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

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4 5	2	health records
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23 24 25	12	
25 26	13	The authors declare no competing financial interests.
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2 3	15	Abstract
4 5	16 17	Background
6 7	18 19	There is a lack of information about household factors associated with delayed Measles Mumps and
8 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 <sup>st</sup>
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	30	an older child with non-receipt of MMR1 before and after adjustment for individual-, household-, and
29 30	31	area-level covariates. We carried out a sensitivity analysis excluding households where the age
31	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 49 50 51 52 53	40	There is a strong concordance within households of delay in MMR1 receipt independent of household
	41	size and composition. Lack of timely protection within households increases the risk of measles
	42	outbreaks. There is a need for household-based interventions to improve MMR1 timeliness.
	43	
54 55	44	Funding
50 57	45	National Institute of Health and Care Research; Barts Charity
58 59 60	46	

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2 3	47	Strengths and limitations
4 5	48	• The strengths of our study include the use of a novel method to create households securely
6 7	49	while maintaining privacy, as well as having access to a large population with EHRs, for a
8 9	50	geographically contiguous area.
10 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. <sup>(1)</sup> 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	- Howayar, we ware able to see a strangthening of appaciation between the vaccination status
30 31 32 33 34 35 36 27	62	• However, we were able to see a strengthening of association between the vaccination status
	62	or a younger and inneed older child in the sensitivity analyses when excluding children with an
	64	the decision making around vaccination for multiple young children in a household
	65	
38 39	66	
40 41	67	Introduction
42	68	Childhood vaccinations form an essential part of public health interventions provided by primary
43 44 45	69	care. <sup>(2)</sup> In England and Wales, it is recommended that children receive a first dose of Measles,
46 47	70	Mumps and Rubella (MMR) vaccine by age 12 months <sup>(3)</sup> : currently only 89% receive a first dose by
47 48 40	71	age 24 months, and only 84% a second dose by age five years. <sup>(4)</sup> 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. <sup>(5)</sup> 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 59 60	76	in England suggest that this will not be sustained. <sup>(6)</sup> Clusters of inequalities in MMR coverage

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exacerbate existing outbreaks - a large proportion have been in London, an area with both low and profoundly inequitable coverage.<sup>(4)</sup> 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.<sup>(7)</sup> 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.<sup>(8)</sup> It is known that equity in vaccination coverage is impacted by social determinants such as deprivation,

ethnicity and area-level variation in healthcare services.<sup>(9, 10)</sup> 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.<sup>(11)</sup> We and others <sup>(12)</sup> 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.<sup>(15)</sup> 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. Erasmushogeschool . Protected by copyright, including for uses related to text and data mining, Al training, and similar technologies.

3 4	107	Data Sources
5 6	108	Pseudonymised data were provided from the NEL Discovery Data Service (DDS), which receives
7	109	primary care EHR data in near-real time for all general practices (GPs) in NEL. (16) Unique Property
o 9 10	110	Reference Numbers (UPRNs) are allocated to all GP-recorded patient addresses in DDS using a
10 11	111	quality-assured and validated address-matching algorithm. <sup>(17)</sup> UPRNs are pseudonymised into
12 13	112	Residential Anonymous Linking Fields (RALF) <sup>(18)</sup> 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 23 <sup>rd</sup> 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 1st January 2014 and 28th 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	122	eligible for inclusion (see flow chart S1).
33 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 41 42	126	MMR1 date or 24 months of age, whichever is the earliest. Index and older children sharing a RALF
	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 47 48 49 50 51 52 53 54	129	52,693 children without an older child in the household, and 15,516 older children who were already
	130	included as index children, leaving 71,509 index children with at least one older child sharing their
	131	household at the index child's MMR1 date or second birthday (see flow chart S2). These 71,509
	132	children are henceforth referred to as the "linked index cohort" and the older children with whom they
	133	share a household as the "linked older children's cohort".
55 56	134	
57 58	135	The study methodology has been reported against both the STrengthening the Reporting of
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	138	S4). <sup>(19, 20)</sup>
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. <sup>(21)</sup>
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	146	of the week of the calendar week of birth with month and year of birth. We excluded duplicated
23 24 25	147	events, and events without correct clinical codes. We assumed MMR1 was not given if there was no
25 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 31 32 33 34 35 36 37 38	150	children with non-receipt of MMR1.
	151	Explanatory variable
	152	The main explanatory variable was non-receipt of MMR1 in the linked older child defined as no record
	153	of MMR1 given between 12 and 24 months of age.
39 40 41	154	Covariates
42 43 44	155	Individual-level
44 45 46 47 48 49 50 51 52 53 54 55	156	Individual-level covariates were sex and ethnic group. We categorised ethnic group of the index
	157	children using the NHS 5+1 classification using information recorded in the EHR. <sup>(22)</sup> We created five
	158	mutually exclusive ethnic groups: white ('white British', 'white Irish' or 'any other white background');
	159	black ('black African', 'black Caribbean' or 'any other black background'); South Asian ('Indian',
	160	'Pakistani', 'Bangladeshi' or 'Sri Lankan'); mixed/other ('any other ethnic background', 'mixed
	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 60	163	Household-level

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1 2		
2 3 4	164	All household members sharing a household at the index child's MMR1 date were identified. We
5	165	excluded households with more than ten members, only one child, or no adults aged $\geq$ 18.0 years.
0 7 8	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 <sup>(23)</sup> 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.
28 29	176	Area-level
30 31	177	We merged 2019 Index of Multiple Deprivation (IMD) decile <sup>(24)</sup> 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	180	deprived (5).
38 39 40	181	We compared the linked index cohort (n=71,509) with the cohort of eligible children ( $n$ =70,753) not
40	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.
47 48	185	
49 50	186	Statistical Methods
50 51 52	187	We calculated the proportion of the index and linked older child cohorts receiving MMR1 by 24
53 54	188	months of age. We examined variation in MMR1 receipt in the index cohort by individual-, household-,
55 56	189	and area-level characteristics, as well as by MMR1 receipt in the linked older children's cohort.
57 58 59 60	190	

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59 220 Results

60

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.<sup>(25)</sup> 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.<sup>(26)</sup>

3 4 207

6 208 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.<sup>(27)</sup> 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

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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 

record of MMR1 receipt in the EHR by November 2021 when data were extracted (Table 2). This suggests that just over one third of index children did eventually receive MMR1 but significantly later than the recommended age. Almost half (47%) of the linked older children without MMR1 receipt between 12 and 24 months of age also eventually received MMR1 and this was also significantly later than the recommended age. Post-hoc power calculations demonstrated that a sample size of 52,000 in the index cohort would provide 90% power to detect a 2 percentage point difference significant at the 1% level in MMR1 receipt by 24 months of age in the index child between those with and without a linked older child with no MMR1 receipt by 24 months. 

	Table 1: MMR1 recei	pt in linked index children b	v individual, household a	nd area-level characteristics
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able 1: MMP1 receipt in linked index	children by individual by		BMJ Open	haractoristi	65	36/bmjopen-2 vy copyright,				
Ible 1: MMR1 receipt in linked index children by individual, household and area-level characteristics       Ible 1: MMR1 receipt in linked index children by individual, household and area-level characteristics         Vaccinated       Non- Vaccinated       Ible 2: Waccinated										
	<b>N=</b> 59,851 <b>(84.</b> ′	1%)		<b>N =</b> 11,65	8 <b>(15.9%</b> )	7559 o	N=71,50	9		
	Received first l 24 months of a	MMR betwe	een 12 and	Did not re between a	ceive first 12 and 24	n 2 MMFs re MMFs re mon锤纸ou				
	A			age		025. Dov asmusho ed to te:				
	N	%	95% CI	n	%	95%ances	n	%	95% CI	
MMR1 Status of Oldest Child	De		1	I	I	hool f data	<u>                                     </u>			
Vaccinated	53198	88.4	88.1, 88.6	6987	11.6		60185	84.2	83.9 , 84.	
Non-vaccinated	6653	58.8	57.8, 59.7	4671	41.2	40.\$, 422	11324	15.8	15.6, 16.	
ndividual covariates			C/		1	traini	1 1			
Ethnic Background			- (	91		en.bn İng, aı				
South Asian	16963	88.0	87.6, 88.5	2305	12.0		19268	25.5	25.1, 25.	
White	16625	83.8	83.3, 84.3	3219	16.2	15.æ	19844	28.3	27.9-28.	
Black or Black British	5703	82.2	81.2,83.1	1238	17.8	16.9,1827	6941	10.0	9.8,10.	
Mixed and Other	4847	78.8	77.8,79.8	1303	21.2	20,00,22,2	6150	8.5	8.3,8.	
Missing**	15713	81.4	80.8,81.9	3593	18.6	18.1,19 2	19306	27.7	27.4,28.	
Sex	I		1	1	1	)epart	1 1		<u> </u>	
Female	29399	84.0	83.6,84.3	5614	16.0	15.6,16	35013	48.9	48.5,49.	
	1	<u> </u>	1	1	1	GEZ-L	1	1	L	

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Male	30452	83.4	83,83.8	6044	16.6	16 <u>,36</u> 9	36496	51.1	50.7,5
Household-level covariates			I	I		t, incl			
Household size						uding			
3-4	18695	86.1	85.7-86.6	2976	13.9	13.4.3	21671	30.3	30 ,3
5 to 7	26867	84.0	83.6,84.4	5097	16.0	15.86,1624	31964	44.8	44.4,4
8 to 10	9397	80.6	79.9,81.3	2264	19.4		11661	16.3	16,1
Missing**	4881	78.7	77.7,79.7	1320	21.3	20.9 1 20.9 2 3	6201	8.6	8.4,
Household Composition	Ur b		I	I		wnloa ogesc xt and			
Two working age adults with children	42380	84.6	84.3,84.9	7713	15.4	15.84 15.84 15.84 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.85 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95 15.95	50093	76.7	76.4
Single working age adult with children	7699	81.5	80.7,82.3	1747	18.5	17. <b>2</b> ,19 <b>3</b>	9446	14.5	14.2,1
Three-generational household	4891	84.8	83.8, 85.7	878	15.5	14.5,164	5769	8.8	8.
Missing**	4881	78.7	77.7,79.7	1320	21.3	20.8.223	6201	8.6	8.4,
No. of children in the household									
2 to 3	43968	85.4	85.0,85.7	7527	14.6		51495	72	71.7,7
4 to 6	10669	80.2	79.5,80.8	2629	19.8	19. <b>2</b> ,2025	13298	18.7	18.4
7 to 9	333	64.7	60.4,68.8	182	35.3	31.27,3986	515	0.7	0.6,
Missing**	4881	78.7	77.7,79.7	1320	21.3	2000,223	6201	8.6	8.4,
Area level covariates						<u>s</u> at D			
Index of Multiple Deprivation Quintile									
1 (most deprived)	23861	83.9	83.5,84.3	4587	16.1	15.7,1655	28448	40	39.7,4

