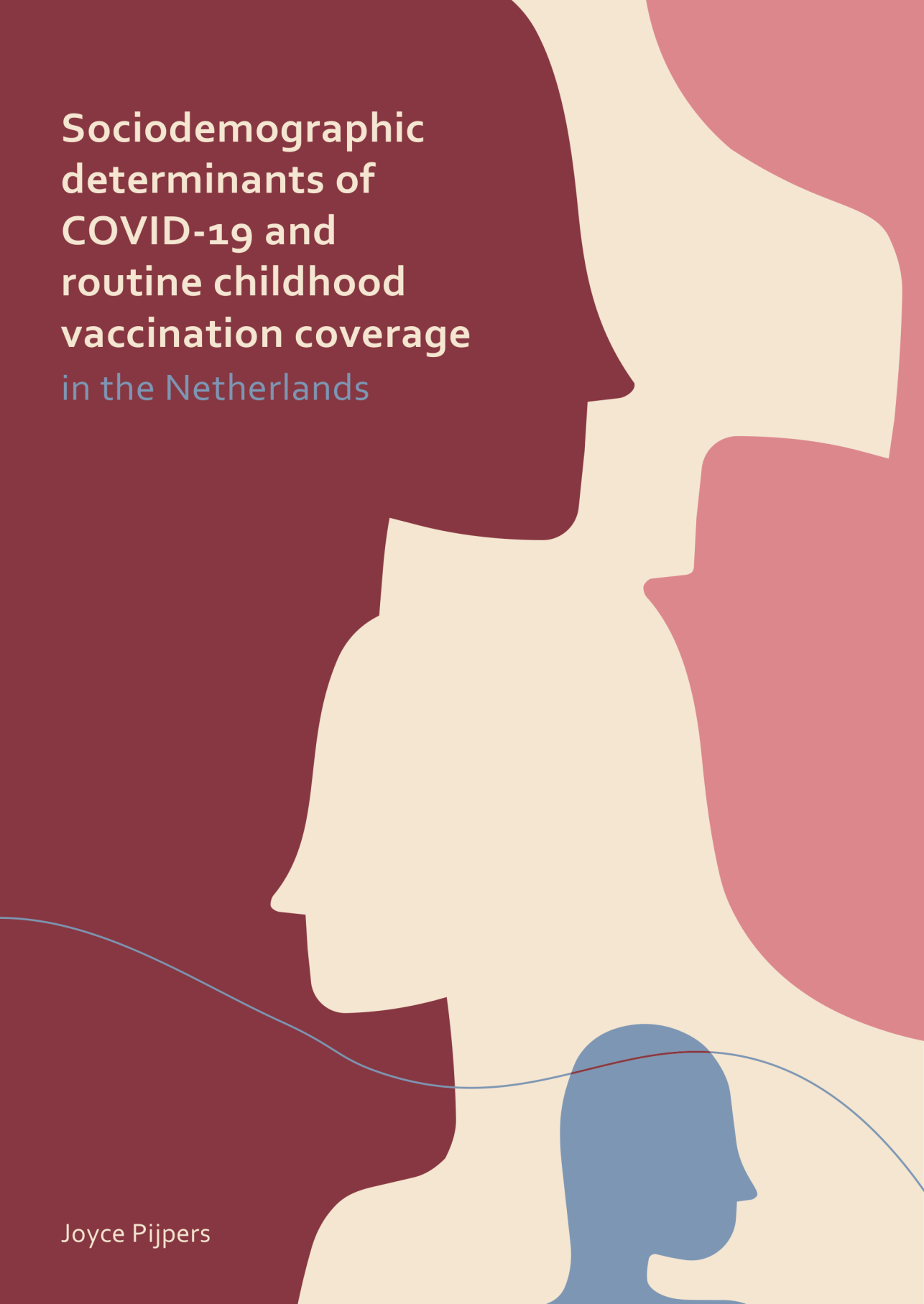




Sociodemographic determinants of COVID-19 and routine childhood vaccination coverage in the Netherlands

Joyce Pijpers

**Sociodemographic Determinants
of COVID-19 and
Routine Childhood
Vaccination Coverage
in The Netherlands**

Joyce Pijpers

The research presented in this thesis was conducted at the National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands

The research presented in this thesis was funded by the Ministry of Health, Welfare and Sports

Cover Design: Neline Achterberg

Lay-out: Ridderprint | www.ridderprint.nl

Print: Ridderprint | www.ridderprint.nl

Copyright 2026 © Joyce Pijpers

All rights reserved. No part of this thesis may be reproduced, stored or transmitted in any form or by any means without prior written permission of the copyright author.

