Title: Factors associated with delayed infant immunisation in a nationally representative cohort study

Short title: Predictors of delayed infant immunisation

Authors:

Dr Jacqueline Homel. BA(Hons), PhD.

Griffith Criminology Institute, Griffith University, 176 Messines Ridge Road, Mount Gravatt, QLD 4122 Australia. j.homel@griffith.edu.au Ph +61 7 3735 3452

Associate Professor Ben Edwards. BA(Hons), PhD.

ANU Centre for Social Research and Methods, The Australian National University, Acton, ACT 2601 Australia. ben.edwards@anu.edu.au Ph: +61 2 6125 7838

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ABSTRACT

Background: Many children in developed countries do not receive recommended vaccines on time. However, knowledge about factors related to timeliness remains limited. Quantifying the relative impact of parental attitudes compared to socio-demographic factors for delayed immunisation would inform policy responses.

Methods: Participants in the nationally representative Longitudinal Study of Australian Children were matched with their vaccination histories in the Australian Childhood Immunisation Register (N=4,121). Information about the children and their families were collected in face-to-face interviews in 2003-2004. We considered whether children had completed the primary course for each recommended antigen due by six months old. Children were categorized as either fully immunised, delayed, or totally non-immunised. The outcome was examined using logistic regression. Population attributable fractions were estimated for key predictors.

Results: Delayed immunisation was significantly associated with indicators of social disadvantage as well as parental disagreement with immunisation. Attributable fractions for delayed immunisation included lone motherhood (3.8%; 95% CI 0.8, 6.7), larger family size (39.5%; 95% CI 31.2, 46.8), residential mobility (3.3%; 95% CI 0.1, 6.5), lack of private hospital insurance (9.4%; 95% CI 0.7, 17.3), a medical condition in the child (2.0%; 95% CI 0.2, 3.9), and parental disagreement with immunisation (2.1%; 95% CI 0.3, 3.9).

Conclusions: Parental attitudes accounted for a relatively small percentage of delayed infant immunisation. In contrast, many children who did not receive vaccines on time were characterized by social disadvantage, especially larger family size. Researchers and policy-makers should consider how to make timely immunisation easier for busy parents.

Key messages

- Both social disadvantage and parental vaccine objection are associated with incomplete childhood immunisation in developed countries. However, knowledge about the relative impact of factors associated with immunisation timeliness is limited.
- To our knowledge, this is the first study to use representative cohort data combined with immunisation register data to examine factors relating to delayed immunisation in infancy.
- Indicators of social disadvantage were more strongly related to delayed immunisation than parent objection to vaccines.
- Larger family size was the greatest correlate of delayed immunisation.
- These results suggest that timeliness might be improved through multicomponent, family-focused strategies including reminders to parents and removal of barriers to immunisation for busy families.

INTRODUCTION

High-income countries achieve very good coverage for up-to-date immunisation assessed at key ages, such as 12- and 24 months (de Cantuária Tauil, Sato & Waldman, 2016). However, these figures mask delays in the administration of vaccines at appropriate ages (Dombkowski, Lantz & Freed, 2004). For example, in the United States, a recent study showed that only 26% of children had received all doses of the six vaccines recommended by 24 months on time (Kurosky, Davis & Krishnarajah, 2016), and in 2013 up to half of Australian infants were at least a month late in completing vaccinations in the primary series due by 6 months (Hull et al., 2016). Immunisation timeliness is a concern because the effectiveness of vaccine programs for reducing the burden of disease might be compromised if large proportions of children are not vaccinated on time (Clark & Sanderson, 2009). Efforts to improve timeliness will benefit from high-quality data about the risk factors associated with delays.

Research in high-income countries has shown that incomplete immunisation is attributable to both socioeconomic disadvantage, which can create barriers to accessing immunisation, and to parental concerns about the validity of vaccines (Bond, Nolan & Lester, 1999; de Cantuária Tauil et al, 2016; Dubé, Vivion & MacDonald, 2015; Haynes & Stone, 2004). However, in this literature immunisation completeness is typically assessed at milestone ages, such as 12- or 24 months, several months after the vaccinations were actually due (Kurosky et al., 2016; Clark & Sanderson, 2009). This limits the relevance of these findings to immunisation timeliness. For instance, because many children who are not vaccinated on time do eventually receive vaccines (Hull & McIntyre, 2006), children with parents who object to vaccines may comprise a large percentage of those who remain incompletely immunised at milestone ages. Analysis of incomplete immunisation at milestone ages may then emphasise the importance of vaccine refusal for a small number of children at the cost of other socio-demographic factors that may underlie delayed immunisation for a much larger number of children.

A recent review (de Cantuária Tauil et al, 2016) did distinguish between factors associated with both incomplete and delayed immunisation. Of studies that examined immunisation timeliness, only four were from high-income countries: three from the United States (Cotter et al., 2003; Luman, Barker, Shaw, McCauly, Buehler & Pickering, 2005; Williams, Milton, Farrell & Graham, 1995) and one from Belguim (Theeten et al., 2007). These showed that delayed immunisation was associated with lone motherhood, low maternal education, larger family size, and low socioeconomic status. However, none of these studies considered the role of parental attitudes to immunisation. Given the importance of parental attitudes to immunisation decisions, this is a significant limitation in the existing literature.