		E	3MJ Open			l 136/bn I by col			
2	23512	82.3	81.7,82.8	5052	17.7	17 <u>3</u> ,1891	28564	39.8	39.5,40.1
3	7600	83.9	83.2,84.7	1454	16.1	15.3,1688 c 24	9054	12.6	12.4,12.8
4	3345	88.9	87.9,89.9	417	11.1	10.5 10.5 10.5	3762	5.2	5,5.4
5 (least deprived)	1533	91.2	89.7,92.5	148	8.8	7.9,10,92	1681	2.3	2.2,2.4
* Children that could not be linked to oth Missing' Fable 2. MMR1 receipt in Index and Olde	er members of the hous	sehold apa R1 receipt l	ort from the olde	est child we d 24 monthe	re docun s of age.	ay 2025. Downloaded fr Erasmushogeschool elaged to text and data	ving houseł	nold demo	igraphics as
Non-vaccinated groups	Index	c Child (N =	= 11658)	%	OI	der Canilda N=	=11324)	%	]
MMR1 receipt <12 months of age	516		6	44	ga	13 🤤 📅		8.8	7

Non-vaccinated groups	Index Child (N = 11658)	%	Older Child (N=11324)	%
MMR1 receipt <12 months of age	516	4.4	993 <b>G</b> , <b>P</b>	8.8
MMR1 receipt between 24 and 2y40 months of age	2893	24.8	2642 rainin	23.3
MMR1 receipt > 40 months of age	749	6.4	1689 <b>g. n.</b> an	14.9
No record of MMR1 receipt in period of follow-up	7500	64.3	6000 d simi	53.0
Total	11658	100.0	11324 Par 9 66 A	100.0

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Page 15 of 50				BMJ Open		136/b  1 by cc		
1	Figure 1. Forest Plot of	MMR1* Vaccina	tion Prevalence Ratio	s by 24 months of age us	sing stepwise Poisso	on Regression		
2 3				Less likely	More likely	n-2024-C nt, inclu		
4 5						)97559 ding fo	PR (95% CI)	
7 8	Unadjusted model: – Vaccination status of	Vaccinated			+	) on 2 M or uses	reference	
9 10	older child	Non-vaccinated	⊢∎⊣			∕ay 202 Eras ⊧relate	0.66 (0.65,0.67)	
11 12 13	+ Demographics: Model 2 †	Vaccinated			+	25. Dov mushc d to tex	reference	
14 15		Non-vaccinated	⊢∎⊣			vnload ogesch (t and c	0.66 (0.65,0.67)	
16 17	+ Household Size : Model 3 †	Vaccinated			•	ed from ool . data mi	reference	
19 20		Non-vaccinated	⊢∎⊣			، http:// ning, ۵	0.66 (0.65,0.67)	
21 22	+ Household Composition:	Vaccinated			•	'bmjop J traini	reference	
23 24 25	Model 4 †	Non-vaccinated				en.bmj ng, and	0.67 (0.66,0.68)	
26 27	+ No. of Children	Vaccinated			•	.com/ c d simila	reference	
28 29 20	Model 5 †	Non-vaccinated	+=+			on May ar techi	0.67 (0.66,0.68)	
30 31 32	+ IMD Quintile:	Vaccinated			•	20, 202 10logie	reference	
33 34		Non-vaccinated	H <b>H</b> H			95 at De s.	0.67 (0.66,0.68)	
35 36 37	0.4			0.8	1.0	spartme	1.6	
38 39 40			Adjuste	ed prevalence ratios for MMR1 vaco	cination (log scale)	int GEZ-		
41 42						-LTA		1 Л
43 44 45			For peer review only	/ - http://bmjopen.bmj.com	n/site/about/guidelin	es.xhtml		14
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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.

<sup>5</sup> 273

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.<sup>(3)</sup> 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.<sup>(28, 29)</sup> 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 ∡	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 8 9 10 11 12 13	292					
	293	This is to our knowledge the first study to examine associations within households of MMR1				
	294	coverage, so direct comparisons with existing literature are not possible. Previous studies have found				
	295	that vaccine coverage is lower in families with larger numbers of children and in single-parent				
14 15	296	households. <sup>(30) (31)</sup> 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. <sup>(13) (32)</sup>				
20 21	299	Vaccination delay may also be non-intentional; parents may delay vaccinations due to a child's				
22 23	300	illness. <sup>(33)</sup> 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 30 31	303	delayed, partial or non-vaccination of children highlight the importance for parents of shared decision-				
	304	making with clinicians, and the strong association between trust in healthcare professionals and				
32 33	305	vaccine hesitancy in parents or caregivers. Parents or caregivers who have some trust in the				
34 35	306	information given by healthcare professionals may delay rather than completely refuse a child's				
36 37 38	307	vaccination, and this may be a consistent factor for all children in the household. <sup>(34)</sup> One study looking				
	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. <sup>(35)</sup>				
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 49 50 51 52	313	insufficient, or if they have concerns about overburdening a child's immune system. (36, 37) Parental or				
	314	caregiver disagreement around childhood vaccination may also contribute to delay. <sup>(14)</sup>				
	315					
52 53 54	316	Further qualitative research is needed to tease out the likely heterogenous reasons for MMR1 delay				
55 56	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. <sup>(38)</sup> 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.<sup>(39)</sup> 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.<sup>(40)</sup> 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.<sup>(41)</sup> 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.<sup>(35)</sup> 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.<sup>(38)</sup> Robust re-call methods are cited as an effective way to vaccinate children with delayed vaccinations.<sup>(42)</sup> 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.<sup>(43)</sup> 

1 2						
2 3 4	349	Future research				
5 6 7 8 9 10 11	350	We have shown that non-receipt of MMR1 by 24 months of age is clustered in households. However,				
	351	a significant proportion of children do ultimately receive MMR1 in the preschool years and later				
	352	childhood, with no clear evidence of MMR1 receipt in the remainder. Qualitative research is needed to				
	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. <sup>(4)</sup> 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 31	363	Acknowledgements				
32	364	We are grateful to colleagues within the Clinical Effectiveness Group for access to and expertise in				
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.				
41 42	369					
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51 52	374	not necessarily those of the NIHR or the Department of Health and Social Care.				
53 54	375					
54 55 56	376					
50 57	377	Contributions				
58 59						
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4 5 6 7 8 9 10 11 12 13 14	270	As per credit accreditation, significant contributions to: Conceptualisation (MM, CD, NF, MW),					
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	380	Analysis (MM, NF, CD), Writing-Original Draft (MM, CD), Review and Editing (MM, AG, NF, MW, KS,					
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	382	Acquisition (MM, CD).					
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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.					
27 28 29	391						
30 21	392	Ethics approval					
32 33 34	393	Access to general practice data is enabled by data sharing agreements between the Discovery Data					
	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.					
47 48	401						
48 49 50 51 52 53 54 55 56 57 58 57	402	References					
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## Figure S1- Inclusion and Exclusion Criteria for Sample population with a valid Residential Anonymised Linkage Field (RALF)



<sup>1</sup> Date of Birth

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

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Residential Anonymised Linkage Field

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Background/rationale	2	Explain the scientific background and rationale for the investigation being reported $\overline{\underline{z}}$ .	3	
Objectives	3	State specific objectives, including any prespecified hypotheses	3-4	
Methods		, j		
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 recruitment exposure, follow-up, and data collection	4-7	
Participants	6	<ul> <li>(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up</li> <li><i>Case-control study</i>—Give the eligibility criteria, and the sources and methods of cases and controls</li> <li><i>Cross-sectional study</i>—Give the eligibility criteria, and the sources and methods of selection of participants</li> <li><i>Choort study</i>—For matched studies, give matching criteria and number of exposed</li> </ul>	4-7	
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31       (c) Cohort study—Summarise follow-up time (eg, average and total amount)       a       N/A         32       Outcome data       15*       Cohort study—Report numbers of outcome events or summary measures over time       b       N/A         33       Outcome data       15*       Cohort study—Report numbers in each exposure category, or summary measures       b       b         34       Case-control study—Report numbers in each exposure category, or summary measures       a       b       c         35       Outcome data       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       a       a       a         40       0       0       0       0       0       0	30			(b) Indicate number of participants with missing data for each variable of interest	Š	<b>3</b> 9
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Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision	<u>g</u> n⊳	p://	14
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Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplic	<u>∄</u> y	ope	14-16
Generalisability	21	_of analyses, results from similar studies, and other relevant evidence	ğ	<u>n</u> .b	14-16
			and	<u>.</u>	
Other Informati	<u>on</u> 22	Cive the source of funding and the role of the funders for the present study and if applicat		<u>§</u>	17
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	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	reviel	RECORD 1.1: The top of data used should be specified in the title or abstract. When possible, the game of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract.	Abstract- Separate File
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Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection		r uses related	on 2 May_202	3
Participants	6	<ul> <li>(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</li> <li>(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</li> </ul>	terier	RECORD 6.1: There algorithms used to be listed in detail. If the explanation should be recodes or algorithms used validation was considered and results should be RECORD 6.2: Any population should be validation was considered and results should be RECORD 6.3: If the sof databases, considered diagram or other grap demonstrate the data including the number linked data at eachest	emods of study such as codes or such as codes or suffy subjects) should is not possible, an arrovided. Sufficient of the sed to select the referenced. If sufficient of this study and see, detailed methods provided. Sufficient of a flow sufficient of a flow suff	4

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3 4 5 6 7 8 9	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A calgorithms used to outcomes, confour modifiers should be cannot be reported be provided.	mplete list of codes and classify exposures, derg, and effect provided. If these arrexplanation should	5
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19 20	Bias	9	Describe any efforts to address potential sources of bias	10	Ģ	http://b	4
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				information on the data cleaning methods used in the study.	3

