed MMR1 receipt. These findings suggest that caregivers' actions related to attendance for child vaccinations may be consistent across children in the household, particularly among children who are close in age.

While our study focused on MMR1 receipt within the UK recommended age range at the time of the study, we were able to show that one third of index children did receive MMR1 at both younger and older ages. There are a number of explanations for this. UK vaccine guidance states that MMR1 may be given under 12 months of age in the context of outbreaks or exposure to measles. However, as there is evidence that this doesn't produce a strong antibody response, it is recommended that MMR1 must be given again within the scheduled age range.⁽³⁾ Parents may not agree to a second MMR1, especially if this was given close to the first birthday. Furthermore, a proportion of MMR1 events under 12 months of age were assigned an implausible date (e.g. given at birth date), and we are aware that GP practices may use this to record vaccines given in other countries for which the caregiver is unable to provide a date. London includes a significant proportion of children who are non-UK born and who migrate after the age of primary immunisations, many of whom anecdotally also spend periods back in their country of birth.^(28, 29) This complicates administration and recording of vaccines, and may create different expectations among parents or caregivers regarding vaccine schedules. Opportunistic catch up of MMR1 has also been initiated on a number of occasions, and appointments for the second dose may be the opportunity to give the first dose: almost one quarter of index and linked older children were given MMR1 between 24 and 40 months of age. So while we

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3 4	290	were unable to confirm MMR1 receipt in two thirds of index and one half of linked older children, a
5	291	significant proportion were delayed rather than never immunised.
6 7	292	
8 9	293	This is to our knowledge the first study to examine associations within households of MMR1
10 11	294	coverage, so direct comparisons with existing literature are not possible. Previous studies have found
12 13	295	that vaccine coverage is lower in families with larger numbers of children and in single-parent
14 15	296	households. ^{(30) (31)} It has been suggested that the main drivers of vaccination delay in these
16 17	297	households are access-based, with vaccination services and appointments less suitable for families
18 19	298	with larger numbers of children, or for parents requiring more flexible clinic appointments. ^{(13) (32)}
20 21	299	Vaccination delay may also be non-intentional; parents may delay vaccinations due to a child's
22 23	300	illness. ⁽³³⁾ This may explain some of the factors driving delayed MMR1 receipt in our study.
24 25	301	
26 27	302	There may be other reasons for delayed MMR1 receipt. Qualitative research around reasons for
28 29	303	delayed, partial or non-vaccination of children highlight the importance for parents of shared decision-
30 31	304	making with clinicians, and the strong association between trust in healthcare professionals and
32	305	vaccine hesitancy in parents or caregivers. Parents or caregivers who have some trust in the
33 34	306	information given by healthcare professionals may delay rather than completely refuse a child's
35 36	307	vaccination, and this may be a consistent factor for all children in the household. ⁽³⁴⁾ One study looking
37 38	308	at decision-making in a household between adults and adolescents for the Men ACWY vaccination
39 40	309	found that information gathering outside of a healthcare setting even prior to invitation for vaccination
41 42	310	significantly impacted the decision made. ⁽³⁵⁾
43 44	311	
45 46	312	Vaccinations can also be delayed by parents if they feel that data around the safety of a vaccine is
47 48	313	insufficient, or if they have concerns about overburdening a child's immune system. ^(36, 37) Parental or
49 50	314	caregiver disagreement around childhood vaccination may also contribute to delay. ⁽¹⁴⁾
51 52	315	
53	316	Further qualitative research is needed to tease out the likely heterogenous reasons for MMR1 delay
54 55	317	at a household level and to understand household factors that interact with access and the decision-
56 57 58 59 60	318	making process. ⁽³⁸⁾ Delay in primary vaccinations against diphtheria, pertussis, polio, tetanus and

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Haemophilus influenza has been shown to be associated with an incomplete vaccination schedule by 24 months of age.⁽³⁹⁾ We were not able to examine this in our study. Implications for practice Our study has demonstrated that delay in MMR1 receipt is strongly clustered within households. This lack of timely protection or any protection within households increases the risk of measles outbreaks. This suggests the need for household-based interventions to improve vaccination coverage and timeliness. Knowing the household composition of children with delayed or non-vaccination can allow a healthcare professional (HCP) to tailor their approach to organising vaccination appointments. For example, if it is known that there is more than one child in the household needing vaccination, a HCP can arrange an appropriate appointment for two children at one time. In England, the EHR in GPs allows a HCP to view the household of a selected patient. Household-based interventions could also be considered by public health and service commissioners. Setting up services tailored to households with non- or partially-vaccinated children aligns with documented interventions recommended to improve vaccination coverage.⁽⁴⁰⁾ The same principle applies to providing wider public health education about vaccination for these households:- the interventions can be more targeted when non- or partially-vaccinated households are identified. Emerging interventions using enhanced information and educational programmes and vaccination delivery by health visitors could be tailored to target more vulnerable households.⁽⁴¹⁾ Evidence from adolescent/adult decision making about vaccines in a household reinforces the importance of giving parents relevant information before the offer of vaccination from a healthcare provider.⁽³⁵⁾ Existing literature cites multi-component interventions as the most effective interventions for increasing vaccination coverage in deprived communities with intersectional inequalities - these would include information, education and re-call measures.⁽³⁸⁾ Robust re-call methods are cited as an effective way to vaccinate children with delayed vaccinations.⁽⁴²⁾ We are evaluating a quality improvement programme that aims to improve timeliness and equity of pre-school immunisations in NEL, focussing on data-enabled call and recall for immunisation.⁽⁴³⁾

1 2		
2 3 4	349	Future research
5	350	We have shown that non-receipt of MMR1 by 24 months of age is clustered in households. However,
7	351	a significant proportion of children do ultimately receive MMR1 in the preschool years and later
8 9	352	childhood, with no clear evidence of MMR1 receipt in the remainder. Qualitative research is needed to
10 11	353	understand the decision-making processes underlying this heterogenous group. Similar research in
12 13	354	demographically different areas of the UK may help understand the extent to which these findings are
14 15	355	generalisable to households in a different socioeconomic context.
16 17	356	
18 19	357	Conclusion
20 21	358	Our study suggests a strong concordance in MMR1 vaccine delay between children sharing the same
22 23	359	household in a region with the lowest MMR vaccination coverage in the UK. ⁽⁴⁾ These findings have
24 25	360	implications for the planning and delivery of vaccination services that consider children in their
26 27	361	household context.
28 29	362	
30	363	Acknowledgements
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33 34	365	using general practice data. This work uses data provided by patients and collected by the NHS as
35 36	366	part of their care and support. We would also like to acknowledge our PPI participants for their
37 38	367	invaluable insight into patient perspectives around dissemination of our research to the wider
39 40	368	community.
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51	374	not necessarily those of the NIHR or the Department of Health and Social Care.
52 53	375	
54 55	376	
56 57	377	Contributions
58 59		
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2		
3 4	378	As per CrEdit accreditation, significant contributions to: Conceptualisation (MM, CD, NF, MW),
5 6	379	Methodology (MM, CD, MW, NF), Resources (CD, AG), Data Curation (MM, AG, NF, MW, KS), Data
7	380	Analysis (MM, NF, CD), Writing-Original Draft (MM, CD), Review and Editing (MM, AG, NF, MW, KS,
8 9	381	CD), Formal Analysis (MM, CD), Validation (AG, MM), Visualisation (MM), Supervision (CD), Funding
10 11	382	Acquisition (MM, CD).
12 13	383	
14 15	384	
16 17	385	Competing interests declaration
18 19	386	All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/disclosure-of-
20 21	387	interest/ and declare: no support from any organisation for the submitted work; no financial
22 23	388	relationships with any organisations that might have an interest in the submitted work in the previous
24 25	389	three years; no other relationships or activities that could appear to have influenced the submitted
26 27	390	work.
28 29	391	
30 31 32	392	Ethics approval
	393	Access to general practice data is enabled by data sharing agreements between the Discovery Data
33 34	394	Service and general practice data controllers. The Discovery Programme Board has approved data
35 36	395	access by the REAL Child Health programme.
37 38	396	
39 40	397	Data sharing
41 42	398	The senior author (CD) was granted access to de-identified data by the data controllers for this work
43 44	399	and onward sharing of data is not permitted. The R codes used in the analyses are available at
45 46	400	https://github.com/mmarszalek1991/mmarszalek1991households/tree/main1.
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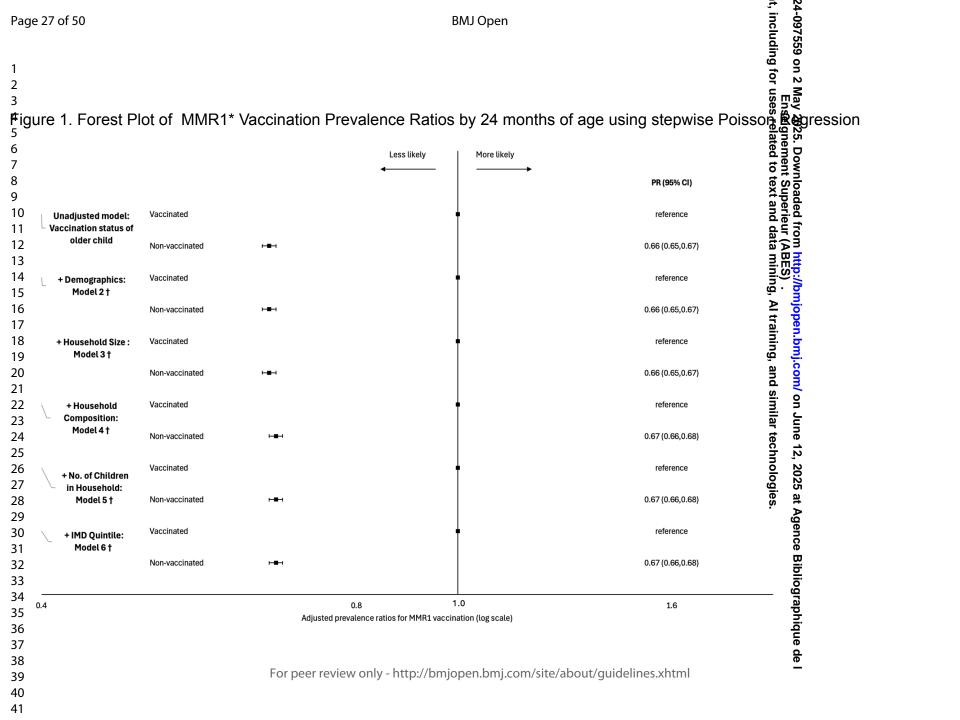
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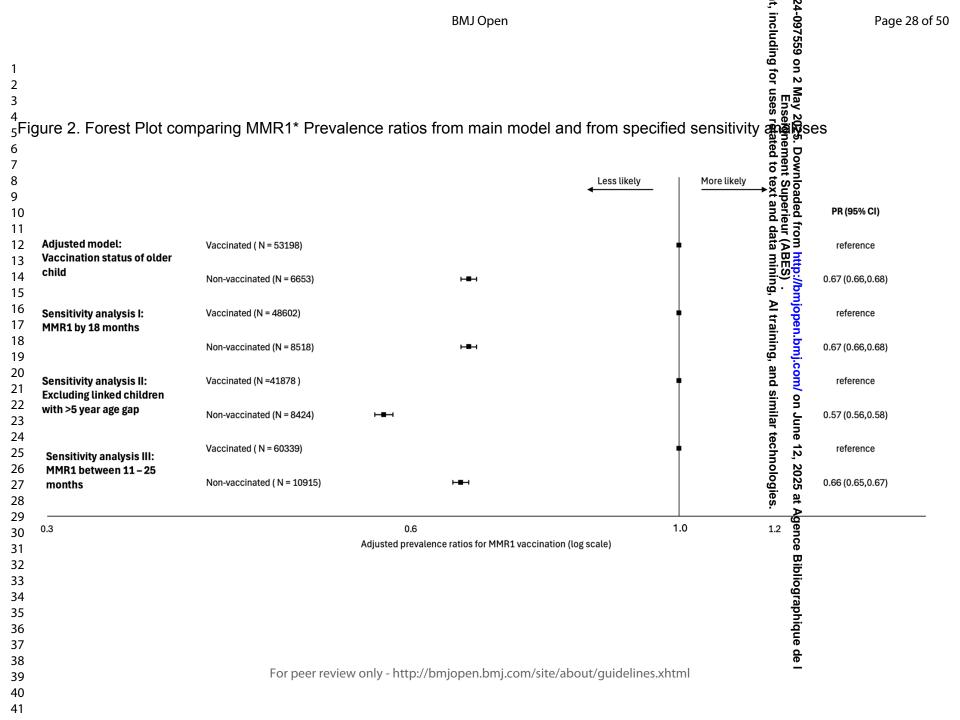
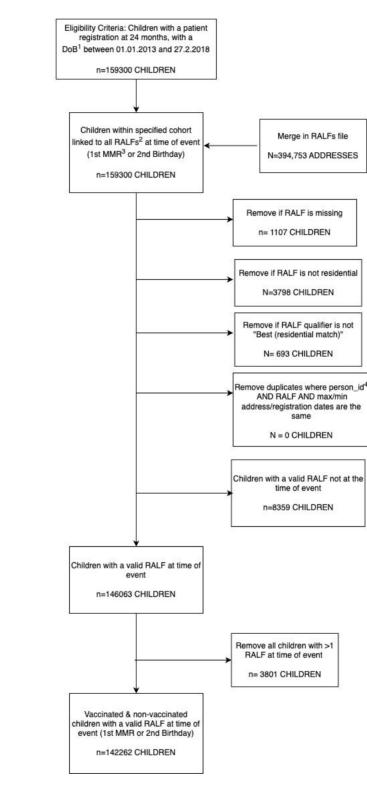