To date the relative size of the influence of socio-demographic factors on immunisation timeliness compared to parent attitudes has not been quantified. Policy-makers would benefit from this information, as it would provide guidance on where resources should be directed in efforts to improve timeliness. However, data that are representative of the population are best suited to this exercise. National immunisation registers provide a very useful source of information about immunisation timeliness. Increasingly implemented in a number of countries (Crowcroft & Levy-Bruhl, 2017), national registers are confidential systems that contain vaccination histories. The Australian Childhood Immunisation Register (ACIR) was established in 1996 and is a near-complete population register (Chin, Crawford, Rowles & Buttery, 2012). In this study we match records from the ACIR to Australian-born children in the nationally representative Longitudinal Study of Australian Children (LSAC; Edwards, 2012). To our knowledge this is the first time that rich socio-demographic data available on children and families available in a nationally representative cohort study has been combined with immunisation register data.

Using these data, we address the following research question: how strongly associated with delayed infant immunisation are socio-demographic factors compared to parental attitudes? We consider the series of vaccinations due by six months old because delays in the acquisition of immunity for serious infections such as pertussis are especially concerning for young infants. Although we are primarily interested in delayed immunisation, to avoid conflating children who are delayed with those who never receive any vaccinations, we also consider predictors of total non-immunisation in the first 12 months of life.

METHODS

Participants

LSAC is a nationally representative study of children and their families that commenced in 2004 (Edwards, 2012). This study received ethics approval from the Australian Institute of Family Studies Human Research Ethics Committee. Informed consent was obtained from children's primary caregiver. The present study used the younger cohort of 5,107 infants born between March 2003 and February 2004, aged 3 to 19 months old in the first wave of the study. Because we were interested in the timeliness of immunisation with regard to the series of vaccinations due by six months old, we utilised a subsample of 4,121 children who were at least 7 months old at wave 1.

Written consent to match to ACIR was obtained from parents in the wave 1 LSAC interview. Deterministic matching using Medicare number, name and address was used to match study children to ACIR records. Records for 267 children could not be matched.

Outcome variable: immunisation status at 7 months old

We created an outcome variable with three categories, including (1) immunised on time, (2) delayed immunisation and (3) totally non-immunised. To define this variable, we considered whether children who were at least 7 months old at the start of the study had received the final dose of the primary course for each antigen listed in the Australian Standard Vaccination Schedule in 2004-2005 (NHMRC 2000; 2003). All due at 6 months, these doses included the third doses of the diphtheria, tetanus, and acellular pertussis (DTPa) and inactivated polio (IPV) vaccines, and the second or third doses of the haemophilus influenzae type b (Hib) and hepatitis B vaccines. We assumed that by completion of the third dose, the first and second doses had also been received (Hull & McIntyre, 2000). Children were defined as delayed if they had not received all of these doses by 30 days after their 6-month birthday. A one-month delay for infant doses is considered overdue according the ACIR (Department of Human Services, 2016) and other studies of timeliness have also considered 'vaccination delay' to begin at one month after a dose was due (e.g. Hull & McIntyre, 2006). Children were defined as totally non-immunised if they had not received any doses by 12 months old.

Predictor variables

All predictor variables were derived from the 2004 wave 1 primary caregiver interview and survey. In 99.75% of cases the respondent was the child's biological parent (98.59% mother). Details of variables and distributions are listed in Table 1. We included four domains of socio-demographic variables that have been related to incomplete immunisation in past research (de Cantuária Tauil et al., 2016; Haynes & Stone, 2004; Samad et al., 2006). These included demographics and household factors, education and income, community characteristics, and child health and service use.

Maternal attitude to immunisation was assessed with the question: “Overall, how much do you agree with children being immunised, that is having their needles or injections?” Responses were categorised into (1) agree (very strongly or quite strongly agree), (2) neutral (neither agree nor disagree), and (3) disagree (quite strongly or very strongly disagree). This item was developed for LSAC and was subject to cognitive testing and piloting prior to data collection (Australian Institute of Family Studies, 2015).

Missing data

There were missing data on predictor variables for 681 cases (16.50%). The majority of missing data were for child service use (647 missing; 15.70%) because the responding parent did not return the self-complete part of the wave 1 survey. The proportion of missing data for all other variables with missing values was less than 1%. Univariate logistic regression models showed that the likelihood of missing data was higher for mothers who were young, Aboriginal or Torres Strait Islander, lone parents, living in public housing, living in more disadvantaged areas, who did not speak English at home, had moved since the child’s birth, had education below a Bachelor degree, did not have private hospital insurance, had lower incomes, and whose children were incompletely immunised at 7 months. The probability of a child not being matched to the ACIR, and therefore missing data on the outcome variable, was higher for children of parents with low incomes, living in remote locations, who did not speak English at home, and who were neutral about childhood immunisation.

Multiple imputation with chained equations was used to account for missing data, assuming data were missing at random. The imputation model included all the dependent and independent variables in the model, as well as the proportion of residents in the child's postcode who were Aboriginal or Torres Strait Islander, had completed high-school, and were employed. Ten datasets were imputed and coefficients were combined using Rubin's Rules (Sterne et al., 2009).