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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	RECORD 13.1: Description included in the selection of the personal included in the study ( <i>i.e.</i> , study perpletion selection) including filtering bases on data quality, data availability and that age. The selection of included personal case be described in the text and/or by means of the study flow diagram.
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		category, or summary measures of exposure <i>Cross-sectional study</i> - Report numbers of outcome events or summary measures			2025. Download rasmushogesci		
Main results	16	<ul> <li>(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</li> <li>(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period</li> </ul>	revieu		ded from http://bmjopen.bmj.com/ on May 20, 2 hool . data mining. Al training. and similar technolog	7-10	
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*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Eim E, Lander M, in the RECORD Working Con The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *Checklist is protected under Creative Commons Attribution (CC BY) license.	nmittee.
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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	Code description
28508000	28508000		
30398009	3039009	SNOWED	weasies-mumps-rubella
	65M1	Bood y/2	Mocoloc/mumpo/rubollo
		Reau vz	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
30808100000105	65M10	Read v2	First MMR (measles
			mumps and rubella)
			vaccination
	Xaeec	Read v3	First MMR (measles
			mumps and rubella)
			vaccination
		EMIS local	Measles mumps and
	~ESCTME809974	LIVIIS IOCAI	measies mumps and
	^ESCTME809974	LIMIS IOCAI	rubella vaccination - first

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50500100000100	Oki1	Pood v2	MMP catch up vaccination
50500100000109	SKIT.	Redu VZ	
			- 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- and area-level
variables

	Linked	Linked cohort (n = 71509)			Unlinked cohort (n = 70753 )			
	N	%	95% CI	N	%	95% CI		
Individual Variables			1					
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								
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								
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		1						
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		1	1					
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		1	1					
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		
	1	1	1	1	1	1		

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

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	PR <sup>1</sup>	95% Cl <sup>1</sup>	p-value	<b>PR</b> <sup>1</sup>	95% CI <sup>1</sup>	p-value
Individual characteristic	cs					
Vaccination status of	older child					
Vaccinated	Reference			Reference		
Non-vaccinated	0.66	0.66, 0.67	<0.001	0.67	0.67, 0.68	<0.001
Sex		•	•			
Male	Reference			Reference		
Female	0.99	0.99, 1.00	0.073	0.99	0.99,1.00	0.07
Ethnic background						
Asian or Asian British	1.04	1.03, 1.05	<0.001	1.05	1.04, 1.06	<0.001
White	Reference			Reference		
Missing	0.97	0.96, 0.98	<0.001	0.98	0.97, 0.99	<0.001
Black or Black British	0.98	0.97, 0.99	0.001	1.00	0.98, 1.01	0.4
Mixed and Other	0.95	0.94, 0.97	<0.001	0.97	0.95, 0.98	<0.001
Household-level Variat	bles			1		1
Number of children p	er household	d				
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	on		·			
Two adults with children	Reference			Reference		
Single adult with children	0.97	0.96,0.97	<0.001	0.95	0.94,0.96	<0.001
Three generational household	1.00	0.98,1.01	0.7	1.00	0.99,1.01	0.7
Missing	0.95	0.94,0.96	<0.001	0.92	0.90,0.93	<0.001
Area-level Variables		•	•		•	
IMD Quintile						
IMD1 (Most deprived)	Reference			Reference		
IMD2	0.99	0.98.1.00	0.002	0.99	0.98.0.99	<0.001
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	1.07	1 04 1 09	<0.001	1.05	1 03 1 08	<0.001
deprived)			al			0.001

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

	Vaccinated			Non-Vaccinated			All Index cohort		
	N= 56641	)	N = 1	N = 14889 (20.8%)			N=71530		
	Received 12 and 18	first MM 8 months	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
Individual-level			I		I	I			1
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						<u> </u>	1		<u> </u>
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									
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 adult	ts and chil	dren pe	r household			<u> </u>	.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
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

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Missing	4527	72.4	71.2-73.5	1729	27.6	26.5-28.8	6256	8.7	8.5-8.9
Area-level characteristics									
Index of Multiple Deprivation quintile									
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

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### Table S5- Sensitivity analyses I- unadjusted and adjusted prevalence ratios for 1<sup>st</sup> Measles, Mumps and Rubella vaccination receipt by 18 months of age

			value			Praide		
	Unadjusted	Unadjusted Variable			Adjusted Variable			
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	< 0.001		
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	<0.001		
White	Reference			Reference				
Missing	0.96	0.95,0.97	<0.001	0.97	0.96,0.98	<0.001		
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	< 0.001		
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	< 0.001		
8 to 10	0.95	0.94,0.96	< 0.001	0.96	0.94,0.97	<0.001		
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	< 0.001		
7 to 9	0.72	0.68,0.76	< 0.001	0.75	0.71,0.80	< 0.001		
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	< 0.001		
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	< 0.001		
IMD5 (Least deprived)	1.10	1.07,1.12	< 0.001	1.08	1.05,1.11	<0.001		
<sup>1</sup> PR = Prevalence Ratio. C	I = Confidence	e Interval	1		, ,	1		

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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 <sup>1</sup>	95% Cl <sup>1</sup>	p-value	PR <sup>1</sup>	95% CI <sup>1</sup>	p-value	
	Unadjusted			Adjusted			
Individual Characteristic	S						
Vaccination status of c	older 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	cs	,	-		,	-	
Household compositio	n						
Two adults with	Reference	_		Reference			
children							
Single adult with	0.07	0.06.0.08	<0.001	0.95	0.94,0.97	<0.001	
children	0.97	0.96, 0.96	<0.001				
Three generational	1.00	0.09 1.01	0.6	1.00	0.98,1.01	>0.9	
household	1.00	0.96, 1.01	0.0				
Missing	0.96	0.95, 0.97	<0.001	NA	NA	NA	
No of children in house	ehold						
2 to 3	Reference	- A		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	S				·		
IMD Quintile							
IMD 1 (Most	Reference	—	9	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	1.00	1 05 1 10	-0.001	1.06	1.03,1.09	<0.001	
deprived)	1.08	1.05, 1.10	<u><u><u></u></u></u>				
<sup>1</sup> PR = Prevalence Ratio	, CI = Confide	ence Interval					

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

Characteristic	95% Cl <sup>1</sup> p-value		PR <sup>1</sup>	<b>PR</b> <sup>1</sup> <b>95% CI</b> <sup>1</sup>		
	Univariable				е	
Individual Characteristics						
Vaccination status of old	der child					
Vaccinated	Reference	<u> </u>		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						
Household Composition	l					
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
<sup>1</sup> PR = Prevalence Ratio,	CI = Confider	nce Interval				

# **BMJ Open**

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

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1	Household determinants of delayed MMR vaccination: longitudinal analysis using electronic
2	health records in north east London, United Kingdom
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12	
13	The authors declare no competing financial interests.
14	

2 3 4 5	15 16 17	Abstract
5 6 7	18	Objectives
8	20	There is a lack of information about household factors associated with delayed Measles Mumps and
9 10	21	Rubella (MMR) vaccination. We examined whether timeliness of first MMR (MMR1) receipt is
11 12 13 14	22	associated with sharing a household with an older child with non-receipt of MMR1 independent of
	23	household composition and size.
15 16	24	Design
17 18	25	Longitudinal observational study using linked electronic health records
19 20	26	Setting:
21 22	27	North east London, United Kingdom
23 24	28	Participants:
25 26	29	The index cohort comprised 71,509 children (51.0% males) eligible to receive MMR1 between 1st
27 28	30	January 2014 and 28 <sup>th</sup> February 2020.
20 29	31	Methods
30 31	32	The primary outcome was MMR1 receipt between age 12 and 24 months. The explanatory variable
33 34	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 52	43	0.18,0.20). This association strengthened after excluding households with an age interval greater
55 54	44	than five years: OR: 0.14 (0.13,0.15)
55 56 57 58 59 60	45	Conclusions

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1 2		
3 4	46	There is strong concordance within households of delay in MMR1 receipt independent of household
5	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 12 13	50	
	51	
14 15	52	
16 17 18 19 20 21	53	Strengths and limitations
	54	We used a novel method to link individuals into households while maintaining privacy and
	55	confidentiality using electronic health records (EHRs) for a large population.
22 23	56	<ul> <li>We obtained high quality, accurately coded and validated MMR data in the EHR.</li> </ul>
24 25 26 27 28 29 30	57	We used robust statistical methods to assess relationships between the exposure and
	58	outcome variables.
	59	Processes of, and influences on, decision-making about vaccines between the linked younger
	60	and older children may have differed. We were not able to examine associations with delayed
32 32	61	receipt of primary vaccinations against diphtheria, pertussis, polio, tetanus and Haemophilus
33 34	62	influenza.
35 36	63	More granular categorisation of ethnic groups, as suggested by our patient and public
37 38	64	involvement group, was not possible due to limited sample size.
39 40	65	
41 42	66	
43 44	67	
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50 57 50	74	
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00		

2 3	76	Introduction							
4 5	77	Childhood vaccinations form an essential part of public health interventions provided by primary care. <sup>1</sup>							
6 7	78	In England and Wales, it is recommended that children receive a first dose of Measles, Mumps and							
8 9	79	Rubella (MMR) vaccine between age 12 and 13 months <sup>2</sup> : currently only 89% receive a first dose by							
10 11	80	age 24 months, and only 84% a second dose by age five years. <sup>3</sup> 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. <sup>4</sup> 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. <sup>5</sup> 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. <sup>3</sup>							
26 27	88								
28 29	In light of these public health concerns, and with the first dose conferring 93% protection against								
30 31	90	infection, there has been increasing emphasis on the importance of timely receipt of MMR1. <sup>6</sup> In the							
32	91 UK, national targets to ensure receipt of first MMR (MMR1) between 12 and 24 months of a								
33 34	92	been recently replaced by a 12-18 month target reflecting this emphasis on timeliness. <sup>7</sup>							
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. <sup>8, 9</sup> There is strong evidence demor								
41 42	96	that children from more deprived areas are less likely to receive MMR vaccination compared to those							
43 44	97	living in affluent areas. <sup>10</sup> We and others 11 have previously shown that family size is an important							
45 46	98	determinant of partial or non-immunisation with MMR, suggesting that access to services may play an							
47 48	99	important role. <sup>12 13</sup>							
49 50	100								
51 52	101	Identifying factors at a household level can create actionable insights into how services might be							
53 54	102	tailored to improve receipt of vaccinations. <sup>14</sup> The current pressures on the UK National Health							
55 56	103	Service have significantly impacted the delivery of vaccinations in primary care- therefore new ways							
50 57	104	of working to vaccinate the most vulnerable children in a resource-tight setting are needed. <sup>15, 16</sup> We							
58 59 60	105	used electronic health records (EHRs) for an ethnically diverse and disadvantaged population, with							