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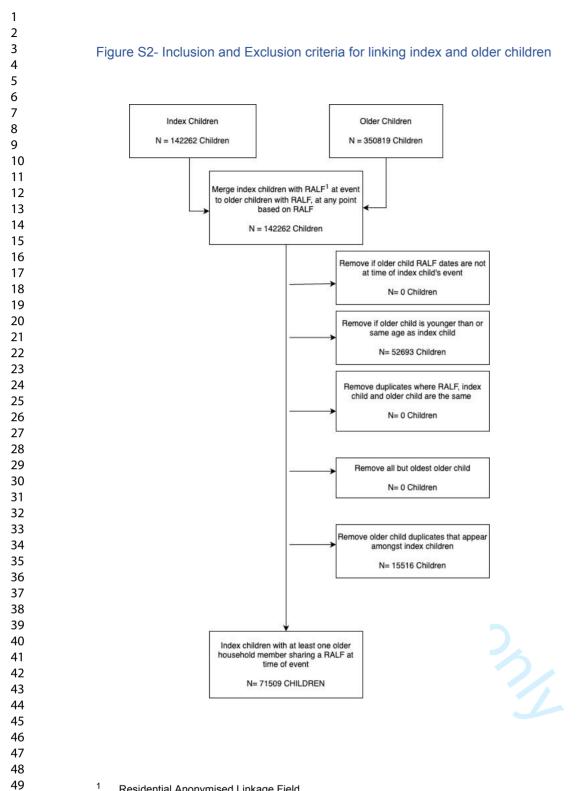
Figure S1- Inclusion and Exclusion Criteria for Sample population with a valid Residential Anonymised Linkage Field (RALF)



¹ Date of Birth

- ² Residential Anonymised Linkage Field
- ³ Measles, Mumps & Rubella vaccination
- ⁴ Individual person identifier

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Residential Anonymised Linkage Field

		BMJ Open BMJ Open-2022		Page
Supplementary file 3 (S3 STROBE Statement—cl		inclu		
	ltem No.	Recommendation d to t	Page No.	Relevant text from manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract of (b) Provide in the abstract an informative and balanced summary of what was done and what was found	1 2	
Introduction		and what was found and the region of the reg		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3	
Objectives	3	State specific objectives, including any prespecified hypotheses	3-4	
Methods				
Study design	4	Present key elements of study design early in the paper	4	
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitmen exposure, follow-up, and data collection	4-7	
Participants	6	 (a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants 	4-7	
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case		
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4-7	
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7	
Bias	9	Describe any efforts to address potential sources of bias	6	
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Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe	2025. ieigne	6-7
Statistical	12	(a) Describe all statistical methods, including those used to control for confounding	. Dow	7
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		(c) Explain how missing data were addressed	<u>ب</u> ا ع	7
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		(e) Describe any sensitivity analyses		7
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		(b) Give reasons for non-participation at each stage	Sup ¥ile	pplementary
		(c) Consider use of a flow diagram	Sup Eile	pplementary
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	ne 12,	8
		(b) Indicate number of participants with missing data for each variable of interest	2025	9
		(c) Cohort study—Summarise follow-up time (eg, average and total amount)		N/A
Outcome data	a 15*	Cohort study—Report numbers of outcome events or summary measures over time	at A	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	enc	
		Cross-sectional study—Report numbers of outcome events or summary measures	ë <u>B</u>	9
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	ibliogup apile	plementary
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 Supplementary file 4 (S4) - RECORD checklist

 The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported imposervational studies using routinely collected health data.

	ltem No.	STROBE items	Location in manuscript where items are reported	RECORD items es related to	Location in manuscript where items are reported
Title and abstract	1			tex sign	
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	revie	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If approable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	
Introduction				10 logies	
Background rationale	2	Explain the scientific background and rationale for the investigation being reported		at Agenc	2
Objectives	3	State specific objectives, including any prespecified hypotheses		e Bibliographique de	2-3

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Methods				D975	
Study Design	4	Present key elements of study design early in the paper		ding fo	3
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection		2 May 2025. Do Enseigneme ruses related	3
Participants	6	 (a) Cohort study - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study - Give the eligibility criteria, and the sources and methods of selection of participants (b) Cohort study - For matched studies, give matching criteria and number of exposed and unexposed Case-control study - For matched studies, give matching criteria and the number of controls per case 	revieu	RECORD 6.1: The methods of study population selection such as codes or algorithms used to the first is not possible, an explanation should be provided. RECORD 6.2: Any will align studies of the codes or algorithms used to select the population should be referenced. If validation was conduced for this study and not published else where, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, conside use of a flow diagram or other graphical display to demonstrate the data inkage process, including the number of individuals with linked data at each stage.	4

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1 2 3 4 5 6 7 8	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A c algorithms used to outcomes, confour modifiers should b	Emplete list of codes and Eclassify exposures, ederg, and effect e provided. If these	5
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Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) Cohort study - If applicable, explain how loss to follow-up was addressed Case-control study - If applicable, explain how matching of cases and controls was addressed Cross-sectional study - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	revieu	RECORD 12.1: Authors should describe	6-7
cleaning methods				the extent to which the investigators had access to the data base population used to create the study papulation.	5
				RECORD 12.2: Authors should provide information on the datecleaning methods used in the study.	3

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	Linkage				RECORD 12.3: State included person-legel, institutional-level, or of across two or more da methods of linkag quality evaluation state regin	ଞ୍ଚ ger data linkage abases. The rethods of linkage	4
	Results				d to	DI	
	Participants	13	 (a) Report the numbers of individuals at each stage of the study (e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for nonparticipation at each stage. (c) Consider use of a flow diagram 	r revie	RECORD 13.1: Description selection of the person study (<i>i.e.</i> , study per including filtering base data availability and to of included persons text and/or by means diagram.	bincluded in the tion selection) on data quality, age. The selection be described in the	3-5
	Descriptive data	14	 (a) Give characteristics of study participants (<i>e.g.</i>, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) <i>Cohort study</i> - summarise follow-up time (<i>e.g.</i>, average and total amount) 		nologies.	om/ on June 12, 2025 at Agence Bibl	7
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Outcome data	15	Cohort study - Report numbers of outcome events or summary measures over time Case-control study - Report numbers in each exposure		/bmjopen-2024-097559 on 2 May 2 Ens I by copyright, including for uses	7-9
		category, or summary measures of exposure <i>Cross-sectional study</i> - Report numbers of outcome events or summary measures		2025. Downloaded t eignement Superie related to text and	
Main results	16	 (a) Give unadjusted estimates and, if applicable, confounderadjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period 	elien o	from http://bmjopen.bmj.com/ on June 12, 2025 at ur (ABES) . data mining, Al training, and similar technologies.	7-10
Other analyses	17	Report other analyses done— e.g., analyses of subgroups and interactions, and sensitivity analyses		Agence	10-14
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Key results	18	Summarise key results with reference to study objectives		Bibliographique de I	15

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Limitationa	10	Discuss limitations of the study	, 4 n 0
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	RECORD 19.1: Discuss the 17 implications of using deta that were not created or collected togenswer the specific research question (). Include discussion of misclassification brand and changing confounding, missing that, and changing eligibility over times they pertain to the study being report
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Interpretation	20	Give a cautious overall interpretation of results considering objectives,	Superieur (dat
		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	ABES) . a mining, Al tr
Generalisability	21	Discuss the generalisability (external validity) of the study results	ainning 17
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Accessibility of protocol, raw data and programming code	,		RECORD 22.1: Authors should provide 19 information on how to access any supplemental informaton such as the study protocol, raw data, or programming code.

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*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langen SM, the RECORD Working Committee The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement.	<u>).</u>
*Reference: Benchimol EI. Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von EIm E, Lang du on Y May 2025. Downloaded from http://oniopen.bml.com/ on June 72, 2025 at Medicine 2015; in press. *Checklist is protected under Creative Commons Attribution (CC BY) license.	
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Table S1- Systematized Nomenclature of Medicine (SNOMED) clinical codes for first Measles, Mumps and Rubella vaccination procedures

Events recorded in the primary care electronic heath record using another clinical coding system (e.g. Read v2 or EMIS local codes) have been mapped to relevant SNOMED codes within the Discovery Data Service. This ensures that searching the database using SNOMED codes captured all events regardless of the clinical coding system used.

SNOMED concept ID	Other code	Clinical coding scheme	Code description
38598009	38598009	SNOMED	Measles-mumps-rubella vaccination (procedure)
	65M1.	Read v2	Measles/mumps/rubella vaccn.
	^ESCT1405772	EMIS local	Administration of measles and mumps and rubella vaccine
47435007	47435007	SNOMED	Measles vaccination (procedure)
	65A	Read v2	Measles vaccination
	65A1.	Read v2	Measles vaccination
	ZV042	Read v2	[V]Measles vaccination
	^ESCT1405845	EMIS local	Administration of measles vaccine
50583002	50583002	SNOMED	Mumps vaccination (procedure)
	65F5.	Read v2	Mumps vaccination
	ZV046	Read v2	[V]Mumps vaccination
	^ESCT1405876	EMIS local	Administration of mumps vaccine
82314000	65B	Read v2	Rubella vaccination
	ZV043	Read v2	[V]Rubella vaccination
	^ESCT1406118	EMIS local	Administration of rubella vaccine
170364006	65A2.	Read v2	Measles vaccin.+immunoglobulin
432636005	^ESCT1408534	EMIS local	Administration of measles and mumps and rubella and varicella virus vaccine
871909005	^ESCT1397548	EMIS local	Administration of first dose of measles and mumps and rubella and varicella virus vaccine
150971000119104	ZV064	Read v2	[V]Measles-mumps-rubella (MMR) vaccination
308081000000105	65M10	Read v2	First MMR (measles mumps and rubella) vaccination
	Хаеес	Read v3	First MMR (measles mumps and rubella) vaccination
	^ESCTME809974	EMIS local	Measles mumps and rubella vaccination - first dose

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505001000000109	9ki1.	Read v2	MMR catch-up vaccination - enhanced services administration
	XaQPr	Read v3	Measles mumps rubella catch-up vaccination
571591000119106	^ESCT1409651	EMIS local	Administration of live attenuated measles mumps and rubella vaccine
1037251000000100	65M11	Read v2	First MMR vaccination given by other healthcare provider
	Xaeeq	Read v3	First MMR vaccination given by other healthcare provider

We included clinical codes relating to administration of mono-components of the first MMR vaccination. After removal of duplicate data entries and merging to the study cohort, 584989 children had a clinical code for measles vaccination, and two for mumps vaccination, as opposed to a combined MMR vaccination.

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Table S2. Demographics of linked and unlinked cohorts by individual-, household- ar	nd area-level
variables	

	Linked	Linked cohort (n = 71509)			Unlinked cohort (n = 70753)			
	N	%	95% CI	N	%	95% CI		
Individual Variables	-							
MMR status								
Vaccinated	59851	83.6	83.3-83.9	60512	85.5	85.3-85.8		
Non-Vaccinated	11658	16.4	16.1-16.6	10240	14.5	14.2-14.7		
Sex		1						
Female	35013	48.9	48.5-49.3	34885	49.3	48.9-49.7		
Male	36496	51.1	50.7-51.4	35867	50.7	50.3-51.1		
Ethnic Background		1						
Asian or Asian British	19268	25.5	25.1-25.8	16073	22.7	22.4-23		
White	19844	28.3	27.9-28.6	23536	33.3	32.9-33.6		
Missing	19306	27.7	27.4-28.1	18807	26.6	26.3-26.9		
Black or Black British	6941	10.0	9.8-10.2	5467	7.7	7.5-7.9		
Mixed and Other	6150	8.5	8.3-8.7	6869	9.7	9.5-9.9		
Household-level Variables		1						
Number of Children per house	hold							
2 to 3	51495	72.0	71.7-72.3	59151	83.6	83.3-83.9		
4 to 6	13298	18.7	18.4-19	4486	6.3	6.1-6.5		
7 to 9	515	0.7	0.6-0.8	270	0.4	0.3-0.5		
Missing	6201	8.6	8.4-8.8	6845	9.7	9.4-10		
Household size	-							
3 to 4	21683	30.3	30 - 30.6	37417	52.9	52.5-53.3		
5 to 7	31964	44.7	44.3-45.1	18976	26.8	26.5-27.1		
8 to 10	11661	16.3	16-16.6	7514	10.6	10.4-10.8		
Missing	6201	8.7	8.5-8.9	6845	9.7	9.4-10		
Household composition								
Two adults with children	50093	70.0	69.7-70.3	46906	66.3	66-66.6		
Single adult with children	9446	13.2	13-13.4	10356	14.6	14.4-14.9		
Three generational household	5769	8.1	7.9-8.3	6645	9.4	9.2-9.6		
Missing	6201	8.7	8.5-8.9	6845	9.7	9.5-9.9		
Area-level Variables		I						
IMD Quintile								
IMD1 (Most deprived)	28448	40.0	39.7-40.3	26062	36.8	36.5-37.2		
IMD2	28564	39.8	39.5-40.1	28972	40.9	40.5-41.3		
IMD3	9054	12.6	12.4-12.8	9602	13.6	13.3-13.8		
IMD4	3762	5.2	5-5.4	4311	6.1	5.9-6.3		
IMD5 (Least deprived)	1681	2.3	2.2-2.4	1805	2.5	2.4-2.6		

Table S3. Unadjusted and adjusted prevalence ratios for 1st Measles, Mumps and Rubella vaccination by 24 months of age, by individual-, household-, and area-level characteristics:

	PR ¹	95% CI ¹	p-value	PR ¹	95% Cl ¹	p-value
Individual characteristic	ĊS	1			1	
Vaccination status of	older child					
Vaccinated	Reference			Reference		
Non-vaccinated	0.66	0.66,	< 0.001	0.67	0.67,	< 0.001
		0.67			0.68	
Sex	-	-				
Male	Reference			Reference		
Female	0.99	0.99,	0.073	0.99	0.99,1.00	0.07
		1.00				
Ethnic background						
Asian or Asian British	1.04	1.03,	<0.001	1.05	1.04,	<0.001
		1.05			1.06	
White	Reference			Reference		
Missing	0.97	0.96,	<0.001	0.98	0.97,	<0.001
		0.98			0.99	
Black or Black British	0.98	0.97,	0.001	1.00	0.98,	0.4
		0.99			1.01	
Mixed and Other	0.95	0.94,	<0.001	0.97	0.95,	<0.001
		0.97			0.98	
Household-level Variat						
Number of children p	er household	ł				
2 to 3	Reference			Reference		
4 to 6	0.95	0.94,0.96	< 0.001	0.97	0.96,0.98	< 0.001
7 to 9	0.82	0.78,0.85	< 0.001	0.85	0.82,0.89	< 0.001
Missing	0.94	0.93,0.96	<0.001	NA	NA	NA
Household size						
3 to 4	Reference			Reference		
5 to 7	0.98	0.98,0.99	< 0.001	0.97	0.96,0.98	< 0.001
8 to 10	0.96	0.95,0.97	<0.001	0.96	0.94,0.97	< 0.001
Missing	0.94	0.93,0.95	< 0.001	NA	NA	NA
Household compositi		, ,				
Two adults with	Reference			Reference		
children						
Single adult with	0.97	0.96,0.97	<0.001	0.95	0.94,0.96	< 0.001
children						
Three generational	1.00	0.98,1.01	0.7	1.00	0.99,1.01	0.7
household						
Missing	0.95	0.94,0.96	<0.001	0.92	0.90,0.93	< 0.001
Area-level Variables				1	,	
IMD Quintile						
IMD1 (Most deprived)	Peferonco			Reference		
IMD1 (Most deprived)	Reference 0.99	0.08.1.00	0.002		0.08.0.00	<0.001
		0.98,1.00		0.99	0.98,0.99	
IMD3	1.00	0.99,1.01	0.8	0.99	0.98,1.00	0.13
IMD4	1.04	1.03,1.06	<0.001	1.03	1.02,1.05	< 0.001
IMD5 (Least deprived)	1.07	1.04,1.09	<0.001	1.05	1.03,1.08	<0.001
						1

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Table S4- Sensitivity analysis: timely Measles, Mumps and Rubella vaccination status at 18 months of age, by individual-, household-, and area-level characteristics

	Vaccinate		Non-Vaccinated			All Index cohort				
	N= 56641)	N = 1	N = 14889 (20.8%)			N=71530			
	Received 12 and 18		IR between s of age	Did not receive first MMR between 12 and 18 months of age						
	n	%	95% CI	n	%	95% CI	n	%	95% CI 26.5-27.2	
Individual-level		1	1	1	1	I	1	1	I	
Ethnic Background										
Asian or Asian British	16214	84.3	83.8-84.9	3007	15.6	15.1-16.2	19221	26.9	26.5-27.2	
White	15834	79.9	79.3-80.5	3978	20.1	19.5-20.6	19812	27.7	27.4-28	
Missing	14803	76.5	75.9-77.1	4554	23.5	22.9-24.1	19357	27.1	26.7-27.4	
Black or Black British	5342	76.9	75.9-77.9	1605	23.1	22.1-24.1	6947	9.7	9.5-9.9	
Mixed and Other	4448	71.8	70.7-72.9	1745	28.2	27.1-29.3	6193	8.7	8.5-8.9	
Sex			r 🔺	1	1		1	I	1	
Female	27814	79.4	79-79.8	7206	20.6	20.2-21	35020	49.0	48.6-49.3	
Male	28827	79	78.5-79.4	7683	21	20.6-21.5	36510	51.0	50.6-51.4	
Household -level					I					
MMR vaccination sta	tus of olde	r house	hold child							
Vaccinated	48602	85.8	85.5-86.1	8039	14.2	13.9-14.5	56641	79.2	78.9-79.5	
Non-vaccinated	8518	57.2	56.4-58.0	6371	42.8	42-43.6	14889	20.8	20.5-21.1	
Total number of adul	ts and chil	dren pe	r household			I	1		1	
0-4	17848	82.4	81.9-82.9	3819	17.6	17.1-18.1	21655	30.3	29.9-30.6	
5 to 7	25460	79.7	79.2-80.1	6492	20.3	19.9-20.8	31952	44.7	44.3-45	
8 to 10	8806	75.5	74.7-76.3	2849	24.4	23.7-25.2	11655	16.3	16-16.6	
Missing	4527	72.4	71.2-73.5	1729	27.6	26.5-28.8	6256	8.7	8.5-8.9	
Household composit	ion		1	1			.1	<u> </u>	<u>I</u>	
Two adults with children	40292	80.5	80.1-80.8	9773	19.5	19.3-19.9	50065	70	69.6-70.4	
Single adult with children	7187	76.1	75.2-77.0	2256	23.9	23.0-24.8	9443	13.2	13-13.4	
Three generational household	4625	80.3	79.5-81.6	1131	19.7	18.7-20.8	5766	8.1	7.9-8.3	
Missing	4527	72.4	71.2-73.5	1729	27.6	26.5-28.8	6256	8.7	8.5-8.9	
Number of Children i	n househo	ld								
2 to 3	41973	81.6	81.2-81.9	9494	18.4	18.1-18.8	51467	71.9	71.6-72.2	
4 to 6	9875	74.2	73.5-75.0	3422	25.7	25.0-26.5	13297	18.6	18.3-18.9	
7 to 9	266	52.1	47.7-56.5	244	47.8	43.4-52.3	510	0.7	0.6-0.8	

Missing	4527	72.4	71.2-73.5	1729	27.6	26.5-28.8	6256	8.7	8.5-8.9	
Area-level characteris									1	
Index of Multiple Dep	rivation qu	intile								
IMD 1 (most deprived)	22451	78.9	78.4-79.4	5998	21.0	20.6-21.6	28449	39.8	39.4-40.1	
IMD 2	22180	77.6	77.1-78.1	6390	22.4	21.9-22.9	28570	39.9	39.6-40.3	
IMD 3	7273	80.3	79.4-81.1	1786	19.7	18.9-20.5	9059	12.7	12.4-12.9	
IMD 4	3238	85.9	84.8-87	530	14	13-15.2	3768	5.3	5.1-5.4	
IMD 5 (least deprived)	1499	89	87.4-90.5	185	11	9.5-12.5	1684	2.3	2.3-2.4	Pro
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Table S5- Sensitivity analyses I- unadjusted and adjusted prevalence ratios for 1st Measles, Mumps and Rubella vaccination receipt by 18 months of age

	PR ¹	95% Cl ¹	p- value	PR ¹	95% Cl ¹	p-valu
	Unadjusted	l Variable	1	Adjusted Va	riable	1
Individual characteristics				· •		
Vaccination status of old	er child					
Vaccinated	Reference			Reference		
Non-vaccinated	0.66	0.65,0.66	< 0.001	0.67	0.66,0.68	< 0.00
Sex						
Female	Reference			Reference		
Male	1.00	0.99,1.00	0.2	1.00	0.99,1.00	0.13
Ethnic Background		•			•	
Asian or Asian British	1.04	1.03,1.05	<0.001	1.06	1.05,1.07	< 0.00
White	Reference			Reference		
Missing	0.96	0.95,0.97	< 0.001	0.97	0.96,0.98	< 0.00
Black or Black British	0.96	0.95,0.98	< 0.001	0.99	0.97,1.00	0.042
Mixed and Other	0.92	0.95,0.97	< 0.001	0.94	0.96,0.98	< 0.00
Household-level variables				•		
Household size						
3 to 4	Reference			Reference		
5 to 7	0.98	0.97,0.99	<0.001	0.97	0.96,0.98	<0.00
8 to 10	0.95	0.94,0.96	<0.001	0.96	0.94,0.97	<0.00
Number of children per h	ousehold					
2 to 3	Reference			Reference		
4 to 6	0.93	0.92,0.94	<0.001	0.95	0.94,0.96	<0.00
7 to 9	0.72	0.68,0.76	< 0.001	0.75	0.71,0.80	<0.00
Household composition						
Two adults with children	Reference			Reference		
Single adult with children	0.95	0.94,0.96	< 0.001	0.94	0.93,0.95	< 0.00
Three generational	0.99	0.98,1.01	0.3	0.99	0.98,1.01	0.4
household						
Area-level variables						
IMD Quintile						
IMD1 (Most deprived)	Reference			Reference		
IMD2	0.99	0.98,1.00	0.013	0.99	0.98,0.99	0.001
IMD3	1.01	1.00,1.02	0.062	1.00	0.99,1.01	>0.9
IMD4	1.06	1.04,1.08	< 0.001	1.05	1.03,1.07	< 0.00
IMD5 (Least deprived)	1.10	1.07,1.12	< 0.001	1.08	1.05,1.11	< 0.00
¹ PR = Prevalence Ratio, C	-				,	

Table S6- Sensitivity analyses II- Unadjusted and adjusted prevalence ratios in multivariable analysis: Index and linked older cohort children with an age gap greater than five years excluded

	PR ¹	95% Cl ¹	p-value	PR ¹	95% Cl ¹	p-value
	Unadjusted		-	Adjusted		
Individual Characteristic	6					
Vaccination status of c	lder child					
Vaccinated	Reference	—		Reference		
Non-vaccinated	0.56	0.56, 0.57	<0.001	0.57	0.57,0.58	<0.001
Ethnicity						
White	Reference	—		Reference		
Asian or Asian British	1.03	1.02, 1.04	<0.001	1.04	1.03,1.06	<0.001
Black or Black British	0.98	0.96, 0.99	0.006	1.00	0.98,1.01	>0.9
Mixed and Other	0.96	0.94, 0.97	<0.001	0.97	0.95,0.98	<0.001
Missing	0.97	0.96, 0.98	<0.001	0.98	0.97,0.99	<0.001
Sex						
Male	Reference	—		Reference		
Female	1.0	0.99, 1.00	0.2	1.0	0.99,1.00	0.2
Household characteristic	s		-			
Household compositio	n					
Two adults with children	Reference	—		Reference		
Single adult with children	0.97	0.96, 0.98	<0.001	0.95	0.94,0.97	<0.001
Three generational household	1.00	0.98, 1.01	0.6	1.00	0.98,1.01	>0.9
Missing	0.96	0.95, 0.97	<0.001	NA	NA	NA
No of children in house	ehold	,				
2 to 3	Reference			Reference		
4 to 6	0.94	0.93, 0.95	< 0.001	0.96	0.95, 0.97	<0.001
7 to 9	0.85	0.81, 0.89	< 0.001	0.88	0.84, 0.93	<0.001
Missing	0.95	0.94, 0.96	< 0.001	NA	NA	NA
Area level characteristic	5	· ·				
IMD Quintile						
IMD 1 (Most	Reference	_		Reference		
deprived)						
IMD 2	0.99	0.98, 1.00	0.2	0.99	0.98,1.00	0.019
IMD 3	1.01	1.00, 1.03	0.041	1.00	0.99,1.02	0.5
IMD 4	1.05	1.03, 1.07	<0.001	1.04	1.02,1.06	<0.001
IMD 5 (Least deprived)	1.08	1.05, 1.10	<0.001	1.06	1.03,1.09	<0.001
¹ PR = Prevalence Ratio	, CI = Confide	nce Interval				•

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Table S7- Sensitivity analyses III- Unadjusted and adjusted prevalence ratios in multivariable analysis: 1st Measles, Mumps and Rubella vaccination receipt between 11-25 months of age

Characteristic	PR ¹	95% Cl ¹	p-value	PR ¹	95% CI1	p-value	
Univariable				Multivariable			
Individual Characteristics							
Vaccination status of old	der child						
Vaccinated	Reference	—		Reference			
Non-vaccinated	0.65	0.64, 0.65	<0.001	0.66	0.65, 0.66	<0.001	
Ethnicity							
White	Reference	—		Reference			
Asian or Asian British	1.03	1.02, 1.04	<0.001	1.05	1.04, 1.05	<0.001	
Black or Black British	0.98	0.97, 0.99	0.003	1.00	0.98, 1.01	0.3	
Mixed and Other	0.96	0.95, 0.97	<0.001	0.97	0.96, 0.98	<0.001	
Missing	0.97	0.97, 0.98	<0.001	0.98	0.97, 0.99	< 0.001	
Sex							
Male	Reference	_		Reference			
female	1.0	0.99, 1.00	0.1	1.0	0.99, 1.00	0.2	
Household Characteristics	3		-				
Household Composition	1						
Two adults with children	Reference	_		Reference			
Single adult with children	0.97	0.96, 0.98	<0.001	0.97	0.96, 0.98	<0.001	
Three generational household	1.00	0.98, 1.01	0.4	0.99	0.98, 1.00	0.042	
Missing	0.94	0.92, 0.95	<0.001	0.92	0.91,0.93	<0.001	
No of Children in House	hold				-		
2 to 3	Reference			Reference			
4 to 6	0.96	0.95, 0.96	< 0.001	0.96	0.95, 0.96	<0.001	
7 to 9	0.83	0.80, 0.86	< 0.001	0.84	0.81, 0.88	<0.001	
Missing	0.93	0.92, 0.94	< 0.001	NA	NA	NA	
Area level characteristics							
IMD Quintile							
IMD 1 (Most deprived)	Reference			Reference			
IMD 2	0.99	0.98, 1.00	0.001	0.99	0.98, 0.99	<0.001	
IMD 3	1.00	0.99, 1.01	0.8	0.99	0.98, 1.00	0.2	
IMD 4	1.03	1.02, 1.05	<0.001	1.03	1.01, 1.04	< 0.001	
IMD 5 (Least deprived)	1.06	1.04,1.08	<0.001	1.06	1.03, 1.08	<0.001	

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Household determinants of delayed MMR vaccination: longitudinal analysis using electronic health records in north east London, United Kingdom

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Household determinants of delayed MMR vaccination: longitudinal analysis using electronic
health records in north east London, United Kingdom
Milena Marszalek ¹ , Nicola Firman ¹ , Marta Wilk ¹ , Ana Gutierrez ¹ , Kelvin Smith ¹ , Carol Dezateux ¹
¹ Centre for Primary Care, Wolfson Institute of Population Health, Faculty of Medicine and Dentistry,
Queen Mary University of London, Yvonne Carter Building, 58 Turner Street, London, E1 2AB
Corresponding author: Milena Marszalek; Centre for Primary Care, Wolfson Institute of Population Health, Faculty of Medicine and Dentistry, Queen Mary University of London, Yvonne Carter Building,
58 Turner Street, London, E1 2AB; m.marszalek@qmul.ac.uk; 0207 882 6806
The authors declare no competing financial interests.