Statistical analysis

We used multinomial logistic regression to examine associations between the predictors and the relative risk of delayed immunisation or total non-immunisation compared to on-time immunisation at 7 months old. We report unadjusted risk ratios from univariate models, as well as adjusted estimates from a model with all predictors included. Following the regression analysis, we estimate the population attributable fractions for variables in the adjusted model that were significantly associated with immunisation status. Analyses were weighted to take account of the survey design (Australian Institute of Family Studies, 2015). All analyses were carried out using Stata 13.1.

RESULTS

Of the 4,121 children, 938 (22.5% [95% CI 20.1, 24.0]) were incompletely immunised, or delayed, at seven months old, and 99 (2.4% [95% CI 1.9, 2.9]). were totally non-immunised This equates to about 45,000 and 4,729 children in the Australian population respectively. Of the children who were incompletely immunised at 7 months, 81.0% had caught up by 12 months (95% CI 79.2, 83.6).

Table 2 shows the adjusted and unadjusted estimates for associations between the predictors and immunisation status at 7 months. Socio-demographic variables that were independently associated with delayed immunisation (compared to up-to-date immunisation) were lone motherhood, the child having been born overseas, having more siblings in the household, lack of private hospital insurance, the child not having visited a general practitioner (GP, or family physician), and the child having a medical condition. Increasing numbers of siblings in the household was the strongest socio-demographic correlate of delayed immunisation.

Maternal attitudes were also associated with delayed immunisation. Both neutrality and disagreement (compared to agreement) increased the likelihood of delayed immunisation. However, parental disagreement was a far stronger correlate of total non-immunisation, and few socio-demographic variables were related to non-immunisation in either the unadjusted or adjusted model.

Table 3 shows the population attributable fractions (PAFs) for delayed immunisation and total non-immunisation associated with factors uniquely related to the outcomes in the adjusted model (see Hanley, 2001, for the formula to calculate PAF). In the present study PAFs (which do not sum to 100%) are useful for comparing the impact of various risk factors on immunisation coverage. Although not all factors were significantly associated with both delayed immunisation and non-immunisation, we show the PAFs for both outcomes. Overall, the greatest PAF for delayed immunisation was associated with the number of siblings in the study child's household. Cumulatively, almost 40% of delayed immunisation was attributable to having any siblings, compared to none. The next largest PAF for delayed immunisation was lack of private hospital insurance, although the wide confidence interval indicated a lack of precision for this estimate. The estimated PAFs for delayed immunisation for the remaining factors (parental attitude, lone-parent household, residential mobility, and the study child having a health condition) were all around 2% to 4%. The largest PAF for total non-immunisation was the study child having an ongoing medical condition or disability, but as only one non-immunised child in the sample was reported to have a health condition, the precision for this estimate was low and must be treated with caution. Consistent with the estimates from the regression, about two-thirds of all non-immunisation was attributable to parental disagreement with immunisation.

We compared the reported estimates with those obtained with complete, non-imputed data (see Supplementary Material). The percentage of children delayed at 7 months was 0.30 per cent lower in the complete data, and the percentage of children non-immunised was 0.10 per cent lower. Estimated proportions for immunisation status using imputed data were within the confidence intervals for estimates obtained using complete data. Substantive results in the regression model and for PAF estimates were the same in complete and imputed data.

DISCUSSION

This is the first study to compare socio-demographic factors and parental attitudes as correlates of infant immunisation status using representative cohort data linked to national immunisation register data. We found that while parental disagreement with immunisation increased the likelihood of delayed immunisation, socio-demographic factors overall were more strongly related to delayed immunisation. These included lone parenthood, larger family size, residential mobility, lack of private hospital insurance, and the child not having seen a GP. In addition, results suggested that children with ongoing health conditions or a disability were more likely to experience delayed immunisation, but were less likely to be totally non-immunised. The leading factor amongst all socio-demographic factors was larger family size, with around 40% of delayed immunisation attributable to increasing numbers of siblings in the household (compared to no siblings), compared with around 2% to 10% of delayed immunisation attributable to other socio-demographic factors.

Family size has been independently associated with incomplete immunisation in many studies conducted across the developed world (de Cantuária Tauil et al, 2016; Luman et al., 2005; Haynes & Stone, 2004). However, there is little direct evidence for the mechanisms underlying this association. In high-income countries family size is correlated with indicators of material deprivation, including lower incomes, low parental education and lone parenthood (Crosnoe, Mistry & Elder, 2002). Childhood vaccines in Australia are provided free of charge, and largely administered free of charge, although some GPs may charge a consultation fee. Therefore, difficulty paying for children’s vaccines is unlikely to be the explanation for the association between family size and delayed immunisation. Other barriers to timely immunisation that may be more prevalent in larger families include more frequent illnesses in the target child, lack of transport, lack of access to care for older children while infants receive vaccinations (Reading & Surridge, 2004), and time scarcity (Strazdins et al., 2011). For instance, lower-income families living in outer-urban areas of Australia where housing is more affordable face poorer access to services, including public transport and GPs (Roeger, Reed & Smith, 2010). It is also likely that larger families where children are not immunised on time experience high levels of stress. Fairbrother and colleagues (2005) consider large family size a profound family stressor, and argue that stress makes it difficult for families to overcome barriers such as transport difficulties in order to keep up with routine, preventive health visits for children.