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2 3	106	among the lowest proportion of children receiving MMR1 by 24 months of age in the UK, to							
4 5	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	109	months were more likely to share a household with an older child with non-receipt of MMR1 at these							
10 11	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 21	120	primary care EHR data in near-real time for all general practices (GPs) in NEL. 17 Unique Property							
31	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. <sup>18</sup> UPRNs are pseudonymised into							
35 36	123	Residential Anonymous Linking Fields (RALF) <sup>19</sup> 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								
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 50	130	second birthday and eligible to receive MMR1 between 1 <sup>st</sup> January 2014 and 28 <sup>th</sup> February 2020. We							
51 52	131	excluded 17,038 children without a RALF, with a non-residential RALF, with a poor-quality RALF							
53 54	132	match, or with more than one RALF at time of MMR1 or second birthday, leaving 142,262 children							
55 56	133	eligible for inclusion (supplementary file 1 figure S1).							
57	134								
58 59 60	135	Identifying children sharing a household							

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2 3	136	We identified older children charing a household with the 142 262 index children at the index child's
4	127	MMD1 date or 24 months of any whichever is the particlet Index and older shildren shering a DALE
6	137	MINE I date of 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 10	139	household. We identified all children in DDS based on the index children's RALFs and excluded
10 11 12	140	52,693 children without an older child in the household, and 15,516 older children who were already
12	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	
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 34	151	the Cover of Vaccination Evaluated Rapidly (COVER) measures in place during the study period. <sup>22</sup>
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
49 50	159	defined as children with non-receipt of MMR1.
51 52 53	160	Explanatory variable
54 55	161	The main explanatory variable was non-receipt of MMR1 in the linked older child defined as no record
56 57 58	162	of MMR1 given between 12 and 24 months of age.
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.<sup>23</sup> 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
 174 excluded households with more than ten members, only one child, or no adults aged ≥18.0 years.
 175 Household information was available for 65,308 households containing index and linked older
 176 children.

We categorised household composition using an adapted Harper and Mayhew method<sup>24</sup> 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.

<sup>7</sup> 185 Area-level

186 We merged 2019 Index of Multiple Deprivation (IMD) decile<sup>25</sup> 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	104	adulte							
8	104								
9 10	195								
11 12	196	Statistical Methods							
13 14	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.							
20 21 22	201								
22	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	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	212	Outcomes Framework targets introduced in 2021. <sup>26</sup> 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 58 59 60	220	provide 90% power to detect a two percentage point difference significant at the 1% level in MMR1							

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3 4	221	receipt between 12 and 24 months of age in the index child between those with and without a linked
5 6	222	older child with no MMR1 receipt between 12 and 24 months.
7	223	
8 9	224	Patient and public involvement
10 11	225	We involved patients and the public in the communication of study results and dissemination within
12 13	226	the local community, in line with accepted principles from the UK Standards for Public Involvement. <sup>28</sup>
14 15	227	The aim was to raise awareness of the importance of inequalities in timely childhood vaccinations. We
16 17	228	established a patient advisory group, comprising six parents, to co-produce dissemination materials.
18 19	229	The patient and public involvement group reflected on vaccination inequalities, the study design and
20 21	230	how results were delivered. Participants expressed reservations about the categorisation of ethnic
22 23	231	group and whether more granular categories could be used in future research. They discussed
24 25	232	communication and visualisation of results. Dissemination of results is ongoing and informed by
26 27	233	advice about accessing seldom-heard as well as and existing community groups.
28	234	
29 30 21	235	Results
32	236	The index cohort comprised 71,509 children (51% males) of whom 11,658 (16.4%) had not received
33 34	237	MMR1 vaccine between 12 and 24 months of age. Children in the index cohort who did not receive
35 36	238	MMR1 between 12 and 24 months of age were more likely to live with a linked older child who
37 38	239	similarly had not received MMR1 between 12 and 24 months of age (Table 1). Index children
39 40	240	receiving MMR1 between 12 and 24 months of age were more likely to be from South Asian ethnic
41 42	241	groups, or living in households with fewer adults and fewer children, or in households with two or
43 44	242	more working age adults or three generation households. Children in single adult households or in
45 46	243	households with a larger number of children were less likely to receive MMR1 between 12 and 24
47 48	244	months. There was a marked gradient in timely MMR1 receipt by IMD quintile with an absolute
40 49 50 51	245	difference of 7.3% in MMR1 receipt between 12 and 24 months of age between the least and most
	246	deprived quintiles.
53	247	
54 55	248	In the unadjusted model, MMR1 receipt between 12 and 24 months of age was less likely among
56 57	249	children in the linked index cohort sharing a household with a linked older child with no MMR1 receipt
58 59 60	250	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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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 9	253	
o 9	254	In sensitivity analyses (Figure 2), the proportion of index children with MMR1 receipt between age 12
10 11	255	and 18 months (79.2%; 95% CI: 78.9,79.5) was, as expected, lower than the proportion with MMR1
12 13	256	receipt between 12 and 24 months (83.6%; 95% CI: 83.3,83.9) (supplementary file 1 Table S4).
14 15	257	Associations were weaker in sensitivity analyses using this measure as the primary outcome (OR:
16 17	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	262	findings: OR: 0.18 (0.17,0.19) (supplementary file 1 Table S7).
26 27	263	
28	264	While our study focussed on MMR1 receipt within the UK recommended age range at the time of the
29 30 21	265	study, it is possible that children were vaccinated before or after the recommended age range. We
32	266	searched for MMR1 dates for those with no MMR1 date within the 12-24 month age range. Of the
33 34	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	270	months of age, and 7,500 (64.3%) had no record of MMR1 receipt in the EHR by November 2021
41 42	271	when data were extracted (Table 2). This suggests that just over one third of index children did
43 44	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.