BMJ Open

2	. –	
3 4	15 16	Abstract
5 6	17 18	Objectives
7 8	19 20	There is a lack of information about household factors associated with delayed Measles Mumps and
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26	21	Rubella (MMR) vaccination. We examined whether timeliness of first MMR (MMR1) receipt is
	22	associated with sharing a household with an older child with non-receipt of MMR1 independent of
	23	household composition and size.
	24	Design
	25	Longitudinal observational study using linked electronic health records
	26	Setting:
	27	North east London, United Kingdom
	28	Participants:
	29	The index cohort comprised 71,509 children (51.0% males) eligible to receive MMR1 between 1 st
27	30	January 2014 and 28 th February 2020.
28 29 30 31 32 33	31	Methods
	32	The primary outcome was MMR1 receipt between age 12 and 24 months. The explanatory variable
	33	was non-receipt of MMR1 between age 12 and 24 months in the oldest child sharing the same
34 35	34	household. We examined the likelihood of MMR1 receipt in index children sharing a household with
36 37	35	an older child with non-receipt of MMR1 between 12 and 24 months using logistic regression to
38 39	36	estimate odds ratios (OR) and 95% confidence intervals (CI) before and after adjustment for
40 41	37	individual-, household-, and area-level covariates. We carried out sensitivity analyses excluding
42 43	38	households with an age interval between oldest and youngest child greater than five years.
44 45	39	Results
46 47	40	59,851 (83.6%) index children received MMR1 between age 12 and 24 months. After adjustment for
48 49	41	household composition and size, MMR1 receipt was less likely in index children sharing a household
50 51	42	with an older child with non-receipt of MMR1 between age 12 and 24 months: OR: 0.19 (95% CI:
52	43	0.18,0.20). This association strengthened after excluding households with an age interval greater
53 54	44	than five years: OR: 0.14 (0.13,0.15)
55 56	45	Conclusions
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3 4	46	There is strong concordance within households of delay in MMR1 receipt independent of household
5 6	47	size and composition. Lack of timely protection within households increases the risk of measles
7	48	outbreaks. There is a need for household-based interventions to improve MMR1 timeliness.
8 9	49	
10 11	50	
12 13	51	
14 15	52	
16 17	53	Strengths and limitations
18	54	We used a novel method to link individuals into households while maintaining privacy and
19 20	55	confidentiality using electronic health records (EHRs) for a large population.
21 22	56	 We obtained high quality, accurately coded and validated MMR data in the EHR.
23 24	57	 We used robust statistical methods to assess relationships between the exposure and
25 26	58	outcome variables.
27 28	59	
29 30	60	<u> </u>
31		and older children may have differed. We were not able to examine associations with delayed
32 33	61	receipt of primary vaccinations against diphtheria, pertussis, polio, tetanus and Haemophilus
34 35	62	influenza.
36 37	63	More granular categorisation of ethnic groups, as suggested by our patient and public
38	64	involvement group, was not possible due to limited sample size.
39 40	65	
41 42	66	
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2								
3 4	76	Introduction						
5 6	77	Childhood vaccinations form an essential part of public health interventions provided by primary care. ¹						
7 8	78	In England and Wales, it is recommended that children receive a first dose of Measles, Mumps and						
9	79	Rubella (MMR) vaccine between age 12 and 13 months ² : currently only 89% receive a first dose by						
10 11	80	age 24 months, and only 84% a second dose by age five years. ³ This countrywide statistic conceals						
12 13	81	marked geographic inequalities linked to deprivation. The World Health Organization (WHO)						
14 15	82	recommends that 95% of the population are given two MMR doses to achieve herd immunity and						
16 17	83	eliminate measles. ⁴ The United Kingdom (UK) lost measles elimination status in 2018 and while this						
18 19	84	was reinstated in 2021, measles outbreaks in areas with high measles susceptibility in young children						
20 21	85	in England suggest that this will not be sustained. ⁵ Clusters of inequalities in MMR coverage						
22 23	86	exacerbate existing outbreaks – a large proportion have been in London, an area with both low and						
24 25	87	profoundly inequitable coverage. ³						
26 27	88							
28	89	In light of these public health concerns, and with the first dose conferring 93% protection against						
29 30	90	infection, there has been increasing emphasis on the importance of timely receipt of MMR1. ⁶ In the						
31 32	91	UK, national targets to ensure receipt of first MMR (MMR1) between 12 and 24 months of age have						
33 34	92	been recently replaced by a 12-18 month target reflecting this emphasis on timeliness. ⁷						
35 36	93							
37 38	94	It is known that equity in vaccination coverage is impacted by social determinants such as deprivation,						
39 40	95	ethnicity and area-level variation in healthcare services. ^{8,9} There is strong evidence demonstrating						
41 42	96							
43 44	97							
45 46	98	determinant of partial or non-immunisation with MMR, suggesting that access to services may play an						
47 48	99	important role. ^{12 13}						
49 50	100							
51	101	Identifying factors at a household level can create actionable insights into how services might be						
52 53	102	tailored to improve receipt of vaccinations. ¹⁴ The current pressures on the UK National Health						
54 55	103	Service have significantly impacted the delivery of vaccinations in primary care- therefore new ways						
56 57	104	of working to vaccinate the most vulnerable children in a resource-tight setting are needed. ^{15, 16} We						
58 59 60	105	used electronic health records (EHRs) for an ethnically diverse and disadvantaged population, with						

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1 2		
3 4 5	106	among the lowest proportion of children receiving MMR1 by 24 months of age in the UK, to
	107	investigate whether non-receipt of MMR1 between 12 and 24 months of age is clustered in
6 7	108	households. Specifically, we hypothesised that children with non-receipt of MMR1 between 12 and 24
8 9 10 11	109	months were more likely to share a household with an older child with non-receipt of MMR1 at these
	110	ages, independently of the number of children in the household and household composition.
12 13	111	
14 15 16 17	112	Methods
	113	Study design and setting
18 19	114	We conducted a longitudinal observational study using primary care EHRs from 266 general practices
20 21	115	in seven north east London (NEL) localities: Barking & Dagenham, City & Hackney, Havering,
22 23	116	Newham, Redbridge, Tower Hamlets, and Waltham Forest.
24 25	117	
26 27 28	118	Data Sources
	119	Pseudonymised data were provided from the NEL Discovery Data Service (DDS), which receives
29 30	120	primary care EHR data in near-real time for all general practices (GPs) in NEL. 17 Unique Property
31 32	121	Reference Numbers (UPRNs) are allocated to all GP-recorded patient addresses in DDS using a
33 34	122	quality-assured and validated address-matching algorithm. ¹⁸ UPRNs are pseudonymised into
35 36	123	Residential Anonymous Linking Fields (RALF) ¹⁹ using a study-specific encryption key. We used
37 38	124	RALFs to link children in households for address records and registrations from 2014 onwards, when
39 40	125	data flow for address registrations into NEL DDS commenced. Data were extracted on 23rd November
41 42	126	2021.
43 44	127	2021.
45 46	128	Study population
47 48	129	The study population comprised 159,300 children registered with a NEL GP at the time of their
49	130	second birthday and eligible to receive MMR1 between 1 st January 2014 and 28 th February 2020. We
50 51	131	excluded 17,038 children without a RALF, with a non-residential RALF, with a poor-quality RALF
52 53	132	match, or with more than one RALF at time of MMR1 or second birthday, leaving 142,262 children
54 55	133	eligible for inclusion (supplementary file 1 figure S1).
56 57	134	
58 59 60	135	Identifying children sharing a household

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1 2								
- 3 4 5 6	136	We identified older children sharing a household with the 142,262 index children at the index child's						
	137	MMR1 date or 24 months of age, whichever is the earliest. Index and older children sharing a RALF						
7 8	138	at index child's MMR1 date, or at the index child's second birthday were considered to share a						
9	139	household. We identified all children in DDS based on the index children's RALFs and excluded						
10 11 12 13	140	52,693 children without an older child in the household, and 15,516 older children who were already						
	141	included as index children, leaving 71,509 index children with at least one older child sharing their						
14 15	142	household at the index child's MMR1 date or second birthday (supplementary file 1 figure S2). These						
16 17	143	71,509 children are henceforth referred to as the "linked index cohort" and the older children with						
18 19	144	whom they share a household as the "linked older children's cohort".						
20 21	145							
22 23	146	The study methodology has been reported against the REporting of studies Conducted using						
24 25	147	Observational Routinely-collected health Data (RECORD) statement (supplementary file 2).20, 21						
26 27	148							
27 28 29	149	Primary outcome						
30 31	150	The primary outcome is receipt of MMR1 between 12 and 24 months of age, which is consistent with						
32 33	151	the Cover of Vaccination Evaluated Rapidly (COVER) measures in place during the study period. ²²						
34 35 36	152	We extracted sociodemographic and area-level data for the linked index and linked older child						
37 38	153	cohorts, together with all clinical events relating to MMR1 procedures (supplementary file 1 Table S1).						
39 40	154	We derived a proxy date of birth from calendar week, month and year of birth by combining the date						
41 42	155	of the first day of the week of the calendar week of birth with month and year of birth. We excluded						
43 44	156	duplicated events, and events without correct clinical codes. We assumed MMR1 was not given if						
45 46	157	there was no record of MMR1 being given in the primary care EHR. If a child did not have a record of						
47	158	a MMR1 vaccination, they were linked to a RALF at the time of their second birthday, and were						
48 49 50 51 52	159	defined as children with non-receipt of MMR1.						
	160	Explanatory variable						
53 54								
55 56	161	The main explanatory variable was non-receipt of MMR1 in the linked older child defined as no record						
57	162	of MMR1 given between 12 and 24 months of age.						
58 59 60	163	Covariates						

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164 Individual-level

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Individual-level covariates were sex and ethnic group. We categorised ethnic group of the index
children using the NHS 5+1 classification using information recorded in the EHR.²³ We created five
mutually exclusive ethnic groups: white ('white British', 'white Irish' or 'any other white background');
black ('black African', 'black Caribbean' or 'any other black background'); South Asian ('Indian',
'Pakistani', 'Bangladeshi' or 'Sri Lankan'); mixed/other ('any other ethnic background', 'mixed
ethnicity', 'Chinese' or 'Asian other'); and missing category (ethnicity code in the primary care record
missing or 'not stated' category selected).

172 Household-level

All household members sharing a household at the index child's MMR1 date were identified. We
excluded households with more than ten members, only one child, or no adults aged ≥18.0 years.
Household information was available for 65,308 households containing index and linked older
children.

We categorised household composition using an adapted Harper and Mayhew method²⁴ into one of
 three mutually exclusive categories: working-age adults (aged 18-64 years) with children; single
 working-age adult with children, or at least one working-age and one older adult (aged >65 years)
 with children (three-generation household). We included households with at least one older adult with
 children but no working-age adult (skipped generation households) in the three-generation household
 group.

183 We calculated the total number of household members, as well as the number of children within a
 184 household at the index child's MMR1 date or 24 months of age for those with no MMR1 date.

⁷ 185 Area-level

186 We merged 2019 Index of Multiple Deprivation (IMD) decile²⁵ into the datafile using the 2011 Lower
 187 layer Super Output Area (LSOA), an area with an average population of 1,500 people or 650
 188 households, as the linkage field. IMD deciles were concatenated into quintiles from most (1) to least
 189 deprived (5).