Finally, parental objection to immunisation was overwhelmingly the clearest factor underlying total non-immunisation. This result highlights the importance of identifying the small percentage of children who are totally non-immunised in studies of immunisation timeliness, to avoid conflating these subgroups with different underlying reasons for immunisation incompleteness.

Strengths and limitations

A strength of this study is the use of rich, nationally representative data from LSAC with linked data from the ACIR. This has the benefit of avoiding uncertainty around mothers' reports of children's vaccination histories (Miles, Ryman, Dietz, Zell & Luman, 2013), and permitting the examination of immunisation timeliness. In addition, because LSAC is a general study and questions about immunisation attitudes and health were not asked at the same time as immunisation administration, counselling or a specific immunisation survey, bias due to social desirability is reduced. A weakness is that temporary residents, which include newly arrived migrants, were not sampled in LSAC. Australian research shows that a high proportion of children with incomplete vaccination records were born overseas (Beard et al., 2016; Gibbs, Hoskins & Effler, 2015). Although our results showed that the few overseas-born children in the sample were at increased risk of delayed immunisation, this underestimates the extent of incomplete immunisation amongst migrant and refugee families in the community. Another limitation is that our single-item measure of attitude may have underestimated hesitancy by failing to capture the range of reasons why parents are hesitant about immunisation (Larson et al., 2015). In addition, because immunisation items were answered only by the child's primary caregiver, who were mostly mothers, the role of fathers' attitudes is unknown. We also did not consider the sub-group of objectors who start vaccinating and then cease.

Finally, these children were 12 months old in 2004-2005. Until 2016, some government payments to families that were contingent on children being up-to-date with immunisations could still be paid to incompletely immunised children if parents were registered conscientious objectors. This provision was removed in January 2016 as part of 'No Jab No Pay' legislation. While this change may have caused children of some objecting parents to be immunised, it is reasonable to assume that vaccine hesitancy and the sociodemographic barriers highlighted in this study continue to be related to non-immunisation and delayed immunisation in Australia (Beard, Leask & McIntyre, 2017).

Conclusions

Almost a quarter of children in this representative sample were at least a month late in receiving the series of vaccinations due by 6 months old. Our results suggest that improving immunisation timeliness among infants in larger families in particular may substantially reduce the number of children who are not immunised on time. Reminders to parents such as letters and phone calls have been shown to be effective in improving timeliness (Harvey, Reissland & Mason, 2015), and text-message reminders are an obvious strategy in the context of high mobile phone ownership. A stepped intervention, in which families received reminders initially and then increasing levels of support if reminders failed, increased immunisation rates in a group of low-SES infants in the United States (Hambidge, Phibbs, Chandramouli, Fairclough & Steiner, 2009). A number of authors stress the importance of making access to childhood immunisations easier for parents (Samad et al., 2006; Luman et al., 2005; Ward, Chow, King & Leask, 2012). Strategies to achieve this include the use of alternative public and private venues for vaccine administration, including child health clinics and during home visits (Hambidge et al., 2009). Providing vaccines in easy-to-access locations outside business hours, as well as administering vaccines on the same day the parent calls to make an appointment, could also create more immunisation opportunities for busy families (Frew & Lutz, 2017).

While all these strategies have some support in the literature, they stand in contrast to penalty-based policy initiatives such as Australia's 'No Jab No Pay' which is likely to only . change behaviour only in a small proportion of the already small group of objectors and does not support the larger group of incompletely immunised children living in families with access issues (especially migrant families). In addition, some Australian states and international jurisdictions such as California do not allow incompletely immunised children to access childcare, which may compound disadvantage for vulnerable families (Beard et al., 2017; Leask & Danchin, 2016; Paxton, Tyrrell, Oldfield, Kiang & Danchin, 2016). To improve timely immunisation for all children, what is needed is far better knowledge – both qualitative and quantitative- of specific processes involved in timely and delayed childhood immunisation across diverse family types. Future research should consider immunisation timeliness in a family-centred framework, informed by scholarship on family stress and structural health inequalities.

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Table 1: Distribution of predictor variables used to examine immunisation status at 7 months