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Table 1: MMR1 receipt in linked index childr	en by individual, h	ousehold a	nd area-level c	haracteristi	cs	n-2024-097559 ht, including fo				
	Vaccinated			Non-vaco	inated	or us	All linke	d index o	children	
	N=59,851 (83.	6%)		N=11,658	(16.4%)	es I	N=71,50	9		
	Received first 24 months of a	MMR betwo nge	een 12 and	Did not re between t age	ceive first 12 and 24	MMPated to				
	N	%	95% CI	N	%	95%	n	%	95% C	
MMR1 status of oldest child						t ar	<u> </u>			
Vaccinated	53198	88.4	88.1, 88.6	6987	11.6	11.5,9409	60185	84.2	83.	
Non-vaccinated	6653	58.8	57.8, 59.7	4671	41.2	40.3 42.2	11324	15.8	15	
Individual covariates	C	0	1	1	I	<u> </u>	11		1	
Ethnic background										
South Asian	16963	88.0	87.6, 88.5	2305	12.0	11.5 124	19268	25.5	25.	
White	16625	83.8	83.3, 84.3	3219	16.2	15. <del>3</del> ,16 <mark>3</mark> 7	19844	28.3	27.	
Black or Black British	5703	82.2	81.2, 83.1	1238	17.8	16.9,187	6941	10.0	9	
Mixed and Other	4847	78.8	77.8, 79.8	1303	21.2	20.8 22 2	6150	8.5	8	
Missing**	15713	81.4	80.8, 81.9	3593	18.6	18. <b>g</b> ,19 <mark>5</mark> 2	19306	27.7	27.	
Sex			I			sir	1 1		1	
Female	29399	84.0	83.6, 84.3	5614	16.0	15.80,1604	35013	48.9	48.	
Male	30452	83.4	83.0, 83.8	6044	16.6	16.2,1629	36496	51.1	50.	
Household-level covariates		I	,	I	-	chr	1			
Household size		1	1			10 0	1		1	
3-4	18695	86.1	85.7, 86.6	2976	13.9	1344,1483	21671	30.3	30.	
5 to 7	26867	84.0	83.6, 84.4	5097	16.0	15.80,164	31964	44.8	44.	
8 to 10	9397	80.6	79.9, 81.3	2264	19.4	18.7, 2051	11661	16.3	16	
Missing**	4881	78.7	77.7, 79.7	1320	21.3	20.3, 2 <b>2 </b> 3	6201	8.6	8	
Household composition				-		Irtn				
Two working age adults with children	42380	84.6	84.3, 84.9	7713	15.4	15.1,15 <b>5</b> 7	50093	76.7	76.	
Single working age adult with children	7699	81.5	80.7, 82.3	1747	18.5	17.7,19 <b>5</b> 3	9446	14.5	14	
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3	Three-generational household	4	891	84.8	83.8, 85.7	878	15.5	14.5	,164	5769	8.8	8.6, 9.0
4	Missing**	4	881	78.7	77.7, 79.7	1320	21.3	20.3	22,3	6201	8.6	8.4, 8.8
6	Number of children in household				-				559			
7	2 to 3	43	968	85.4	85.0, 85.7	7527	14.6	14.5	14-9	51495	72	71.7, 72.3
8	4 to 6	10	669	80.2	79.5. 80.8	2629	19.8	19.2	2055	13298	18.7	18.4.19.0
9	7 to 9		333	64.7	60.4, 68.8	182	35.3	31.2	<b>36</b> 5€6	515	0.7	0.6, 0.8
10	Missing**	4	881	78.7	77.7, 79.7	1320	21.3	20.3	<b>2</b> 23	6201	8.6	8.4, 8.8
11	Area level covariates		•	•					5. 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			
12	Index of Multiple Deprivation (IMD) Quintil	е						5	Do			
13	1 (most deprived)	23	861	83.9	83.5, 84.3	4587	16.1	15.	<b>965</b> 5	28448	40	39.7, 40.3
14	2	23	512	82.3	81.7, 82.8	5052	17.7	17.		28564	39.8	39.5, 40.1
15	3	7	600	83.9	83.2, 84.7	1454	16.1	15.	3,8688	9054	12.6	12.4,12.8
10	4	3	345	88.9	87.9, 89.9	417	11.1	10.8	1, <b>12-</b> 1	3762	5.2	5.0, 5.4
18	5 (least deprived)	1	533	91.2	89.7, 92.5	148	8.8	7.5	,1052	1681	2.3	2.2, 2.4
22 280 23 280 24 281	Table 2: MMR1 receipt in linked Index and Old	er Children	withou	t MMR1 ra	acaint between	a 12 and 2/	1 months	و پو مر عرم	njopen.br			
25			i withou			1 12 810 2-			nj.c			
26	Non-vaccinated groups		Index	Child (N	= 11658)		% 0	)lder Ğ	hil <mark>ð</mark> (N	=11324)	%	7
27	MMR1 receipt <12 months of age				51	6	4.4		or	993	8.8	
29	MMR1 receipt between 24 and 40 months of	of age			289	93	24.8	ler	h Ma	2642	23.3	
30 21	MMR1 receipt >40 months of age				74	19	6.4		y 20	1689	14.9	
32	No record of MMR1 receipt in period of follo	w-up			750	0	64.3		, 20	6000	53.0	
33	Total				1165	58	100.0	ÿ	່ <u>ອ</u>	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.<sup>2</sup> 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.<sup>29, 30</sup> 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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315       months of age. So, while we were unable to contirm MMN receipt in two thirds of index and one hat         316       of linked older children, a significant proportion were delayed rather than never immunised.         317       This is to our knowledge the first study to examine associations within households of MMR1         318       This is to our knowledge the first study to examine associations within households of MMR1         319       timeliness, so direct comparisons with existing literature are not possible. Previous studies have four         320       that vaccine coverage is lower in families with larger numbers of children and in single-parent         321       households. <sup>31,2</sup> It has been suggested that the main drivers of vaccination delay in these households         322       are access-based, with vaccination services and appointments less suitable for families with larger         322       numbers of children, of for parents requining more flexible clinic appointments. <sup>12,33</sup> Vaccination delay         324       may also be non-intentional: parents may delay vaccinations due to a child's illness. <sup>34</sup> This may         325       explain some of the factors driving delayed MMR1 receipt in our study.         326       There may be other reasons for delayed MMR1 receipt and the parents of shared decision         329       making with clinicians, and the strong association between trust in healthcare professionals and         330       vaccine hesitancy in parents or caregivers who have some trust in the </th <th>2</th> <th>045</th> <th></th>	2	045							
316       of linked older children, a significant proportion were delayed rather than never immunised.         317         318       This is to our knowledge the first study to examine associations within households of MMR1         11       111       111         319       timeliness, so direct comparisons with existing literature are not possible. Previous studies have four         320       that vaccine coverage is lower in families with larger numbers of children and in single-parent         14       households. <sup>3132</sup> It has been suggested that the main drivers of vaccination delay in these households         321       are access-based, with vaccination services and appointments less suitable for families with larger         18       are access-based, with vaccination services and appointments less suitable for families with larger         18       are access-based, with vaccination services and appointments less suitable for families with larger         19       may also be non-intentional: parents requiring more flexible clinic appointments. <sup>12,33</sup> Vaccination delay         22       may also be non-intentional: parents may delay vaccinations due to a child's illness. <sup>34</sup> This may         23       explain some of the factors driving delayed MMR1 receipt in our study.         326       strain or non-vaccination of children highlight the importance for parents of shared decision         327       There may be other reasons for delayed MMR1 receipt. Qualitative research around reasons for <td>4</td> <td>315</td> <td>months of age. So, while we were unable to confirm MMR1 receipt in two thirds of index and one half</td>	4	315	months of age. So, while we were unable to confirm MMR1 receipt in two thirds of index and one half						
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<ul> <li>336</li> <li>337 Vaccinations can also be delayed by parents if they feel that information around the safety of a</li> <li>vaccine is insufficient, or if they have concerns about overburdening a child's immune system.<sup>37, 38</sup></li> <li>vaccine is insufficient, or if they have concerns about overburdening a child's immune system.<sup>37, 38</sup></li> <li>Parental or caregiver disagreement around childhood vaccination may also contribute to delay.<sup>13</sup></li> <li>340</li> <li>S41</li> <li>Further qualitative research is needed to tease out the likely heterogenous reasons for MMR1 delay</li> <li>or non-receipt at a household level and to understand household factors that interact with access and</li> <li>the decision-making process.<sup>39</sup> Delay in primary vaccinations against diphtheria, pertussis, polio,</li> </ul>	41 42	335	significantly impacted the decision made. <sup>36</sup>						
<ul> <li>Vaccinations can also be delayed by parents if they feel that information around the safety of a</li> <li>vaccine is insufficient, or if they have concerns about overburdening a child's immune system.<sup>37, 38</sup></li> <li>Parental or caregiver disagreement around childhood vaccination may also contribute to delay.<sup>13</sup></li> <li>Parental or caregiver disagreement around childhood vaccination may also contribute to delay.<sup>13</sup></li> <li>Further qualitative research is needed to tease out the likely heterogenous reasons for MMR1 delay</li> <li>or non-receipt at a household level and to understand household factors that interact with access and the decision-making process.<sup>39</sup> Delay in primary vaccinations against diphtheria, pertussis, polio,</li> </ul>	43	336							
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<ul> <li>340</li> <li>341 Further qualitative research is needed to tease out the likely heterogenous reasons for MMR1 delay</li> <li>342 or non-receipt at a household level and to understand household factors that interact with access and</li> <li>343 the decision-making process.<sup>39</sup> Delay in primary vaccinations against diphtheria, pertussis, polio,</li> </ul>	48 49	339	Parental or caregiver disagreement around childhood vaccination may also contribute to delay. <sup>13</sup>						
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	55 56 57 58 59 60	343	the decision-making process. <sup>39</sup> Delay in primary vaccinations against diphtheria, pertussis, polio,						

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3 4	344	tetanus and Haemophilus influenza has been shown to be associated with an incomplete vaccination
5	345	schedule by 24 months of age. <sup>40</sup> We were not able to examine this in our study.
7	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	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	357	Household-based interventions could also be considered by public health and service commissioners.
29 30 21	358	Setting up services tailored to households with non- or partially-vaccinated children aligns with
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. <sup>42</sup> 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. <sup>36</sup>
45 46	366	
47 48	367	Existing literature cites multi-component interventions as the most effective interventions for
49 50	368	increasing vaccination coverage in deprived communities with intersectional inequalities, including
50 51 52	369	information, education and re-call measures. <sup>39</sup> Robust re-call methods are cited as an effective way to
53 54	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
50 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	375	We have shown that non-receipt of MMR1 between 12 and 24 months of age is clustered in							
6 7	376	households. However, a significant proportion of children in our study ultimately received MMR1 in the							
8 9	377	preschool years and later childhood, with no clear evidence of MMR1 receipt in the remainder.							
10 11	378	Qualitative research is needed to understand the decision-making processes underlying this							
12 13	379	heterogenous group. Similar research in demographically different areas of the UK may help							
14 15	380	understand the extent to which these findings are generalisable to households in a different							
16 17	381	socioeconomic context.							
18 19	382								
20 21 22 23 24 25 26 27	383	Strengths and limitations							
	384	The strengths of our study include the use of a novel method to create households securely while							
	385	maintaining privacy, as well as having access to a large population with EHRs for a geographically							
	386	contiguous area. Additionally, we have access to high quality MMR data, that is recorded accurately							
28	387	in the EHR through data recording templates. <sup>45</sup> The codeset used to identify MMR1 in the EHR was							
29 30 31	388	validated. We used robust statistical methods to assess relationships between the exposure and							
32 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	392	We were not able to examine associations with delayed receipt of primary vaccinations against							
39 40	393	diphtheria, pertussis, polio, tetanus and Haemophilus influenza. More granular categorisation of							
41 42	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 56	401	There is strong concordance in MMR1 vaccine delay or non-receipt between children sharing the							
57 58 59 60	402	same household in a region with the lowest MMR vaccination coverage in the UK. <sup>3</sup> These findings							

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2 3 4 5 6 7 8 9 10 112 3 4 5 6 7 8 9 10 112 3 4 5 6 7 8 9 10 112 3 4 5 6 7 8 9 10 112 3 4 5 6 7 8 9 10 122 3 222 2222 22 22222 22 22 22 22 22 22	403	have implications for the planning and delivery of vaccination services that consider children in their
	404	household context
	405	
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	407	
	407	we are grateful to general practitioners in north east London for making electronic health record data
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	409	Group for their support in extracting, and expertise in using, general practice data. This research uses
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	413	
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	419	
	420	
	421	Contributions
	422	As per CrEdit accreditation, significant contributions to: Conceptualisation (MM, CD, NF, MW),
	423	Methodology (MM, CD, MW, NF), Resources (CD, AG), Data Curation (MM, AG, NF, MW, KS), Data
	424	Analysis (MM, NF, CD), Writing-Original Draft (MM, CD), Review and Editing (MM, AG, NF, MW, KS,
	425	CD), Formal Analysis (MM, CD), Validation (AG, MM), Visualisation (MM), Supervision (CD), Funding
	426	Acquisition (MM, CD). CD is the guarantor for this research.
	427	
	428	
	429	Competing interests declaration
	430	All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/disclosure-of-
	431	interest/ and declare: no support from any organisation for the submitted work; no financial
	432	relationships with any organisations that might have an interest in the submitted work in the previous
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2	400	
4	433	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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### Figure 2. Forest Plot of MMR1\* vaccination odds ratios (OR) and 95% Confidence Intervals (CI) from

- 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



			Loss likely	Morolikoly	
					OR (95 % CI)
Unadjusted model:	Vaccinated			÷	reference
Vaccination status of older child	Non-vaccinated				0.19 (0.18,0.20)
+ Demographics:	Vaccinated			+	reference
Houer 2	Non-vaccinated	HEH			0.20 (0.19,0.21)
+ Household Size : Model 2 +	Vaccinated			÷	reference
Hodel 3	Non-vaccinated	HEH			0.20 (0.19,0.21)
+ Household	Vaccinated			+	reference
Model 4 †	Non-vaccinated	HEH			0.20 (0.19,0.21)
+ No. of Childron in	Vaccinated			+	reference
Household: Model 5 †	Non-vaccinated	HEH			0.20 (0.19,0.21)
+ IMD Quintile:	Vaccinated			÷	reference
Model 6 †	Non-vaccinated	H <b>B</b> -1			0.20 (0.19,0.21)
).05		0.25		1.25	6.25
		Adj	justed odds ratios for MMR1 vaccination	(log scale)	

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

286x179mm (300 x 300 DPI)