ISBN: 978-94-6537-653-0

Sociodemographic determinants of COVID-19 and routine childhood vaccination coverage in The Netherlands

Proefschrift

ter verkrijging van

de graad van doctor aan de Universiteit Leiden,
op gezag van rector magnificus prof.dr. S. de Rijcke,
volgens besluit van het college voor promoties
te verdedigen op woensdag 30 september 2026

klokke 13:00 uur

door

Joyce Pijpers
geboren te Zwolle
in 1992

Promotores:

Prof. dr. S. van den Hof

Prof. dr. I.A. van Gaalen (Universiteit van Amsterdam)

Copromotor:

Dr. H.E. de Melker (Rijksinstituut voor Volksgezondheid en Milieu)

Promotiecommissie:

Prof. dr. F.R. Rosendaal

Prof. dr. P.C.J.L. Bruijning – Verhagen (Universitair Medisch Centrum Utrecht)

Prof. dr. M. Das (Erasmus Universiteit Rotterdam)

Prof. dr. M.E.T.C. van den Muijsenbergh (Radboud Universitair Medisch Centrum)

TABLE OF CONTENTS

Chapter 1	General introduction	6
Part I	Routine childhood vaccination coverage	22
Chapter 2	The decrease in childhood vaccination coverage and its sociodemographic determinants, the Netherlands, birth cohort 2008-2020 Eurosurveillance, 2025	24
Chapter 3	Large differences in childhood vaccination coverage among primary schools of various denominations, the Netherlands, 2024 Vaccine, 2026	78
Chapter 4	Assessing the impact of the COVID-19 pandemic on routine childhood vaccination uptake in the Netherlands Submitted	114
Part II	COVID-19 vaccination coverage and interventions	142
Chapter 5	Determinants of COVID-19 vaccine uptake in The Netherlands: a nationwide registry-based study Vaccines, 2023	144
Chapter 6	Mobile vaccination units to increase COVID-19 vaccination uptake in areas with lower coverage: a within neighbourhood analysis using national registration data, the Netherlands, September-December 2021 Eurosurveillance, 2024	180
Chapter 7	Summary and general discussion	210
Appendices		238
	Nederlandse samenvatting	240
	List of publications	246
	PhD Portfolio	248
	Dankwoord	250
	Curriculum Vitae	252



Chapter 1

General Introduction

A brief history of vaccination and the impact on public health

Vaccination is widely regarded as one of the most effective public health measures for reducing the incidence and impact of infectious diseases. The practice originated in the late eighteenth century with Edward Jenner's observation that inoculation with cowpox conferred protection against smallpox. Since then, the development and implementation, particularly during the twentieth century, of vaccines have become central to public health strategies worldwide. The World Health Organization's Expanded Programme on Immunisation (EPI), initiated in 1974, marked a coordinated global effort to increase access to essential vaccines, particularly in low- and middle-income countries. One of the most notable achievements of these efforts is the eradication of smallpox in 1980.

Currently, nearly all countries have established national immunisation programmes that offer routine childhood vaccinations for diseases such as measles, polio, diphtheria, pertussis and tetanus. The long-term impact of childhood vaccination programmes is considerable. A recent modelling study estimated that, over the past 50 years, vaccination through the EPI has averted approximately 154 million deaths globally, with 146 million of these averted in children under five years of age [1]. This substantial reduction in child mortality directly contributes to the United Nations Sustainable Development Goals (SDG), particularly SDG 3, which aims to ensure healthy lives and promote well-being for all at all ages. One of the key targets of SDG 3 is to end preventable deaths of newborns and children under five, an objective to which routine childhood immunisation programmes are essential [2]. In addition to protect the individuals targeted and reduce the burden of disease, another important aim of mass vaccination is to reduce health inequalities [3]. By providing equitable access to vaccines regardless of socioeconomic status, geographic location, or other sociodemographic factors, immunisation programmes can help ensure that vulnerable and underserved populations receive the same level of protection as the general population.