We compared the linked index cohort (n=71,509) with the cohort of eligible children (*n*=70,753) not
linked to another older child (supplementary file 1 Table S2). The linked sample had a lower

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2 3	192	proportion with receipt of MMR1 between 12 and 24 months of age, were less likely to be from a white
4 5	193	ethnic background, from smaller households, or from households with two or more working age
6 7	194	adults.
8 9	405	
10 11	195	
12 13 14	196	Statistical Methods
	197	We calculated the proportion of the linked index and older child cohorts receiving MMR1 between 12
15 16	198	and 24 months of age. We examined variation in MMR1 receipt in the linked index cohort by
17 18	199	individual-, household-, and area-level characteristics, as well as by MMR1 receipt in the linked older
19 20	200	children's cohort.
21	201	
22 23	202	We estimated the likelihood of MMR1 vaccination between age 12 and 24 months in the linked index
24 25	203	cohort using binary logistic regression and estimated odds ratios (OR) and 95% confidence intervals
26 27	204	(CI) for those sharing a household with a linked older child with non-receipt of MMR1 between 12 and
28 29	205	24 months of age, before and after adjustment for individual-, household-, and area-level covariates.
30 31	206	Covariates with of p<0.1 in the univariable logistic regression models were included in a multivariable
32 33	207	logistic regression model following a step-wise model selection strategy. Variables were retained in
34 35	208	the final multivariable model if $p \le 0.05$.
36 37	209	
38 39	210	We performed three sensitivity analyses. In the first, we changed the definition of the primary outcome
40	211	to receipt of MMR1 between 12 and 18 months of age in line with the recently introduced Quality and
41 42	212	Outcomes Framework targets introduced in 2021.26 In the second, we excluded households
43 44	213	containing index and linked older children with an age gap of more than five years. In the third, we
45 46	214	extended the age range for MMR1 receipt in the index children from 12-24 months to 11-25 months to
47 48	215	allow for potential misclassification of ages related to method for assigning date of birth. We
49 50	216	performed post-hoc power calculations to determine an appropriate sample size to power our study
51 52	217	for the primary outcome. All analyses were conducted using R Studio.27
53 54	218	
55 56	219	Post-hoc power calculations demonstrated that a sample size of 52,000 in the index cohort would
57	220	provide 90% power to detect a two percentage point difference significant at the 1% level in MMR1
58 59 60		

receipt between 12 and 24 months of age in the index child between those with and without a linked older child with no MMR1 receipt between 12 and 24 months. Patient and public involvement We involved patients and the public in the communication of study results and dissemination within the local community, in line with accepted principles from the UK Standards for Public Involvement.²⁸ The aim was to raise awareness of the importance of inequalities in timely childhood vaccinations. We established a patient advisory group, comprising six parents, to co-produce dissemination materials. The patient and public involvement group reflected on vaccination inequalities, the study design and how results were delivered. Participants expressed reservations about the categorisation of ethnic group and whether more granular categories could be used in future research. They discussed communication and visualisation of results. Dissemination of results is ongoing and informed by advice about accessing seldom-heard as well as and existing community groups. **Results** The index cohort comprised 71,509 children (51% males) of whom 11,658 (16.4%) had not received MMR1 vaccine between 12 and 24 months of age. Children in the index cohort who did not receive MMR1 between 12 and 24 months of age were more likely to live with a linked older child who similarly had not received MMR1 between 12 and 24 months of age (Table 1). Index children receiving MMR1 between 12 and 24 months of age were more likely to be from South Asian ethnic groups, or living in households with fewer adults and fewer children, or in households with two or more working age adults or three generation households. Children in single adult households or in households with a larger number of children were less likely to receive MMR1 between 12 and 24 months. There was a marked gradient in timely MMR1 receipt by IMD quintile with an absolute difference of 7.3% in MMR1 receipt between 12 and 24 months of age between the least and most deprived quintiles. In the unadjusted model, MMR1 receipt between 12 and 24 months of age was less likely among children in the linked index cohort sharing a household with a linked older child with no MMR1 receipt between 12 and 24 months of age (OR: 0.19, 95% CI: 0.18, 0.20). The effect size and direction did not

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2 3	254	
3 4	251	change after stepwise introduction of individual-, household-, and area-level covariates resulting in an
5 6	252	adjusted OR of 0.20 (0.19,0.21) in the final model (Figure 1; supplementary file 1 Table S3).
7	253	
8 9 10 11 12 13 14 15 16 17	254	In sensitivity analyses (Figure 2), the proportion of index children with MMR1 receipt between age 12
	255	and 18 months (79.2%; 95% CI: 78.9,79.5) was, as expected, lower than the proportion with MMR1
	256	receipt between 12 and 24 months (83.6%; 95% CI: 83.3,83.9) (supplementary file 1 Table S4).
	257	Associations were weaker in sensitivity analyses using this measure as the primary outcome (OR:
	258	0.24; 0.23,0.25) (supplementary 2 file Table S5). By contrast, associations were stronger in sensitivity
18 19	259	analyses restricted to households containing index children and linked older cohort children with an
20 21	260	age gap of less than five years: OR: 0.14 (0.13,0.15) (supplementary file 1 Table S6). Sensitivity
22 23	261	analyses extending the age range for MMR1 receipt to 11-25 months did not change the main
24 25 26 27 28 29 30 31 32 33 34	262	findings: OR: 0.18 (0.17,0.19) (supplementary file 1 Table S7).
	263	
	264	While our study focussed on MMR1 receipt within the UK recommended age range at the time of the
	265	study, it is possible that children were vaccinated before or after the recommended age range. We
	266	searched for MMR1 dates for those with no MMR1 date within the 12-24 month age range. Of the
	267	11,658 index children with no MMR1 receipt between 12-24 months, 516 (4.4%) had a MMR1 record
35 36	268	before age 12 months, 2,893 (24.8%) between age 25 and 40 months (equivalent to 3 years and 4
37 38	269	months when children become eligible for the second dose), 749 (6.4%) received MMR1 after 40
39 40 41 42 43 44	270	months of age, and 7,500 (64.3%) had no record of MMR1 receipt in the EHR by November 2021
	271	when data were extracted (Table 2). This suggests that just over one third of index children did
	272	eventually receive MMR1 but significantly later than the recommended age. Almost half (47%) of the
45 46	273	linked older children without MMR1 receipt between 12 and 24 months of age also eventually
47 48 49 50 51	274	received MMR1 and this was also significantly later than the recommended age.

Table 1: MMR1 receipt in linked index childre	n by individual, h		BMJ Open nd area-level c	haracteristi	cs	/bmjopen-2024-097559 on 2 1 by copyright, including for			
	Vaccinated	C 9/)		Non-vaco		n 2 May 2(Ense for uses r	All linke N=71,509		children
	Received first	Received first MMR between 12 and24 months of age			N=11,658 (16.4%)				
	N	%	95% CI	N	%	95% guper	n	%	95% CI
MMR1 status of oldest child		I	I		1	ade t ar			
Vaccinated	53198	88.4	88.1, 88.6	6987	11.6	11.5, je 1-9 40.3 42-2	60185	84.2	83.9, 84
Non-vaccinated	6653	58.8	57.8, 59.7	4671	41.2	40.8 42 2	11324	15.8	15.6,16
Individual covariates							· ·		
Ethnic background						http://b NBES) . 1 mining			
South Asian	16963	88.0	87.6, 88.5	2305	12.0	11.5 124	19268	25.5	25.1, 2
White	16625	83.8	83.3, 84.3	3219	16.2	15. द ्र,16	19844	28.3	27.9, 2
Black or Black British	5703	82.2	81.2, 83.1	1238	17.8	16. 9 ,18 <mark>,</mark> 7	6941	10.0	9.8,1
Mixed and Other	4847	78.8	77.8, 79.8	1303	21.2	20. 6 , 22 <mark>2</mark> 2	6150	8.5	8.3,
Missing**	15713	81.4	80.8, 81.9	3593	18.6	18. g ,1962	19306	27.7	27.4, 2
Sex	÷					l sin	· ·		
Female	29399	84.0	83.6, 84.3	5614	16.0	15.80,16+4	35013	48.9	48.5, 4
Male	30452	83.4	83.0, 83.8	6044	16.6	16.2,16.9	36496	51.1	50.7, 5 ⁻
Household-level covariates			· · ·			12,			
Household size	40005	00.4	05 7 00 0	0070	40.0		04074	20.0	
3-4	18695	86.1	85.7, 86.6	2976	13.9	13 4 ,1453	21671	30.3	30.0, 3
5 to 7	26867	84.0	83.6, 84.4	5097	16.0	4	31964	_	44.4, 4
8 to 10	9397	80.6	79.9, 81.3	2264	19.4	18.7, 2 %	11661	16.3	16.0,1
Missing**	4881	78.7	77.7, 79.7	1320	21.3	20.3, 22,33	6201	8.6	8.4, 8
Household composition	40000	04.0	94.2.94.0	7740			E0000	76.7	70 4 7
Two working age adults with children	42380	84.6	84.3, 84.9	7713	15.4		50093		76.4, 7
Single working age adult with children	7699	81.5	80.7, 82.3	1747	18.5	17.7,1 9	9446	14.5	14.2,1
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2							024-0 ht, in			
3	Three-generational household	48	891 84.8	83.8, 85.7	878	15.5	14.2,1654	5769	8.8	8.6, 9.0
5	Missing**	48	881 78.7	77.7, 79.7	1320	21.3	20.3 22.3	6201	8.6	8.4, 8.8
б	Number of children in household						n 2 for			
7	2 to 3	439	85.4	85.0, 85.7	7527	14.6	14. 5 , 145 9	51495	72	71.7, 72.3
8	4 to 6	106		79.5, 80.8		19.8	19.2, 20,5	13298	18.7	18.4,19.0
9 10	7 to 9		64.7	60.4, 68.8		35.3	31.2 3 3 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	515	0.7	0.6, 0.8
11	Missing**	48	881 78.7	77.7, 79.7	1320	21.3		6201	8.6	8.4, 8.8
12	Area level covariates	•					1 to 1			
13	Index of Multiple Deprivation (IMD) Quintile		001 000	025 04 2	4507	10.1		20440	10	20 7 40 2
14	1 (most deprived) 2	238 235		83.5, 84.3 81.7, 82.8		16.1 17.7	15.7,565 17.2,7841	28448 28564	40 39.8	<u>39.7, 40.3</u> <u>39.5, 40.1</u>
15	3		00 83.9	83.2, 84.7		16.1	15. ය , සුරු 15. ය , සු , සු	9054	12.6	12.4,12.8
16 17	4		845 88.9	87.9, 89.9		11.1	10. at 3≥2 =1	3762	5.2	5.0, 5.4
18	5 (least deprived)		533 91.2	89.7, 92.5	148	8.8	7. 5 , #0 -2	1681	2.3	2.2, 2.4
²² 280 ²⁴ 281	Table 2: MMR1 receipt in linked Index and Old	ler Children v	without MMR1	receipt between	12 and 24 mc	onths c	ng, mj.com/			
26 27	Non-vaccinated groups		Index Child (N			6 OI	der Ğhil& (N	=11324)	%	
28	MMR1 receipt <12 months of age			516	3 4.	4	Jur	993	8.8	
29	MMR1 receipt between 24 and 40 months o	of age		2893	3 24.	8	ne 1 . tec	2642	23.3	
0	MMR1 receipt >40 months of age			749	9 6.	4	2, 2(hno	1689	14.9	
81 82	No record of MMR1 receipt in period of follo	w-up		7500) 64.	3	025 ; logie	6000	53.0	
33	Total			11658	3 100.	0	at A	11324	100.0	
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285 Discussion

We have shown that 16% of children from an English urban, disadvantaged, and multi-ethnic population with low MMR1 coverage do not receive MMR1 between the recommended age interval of 12 and 24 months, and that they are less likely to do so if they share a household with an older child who did not receive MMR1 between age 12 and 24 months. This association was independent of ethnic group, number of children in the household, household composition, and area-level deprivation, and was strengthened when analyses were confined to household children with an age gap of less than five years. We also found that children in single adult households or in households with a larger number of children are less likely to receive MMR1 between 12 and 24 months of age, consistent with findings from previous studies reporting household characteristics of children with delayed or non-MMR1 receipt. These findings suggest that caregivers' actions related to attendance for child vaccinations may be consistent across children in the household, particularly among children who are close in age.