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OR (95% CI)

reference

0.20 (0.19,0.21)

reference

0.24 (0.23,0.25)

reference

0.14 (0.13,0.15)

reference

0.18 (0.17,0.19)

6.25

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Less likely More likely Adjusted model: accination status o older child Vaccinated (N = 53198) Non-vaccinated (N = 6653) Vaccinated (N = 48602) Sensitivity analysis I: 1st MMR by 18 months on-vaccinate (N = 8518) Sensitivity analysis II: Excluding linked children with >5 year Vaccinated (N =41878) Non-vaccinat (N = 8424) age gap Sensitivity analysis III: 1st MMR between 11 -25 months Vaccinated ( N = 60339) ( N = 10915) 0.05 0.25 1.25 Adjusted odds ratios for MMR1 vaccination (log scale) Figure 2. Forest Plot of MMR1\* vaccination odds ratios (OR) and 95% Confidence Intervals (CI) from main model and from sensitivity analyses 331x142mm (300 x 300 DPI) 

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

Milena Marszalek<sup>1</sup>, Nicola Firman<sup>1</sup>, Marta Wilk<sup>1</sup>, Ana Gutierrez<sup>1</sup>, Kelvin Smith<sup>1</sup>, Carol Dezateux<sup>1</sup>

<sup>1</sup>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

## 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)



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

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



<sup>1</sup> Residential Anonymised Linkage Field

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

 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 SNOREC codes captured all events regardless of the clinical coding system used. uses 

SNOMED concept ID	Other code	Clinical coding scheme	Code description
38598009	38598009	SNOMED	Measles-mumps-rubella vaccination (procedulate)
	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	[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 right right 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) vacciseation
308081000000105	65M10	Read v2	First MMR (measles mumps and rubella graceination
	Xaeec	Read v3	First MMR (measles mumps and rubella vaccination
	^ESCTME809974	EMIS local	Measles mumps and rubella vaccination of first dose
50500100000109	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 mut mps and rubella vaccine
1037251000000100	65M11	Read v2	First MMR vaccination given by other health are provider
	Xaeeq	Read v3	First MMR vaccination given by other health are 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 opported to a combined MMR vaccination. Z-LTA

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Table S2- Characteristics of linked and unlinked cohorts by individual-, household- and area level va	ariable

	Linked coho	ort (n = 71509)		Unlinke	d cohort (	ng= 70753)
	Ν	%	95% Cl <sup>1</sup>	N	% <b>ses</b>	<b>§</b> 5% CI <sup>1</sup>
MMR1 <sup>2</sup> status of oldest child				1	rela	ay_2
Vaccinated	59851	83.6	83.3,83.9	60512	85	85.3,85.8
Non-vaccinated	11658	16.4	16.1,16.6	10240	145	<b>14.2,14.7</b>
Individual covariates		1		1	ioge	wn.
Ethic Background					ind (	oad
South Asian	19268	25.5	25.1,25.8	16073	228	22.4,23
White	19844	28.3	27.9,28.6	23536	33 <b>ਤ</b> ੋਂ	<b>9</b> 32.9,33.6
Black or Black British	6941	10.0	9.8,10.2	5467	7 <b>.</b>	7.5,7.9
Mixed and Other	6150	8.5	8.3,8.7	6869	9 <b>2</b>	9.5,9.9
Missing**	19306	27.7	27.4,28.1	18807	26 🙀	26.3,26.9
Sex					ning,	en.
Female	35013	48.9	48.5,49.3	34885	49	48.9,49.7
Male	36496	51.1	50.7,51.4	35867	50 <b>g</b> .	<b>6</b> 50.3,51.1
Household-level covariates	I	1	1	0	nila	2
Household size					r tec	n Ma
3 to 4	21683	30.3	30.0 ,30.6	37417	523	52.5,53.3
5 to 7	31964	44.7	44.3,45.1	18976	26 <b>8</b>	26.5,27.1
8 to 10	11661	16.3	16,16.6	7514	10.86	<b>3</b> 10.4,10.8
Missing**	6201	8.7	8.5,8.9	6845	9.7	9.4,10.0
Household composition				1		par
Two working age adults with children	50093	70.0	69.7,70.3	46906	66.3	<b>1</b> 66,66.6
Single working age adult with children	9446	13.2	13,13.4	10356	14.6	14.4,14.9

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Three-generational household	5769	8.1	7.9,8.3	6645	9 <sup>9</sup> ud	9.2,9.6
Missing**	6201	8.7	8.5,8.9	6845	97559 99 fr	9.5,9.9
Number of children in household					9 on or u	
2 to 3	51495	72.0	71.7,72.3	59151	8389 N	83.3,83.9
4 to 6	13298	18.7	18.4,19	4486	6∰an	6.1,6.5
7 to 9	515	0.7	0.6,0.8	270	0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	0.3,0.5
Missing	6201	8.6	8.4,8.8	6845	9. <b>5 ust</b>	9.4,10.0
Area level covariates					noge ext a	
Index of Multiple Deprivation (IMD) quintile					oad Ind	
IMD 1 (Most deprived)	28448	40.0	39.7,40.3	26062	36 <b>8 0 6</b>	36.5,37.2
IMD 2	28564	39.8	39.5,40.1	28972	40 <b>3</b> 9. m	40.5,41.3
IMD 3	9054	12.6	12.4,12.8	9602	13 👸 📑	13.3,13.8
IMD 4	3762	5.2	5.0,5.4	4311	6 4 5	5.9,6.3
IMD 5 (Least deprived)	1681	2.3	2.2,2.4	1805	2 <b>5</b> 5	2.4,2.6

 IMD 5 (Least deprived)
 1681
 2.3
 2.2,2.4
 1805
 2 model
 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'

 \*CI – Confidence interval

 \* Vaccinated signifies receipt of MMR1 between 12 and 24 months of age

 \* Vaccinated signifies receipt of MMR1 between 12 and 24 months of age

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	Table S3- Unadjusted and adjusted odds ratios for 1 <sup>st</sup> Measles, Mumps and Rubella (MMR) vaccination individual-, household-, and area level characteristics:	pyright, inc	ecc/ ورقع znz-ulopen-	een 12 and 24 months of age, by

	OR <sup>1</sup>	95% Cl <sup>2</sup>	p-value	OR <sup>1</sup>	95% <b>Ç</b> l <sup>2</sup> S	p-value
	Unadjusted	1	1	Adjusted	es Ma	1
MMR1 <sup>3</sup> status of oldest child				1	elat	
Vaccinated	Reference			Reference	025 asm	
Non-vaccinated	0.19	0.18, 0.20	<0.001	0.20	0 <sup>0</sup> 15,00.21	< 0.001
Individual covariates	0h	1	l		wnl xt a	1
Ethnic background					oad and	
South Asian	1.34	1.26, 1.42	<0.001	1.46	1 a 3 a . 55	<0.001
White	Reference			Reference	a fr m on	
Black or Black British	0.88	0.82, 0.95	<0.001	0.97	0589, ₹.04	0.40
Mixed and Other	0.76	0.71, 0.82	< 0.001	0.83	0,77,50.90	< 0.001
Missing	0.84	0.79, 0.88	<0.001	0.87	0_82,9.92	<0.001
Sex	·				aini	
Male	Reference			Reference	ng,	
Female	0.96	0.92, 1.00	0.061	0.96	<b>92<u>3</u>.00</b>	0.06
Household level covariates		1			sin on	1
Household size					nilar or	
3 to 4	Reference			Reference	. tec	
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	0,666,0.77	< 0.001
Missing**	0.68	0.63, 0.73	<0.001	NA	es. 25 NA	NA
Household composition					at E	
Two working age adults with children	Reference			Reference	ep;	
Single working age adult with children	0.80	0.75, 0.85	<0.001	0.72	0.67, 2.77	< 0.001
Three generational household	0.97	0.90,1.05	0.40	0.98	0.91 2.07	0.70
Missing**	0.74	0.69.0.79	< 0.001	0.56	0.52. <b>9</b> .61	< 0.001

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					pen- ight		
					-202		
Number of children in househol					4-09		
2 to 3	Reference	0.00.0.77	.0.001	Reference	ing	7	
4 to 6	0.73	0.69, 0.77	<0.001	0.82	8.60,7% 00 	37 <0.001	
7 to 9	0.42	0.35, 0.52	<0.001	0.57	0546,=0./	<b>70</b> <0.001	
Missing	0.71	0.66, 0.76	<0.001	NA	s sn re_s	A NA	
Area level					r 20) Eras		
Index of Multiple Deprivation (IN	ID) quintile				smu d to		
IMD1 (Most deprived)	Reference			Reference	o tey		
IMD2	0.93	0.89, 0.97	<0.001	0.91	0;3;2;5).9	95 <0.001	
IMD3	1.01	0.95, 1.08	0.80	0.96	କ୍ରେମ୍ବର୍ଯ୍ୟୁ .C	0.20	
IMD4	1.40	1.25, 1.56	<0.001	1.33	12 10 0 1 .4	48 <0.001	
IMD5 (Least deprived)	1.81	1.52, 2.16	<0.001	1.69	1⊒42,92.0	02 <0.001	
<sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confider <sup>3</sup> Vaccinated signifies receipt of M * Children that could not be linked Vissing'	nce Interval MR1 between 12 and 24 m to other members of the ho	oonths of age	om the oldest	t child were docum	nttp://bmjopes.bmj.co ing, Al training, and s	aving household der	nograph
<sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confider <sup>3</sup> Vaccinated signifies receipt of M * Children that could not be linked Missing'	nce Interval MR1 between 12 and 24 m to other members of the ho	oonths of age	om the oldest	t child were docum	nttp://bmjopen.bmj.com/ on May 20, 2025 at Departm ing, Al training, and similar technologies.	aving household der	nograph

 