Despite important achievements, vaccination programmes continue to face challenges, including concerns about vaccine safety, fluctuating public confidence, and disparities in vaccination coverage among different population groups [3]. Paradoxically, the very success of these programmes contributes to a decline in the perceived risk of vaccine-preventable diseases, which may lead to complacency and increased hesitancy—a phenomenon often referred to as the vaccination paradox [4, 5]. This process is illustrated in Figure 1, which shows how declining disease incidence and visibility can shift public perception [4]. As immunisation programmes succeed and disease incidence drops, the visibility of many infectious diseases diminishes. This reduction in disease burden leads to a shift in public perception: the risks associated with the diseases themselves become less prominent, while concerns about vaccine safety and possible side effects gain more attention. As a result, the perceived need for vaccination decreases, potentially leading to reduced

coverage and an increased risk of outbreaks. While the likelihood of contracting vaccine-preventable diseases is now much lower due to high vaccination coverage, the risk of severe illness remains—especially among unvaccinated or vulnerable individuals. For many of these diseases, the individual risk of severe outcomes may seem low; however, a decline in vaccination coverage at the population level can result in significant outbreaks and increased morbidity and mortality. This dynamic underscores the ongoing need for surveillance, research, and public engagement to sustain high vaccination uptake and ensure continued protection of public health.

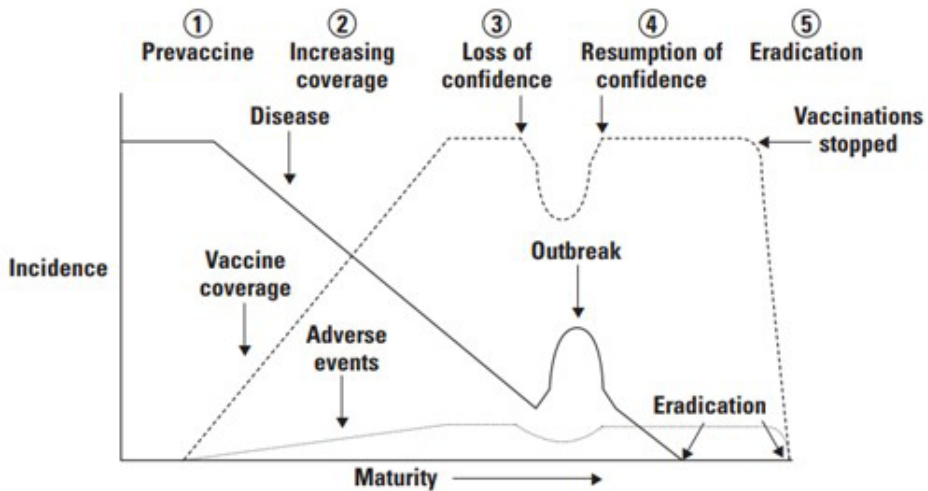


Figure 1. Evolution of immunisation programmes and changes in public perception of disease risk. Adapted from Chen et al [4].

National Immunisation Programme in the Netherlands

History and strategies of the programme

Similar to the substantial public health benefits observed globally following the introduction of vaccination programmes, the implementation of the National Immunisation Programme (NIP) in the Netherlands has led to marked reductions in mortality, morbidity, and healthcare costs associated with vaccine-preventable diseases [6-8]. The Dutch NIP was established in 1957, initially offering vaccination against diphtheria, tetanus, and pertussis to all children [9]. Over subsequent decades, the programme has expanded to include vaccines against poliomyelitis, measles, mumps, rubella, invasive *Haemophilus influenzae* type b disease, meningococcal disease, pneumococcal disease, and human papillomavirus related disease, among others. The primary strategy of the programme is to provide free, voluntary vaccination to all children residing in the Netherlands, with the aim of achieving and maintaining high vaccination coverage to protect both individuals and the wider population [9].