	% (95% CI)	**N**
Demographics and household factors		
Study child male	49.0 (47.4, 50.5)	2097
Mother of Aboriginal or Torres Strait Islander origin	3.5 (2.6, 4.4)	135
Mother born outside Australia	20.4 (18.5, 22.3)	788
Study child born outside Australia	0.3 (0.1, 0.5)	13
Household is lone-parent family	10.5 (9.3, 11.7)	385
Number of siblings of study child in household		
None	38.7 (36.9, 40.4)	1615
One	36.5 (35.0, 38.0)	1517
Two	16.5 (15.3, 17.8)	667
Three or more	8.3 (7.2, 9.4)	322
Education and income		
Mother's education		
Bachelor degree	29.1 (26.7, 31.4)	1356
Advanced diploma	9.5 (8.5, 10.4)	407
Certificate	26.8 (25.0, 28.6)	1021
Year 12	12.7 (11.6, 13.8)	640
Year 11 or less	22.0 (20.1, 23.9)	697
Household has private hospital insurance	44.1 (41.2, 47.0)	1912
Household lives in public housing	5.9 (4.7, 7.1)	213
Mother and father combined income		
1st quintile (lowest)	21.5 (19.8, 23.2)	804
2nd quintile	19.9 (18.4, 21.3)	809
3rd quintile	20.1 (18.6, 21.6)	838
4th quintile	19.0 (17.7, 20.3)	813
5th quintile	19.5 (17.2, 21.8)	857
Community characteristics		
SEIFA[1] index of postcode advantage and disadvantage		
1st quartile (most disadvantaged)	28.7 (24.5, 32.9)	1225
2nd quartile	24.3 (20.0, 28.7)	995
3rd quartile	23.6 (19.3, 27.9)	944
4th quartile	23.4 (19.1, 27.6)	957
Residence in regional area	33.6 (32.0, 35.2)	1553
Child Health and Service Use		
Study child birth weight <2,500g	5.8 (4.9, 6.6)	226
Services used for the study child in the last 12 months		
Maternal and child health centre or visits	80.0 (78.2, 81.8)	3360
General practitioner	80.0 (78.4, 81.7)	3329
Study child has an ongoing medical condition or disability	6.0 (5.2, 6.9)	239
Maternal attitude to immunisation		
Agree very strongly or quite strongly	93.7 (92.9, 94.5)	3858
Neutral - neither agree nor disagree	4.1 (3.4, 4.8)	168
Disagree very strongly or quite strongly	2.1 (1.7, 2.5)	95

Note: [1]SEIFA = Socio-Economic Indexes for Areas (ABS, 2003).

Table 2. Risk ratios from logistic regression models predicting immunisation status at 7 months

	Unadjusted estimates				Adjusted estimates			
	Delayed immunisation		**Totally non-immunised**		**Delayed immunisation**		**Totally non-immunised**	
	uRR (95% CI)	***p***	**uRR (95% CI)**	***p***	**aRR (95% CI)**	***p***	**aRR (95% CI)**	***p***
Demographics and household factors								
Study child male	0.9 (0.8, 1.1)	0.331	1.1 (0.7, 1.7)	0.773	0.9 (0.8, 1.1)	0.277	0.9 (0.5, 1.7)	0.831
Mother of Aboriginal or Torres Strait Islander origin	2.1 (1.3, 3.3)	0.002	0.9 (0.2, 3.9)	0.939	1.1 (0.7, 1.9)	0.668	1.0 (0.1, 6.7)	0.973
Mother born outside Australia	0.9 (0.7, 1.1)	0.194	1.0 (0.6, 1.7)	0.935	0.8 (0.7, 1.0)	0.072	1.3 (0.6, 2.6)	0.530
Child born outside Australia[1]	7.9 (2.4, 26.6)	0.001	0.0	-	9.9 (2.8, 35.2)	<0.001	0.0	-
Lone-parent household	2.0 (1.6, 2.5)	<0.001	1.3 (0.6, 2.6)	0.485	1.6 (1.2, 2.3)	0.004	3.4 (1.0, 11.0)	0.044
Siblings in household (reference = none)								
one	2.0 (1.6, 2.5)	<0.001	1.1 (0.6, 1.9)	0.837	2.2 (1.7, 2.7)	<0.001	1.3 (0.7, 2.6)	0.370
two	3.0 (2.3, 3.8)	<0.001	2.3 (1.2, 4.2)	0.010	3.0 (2.3, 3.8)	<0.001	2.2 (0.9, 5.3)	0.073
three or more	4.1 (3.0, 5.7)	<0.001	2.0 (0.9, 4.4)	0.078	4.0 (2.9, 5.5)	<0.001	2.1 (0.7, 6.4)	0.170
Education and income								
Mother's education (reference = Bachelor)								
Advanced diploma	1.0 (0.8, 1.4)	0.795	1.0 (0.5, 2.0)	0.988	1.0 (0.7, 1.3)	0.916	0.8 (0.3, 2.0)	0.650
Certificate	1.1 (0.9, 1.4)	0.227	0.6 (0.4, 1.1)	0.126	1.0 (0.7, 1.2)	0.732	0.6 (0.3, 1.4)	0.241
Year 12	1.2 (0.9, 1.6)	0.143	0.8 (0.5, 1.5)	0.554	1.1 (0.8, 1.5)	0.520	0.6 (0.3, 1.5)	0.315
Year 11 or less	1.6 (1.2, 2.0)	0.001	0.8 (0.4, 1.5)	0.497	1.1 (0.8, 1.5)	0.480	1.0 (0.4, 2.6)	0.938
Household has private hospital insurance	0.7 (0.6, 0.8)	<0.001	0.8 (0.5, 1.3)	0.443	0.8 (0.7, 1.0)	0.040	1.2 (0.6, 2.3)	0.564
Household lives in public housing	2.1 (1.5, 2.9)	<0.001	1.5 (0.6, 3.6)	0.353	1.2 (0.8, 1.6)	0.389	1.2 (0.3, 5.0)	0.761
Mother and father combined income (reference = 1st quintile, lowest income)								
2nd quintile	0.7 (0.6, 0.9)	0.015	0.9 (0.5, 1.7)	0.759	1.0 (0.7, 1.3)	0.890	1.8 (0.7, 5.2)	0.250
3rd quintile	0.6 (0.5, 0.8)	<0.001	1.0 (0.5, 1.7)	0.889	0.9 (0.6, 1.2)	0.388	1.5 (0.5, 4.4)	0.491
4th quintile	0.6 (0.5, 0.8)	<0.001	0.9 (0.5, 1.9)	0.882	0.9 (0.7, 1.3)	0.676	1.6 (0.4, 5.5)	0.490
5th quintile	0.7 (0.5, 0.9)	0.003	0.9 (0.4, 1.8)	0.716	1.1 (0.8, 1.5)	0.664	1.3 (0.4, 4.5)	0.652
Community characteristics								