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 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
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	Vaccina	ated		Non-vaccir	nated	n 2 N uses	All Index	cohort	
	N=5664	1 (79.2%)		N=14889 (2	20.8%)	lay 2 Er: relat	N=71530		
	Receive and 18 i	ed first MMI months of a	R <sup>1</sup> between 12 age	Did not rece and 18 mor	eive first MN hths of age				
	n	%	95% Cl <sup>2</sup>	n	%	95% CI X a	n	%	95% CI
MMR1 <sup>1</sup> status of oldest child						bade schc nd d	1	1	
Vaccinated	48602	85.8	85.5,86.1	8039	14.2	1 <b>ឆ្ន</b> .9,14.5	56641	79.2	78.9,79.5
Non-vaccinated	8518	57.2	56.4,58.0	6371	42.8	4 <u>5</u> .0,43.6	14889	20.8	20.5,21.1
Individual covariates			· ·		I	ig, A	1	1	I
Ethnic Background						l trai			
South Asian	16214	84.3	83.8,84.9	3007	15.6	15:1,6:2	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	27.4,28.0
Black or Black British	5342	76.9	75.9,77.9	1605	23.1	2 <b>º</b> .1, <b>2</b> 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, 29.3	6193	8.7	8.5,8.9
Missing	14803	76.5	75.9,77.1	4554	23.5	2 <b>5</b> .9, <b>3</b> .1	19357	27.1	26.7,27.4
Sex						20, nolo	1	1	
Female	27814	79.4	79.0,79.8	7206	20.6	2 <b>6</b> :2, <b>2</b> :0	35020	49.0	48.6,49.3
Male	28827	79.0	78.5,79.4	7683	21.0	20.6,241.5	36510	51.0	50.6,51.4
Household-level covariates			I	1	1	bepa	1	1	I
Household size						rtme			
3 to 4	17848	82.4	81.9,82.9	3819	17.6	17.1, <b>1</b> 8.1	21655	30.3	29.9,30.6
			1		1	EZ-L			1
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5 to 7	25460	79.7	79.2,80.1	6492	20.3	12:9,20.8	31952	44.7	44.3,45
8 to 10	8806	75.5	74.7,76.3	2849	24.4	2.3.7,25.2	11655	16.3	16,16.6
Missing**	4527	72.4	71.2,73.5	1729	27.6	28.5,28.8	6256	8.7	8.5,8.9
Household composition						ISES			
Two working age adults with children	40292	80.5	80.1,80.8	9773	19.5	1 <b>1</b> 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	50065	70.0	69.6,70.4
Single working age adult with children	7187	76.1	75.2,77.0	2256	23.9	29.9.24.8	9443	13.2	13,13.4
Three-generational household	4625	80.3	79.5,81.6	1131	19.7	15.20.8	5766	8.1	7.9,8.3
Missing**	4527	72.4	71.2,73.5	1729	27.6	200.00,208.8	6256	8.7	8.5,8.9
Number of Children in household						ded f hool data	I		
2 to 3	41973	81.6	81.2,81.9	9494	18.4	1 <b>8</b> .1, <b>9</b> 8.8	51467	71.9	71.6,72.2
4 to 6	9875	74.2	73.5,75.0	3422	25.7	2 2 .0, 2 .5	13297	18.6	18.3,18.9
7 to 9	266	52.1	47.7,56.5	244	47.8	4 <b>4</b> .4, <b>5</b> 2.3	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 covariates				10		n.bn Ig, al	I		
Index of Multiple Deprivation (IMD) Quin	ntile					nj.co nd s			
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	14.0	<u><u>g</u>3,<b>1</b>5.2</u>	3768	5.3	5.1,5.4
IMD 5 (Least deprived)	1499	89.0	87.4,90.5	185	11.0	9.5, 2.5	1684	2.3	2.3,2.4

<sup>2</sup>CI- Confidence interval

\*\* Children that could not be linked to other members of the household apart from the oldest child were documented a ghaving household demographics as 'Missing' **GEZ-LTA** 



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 Table S5- Sensitivity analysis I- unadjusted and adjusted odds ratios for 1<sup>st</sup> Measles, Mumps and Rubella vaccenation receipt between 12 and 18 months of age

		<b>95% Cl</b> <sup>2</sup>	p-value	<b>OR</b> <sup>1</sup>	5%,€CI1	p-value
	Unadjusted			Adjusted	es N	
MMR1 <sup>3</sup> status of oldest child					rel:	
Vaccinated	Reference			Reference	20) ate	
Non-vaccinated	0.22	0.21,0.23	<0.001	0.24	<b>D</b> <u>ä</u> <u></u> ,0.25	<0.001
Individual covariates		l	1	L	Jish O	I
Ethnic Background					wn oge xt a	
South Asian	1.29	1.22,1.36	<0.001	1.41	<b>17, 34, 1</b> .49	<0.001
White	Reference			Reference	de ho l da	
Black or Black British	0.83	0.78,0.89	<0.001	0.76	<b>1111111111111</b>	<0.001
Mixed and Other	0.69	0.64,0.74	<0.001	0.85	<b>F</b> ).8 <b>2</b> 0.89	<0.001
Missing	0.82	0.78,0.86	<0.001	0.92	<b>₽</b> .8 <b>6</b> 0.99	0.027
Sex					ig,	
Female	Reference			Reference	Al -	
Male	0.97	0.94,1.01	0.20	0.97	<b>a</b> .9 <b>4</b> .1.01	0.20
Household level covariates					ope	
Household size					<mark>ייי.</mark> יקו	
3 to 4	Reference			Reference	an	
5 to 7	0.90	0.86,0.94	<0.001	0.83	<b>3</b> .7 <b>9</b> .78	< 0.001
8 to 10	0.75	0.71,0.79	<0.001	0.75	<b>1</b> .7 <b>0</b> .81	<0.001
Missing**	0.65	0.60,0.69	<0.001	NA	ar of NA	NA
Household composition					teg	
Two adults with children	Reference			Reference	ay chr	
Single adult with children	0.78	0.74,0.82	<0.001	0.71	<b>9</b> .6 <b>8</b> 0.76	<0.001
Three generational household	0.96	0.90,1.04	0.30	0.97	<b>്</b> ള.9 <b>പ്ര</b> 1.04	0.40
Missing**	0.69	0.65,0.74	<0.001	0.53	<b>b</b> .4 <b>\$</b> ,0.57	<0.001
Number of children in household					at	
2 to 3	Reference			Reference	De	
4 to 6	0.71	0.68,0.74	< 0.001	0.79	0.740.83	< 0.001
7 to 9	0.35	0.29,0.42	< 0.001	0.46	0.3850.56	< 0.001
Missing**	0.66	0.62,0.70	< 0.001	NA	S NA	NA
Area level covariates					G	
					EZ.	
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Index of Multiple Deprivation (IM	D) quintile				n-2024- ht, inclu		
IMD 1 (Most deprived)	Reference			Reference	097 din		
IMD 2	0.95	0.91.0.99	0.012	0.93	<b>5</b> .8 <b>9</b> 0.97	< 0.001	
IMD 3	1.06	1.00.1.13	0.050	1.00	0.9401.07	0.90	
IMD 4	1.46	1.32.1.61	< 0.001	1.37	<b>4</b> .24.1.52	< 0.001	
IMD 5 (Least deprived)	1.95	1.67.2.30	< 0.001	1.81	<b>9</b> .5 <b>⊈</b> 2.13	< 0.001	
* Children that could not be linked to other Vissing'	members of the household	apart from the o	idest child v	vere documen	wind average by Symbol adogeschool . By tand data mining, Al training, and similar technologies.	household demo	ograp
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able S6-Sensitivity analyses II- Unadjusted and nonths of age: excluding linked index and olde	d adjusted odds rati r cohort children wi	BMJ Open os for 1 <sup>st</sup> Meas ith an age gap g	les, Mumps and greater than five	by copyright, including for Rubella Rubella	anation receipt k	etween 12 and
	OR <sup>1</sup>	95% Cl <sup>2</sup>	p-value	uses related to	2 2 2 95% Cl <sup>2</sup>	p-value
<u> </u>	Unadjusted			Adjusted		
MMR1 <sup>3</sup> status of oldest child		1		and		
Vaccinated	Reference			Reterenación a		
Non-vaccinated	0.13	0.12, 0.14	<0.001	<u>) (</u> କ୍ରୀ <del>4</del> : ପୂଦ୍ଧୀ <del>4</del> :	0.13,0.15	<0.00
Individual covariates				in n	5	
Ethnic background	4.07		0.001	<u> </u>	1 01 1 50	<0.00
	1.27	1.18, 1.36	<0.001		1.31,1.52	<0.00
While Block of Block British	Reference		0.000		0.00.1.09	0.7
Black OF Black Bhlish	0.87	0.79, 0.95	0.003		0.90,1.08	0.7
Mixed and Other	0.77	0.70, 0.97	< 0.001		0.77,0.93	<0.00
Sex	0.82	0.76, 0.87	< 0.001	080 E	0.80,0.92	<0.00
Male	Reference			Reference	3	
Female	0.97	0.92, 1.02	0.20	097.	0.92,1.02	0.2
Household level covariates					3 0	
Household size				ogie	2	
3 to 4	Reference			Reference	й Л	
5 to 7	0.83	0.78,0.88	<0.001	0.78	0.73,0.84	<0.00
8 to 10	0.71	0.66,0.77	<0.001	0.71	0.64,0.79	<0.00
Missing**	0.68	0.62,0.74	<0.001	NA	NA NA	N
Household composition			I			
				r T		