Chapter 1

The implementation of the NIP is a coordinated effort involving several organisations. The Ministry of Health, Welfare and Sports (VWS) sets the overall policy and legal framework for the programme, often based on scientific recommendations from the Health Council of the Netherlands. The National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu, RIVM) coordinates the programme at the national level, managing vaccine procurement and distribution, monitors the cold chain procedures and facilitates invitations of vaccination. The primary role in administering infant vaccines (0-4 years of age) lies with the “well-baby clinics” (consultatiebureaus), which are part of the Youth Health Care system (Jeugdgezondheidszorg). These clinics invite parents to bring their children for scheduled vaccinations, monitor child development, and provide information about vaccines and infectious diseases. For older children and adolescents, as well as catch-up campaigns and specific target groups, the regional public health services (GGD) are responsible for administering vaccinations.

NIP schedule

In 2024, the NIP schedule comprises a series of vaccinations administered from infancy through adolescence (Table 1). During the first year of life, infants receive the DTaP-IPV-Hib-HBV vaccine (protecting against diphtheria, tetanus, pertussis, polio, invasive *Haemophilus influenzae* type b disease, and hepatitis B virus) at 3, 5, and 11 months of age. This schedule was adjusted following the introduction of maternal pertussis vaccination in 2019, which provides newborns with passive immunity through maternal antibodies. Prior to this change, infants received their first dose at 2 months, followed by doses at 3, 5, and 11 months; since 2019, the 2-month dose is only administered if the mother did not receive the maternal pertussis vaccine during pregnancy. Vaccination against pneumococcal disease is also provided at 3, 5 and 11 months. The first dose of the measles, mumps, and rubella (MMR) vaccine is given at 14 months, alongside a meningococcal ACWY conjugate vaccine. Booster doses for DTaP-IPV are provided at 4 and 9 years (DTP), and a second MMR dose is scheduled at 9 years. HPV vaccination is offered at 10 years, and meningococcal ACWY vaccination at 14 years of age.

In 2025, the NIP was further expanded with the introduction of rotavirus vaccination for all infants and respiratory syncytial virus (RSV) immunisation (monoclonal antibodies) for young children. Additionally, the timing of several vaccinations was modified: the second-dose MMR previously given at 9 years was moved to 3 years; for DTaP-IPV, the dose at 11 months was moved to 12 months and the booster given at 4 years was shifted to 5 years of age; and for DTP, the booster at 9 years was rescheduled to 14 years. Of note: The analyses in this thesis focus specifically on the coverage of the primary MMR and DTaP-IPV vaccinations in infants, using data up to and including 2024, prior to the implementation of these scheduled changes. Table 1 therefore shows the NIP schedule in 2024.

Table 1. Schedule of the National Immunisation Programme in 2024

Phase	Age	Vaccine	Disease
Infants	2 months*	DTaP-IPV – Hib – HBV*	Diphtheria, pertussis, tetanus, polio, invasive Haemophilus influenza type b disease/infection, hepatitis B
	3 months	DTaP-IPV – Hib – HBV	Diphtheria, pertussis, tetanus polio, haemophilus influenza type b, hepatitis B virus
		Pneu	Pneumococcal disease
	5 months	DTaP-IPV – Hib – HBV	Diphtheria, pertussis, tetanus polio, haemophilus influenza type b, hepatitis B virus
		Pneu	Pneumococcal disease
	11 months	DTaP-IPV – Hib – HBV	Diphtheria, pertussis, tetanus polio, haemophilus influenza type b, hepatitis B virus
		Pneu	Pneumococcal disease
	14 months	MMR MenACWY	Mumps, measles, rubella Meningococcal disease types ACWY
Pre-school	4 years	DTaP-IPV	Diphtheria, pertussis, tetanus, polio
School age	9 years	DT-IPV Booster	Diphtheria, pertussis, tetanus
		MMR Booster	Mumps, measles, rubella
	10 years	HPV (2nd vaccination 6 months later)	Human papillomavirus related disease
Adolescents	14 years	MenACWY	Pneumococcal disease

* Only when the mother did not receive maternal pertussis vaccination during pregnancy. Updated schedules can be found at <https://rijksvaccinatieprogramma.nl/vaccinaties>

Surveillance of the NIP

The National Immunisation Programme (NIP) in the Netherlands is monitored through a surveillance framework comprising several key pillars [10]. These include: (1) vaccination coverage, which measures the proportion of the target population that has received recommended vaccines, and monitoring of attitudes towards vaccination through repeated surveys or in-depth research; (2) safety surveillance, which monitors and investigates adverse events following immunisation to ensure vaccine safety; (3) disease surveillance, which tracks changes in incidence through