SEIFA[2] index of postcode advantage-disadvantage (ref = 1st quartile, most disadvantaged)								
2nd quartile	0.8 (0.7, 1.0)	0.104	1.1 (0.6, 2.0)	0.823	0.9 (0.7, 1.1)	0.410	1.3 (0.6, 2.8)	0.466
3rd quartile	0.9 (0.7, 1.1)	0.322	1.4 (0.8, 2.6)	0.233	1.1 (0.8, 1.5)	0.437	1.6 (0.7, 3.7)	0.232
4th quartile	0.9 (0.7, 1.2)	0.487	1.1 (0.6, 1.9)	0.749	1.3 (0.9, 1.7)	0.112	1.3 (0.5, 3.6)	0.576
Household in regional area	1.0 (0.9, 1.3)	0.633	1.1 (0.7, 1.7)	0.725	1.0 (0.8, 1.2)	0.826	1.1 (0.5, 2.3)	0.764
Child health and service use								
Low birth weight (<2,500g)	1.4 (1.0, 2.0)	0.083	1.0 (0.4, 3.0)	0.950	1.3 (0.9, 1.9)	0.169	1.1 (0.2, 5.5)	0.864
Services used for the child in the last 12 months								
Maternal and child health visits or clinics	0.6 (0.5, 0.8)	<0.001	0.5 (0.3, 0.9)	0.012	0.8 (0.7, 1.1)	0.135	0.4 (0.2, 0.9)	0.024
General practitioner	0.7 (0.6, 0.9)	0.004	0.5 (0.3, 0.7)	0.001	0.8 (0.6, 1.0)	0.023	0.4 (0.2, 0.9)	0.035
Child has an ongoing medical condition or disability	1.8 (1.3, 2.4)	<0.001	0.2 (0.0, 1.2)	0.072	1.4 (1.0, 2.0)	0.046	0.2 (0.0, 0.7)	0.012
Mother's attitude to immunisation (ref = Agree very strongly or quite strongly)								
Neither agree nor disagree	2.1 (1.4, 3.1)	<0.001	12.7 (6.2, 26.0)	0.000	2.4 (1.6, 3.6)	<0.001	13.7 (6.6, 28.6)	<0.001
Disagree very strongly or quite strongly	3.8 (1.8, 8.4)	0.001	374.3 (179.5, 780.7)	0.000	3.9 (1.8, 8.6)	0.001	498.5 (221.8, 1120.2)	<0.001

Note: [1]zero study children born overseas were totally non-immunised [2]SEIFA = Socio-Economic Indexes for Areas (ABS, 2003)
uRR = unadjusted risk ratio. aRR = adjusted risk ratio. N = 4,121

Table 3: Population attributable fractions for immunisation status at 7 months[1]

	Delayed PAF (95% CI)	*p*	Completely non-immunised PAF (95% CI)	*p*
Lone parent household	4.1% (1.1, 7.0)	0.009	6.4 (-1.8, 13.9)	0.121
Child born overseas[2]	0.7 (0.2, 1.2)	0.012	-	-
Number of siblings				
Compared to no siblings:				
one sibling	18.2 (13.0, 23.0)	<0.001	1.1 (-11.4, 12.2)	0.854
two siblings	12.5 (9.3, 15.6)	<0.001	4.9 (-6.6, 15.3)	0.386
three or more siblings	8.9 (6.5, 11.3)	<0.001	1.4 (-5.7, 8.0)	0.689
Total: Any siblings compared to none	39.6 (31.3, 46.9)	<0.001	7.5 (-17.1, 26.9)	0.518
Household does not have private hospital insurance[3]	9.1 (0.5, 17.0)	0.040	-10.2 (-39.0, 12.6)	0.408
Child has not seen a maternal/child health nurse[3]	2.5 (-1.6, 6.5)	0.224	11.8 (-0.8, 22.7)	0.065
Child has not seen a general practioner[3]	3.4 (-0.1, 6.8)	0.055	10.6 (-1.8, 21.5)	0.091
Child has a disability or medical condition	1.9 (0.1, 3.8)	0.043	-	-
Child does not have a disability or medical condition[4]	-	-	70.9 (17.3, 89.7)	0.021
Parental attitude to immunisation				
Compared to Agree				
Neutral	2.5 (1.0, 4.0)	0.002	11.1 (4.4, 17.4)	0.002
Disagree	-0.4 (-1.2, 0.4)	0.358	56.5 (45.0, 65.6)	<0.001
Total: Neutral or disagree compared to agree	2.1 (0.5, 3.8)	0.012	67.6 (55.8, 76.2)	<0.001