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While we examined MMR1 receipt within the UK recommended age range of 12 to 24 months in place at the time of our study, we were able to show that one third of index children did receive MMR1 at both younger and older ages. There are a number of explanations for this. UK vaccine guidance states that MMR1 may be given under 12 months of age in the context of outbreaks or exposure to measles. However, as there is evidence that this doesn't produce a strong antibody response, it is recommended that MMR1 must be given again within the scheduled age range.² Parents may not agree to a second MMR1, especially if this was given close to the first birthday. Furthermore, a proportion of MMR1 events under 12 months of age were assigned an improbable date (e.g. given at birth date), and we are aware that GP practices may use this to record vaccines given in other countries for which the caregiver is unable to provide a date. London includes a significant proportion of children who are non-UK born and who migrate after the age of primary immunisations, many of whom anecdotally also spend periods back in their country of birth.^{29, 30} This complicates administration and recording of vaccines, and may create different expectations among parents or caregivers regarding vaccine schedules. Opportunistic catch up of MMR1 has also been initiated on a number of occasions, and appointments for the second dose may be the opportunity to give the first dose: almost one guarter of index and linked older children were given MMR1 between 24 and 40

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2	045	
3 4 5 6 7 8	315	months of age. So, while we were unable to confirm MMR1 receipt in two thirds of index and one half
	316	of linked older children, a significant proportion were delayed rather than never immunised.
	317	
9	318	This is to our knowledge the first study to examine associations within households of MMR1
10 11 12 13 14 15	319	timeliness, so direct comparisons with existing literature are not possible. Previous studies have found
	320	that vaccine coverage is lower in families with larger numbers of children and in single-parent
	321	households. ^{31 32} It has been suggested that the main drivers of vaccination delay in these households
16 17	322	are access-based, with vaccination services and appointments less suitable for families with larger
18 19	323	numbers of children, or for parents requiring more flexible clinic appointments. ^{12 33} Vaccination delay
20 21	324	may also be non-intentional: parents may delay vaccinations due to a child's illness. ³⁴ This may
22 23	325	explain some of the factors driving delayed MMR1 receipt in our study.
24	326	
25 26 27	327	There may be other reasons for delayed MMR1 receipt. Qualitative research around reasons for
28	328	delayed, partial or non-vaccination of children highlight the importance for parents of shared decision-
29 30	329	making with clinicians, and the strong association between trust in healthcare professionals and
31 32	330	vaccine hesitancy in parents or caregivers. Parents or caregivers who have some trust in the
33 34	331	information given by healthcare professionals may delay rather than completely refuse a child's
35 36	332	vaccination, and this may be a consistent factor for all children in the household. ³⁵ One study looking
37 38	333	at decision-making between adults and adolescents in a household for the Men ACWY vaccination
39 40	334	found that information gathering outside of a healthcare setting, even prior to invitation for vaccination,
41 42	335	significantly impacted the decision made. ³⁶
43 44	336	
45 46	337	Vaccinations can also be delayed by parents if they feel that information around the safety of a
40 47 48	338	vaccine is insufficient, or if they have concerns about overburdening a child's immune system. ^{37, 38}
49	339	Parental or caregiver disagreement around childhood vaccination may also contribute to delay. ¹³
50 51	340	
52 53	341	Further qualitative research is needed to tease out the likely heterogenous reasons for MMR1 delay
54 55	342	or non-receipt at a household level and to understand household factors that interact with access and
56 57 58	343	the decision-making process. ³⁹ Delay in primary vaccinations against diphtheria, pertussis, polio,
59 60		

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3 4	344	tetanus and Haemophilus influenza has been shown to be associated with an incomplete vaccination
5 6 7	345	schedule by 24 months of age. ⁴⁰ We were not able to examine this in our study.
	346	
8 9	347	Implications for practice
10 11	348	Our study has demonstrated that delay in MMR1 receipt is strongly clustered within households. This
12 13	349	lack of timely protection or any protection within households increases the risk of measles outbreaks.
14 15	350	This suggests the need for household-based interventions to improve vaccination coverage and
16 17	351	timeliness. Knowing the household composition of children with delayed or non-vaccination can allow
18 19	352	a healthcare professional (HCP) to tailor their approach to organising vaccination appointments. For
20 21	353	example, if it is known that there is more than one child in the household needing vaccination, a HCP
22 23	354	can arrange an appropriate appointment for two children at one time. In England, the EHR in GPs
24 25	355	allows a HCP to view other patients registered at the same address as the selected patient.
26 27	356	
28 29	357	Household-based interventions could also be considered by public health and service commissioners.
30	358	Setting up services tailored to households with non- or partially-vaccinated children aligns with
31 32	359	documented interventions recommended to improve vaccination coverage.41 The same principle
33 34	360	applies to providing wider public health education about vaccination for these households:
35 36	361	interventions can be more targeted when non- or partially-vaccinated households are identified.
37 38	362	Emerging interventions using enhanced information and educational programmes and vaccination
39 40	363	delivery by health visitors could be tailored to target more vulnerable households. ⁴² Evidence from
41 42	364	adolescent/adult decision making about vaccines in a household reinforces the importance of giving
43 44	365	parents relevant information before the offer of vaccination from a healthcare provider. ³⁶
45 46	366	
47 48	367	Existing literature cites multi-component interventions as the most effective interventions for
49	368	increasing vaccination coverage in deprived communities with intersectional inequalities, including
50 51	369	information, education and re-call measures. ³⁹ Robust re-call methods are cited as an effective way to
52 53	370	vaccinate children with delayed vaccinations.43 We have shown that a quality improvement
54 55	371	programme that aims to improve timeliness and equity of pre-school immunisations in NEL, focussing
56 57	372	on data-enabled call and recall for immunisation is effective.44
58 59 60	373	

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2 3	374	Future research
4 5 6 7 8 9 10 11 12 13 14 15 16 17	375	We have shown that non-receipt of MMR1 between 12 and 24 months of age is clustered in
	376	households. However, a significant proportion of children in our study ultimately received MMR1 in the
	377	preschool years and later childhood, with no clear evidence of MMR1 receipt in the remainder.
	378	Qualitative research is needed to understand the decision-making processes underlying this
	379	heterogenous group. Similar research in demographically different areas of the UK may help
	380	understand the extent to which these findings are generalisable to households in a different
	381	socioeconomic context.
18 19	382	
20 21 22 23	383	Strengths and limitations
	384	The strengths of our study include the use of a novel method to create households securely while
24 25	385	maintaining privacy, as well as having access to a large population with EHRs for a geographically
25 26 27	386	contiguous area. Additionally, we have access to high quality MMR data, that is recorded accurately
28 29	387	in the EHR through data recording templates. ⁴⁵ The codeset used to identify MMR1 in the EHR was
30	388	validated. We used robust statistical methods to assess relationships between the exposure and
31 32	389	outcome variables, and we selected a time period before lockdowns due to the Coronavirus pandemic
33 34	390	disrupted access to health care in England (March 2020).
35 36	391	
37 38 39 40 41 42	392	We were not able to examine associations with delayed receipt of primary vaccinations against
	393	diphtheria, pertussis, polio, tetanus and Haemophilus influenza. More granular categorisation of
	394	ethnic groups, as suggested by our patient and public involvement group, was not possible due to
43 44	395	limited sample size. Processes of decision-making about vaccines may have differed between the
45 46	396	linked index and older children. However, associations between the vaccination status of a younger
47 48	397	and linked older child strengthened when restricted to children with an age interval of less than five
49 50	398	years.
51 52	399	
53 54	400	Conclusion
55	401	There is strong concordance in MMR1 vaccine delay or non-receipt between children sharing the
56 57 58 59 60	402	same household in a region with the lowest MMR vaccination coverage in the UK. ³ These findings

2	400	
3 4	403	have implications for the planning and delivery of vaccination services that consider children in their
5 6	404	household context.
7 8	405	
9	406	Acknowledgements
10 11	407	We are grateful to general practitioners in north east London for making electronic health record data
12 13	408	available through the Discovery Data Service. We thank colleagues within the Clinical Effectiveness
14 15	409	Group for their support in extracting, and expertise in using, general practice data. This research uses
16 17	410	data provided by patients and collected by the NHS as part of their care and support. We would also
18 19	411	like to acknowledge our PPI participants for their invaluable insights into patient perspectives around
20 21	412	dissemination of our research to the wider community.
22 23	413	
24 25	414	Funding
26 27	415	This research was supported by grants from Barts Charity (ref: G-002256, MGU0419 and MGU0504).
28 29	416	This study was also funded by the National Institute for Health and Care Research (NIHR) School for
30	417	Primary Care Research (Project reference 664). The views expressed are those of the author(s) and
31 32	418	not necessarily those of the NIHR or the Department of Health and Social Care.
33 34	419	
35 36	420	
37 38	421	Contributions
39 40	422	As per CrEdit accreditation, significant contributions to: Conceptualisation (MM, CD, NF, MW),
41 42	423	Methodology (MM, CD, MW, NF), Resources (CD, AG), Data Curation (MM, AG, NF, MW, KS), Data
43 44	424	Analysis (MM, NF, CD), Writing-Original Draft (MM, CD), Review and Editing (MM, AG, NF, MW, KS,
45 46	425	CD), Formal Analysis (MM, CD), Validation (AG, MM), Visualisation (MM), Supervision (CD), Funding
47 48	426	Acquisition (MM, CD). CD is the guarantor for this research.
49 50	427	
50 51 52	428	
53	429	Competing interests declaration
54 55	430	All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/disclosure-of-
56 57	431	interest/ and declare: no support from any organisation for the submitted work; no financial
58 59 60	432	relationships with any organisations that might have an interest in the submitted work in the previous

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2 3	433	three vector as other relationships or activities that could appear to have influenced the submitted
4		three years; no other relationships or activities that could appear to have influenced the submitted
5 6	434	work.
7	435	
8 9	436	Ethics approval
10 11	437	Access to general practice data is enabled by data sharing agreements between the Discovery Data
12 13	438	Service and general practice data controllers. The Discovery Programme Board has approved data
14 15	439	access by the REAL Child Health programme.
16 17	440	
18 19	441	Data sharing
20 21	442	The senior author (CD) was granted access to de-identified data by the data controllers for this work
22 23	443	and onward sharing of data is not permitted. The R codes used in the analyses are available at
24 25	444	https://github.com/mmarszalek1991/mmarszalek1991households/tree/main1.
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- main model and from sensitivity analyses
 - †Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
 - *MMR1: first Measles, Mumps and Rubella dose



				Less likely	More likely	OR (95 % CI)
						OR (95 % CI)
Inadjusted model:	Vaccinated			t		reference
accination status of older child	Non-vaccinated					0.19 (0.18,0.20)
+ Demographics: Model 2 †	Vaccinated			+		reference
Houer2	Non-vaccinated					0.20 (0.19,0.21)
+ Household Size : Model 3 †	Vaccinated			+		reference
Model 3 f	Non-vaccinated	H				0.20 (0.19,0.21)
+ Household Composition:	Vaccinated			+		reference
Model 4 †	Non-vaccinated					0.20 (0.19,0.21)
	Vaccinated			+		reference
+ No. of Children in Iousehold: Model 5†	Non-vaccinated					0.20 (0.19,0.21)
+ IMD Quintile:	Vaccinated			+		reference
Model 6†	Non-vaccinated					0.20 (0.19,0.21)
			0.25		1.25	6.

Figure 1. Forest Plot of MMR1* vaccination odds ratios (OR) and 95% Confidence Intervals (CI) between 12 and 24 months of age using stepwise binary logistic regression

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4			
1 2			
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6		Less likely More likely	
7 8			OR (95% CI)
9	Adjusted model: Vaccinated (N = 53198) Vaccination status of Non-vaccinated	ł	reference
10	older child Non-vaccinated (N = 6653)		0.20 (0.19,0.21)
11	Sensitivity analysis I: Vaccinated 1st MMR by 18 (N = 48602)	Ļ	reference
12	months Non-vaccinated (N = 8518) →		0.24 (0.23,0.25)
13	Sensitivity analysis II: Vaccinated Excluding linked (N =41878)	ł	reference
14 15	children with >5 year Non-vaccinated age gap (N = 8424)		0.14 (0.13,0.15)
16	Sensitivity Vaccinated	ł	reference
17	analysis III: 1st (N=60359) MMR between 11 - (N=10015)		0.18 (0.17,0.19)
18	25 months (N = 10915) 0.05 0.25	1.25	6.25
19		and station for MMR1 vaccination (log scale)	0.20
20 21 Figure 2	Forest Plot of MMR1* vaccination odd	Is ratios (OR) and 95% Confiden	ce Intervals (CI) from main
21 Figure 2. 22	model and	from sensitivity analyses	
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 Household determinants of delayed MMR vaccination: longitudinal analysis using electronic health records in north east London, United Kingdom

Milena Marszalek¹, Nicola Firman¹, Marta Wilk¹, Ana Gutierrez¹, Kelvin Smith¹, Carol Dezateux¹

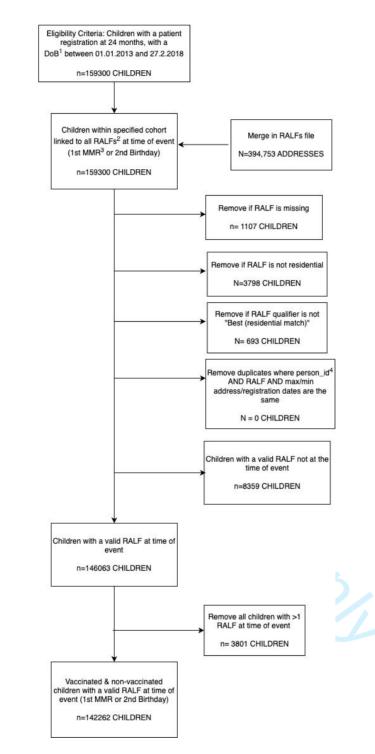
¹Centre for Primary Care, Wolfson Institute of Population Health, Faculty of Medicine and Dentistry,

Queen Mary University of London, Yvonne Carter Building, 58 Turner Street, London, E1 2AB

Supplementary file 1 – additional tables and figures

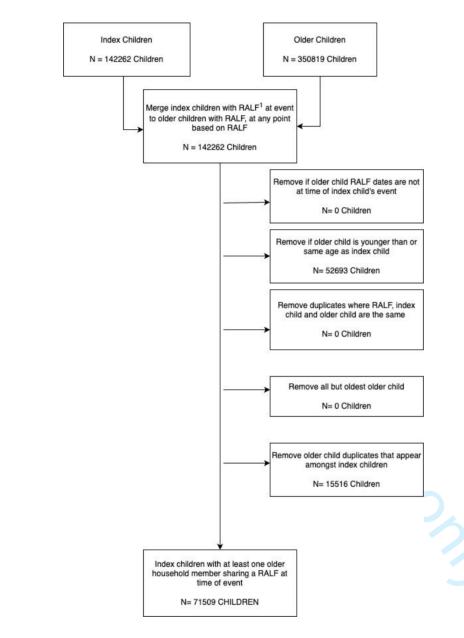
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Figure S1-Inclusion and exclusion criteria for sample population with a valid Residential Anonymised Linkage Field (RALF)



- ¹ Date of Birth
- ² Residential Anonymised Linkage Field
- ³ Measles, Mumps & Rubella vaccination
- ⁴ Individual person identifier

Figure S2- Inclusion and exclusion criteria for linking index and older children



¹ Residential Anonymised Linkage Field

BMJ Open Table S1- Systematized Nomenclature of Medicine (SNOMED) clinical codes for first Measles, Mumps and Euberla vaccination procedures