Chapter 1

the mandatory reporting of notifiable diseases by healthcare professionals; (4) pathogen surveillance, which involves the identification and characterisation of circulating pathogens to detect changes such as new variants or outbreaks; (5) serosurveillance, which assesses population immunity by measuring antibody levels in representative samples. In addition, the NIP provides scientific advice to the Health Council, supports public communication, and coordinates outbreak response efforts. This thesis focuses specifically on the pillar of vaccination coverage, examining sociodemographic determinants and disparities in uptake within the Dutch population.

NIP vaccination coverage

Monitoring vaccination coverage is a key element in the evaluation and optimisation of the NIP [3]. The World Health Organization (WHO) has set ambitious goals for immunisation programmes, recommending at least 90% coverage for all vaccines and 95% coverage for measles-containing vaccines such as MMR, to achieve and sustain population-level protection and progress towards disease elimination [11]. In the Netherlands, vaccination coverage is assessed using Praeventis, the national immunisation register [12]. Praeventis is an electronic system that systematically records all childhood immunisations and supports the implementation of the National Immunisation Programme by sending invitations and reminders to eligible children and their caregivers. Such electronic vaccine registers are considered the gold standard for assessing vaccine coverage, as they enable accurate and comprehensive monitoring. Ideally, the register also supports operational management of the programme, for example by issuing invitations and reminders (as is done in Praeventis), which further enhances data quality and system sustainability. Globally, only a few countries—primarily in northern Europe—have implemented such comprehensive vaccine registers [3].

Trends in MMR and DTaP-IPV vaccination coverage

Annual reports published by RIVM provide insight into the trends in vaccine uptake. Since 1 January 2022, changes in privacy legislation have required youth healthcare services to obtain explicit informed consent from parents or caregivers before sharing personal vaccination data with the RIVM. If consent is not given, vaccinations are registered anonymously, resulting in missing information such as birth year, sex, and municipality. As a consequence, these anonymous vaccinations cannot be included in standard coverage calculations, leading to an underestimation of the true vaccination coverage. The registered vaccination coverage is therefore somewhat lower than the actual coverage. In 2024, the overall proportion of anonymous (non-consented) vaccinations was 2.9% across all vaccine types, and specifically 2.3% for MMR and 2.1% for DTaP-IPV. These percentages vary by year, region, and vaccine type, and should not be directly added to the reported coverage for individual cohorts. This underestimation particularly affects coverage estimates for children born from

2021 onwards, and trends for these cohorts should therefore be interpreted with caution [13].

MMR and DTaP-IPV vaccination coverage among infants (at age 2 years) was consistently high for birth cohorts 2005–2011, with coverage rates above 95% for MMR and above 94% for DTaP-IPV. From the 2012 cohort onward, a gradual decline in coverage is observed for both vaccines. After the initial decline, coverage appeared to stabilise around the 2016 cohort (DTaP-IPV 92.4%, MMR 92.9%), with a slight increase in 2018 (DTaP-IPV 93.1%, MMR 93.6%), before dropping again in subsequent years. Coverage for MMR, which has a WHO target of 95%, dropped below this threshold starting with the 2012 cohort and continued to decrease, with 88.3% registered coverage for the 2021 cohort and 88.1% for the 2022 cohort. DTaP-IPV coverage, for which the WHO target is 90%, also declined over this period, falling below 90% registered coverage for the 2020–2022 cohorts (lowest at 85.4% in 2021). These trends are illustrated in Figure 2.