Note: PAF = population attributable fraction

[1]estimates based on adjusted model N = 4,121. [2]zero study children born overseas were totally non-immunised [3]Reverse-coded for calculation of PAF [4]Poorer study child health was associated with an increased likelihood of delayed immunisation but a decreased likelihood of total non-immunisation. Therefore this item was reverse-coded for calculation of PAF for the non-immunised outcome, and estimates are shown in separate rows for clarity

SUPPLEMENTARY MATERIAL

Table 1 shows results of adjusted and unadjusted multinomial regression models using complete (non-imputed) data, and Table 2 shows population attributable fractions using complete data.

Table 1. Risk ratios from logistic regression models predicting immunisation status at 7 months using complete data

	Unadjusted estimates[1]				Adjusted estimates[2]			
	Delayed immunization		Totally non-immunized		Delayed immunization		Totally non-immunized	
	uRR (95% CI)	*p*	uRR (95% CI)	*p*	aRR (95% CI)	*p*	aRR (95% CI)	*p*
Demographics and household factors								
Study child male	0.9 (0.8, 1.1)	0.289	1.1 (0.7, 1.7)	0.738	0.9 (0.8, 1.1)	0.428	0.9 (0.5, 1.8)	0.779
Mother of Aboriginal or Torres Strait Islander origin	2.1 (1.3, 3.3)	0.002	0.9 (0.2, 3.8)	0.915	0.8 (0.4, 1.5)	0.468	0.6 (0.0, 8.7)	0.692
Mother born outside Australia	0.9 (0.7, 1.1)	0.273	1.1 (0.7, 1.8)	0.738	0.8 (0.6, 1.0)	0.075	2.3 (1.1, 5.0)	0.032
Child born outside Australia					23.6 (4.6, 120.7)	0.000	0.0	-
Lone-parent household	2.0 (1.6, 2.5)	<0.001	1.4 (0.7, 2.8)	0.403	1.4 (0.9, 2.2)	0.116	6.8 (1.8, 25.9)	0.005
Siblings in household (reference = none)								
one	2.1 (1.7, 2.5)	<0.001	1.1 (0.6, 1.9)	0.818	2.1 (1.6, 2.6)	0.000	0.9 (0.4, 2.1)	0.847
two	2.9 (2.3, 3.8)	<0.001	2.3 (1.2, 4.2)	0.009	2.8 (2.1, 3.7)	0.000	2.8 (1.1, 6.9)	0.025
three or more	4.2 (3.2, 5.7)	<0.001	2.2 (1.0, 4.7)	0.051	3.8 (2.7, 5.4)	0.000	1.7 (0.4, 6.8)	0.471
Education and income								
Mother's education (reference = Bachelor)								
Advanced diploma	1.1 (0.8, 1.4)	0.717	1.0 (0.5, 2.0)	0.983	1.1 (0.8, 1.5)	0.634	0.9 (0.3, 2.7)	0.814
Certificate	1.1 (0.9, 1.4)	0.336	0.6 (0.3, 1.1)	0.090	1.1 (0.8, 1.4)	0.531	0.8 (0.3, 2.1)	0.690
Year 12	1.2 (0.9, 1.6)	0.128	0.8 (0.5, 1.5)	0.571	1.1 (0.8, 1.5)	0.512	0.8 (0.3, 2.4)	0.657
Year 11 or less	1.5 (1.2, 2.0)	0.001	0.8 (0.4, 1.4)	0.388	1.1 (0.8, 1.4)	0.687	1.2 (0.4, 3.4)	0.695
Household has private hospital insurance	0.7 (0.6, 0.8)	<0.001	0.8 (0.5, 1.3)	0.436	0.8 (0.6, 1.0)	0.019	1.5 (0.7, 3.2)	0.275
Household lives in public housing	2.1 (1.5, 2.8)	<0.001	1.5 (0.6, 3.7)	0.334	1.1 (0.7, 1.7)	0.682	0.9 (0.2, 4.5)	0.948
Mother and father combined income								
2nd quintile	0.7 (0.6, 0.9)	0.016	1.0 (0.5, 1.8)	0.922	1.0 (0.7, 1.4)	0.912	1.4 (0.4, 5.0)	0.628