Events recorded in the primary care electronic heath record using another clinical coding system (e.g. Read v2 or EMIS local codes) have been mapped to relevant SNOMED codes within the Discovery Data Service. This ensures that searching the database using SNORED codes captured all events regardless of the clinical coding system used. May : Ens

SNOMED concept ID	Other code	Clinical coding scheme	Code description
38598009	38598009	SNOMED	Measles-mumps-rubella vaccination (procession)
	65M1.	Read v2	Measles/mumps/rubella vaccn.
	^ESCT1405772	EMIS local	Administration of measles and mumps a
47435007	47435007	SNOMED	Measles vaccination (procedure)
	65A	Read v2	Measles vaccination
	65A1.	Read v2	Measles vaccination
	ZV042	Read v2	$\neg \square \neg$
	^ESCT1405845	EMIS local	Administration of measles vaccine
50583002	50583002	SNOMED	Mumps vaccination (procedure)
	65F5.	Read v2	Mumps vaccination
	ZV046	Read v2	[V]Mumps vaccination
	^ESCT1405876	EMIS local	Administration of mumps vaccine
82314000	65B	Read v2	Rubella vaccination
	ZV043	Read v2	[V]Rubella vaccination
	^ESCT1406118	EMIS local	Administration of rubella vaccine
170364006	65A2.	Read v2	Measles vaccin.+immunoglobulin 띀 g
432636005	^ESCT1408534	EMIS local	Administration of measles and mumps and rubella and varicella virus vaccine
871909005	^ESCT1397548	EMIS local	Administration of first dose of measles and number and rubella and varicella virus vaccine
150971000119104	ZV064	Read v2	[V]Measles-mumps-rubella (MMR) vaccination
308081000000105	65M10	Read v2	First MMR (measles mumps and rubella vaccination
	Xaeec	Read v3	First MMR (measles mumps and rubella vaccination
	^ESCTME809974	EMIS local	Measles mumps and rubella vaccination first dose
505001000000109	9ki1.	Read v2	MMR catch-up vaccination - enhanced services administration
	XaQPr	Read v3	Measles mumps rubella catch-up vaccination
571591000119106	^ESCT1409651	EMIS local	Administration of live attenuated measles might nps and rubella vaccine
1037251000000100	65M11	Read v2	First MMR vaccination given by other health reprovider
	Xaeeq	Read v3	First MMR vaccination given by other health Fire provider

We included clinical codes relating to administration of mono-components of the first MMR vaccination. After removal d duplicate data entries and merging to the study cohort, 584989 children had a clinical code for measles vaccination, and two for mumps vaccination, as opper det to a combined MMR vaccination.

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able S2- Characteristics of linked and unlinked co		BMJ Open			/bmjopen-2024-097559 4 by copyright, includin ble aria	
able S2- Characteristics of linked and unlinked co		dual-, househ ort (n = 71509)	old- and are	a level va	ariableuding fort (A d cohou	
	N	%	95% Cl ¹	N	% es	5% Cl ¹
MMR1 ² status of oldest child		70	5576 01	1	seign s relat	5% Cl ¹
Vaccinated	59851	83.6	83.3,83.9	60512	8566 T	85.3,85.8
Non-vaccinated	11658	16.4	16.1,16.6	10240		14.2,14.7
Individual covariates		_			loac Sup	,
Ethic Background					2025. Downloaded from h eignement Superieur (AB 85 14 14 22 1 22 1	
South Asian	19268	25.5	25.1,25.8	16073	dur (22.4,23
White	19844	28.3	27.9,28.6	23536	3334 SES	32.9,33.6
Black or Black British	6941	10.0	9.8,10.2	5467	ning, 77	7.5,7.9
Mixed and Other	6150	8.5	8.3,8.7	6869	97 🗧	9.5,9.9
Missing**	19306	27.7	27.4,28.1	18807	269 ning,	26.3,26.9
Sex					ning.	
Female	35013	48.9	48.5,49.3	34885	4980	48.9,49.7
Male	36496	51.1	50.7,51.4	35867	49 and 50 s	50.3,51.7
Household-level covariates						
Household size					te e	
3 to 4	21683	30.3	30.0 ,30.6	37417	52 T N	52.5,53.3
5 to 7	31964	44.7	44.3,45.1	18976	26 8 25	26.5,27.1
8 to 10	11661	16.3	16,16.6	7514	10.66 Pt	10.4,10.8
Missing**	6201	8.7	8.5,8.9	6845	9.7 gence	9.4,10.0
Household composition						
Two working age adults with children	50093	70.0	69.7,70.3	46906	Bibliographique de	66,66.6
Single working age adult with children	9446	13.2	13,13.4	10356	14.6 g	14.4,14.9

		BMJ Open			/bmjopen-2024-097559 4 by copyright, inctudin	
Three-generational household	5769	8.1	7.9,8.3	6645	9 ⁹ 10	9.2,9.6
Missing**	6201	8.7	8.5,8.9	6845	1-097559 on 2 inctuding for	9.5,9.9
Number of children in household					n 2 N for L	
2 to 3	51495	72.0	71.7,72.3	59151	May 2025. Downloaded from Enseignement Superieur (A uses related to text and deta 83 6 0 9 ext and deta 36	83.3,83.9
4 to 6	13298	18.7	18.4,19	4486	692	6.1,6.5
7 to 9	515	0.7	0.6,0.8	270		0.3,0.5
Missing	6201	8.6	8.4,8.8	6845	9.5 min	9.4,10.0
Area level covariates					load Sup ext a	
Index of Multiple Deprivation (IMD) quintile					ed f erieu and	
IMD 1 (Most deprived)	28448	40.0	39.7,40.3	26062	36 8 T G	36.5,37.2
IMD 2	28564	39.8	39.5,40.1	28972	40	40.5,41.3
IMD 3	9054	12.6	12.4,12.8	9602	40 minfag. 13 fag.	13.3,13.8
IMD 4	3762	5.2	5.0,5.4	4311	6 <u>≱</u> <mark>⊰</mark>	5.9,6.3
IMD 5 (Least deprived)	1681	2.3	2.2,2.4	1805	21aini	2.4,2.6

 IMD 5 (Least deprived)
 1681
 2.3
 2.2.2.4
 1805
 23
 2.4.2.6

 ** Children that could not be linked to other members of the household apart from the oldest child were documented as having household demographics as 'Missing'
 as having household demographics as 'Missing'

 *ICI – Confidence interval
 2 Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
 as having household demographics as 'Missing'

 *Z Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
 as having household demographics as 'Missing'

 *Description
 Description
 as having household demographics as 'Missing'

 *CI – Confidence interval
 *CI – Confidence interval
 *CI – Confidence interval
 *CI – Confidence interval

 *2 Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
 *CI – Confidence interval
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 *CI – Confidence interval

 *2 Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
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 *2 Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
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 *2 Vaccinated signifies receipt of MMR1 between 12 and 24 months of age
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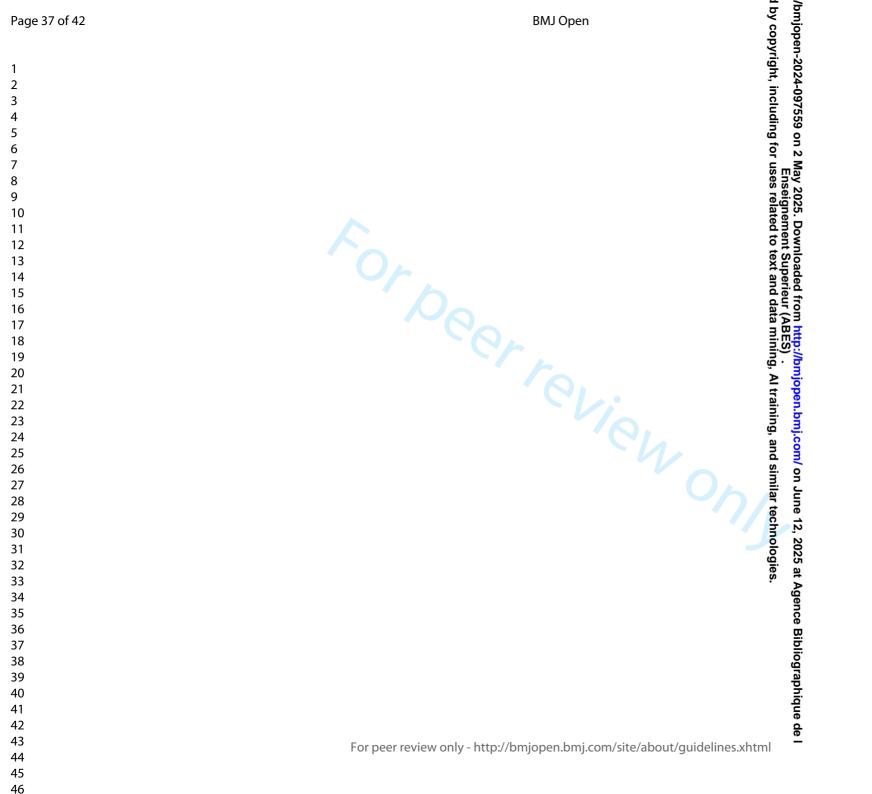
able S3- Unadjusted and adjusted or ndividual-, household-, and area leve					n-2024-09 yright, inc	
able S3- Unadjusted and adjusted or dividual-, household-, and area leve	dds ratios for 1 st N el characteristics:	1easles, Mump	s and Rubel			
		95% Cl ²	p-value	OR ¹	for Uses related to text and dated for Uses related to text and dated for Uses related to text and dated for Uses and dated for Uses related to text and dated for Uses text and to text and taken to text and tak	p-value
	Unadjusted			Adjusted	y 20 nsei ∋s re	
MMR1 ³ status of oldest child)25. 9lati	
Vaccinated	Reference			Reference	Dov ime ed t	
Non-vaccinated	0.19	0.18, 0.20	<0.001	0.20		< 0.001
Individual covariates					bade upe xt a	
Ethnic background					ed f prieu nd o	
South Asian	1.34	1.26, 1.42	<0.001	1.46	dan nitto	< 0.001
Vhite	Reference			Reference	n mi	
lack or Black British	0.88	0.82, 0.95	<0.001	0.97	0389,3.04	0.40
Aixed and Other	0.76	0.71, 0.82	<0.001	0.83	0,77,30.90	< 0.001
Vlissing	0.84	0.79, 0.88	<0.001	0.87	0382,80.92	< 0.001
bex					en.bmj. aining,	
Male	Reference			Reference		
emale	0.96	0.92, 1.00	0.061	0.96	₿ <u></u> 92 <mark>9</mark> .00	0.06
lousehold level covariates					/ on Jur similar	
lousehold size						
3 to 4	Reference			Reference	ne (
5 to 7	0.88	0.84, 0.93	<0.001	0.81	0576,0.86	<0.001
8 to 10	0.74	0.69, 0.79	<0.001	0.71	0576,0.86 066,99.77	<0.001
Missing**	0.68	0.63, 0.73	<0.001	NA	es. at /	NA
lousehold composition	·			·	Age	·
wo working age adults with children	Reference			Reference	gence	
Single working age adult with children	0.80	0.75, 0.85	<0.001	0.72	0.67, 🗳.77	< 0.001
Three generational household	0.97	0.90,1.05	0.40	0.98	0.91 हा.07	0.70
Missing**	0.74	0.69, 0.79	<0.001	0.56	0.52, 👼 .61	< 0.001

		BMJ	Open		/bmjopen-2024-097559 o 4 by copyright, including	
Number of children in househo	old				0978	
2 to 3	Reference			Reference	idin	
4 to 6	0.73	0.69, 0.77	<0.001	0.82	0577.70.87	<0.001
7 to 9	0.42	0.35, 0.52	<0.001	0.57	0 2 May 2025. Downloaded from to texped and data 1 0 and data 1 0 and data 1 0 and data 1 0 and data 1	<0.001
Missing	0.71	0.66, 0.76	<0.001	NA	es r NA	NA
Area level			I		elat	
Index of Multiple Deprivation (MD) quintile				Dov ed t	
IMD1 (Most deprived)	Reference			Reference	o te	
IMD2	0.93	0.89, 0.97	<0.001	0.91	0 38 2.95	<0.001
IMD3	1.01	0.95, 1.08	0.80	0.96	G 90 9 103	0.20
IMD4	1.40	1.25, 1.56	<0.001	1.33		<0.001
IMD5 (Least deprived)	1.81	1.52, 2.16	<0.001	1.69	1345 1345 1345 1345 1345 1345 1345 1345	<0.001
¹ OR = Odds Ratio, ² CI = Confide ³ Vaccinated signifies receipt of N ^{**} Children that could not be linked Missing'		16	om the oldest	t child were docun	≥ Training nentogo astraving	household demogra
		16	om the oldest	t child were docun	njopen.t Al traini	household demogra

 BMJ Open Table S4- Sensitivity analysis I: timely Measles, Mumps and Rubella (MMR) vaccination status between 12 and 38 months of age, by individual-, household-, and area level characteristics