Chapter 1

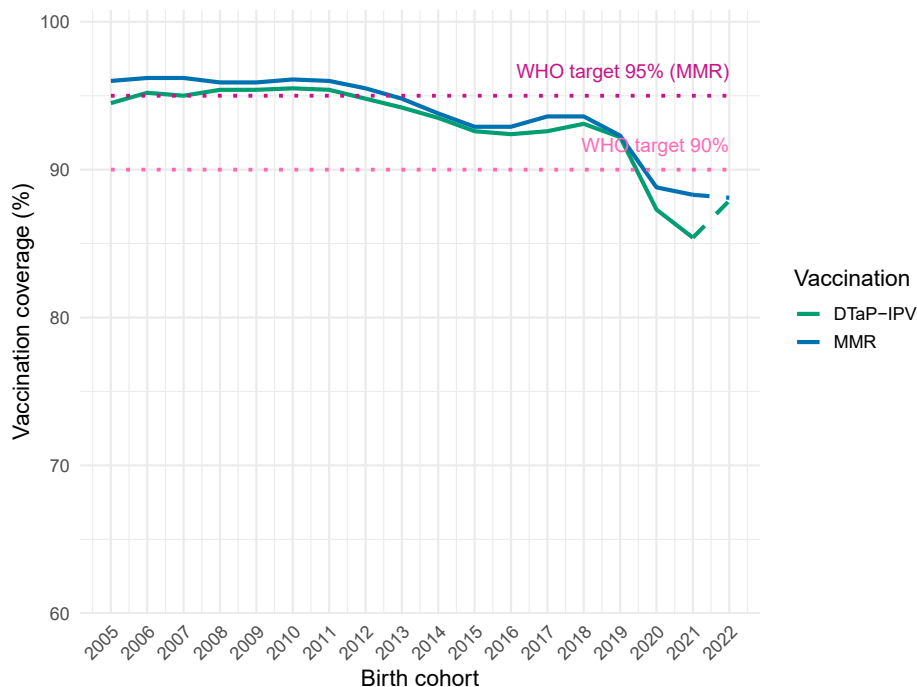


Figure 2. Trends in MMR and DTaP-IPV vaccination coverage by age 2 years from birth cohort 2005 to 2022. Data retrieved from RVIM annual vaccination coverage report [13]. The dashed lines indicate the vaccination coverage is impacted by the informed consent.

Note: changes in registered vaccination coverage in the most recent cohort do not necessarily reflect changes in actual coverage, as recent figures do not yet account for anonymous vaccinations or administrative corrections for missing JGZ indications. For DTaP-IPV, the apparent increase in coverage in cohort 2025 is due to such an administrative correction and does not indicate a true rise in uptake; actual coverage is likely slightly lower than the previous year [13].

Population subgroups with known lower vaccination coverage and associated outbreaks

Despite relatively high national vaccination coverage for most vaccines in the Netherlands, persistent disparities exist between different population subgroups and geographic regions [14-18]. Notably, as established in previous research before the start of this thesis, lower vaccination coverage is observed among the orthodox Protestant community—concentrated in the so-called “Bible Belt”—and among anthroposophical communities, where religious or philosophical objections to vaccination result in socio-geographically clustering of unvaccinated individuals [19]. These clusters have been associated with several outbreaks of vaccine-preventable diseases. In the orthodox Protestant community, major measles outbreaks occurred in 1976–1977, 1983–1984, 1992–1994, 1999–2000, and 2013–2014 [20], with some outbreaks resulting in spread to Canada and, occasionally, the United States, while a significant rubella outbreak took place in 2004–2005 [21]. Polio outbreaks were reported in 1978 and 1992–1993 [22, 23]. Mumps outbreaks have been reported in both orthodox Protestant and anthroposophical communities, including in 2007–2009 [24].

More recently, vaccine-preventable diseases have resurged both in the Netherlands and internationally [10]. In 2024, the WHO European Region reported over 128,000 measles cases, the highest since 1997, while pertussis cases have also increased (largely due to waning immunity) [25-27]. These trends highlight the ongoing risks posed by declining vaccination coverage and clustering of unvaccinated individuals, even in countries with established immunisation programmes.

COVID-19 vaccination

The emergence of the COVID-19 pandemic in early 2020 had a substantial impact on public health worldwide, including in The Netherlands [28]. The development and introduction of the COVID-19 vaccines represented a major milestone in the response to the pandemic. In January 2021 the COVID-19 vaccine was added to the Dutch NIP, initially prioritising healthcare workers, elderly individuals, and those at increased risk of severe disease. As vaccine supply increased, eligibility was progressively expanded to include the general adult population and, later, adolescents and children. The campaign was coordinated at the national level, with regional public health services (GGD) and general practitioners responsible for vaccine administration. Vaccination data were registered in the national COVID-19 vaccination information and monitoring system (CIMS), enabling monitoring of safety, coverage and effectiveness.