3rd quintile	0.6 (0.5, 0.8)	0.001	1.0 (0.6, 1.9)	0.897	0.8 (0.6, 1.2)	0.328	1.0 (0.3, 3.8)	0.991
4th quintile	0.6 (0.5, 0.8)	<0.001	0.9 (0.5, 1.9)	0.871	1.0 (0.7, 1.4)	0.942	1.8 (0.4, 8.0)	0.414
5th quintile	0.7 (0.5, 0.9)	0.004	0.9 (0.5, 1.9)	0.816	1.0 (0.7, 1.5)	0.953	1.0 (0.2, 4.5)	0.968
Community characteristics								
SEIFA index of postcode advantage-disadvantage (ref = 1st quartile, most disadvantaged)								
2nd quartile	0.8 (0.7, 1.0)	0.057	1.1 (0.6, 2.1)	0.687	0.9 (0.7, 1.2)	0.660	1.8 (0.7, 4.5)	0.241
3rd quartile	0.9 (0.7, 1.1)	0.285	1.5 (0.8, 2.7)	0.212	1.1 (0.9, 1.5)	0.370	1.7 (0.8, 3.9)	0.199
4th quartile	0.9 (0.7, 1.1)	0.392	1.1 (0.6, 2.0)	0.687	1.4 (1.0, 1.9)	0.052	1.3 (0.4, 4.2)	0.650
Household in regional area	1.0 (0.9, 1.2)	0.621	1.1 (0.7, 1.7)	0.604	1.0 (0.8, 1.2)	0.706	1.5 (0.7, 3.2)	0.282
Child health and service use								
Low birth weight (<2,500g)	1.3 (0.9, 1.8)	0.180	0.9 (0.3, 2.8)	0.904	1.4 (0.9, 2.2)	0.150	0.6 (0.1, 4.3)	0.583
Services used for the child in the last 12 months								
Maternal and child health visits or clinics	0.6 (0.5, 0.8)	<0.001	0.5 (0.3, 0.9)	0.012	0.8 (0.6, 1.0)	0.065	0.3 (0.2, 0.7)	0.005
General practitioner	0.8 (0.6, 1.0)	0.020	0.5 (0.3, 0.7)	0.001	0.8 (0.6, 1.0)	0.102	0.4 (0.2, 0.9)	0.027
Child has an ongoing medical condition or disability	1.8 (1.3, 2.5)	<0.001	0.2 (0.0, 1.2)	0.080	1.5 (1.0, 2.2)	0.040	0.2 (0.1, 0.6)	0.005
Mother's attitude to immunisation (ref = Agree very strongly or quite strongly)								
Neither agree nor disagree	2.0 (1.3, 2.9)	0.001	13.2 (6.4, 27.0)	<0.001	2.6 (1.6, 4.1)	0.000	22.1 (9.2, 53.3)	0.000
Disagree very strongly or quite strongly	3.3 (1.5, 7.4)	0.004	363.7 (172.9, 765.1)	<0.001	3.7 (1.4, 10.4)	0.011	1275.5 (473.0, 3439.6)	0.000

uRR = unadjusted risk ratio. aRR = adjusted risk ratio.
[1]N ranges from 3,280 to 3,854 [2]N = 3,249

Table 2: Population attributable fractions for immunisation status at 7 months[1] using complete data

	Delayed PAF (95% CI)	*p*	Completely non-immunised PAF (95% CI)	*p*
Lone parent household	2.4% (-1.1, 5.7)	0.177	9.5% (1.0, 17.3)	0.030
Child born overseas[2]	1.1% (0.3, 1.9)	0.007	-0.2% (-0.3, 0.0)	0.070
Number of siblings				
Compared to no siblings:				
one sibling	17.8% (11.8, 23.5)	0.000	11.8% (8.1, 15.4)	0.000
two siblings	8.5% (5.9, 11.1)	0.000	-4.1% (-16.5, 7.0)	0.485
three or more siblings	7.7% (-3.2, 17.4)	0.160	0.3% (-7.3, 7.3)	0.943
Total: Any siblings compared to none	38.2% (28.6, 46.5)	0.000	3.8% (-21.1, 23.6)	0.739
Household does not have private hospital insurance[3]	11.6% (2.3, 19.9)	0.015	-18.1% (-51.5, 8.0)	0.191
Child has not seen a maternal/child health nurse[3]	2.5% (-1.2, 6.1)	0.177	9.6% (-1.0, 19.1)	0.075
Child has not seen a general practioner[3]	3.3% (-1.0, 7.4)	0.129	13.0% (1.6, 23.1)	0.027
Child has a disability or medical condition	2.3% (0.0, 4.4)	0.049	-	-
Child does not have a disability or medical condition[4]	-	-	64.8% (25.0, 83.5)	0.007
Parental attitude to immunisation				
Compared to Agree				
Neutral	2.6% (0.9, 4.3)	0.004	13.4% (5.2, 20.9)	0.002
Disagree	-0.7% (-1.6, 0.2)	0.122	56.7% (44.4, 66.3)	0.000
Total: Neutral or disagree compared to agree	1.9% (0.0, 3.8)	0.054	70.1% (56.8, 79.3)	0.000

Note: PAF = population attributable fraction

[1]estimates based on adjusted model N = 3,249. [2]zero study children born overseas were totally non-immunised [3]Reverse-coded for calculation of PAF [4]Poorer study child health was associated with an increased likelihood of delayed immunisation but a decreased likelihood of total non-immunisation. Therefore this item was reverse-coded for calculation of PAF for the non-immunised outcome, and estimates are shown in separate rows for clarity