	Vaccin	Vaccinated			nated	ay 2 inse inse	All Index	cohort	
	N=5664			N=14889 (2	•	May 2025. Enseigne uses relat	N=71530		
				Did not rece and 18 mor	eive first MN hths of age	AR between terment Superior 95% CI and			
	n	%	95% Cl ²	n	%	95% CI Xt a	n	%	95% CI
MMR1 ¹ status of oldest child						ed fro rrieur nd da		1	
Vaccinated	48602	85.8	85.5,86.1	8039	14.2	1 3 .9674.5	56641	79.2	78.9,79.5
Non-vaccinated	8518	57.2	56.4,58.0	6371	42.8	4 2.06	14889	20.8	20.5,21.1
Individual covariates	I	I		I	I	//bmjc) . ng, Al	I	1	<u> </u>
Ethnic Background						oper I trai			
South Asian	16214	84.3	83.8,84.9	3007	15.6	1 5 .2	19221	26.9	26.5,27.2
White	15834	79.9	79.3,80.5	3978	20.1	1 g .5, 2 0.6	19812	27.7	27.4,28.0
Black or Black British	5342	76.9	75.9,77.9	1605	23.1	2 º .1, 2 4.1	6947	9.7	9.5,9.9
Mixed and Other	4448	71.8	70.7,72.9	1745	28.2	2 <u>a</u> . 1, 2 9.3	6193	8.7	8.5,8.9
Missing	14803	76.5	75.9,77.1	4554	23.5	281 1,25.3 281 1,25.3	19357	27.1	26.7,27.4
Sex				1	I	010		1	
Female	27814	79.4	79.0,79.8	7206	20.6	26.2,21.0	35020	49.0	48.6,49.3
Male	28827	79.0	78.5,79.4	7683	21.0	20.6, & 1.5	36510	51.0	50.6,51.4
Household-level covariates						nce			
Household size						Bibli			
3 to 4	17848	82.4	81.9,82.9	3819	17.6	17.1,478.1 phique de	21655	30.3	29.9,30.6

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						ı-2024-(right, ir			
5 to 7	25460	79.7	79.2,80.1	6492	20.3	19,20.8	31952	44.7	44.3,4
3 to 10	8806	75.5	74.7,76.3	2849	24.4	2,7,25.2	11655	16.3	16,16.
Missing**	4527	72.4	71.2,73.5	1729	27.6	f@.5,28.8 uses es	6256	8.7	8.5,8.
Household composition						lay 2 Ense uses r			
Two working age adults with children	40292	80.5	80.1,80.8	9773	19.5	1 8 6 19 .9	50065	70.0	69.6,70.
Single working age adult with children 🧷	7187	76.1	75.2,77.0	2256	23.9	295 24.8	9443	13.2	13,13.
Three-generational household	4625	80.3	79.5,81.6	1131	19.7	1 6 12	5766	8.1	7.9,8.
Missing**	4527	72.4	71.2,73.5	1729	27.6	15.20.8 15.20.8 2009 28.8	6256	8.7	8.5,8.
Number of Children in household						d from leur (A d data			
2 to 3	41973	81.6	81.2,81.9	9494	18.4	18.6 200	51467	71.9	71.6,72
4 to 6	9875	74.2	73.5,75.0	3422	25.7	2 6 .0, 2 6.5	13297	18.6	18.3,18
7 to 9	266	52.1	47.7,56.5	244	47.8	45.4,52.3	510	0.7	0.6,0.
Missing**	4527	72.4	71.2,73.5	1729	27.6	2 6 .5, 2 8.8	6256	8.7	8.5,8
Area level covariates				- 10		ng, a			
ndex of Multiple Deprivation (IMD) Quir	ntile					and s			
MD 1 (Most deprived)	22451	78.9	78.4,79.4	5998	21.0	28.6,21.6	28449	39.8	39.4,40.
MD 2	22180	77.6	77.1,78.1	6390	22.4	27.9,22.9	28570	39.9	39.6,40
MD 3	7273	80.3	79.4,81.1	1786	19.7	18.9,20.5	9059	12.7	12.4,12
MD 4	3238	85.9	84.8,87	530	14.0	100.5 00.3,165.2	3768	5.3	5.1,5.
MD 5 (Least deprived)	1499	89.0	87.4,90.5	185	11.0	9.5,12.5	1684	2.3	2.3,2



BMJ Open Table S5- Sensitivity analysis I- unadjusted and adjusted odds ratios for 1st Measles, Mumps and Rubella veccess months of age

		9 <u>2</u>				
	OR ¹	95% Cl ²	p-value	OR ¹	r Wes related 70.25	p-value
	Unadjusted			Adjusted	y 2 es	
MMR1 ³ status of oldest child		-			028 rela	
Vaccinated	Reference			Reference	5. [ate	
Non-vaccinated	0.22	0.21,0.23	<0.001	0.24		<0.00
Individual covariates		1	1		te shi	
Ethnic Background					up xt a	
South Asian	1.29	1.22,1.36	< 0.001	1.41	346 1.49	<0.00
White	Reference			Reference	and dafin 1.49 dafi fro dafa fro dafa 1.49 dafa 1.49	
Black or Black British	0.83	0.78,0.89	< 0.001	0.76	5 0, 3€ 1,0.81	<0.00
Mixed and Other	0.69	0.64,0.74	< 0.001	0.85	∃3	<0.00
Missing	0.82	0.78,0.86	< 0.001	0.92	₽.2 6,0.99	0.02
Sex					g, b	
Female	Reference			Reference	≥ 🗧	
Male	0.97	0.94,1.01	0.20	0.97	a .9 4 1.01	0.2
Household level covariates					<mark>1.bmj</mark> ining,	
Household size					nj. 19,	
3 to 4	Reference			Reference	an <mark>c</mark>	
5 to 7	0.90	0.86,0.94	<0.001	0.83) .7 9 .0.88	<0.00
8 to 10	0.75	0.71,0.79	<0.001	0.75	∃ 0.76 € 0.81	< 0.00
Missing**	0.65	0.60,0.69	<0.001	NA		N
Household composition					ne 1 . tec	
Two adults with children	Reference			Reference	Chr 12,	
Single adult with children	0.78	0.74,0.82	< 0.001	0.71	9 .6 2 0.76	<0.00
Three generational household	0.96	0.90,1.04	0.30	0.97	ૡૻ .9 6 ,1.04	0.4
Missing**	0.69	0.65,0.74	< 0.001	0.53	₽ .49 , 0.57	<0.00
Number of children in household					Ag	
2 to 3	Reference			Reference	enc	
4 to 6	0.71	0.68,0.74	< 0.001	0.79	0.74.0.83	<0.00
7 to 9	0.35	0.29,0.42	< 0.001	0.46	0.3850.56	<0.00
Missing**	0.66	0.62,0.70	<0.001	NA	jë na	N
Area level covariates					graphique de	

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Index of Multiple Deprivation (I	MD) quintile				24-0975 1t, inclu		
IMD 1 (Most deprived)	Reference			Reference	din		
IMD 2	0.95	0.91.0.99	0.012	0.93	5 .8 £ 0.97	< 0.001	
IMD 3	1.06	1.00.1.13	0.050	1.00	9 .9 4 1.07	0.90	
IMD 4	1.46	1.32,1.61	< 0.001	1.37	g д 🕰 1.52	< 0.001	
IMD 5 (Least deprived)	1.95	1.67,2.30	< 0.001	1.81	9 8 4 2.13	< 0.001	
Index of Multiple Deprivation (II IMD 1 (Most deprived) IMD 2 IMD 3 IMD 4 IMD 5 (Least deprived) ¹ OR = Odds Ratio, ² CI = Confide ³ Vaccinated signifies receipt of N ** Children that could not be linked to oth 'Missing'					g gaded from http://bmjopen.bmj.com/ on June 12, 2025 at Agence Bibliographique de I Superieur (ABES) . Art and data mining, Al training, and similar technologies.		emographics as
	For peer review only - http://b	omjopen.bmj.cor	n/site/about/gu	idelines.xhtm	e de l		

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	-Sensitivity analyses II- Unadjusted and adjusted odds ratios for 1 st Measles, Mumps and Rubella of age: excluding linked index and older cohort children with an age gap greater than five years OR ¹ 95% Cl ² p-value OR ¹ Unadjusted description					
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				/righ		
				بر بر اب ا	94-0	
					075	
able S6-Sensitivity analyses II- Unadjusted and nonths of age: excluding linked index and olde	d adjusted odds rati r cohort children wi	ios for 1 st Meas ith an age gap (les, Mumps and preater than five	l Rubella ¥acé	gnation receipt b	etween 12 and
				for	5 0	
				use		
				s reig	202 202	
				inem latec	ñ ح	
		95% Cl ²	p-value	OR ¹ to	95% CI ²	p-value
· · · · ·	Unadjusted			Adjusted		
MMR1 ³ status of oldest child				an		
Vaccinated	Reference			Reference	fro	
Non-vaccinated	0.13	0.12, 0.14	<0.001	0ହାଁ≨	0.13,0.15	<0.00
Individual covariates				inii		
Ethnic background				ng,		
South Asian	1.27	1.18, 1.36	<0.001	1 2 41	1.31,1.52	<0.00
White	Reference			Reference		
Black or Black British	0.87	0.79, 0.95	0.003	0 5 98		0.7
Mixed and Other	0.77	0.70, 0.97	<0.001	0985		< 0.00
Missing Sex	0.82	0.76, 0.87	< 0.001	0.86	0.80,0.92	<0.00
Male	Reference	1		Reference		[
Female	0.97	0.92, 1.02	0.20	te d	D	0.2
Household level covariates	0.97	0.92, 1.02	0.20			0.20
Household size				nologie	000 5	
3 to 4	Reference	1		Reference	ע	
5 to 7	0.83	0.78,0.88	< 0.001	0.78		< 0.00
8 to 10	0.71	0.66,0.77	< 0.001	0.71		<0.00
Missing**	0.68	0.62,0.74	< 0.001	NA	N	N/
		_ ,_ ,			5	
Household composition					<u> </u>	

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Reference 7		
<0.001 0.001	0.65,0.77	<0.0
0.60 0 5 99 1	0.89,1.09	0.8
<0.001 0∰77	0.52,0.63	<0.0
es r		
Refere	2 n	
<0.001 0	0.74, 0.86	<0.0
 Reference <0.001 <0.001<td>0.52, 0.81</td><td><0.0</td>	0.52, 0.81	<0.0
<0.001 Control	NA	Ν
hrieu nd c		
dar (p tata		
0.20	0.88,0.99	0.0
0.029 1 23	0.95,1.12	0.
<0.001 1513	1.26,1.64	<0.0
<0.001 1332	1.49,2.24	<0.0
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est child were documented as	having household de	emographic
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	BMJ Open S7-Sensitivity analyses III- Unadjusted and adjusted odds ratios in multivariable analysis: 1 st Mea t between 11–25 months of age						
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able S7-Sensitivity analyses III- Unadjusted	and adjusted odds ratio	s in multivariable and	alysis: 1 st Meas	ت نو le § ,M£µmpsa	nd Rubella vacci	nation	
eceipt between 11–25 months of age							
				May 2 Ens			
		95% Cl ²	p-value	2025. sreigtve	95% Cl ²	p-value	
	Unadjusted		-	Add Husted		-	
MMR1 ³ status of oldest child				tsnl			
Vaccinated	Reference			Te te rence			
Non-vaccinated	0.16	0.16, 0.17	<0.001	Tablerence deficient date date date date date date date dat	0.17, 0.19	<0.00	
Individual covariates		I		rom Jr (A data	I		
Ethnic background							
Asian or Asian British	1.33	1.25, 1.42	<0.001	n.g. 1.46	1.37, 1.55	<0.00	
White	Reference	6		Reference			
Black or Black British	0.88	0.82, 0.96	0.002	tra. 0.96	0.89, 1.04	0.4	
Mixed and Other	0.76	0.71, 0.82	<0.001	1 0.83	0.77, 0.90	<0.00	
Missing	0.84	0.80, 0.89	<0.001	بو جا ۵.88 و م	0.83, 0.93	<0.00	
Sex				nd :			
Male	Reference			Regrence			
Female	0.96	0.92, 1.01	0.084	Jun 0.96	0.92, 1.01	0.08	
Household level covariates				e 12 tech			
Household size				nol			
3 to 4	Reference			Reterence			
5 to 7	0.90	0.85, 0.94	<0.001		0.76, 0.87	<0.00	
8 to 10	0.74	0.69, 0.79	<0.001	gen 0.71	0.65, 0.77	<0.00	
Missing**	0.62	0.57, 0.67	<0.001	N/A	N/A	N/	
Household composition				Bibl		•	
Two working age adults with children	Reference			Regerence			
Single working age adult with children	0.79	0.74, 0.84	<0.001	ap 0.71	0.66, 0.76	<0.00	

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tional household	0.96	0.89, 1.05	0.40	in -0975 0.98	0.90, 1.07	0.6
	0.67	0.62, 0.71	<0.001	cluding 0.51	0.47,0.55	<0.00
hildren in household				on 2 g foi		
	Reference			Reference		
	0.74	0.70, 0.78	<0.001	es relate	0.78, 0.88	<0.00
	0.42	0.34, 0.52	<0.001	elation 0.57	0.46, 0.71	<0.00
	0.64	0.60, 0.69	<0.001	ed to NA	NA	N
ovariates	L		I.	o te	l.	
tiple Deprivation (IMD) quintile				vnloade nt Supe o text al		
t deprived)	Reference			Reference		
	0.92	0.88, 0.97	0.001	data (pm 0.91	0.87, 0.95	<0.00
	0.99	0.92, 1.06	0.70	<u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u>	0.88, 1.01	0.07
	1.34	1.20, 1.50	<0.001	ng 1.27	1.14, 1.43	<0.00
t deprived)	1.85	1.54,2.23	<0.001		1.44, 2.09	<0.00
t deprived) Ratio, ² CI = Confidence Interval signifies receipt of MMR1 between 11 a		1.54,2.23	<0.001	Al training,	1.44, 2.09	

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** Children that could not be linked to other members of the household apart from the oldest child were documented appharman on Lune 12, 2025 at Agence Bibliographics as "Missing"