Two working age adults with children         Reference         Reference         Reference         Reference         Construction           Single working age adults with children         0.80         0.74, 0.86         <0.001         Gf 1         0.65, 0.77         <0.001           Missing**         0.77         0.72, 0.86         <0.001         Gf 7         0.52, 0.63         <00           Number of children in household         0.77         0.72, 0.84         <0.001         Gf 7         0.52, 0.63         <00           2 to 3         Reference         Reference         Reference         2         0.74, 0.86         <00         <0.001         0.965         0.74, 0.86         <00           7 to 9         0.49         0.40, 0.60         <0.001         0.965         NA          <0.97         NA          <0.97         <0.52, 0.81         <00         <0.90         0.90, 0.001         0.965         NA          <0.96         0.91, 1.02         0.001         0.97         NA           <0.96         0.91, 1.02         0.20         0.93         0.80, 0.99         0         <0.91         1.01, 1.19         0.229         1.93         0.95, 1.12            <0.91			BMJ Open		36/br by co		
Two working age adults with children         Reference         Reference         Reference           Single working age adults with children         0.80         0.74, 0.86         <0.001         0.87         0.65,0.77         <0           Three-generational household         0.98         0.89, 107         0.60         0.89         0.89, 1.07         <0.60         0.89         0.89, 1.09           Missing**         0.77         0.72, 0.84         <0.001         0.65         0.74         <0.60         0.89         0.52, 0.63         <0           Mumber of children in household         0.77         0.72, 0.84         <0.001         0.65         0.74, 0.86         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         <0         0					njopen-2 pyright,		
Single working age adult with children         0.80         0.74, 0.86         <0.001	Two working age adults with children	Reference			Referenze 4		
Three-generational household         0.98         0.89, 1.07         0.60         0.89         0.89, 1.09           Missing**         0.77         0.72, 0.84         <0.001	Single working age adult with children	0.80	0.74, 0.86	<0.001		0.65,0.77	<0.
Missing**         0.77         0.72, 0.84         <0.001         OBS7         0.52,0.63         <0           2 to 3         Reference         Reference         Reference         Reference         0.74,0.86         <0	Three-generational household	0.98	0.89, 1.07	0.60	<u>ි ල</u> ම්ව සි	0.89,1.09	(
Number of children in household         Reference         NA           Area level covariates         0.72         0.67, 0.78         <0.001	Missing**	0.77	0.72, 0.84	<0.001	057	0.52,0.63	<0.
2 to 3         Reference         R	Number of children in household				es r		
4 to 6         0.70         0.65, 0.74         <0.001         ORE         0.74, 0.86         <0           7 to 9         0.49         0.40, 0.60         <0.001	2 to 3	Reference			Refere		
7 to 9         0.49         0.40, 0.60         <0.001         0.52, 0.81         <0           Missing**         0.72         0.67, 0.78         <0.001	4 to 6	0.70	0.65, 0.74	<0.001	044	0.74, 0.86	<0.
Missing**       0.72       0.67, 0.78       <0.001       NA         Area level covariates       Reference       Reference of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the se	7 to 9	0.49	0.40, 0.60	<0.001	<b>္ ខ្មែត</b> ្តិ	0.52, 0.81	<0.0
Area level covariates       Index of Multiple Deprivation (IMD) quintile         IMD 1 (Most deprived)       Reference       Reference         IMD 2       0.96       0.91, 1.02       0.20         IMD 3       1.09       1.01, 1.19       0.029       0.963       0.95, 1.12         IMD 4       1.54       1.35, 1.75       <0.001	Missing**	0.72	0.67, 0.78	<0.001		NA	
Index of Multiple Deprivation (IMD) quintile       Reference       Refer	Area level covariates	6		·	bado sch nd o	·	
IMD 1 (Most deprived)       Reference       Ref	Index of Multiple Deprivation (IMD) quintile				ed fi Jata		
IMD 2         0.96         0.91, 1.02         0.20         000000000000000000000000000000000000	IMD 1 (Most deprived)	Reference			Reference g		
IMD 3       1.09       1.01, 1.19       0.029       1.03       0.95, 1.12         IMD 4       1.54       1.35, 1.75       <0.001	IMD 2	0.96	0.91, 1.02	0.20	0 3 3	0.88,0.99	0.
IMD 4       1.54       1.35, 1.75       <0.001       1at 3 a       1.26, 1.64       <0         IMD 5 (Least deprived)       1.98       1.63, 2.44       <0.001	IMD 3	1.09	1.01, 1.19	0.029	1 03	0.95,1.12	C
IMD 5 (Least deprived)     1.98     1.63, 2.44     <0.001	IMD 4	1.54	1.35, 1.75	<0.001	1 🚮 3 🧕	1.26,1.64	<0.
<sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confidence Interval <sup>3</sup> Vaccinated signifies receipt of MMR1 between 12 and 24 months of age ** Children that could not be linked to other members of the household apart from the oldest child were documented as having household demograpi 'Missing' Wissing'	IMD 5 (Least deprived)	1.98	1.63, 2.44	<0.001	1332	1.49,2.24	<0.
<u> </u>	** Children that could not be linked to other members Missing'	of the household ap	part from the olde	est child were doc	d sintar technologies.	aving household de	mograph

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able S7-Sensitivity analyses III- Unadjusted ceipt between 11–25 months of age	and adjusted odds ratio	os in multivariable an	alysis: 1 <sup>st</sup> Meas	lenging Magmps ; in Magnor 2 May 2 in Magnor 1 May 2	and Rubella vacci	p-value
	Unadjusted		•	Adgustied		<b>P</b>
/MR1 <sup>3</sup> status of oldest child				ush te		
/accinated	Reference			Trence		
Non-vaccinated	0.16	0.16, 0.17	<0.001		0.17, 0.19	<0.001
ndividual covariates	20	I	I	ool f	1	
Ethnic background				mir		
Asian or Asian British	1.33	1.25, 1.42	<0.001	<b>j</b> 1.46	1.37, 1.55	<0.001
Vhite	Reference			Reference		
Black or Black British	0.88	0.82, 0.96	0.002	<b>fai</b> <u>3</u> . 0.96	0.89, 1.04	0.40
lixed and Other	0.76	0.71, 0.82	<0.001	<b>Din 0.83</b>	0.77, 0.90	<0.001
Aissing	0.84	0.80, 0.89	<0.001	88.0 و	0.83, 0.93	<0.001
ex					1	1
<i>l</i> lale	Reference			Reterence		
emale	0.96	0.92, 1.01	0.084	ar <u>9</u> 0.96	0.92, 1.01	0.085
lousehold level covariates				May		
lousehold size				20, nold		1
3 to 4	Reference			Reference	-	
5 to 7	0.90	0.85, 0.94	<0.001	<u>ໍ</u> ອີ 0.81	0.76, 0.87	<0.001
3 to 10	0.74	0.69, 0.79	<0.001	0.71	0.65, 0.77	<0.001
/lissing**	0.62	0.57, 0.67	<0.001	Dan N/A	N/A	N/A
lousehold composition				tme		
wo working age adults with children	Reference			Reference		
Single working age adult with children	0.70	074 084	<0.001		0.66.0.76	< 0.001

			BMJ Open		36/bn by col			
					njopen-20 pyright, i			
Three-generational household		0.96	0.89, 1.05	0.40	nclu	0.98	0.90, 1.07	
Missing**		0.67	0.62, 0.71	<0.001	ding	0.51	0.47,0.55	
Number of Children in househo	old				g foi			
2 to 3		Reference			Refer	ence		
4 to 6		0.74	0.70, 0.78	<0.001	es r	0.83	0.78, 0.88	
7 to 9		0.42	0.34, 0.52	<0.001	Era Era	0.57	0.46, 0.71	
Missing**		0.64	0.60, 0.69	<0.001	925. ed t	NA	NA	
Area level covariates		·,	·	· · · ·	Dov Ush o te			
Index of Multiple Deprivation (I	MD) quintile				oge xt a			
IMD 1 (Most deprived)		Reference			a se se se se se se se se se se se se se	ence		
IMD 2		0.92	0.88, 0.97	0.001	ed fi bata	0.91	0.87, 0.95	
IMD 3		0.99	0.92, 1.06	0.70	rom mii	0.94	0.88, 1.01	
		1 34	1 20 1 50	<0.001	ji z	1.27	1.14. 1.43	
IMD 4		1.04	1.20, 1.30	SO.001			, -	
IMD 5 (Least deprived)		1.85	1.54,2.23	<0.001	ig, Al	1.73	1.44, 2.09	
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide	ence Interval	1.85	1.54,2.23	<0.001	t <mark>tp://bmj</mark> 1g, Al tra	1.73	1.44, 2.09	
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M	ence Interval IMR1 between	1.85 11 and 25 months of age	1.54,2.23	<0.001	ttp://bmjoper 1g, Al training	1.73	1.44, 2.09	
IMD 4         IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M         ** Children that could not be linked	nce Interval IMR1 between d to other memi	1.85 11 and 25 months of age bers of the household ap	1.54,2.23	<0.001 <0.001 were documer	ng, Al training, den	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked 'Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age pers of the household ap	1.54,2.23	<0.001	ttp://bmjopen.boonj.co lg, Al training,ognd si	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> Cl = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked 'Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age bers of the household ap	1.54,2.23	<0.001	ttp://bmjopen.temj.com/ و Ig, Al training, and simili	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> Cl = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age pers of the household ap	1.54,2.23	<0.001 <0.001 were documer	ttp://bmjopen.twnj.com/ on ۸ رو, Al training, هام similar te	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age bers of the household ap	1.54,2.23	<0.001	ttp://bmjopen.lagnj.com/ on May 19, Al training, and similar techr	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linker Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age pers of the household ap	1.54,2.23	<0.001	ttp://bmjopen.hanj.com/ on May 20, يق Al training, هام similar technolo	1.73	1.44, 2.09	rapl
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linker Missing'	ence Interval IMR1 between d to other mem	1.85 11 and 25 months of age bers of the household ap	1.54,2.23	<0.001 <0.001	ttp://bmjopen.tomj.com/ on May 20, 202 يع Al training, and similar technologie	1.73	1.44, 2.09	rapl
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> Cl = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linker 'Missing'	ence Interval IMR1 between d to other mem	1.85 11 and 25 months of age bers of the household ap	1.54,2.23	<0.001	ttp://bmjopen.hamj.com/ on May 20, 2025 at g, Al training, and similar technologies.	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked Missing'	ence Interval IMR1 between d to other mem	1.85 11 and 25 months of age bers of the household ap	1.54,2.23	<0.001 <0.001	ttp://bmjopen.tom/ on May 20, 2025 at De يع Al training, and similar technologies.	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> Cl = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linker 'Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age bers of the household ap	art from the oldest child	<0.001	ttp://bmjopen.banj.com/ on May 20, 2025 at Depar g, Al training, and similar technologies.	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked 'Missing'	ence Interval IMR1 between d to other mem	1.85 11 and 25 months of age bers of the household ap	art from the oldest child	<0.001 <0.001	ttp://bmjopen.tom/ on May 20, 2025 at Departme يع, Al training, and similar technologies.	naving h	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked Missing'	ence Interval IMR1 between d to other memi	1.85 11 and 25 months of age bers of the household ap	art from the oldest child	<0.001	ttp://bmjopen.banj.com/ on May 20, 2025 at Department ( g, Al training, and similar technologies.	1.73	1.44, 2.09	rap
IMD 4 IMD 5 (Least deprived) <sup>1</sup> OR = Odds Ratio, <sup>2</sup> CI = Confide <sup>3</sup> Vaccinated signifies receipt of M ** Children that could not be linked Missing'	ence Interval IMR1 between d to other mem	1.85 11 and 25 months of age bers of the household ap	art from the oldest child	<0.001 <0.001	ttp://bmjopen.tom/ on May 20, 2025 at Department GEZ يع Al training, and similar technologies.	1.73	1.44, 2.09	rapl