By the end of 2021, approximately 89% of Dutch adults had received at least one dose of a COVID-19 vaccine, and around 86% had completed the primary vaccination series [29]. Subsequent booster rounds were introduced to maintain immunity and protect against emerging variants, with the first booster campaign launched in late

Chapter 1

2021, followed by additional yearly booster rounds targeting specific groups, such as older adults, healthcare workers, and individuals with underlying health conditions.

Impact COVID-19 vaccination on routine childhood vaccination

In addition to the direct effects of the pandemic and the COVID-19 vaccination campaign on public health, the delivery of routine childhood immunisations was also affected. Some routine vaccination appointments, particularly for older children and adolescents, were postponed or rescheduled due to movement restrictions, staffing challenges, or concerns about visiting healthcare facilities. For infants, however, vaccine delivery was largely maintained, and efforts were made to prioritise and continue these essential vaccinations as much as possible. Nevertheless, temporary disruptions and changes in healthcare-seeking behaviour contributed to fluctuations in routine childhood vaccination coverage during the pandemic. In the Netherlands, a short-term decline in participation in routine infant vaccinations was observed in the initial months following the implementation of COVID-19 measures, but targeted catch-up campaigns by public health services were largely successful in restoring coverage to pre-pandemic levels [30]. While these short-term impacts appear to have been mitigated, the long-term effects of the pandemic on routine vaccination coverage, public trust in immunisation programmes, and vaccine acceptance remain uncertain. There are concerns that the pandemic may have contributed to increased vaccine hesitancy, changes in health-seeking behaviour, and declined trust in governmental authorities, potentially affecting future uptake of both vaccines included in the NIP and COVID-19 vaccines [31].

Equality, equity and sociodemographic determinants in vaccination programmes

Investigating sociodemographic determinants of vaccination is essential for identifying and monitoring groups at increased risk of under-vaccination. Differences in vaccination coverage between population subgroups are often described as inequalities [32]. However, it is important to distinguish between equality and inequity. Equality means that vaccination is made available free of charge and under the same conditions to everyone, regardless of background or circumstances. Equity, on the other hand, recognises that some groups may face additional barriers, such as language, access to information, or practical or structural disadvantages, and may therefore need additional support or targeted interventions to have the same opportunity to be vaccinated [32].

In the context of vaccination programmes, addressing inequities is crucial for ensuring that all children have equal opportunities to benefit from immunisation, regardless of their background [3]. Monitoring equity in vaccination coverage is important not only from an ethical perspective, since inequities are fundamentally unfair and often

affect those, such as children, who lack agency, but also from a broader public health and societal perspective. Persistent inequities do not just disadvantage specific groups; they also contribute to greater societal divisions and undermine social trust and cohesion, as research has shown that health inequalities can weaken the fabric and resilience of society as a whole [33]. Moreover, such inequities can lead to pockets of under-vaccination, increasing the risk of outbreaks that threaten both vulnerable groups and the wider population. Addressing these issues is therefore essential to promote not only fairness and justice but also the overall health, stability, and well-being of society.

Sociodemographic and socioeconomic factors, such as parental education, income, religion, migration background, as well as geographical differences (rural/urban), are associated with vaccination uptake in many countries, including the Netherlands, resulting in disparities within the population [15, 16, 18, 34, 35]. For monitoring vaccination programme equity, it is particularly valuable to present vaccination coverage data by population subgroups. Moreover, to assess the risk of outbreaks or ongoing transmission, it is useful to present coverage by social contact networks (such as schools) rather than solely by large geographic areas, as the latter may mask clusters of unvaccinated individuals [3, 36]. Suitable data for these purposes can be obtained through the linkage of various national registers.

Scope and outline of this thesis

The overall aim of this thesis is to examine the sociodemographic factors associated with routine childhood and COVID-19 vaccination coverage in the Netherlands by analysing linked national registry data, including changes and trends over time. The goal is to identify population subgroups at risk of under-vaccination and provide evidence to support the development of tailored interventions for improving vaccine equity.

In this thesis, several database studies were conducted using individual-level vaccination data from national immunisation registers—specifically Praeventis for routine childhood vaccinations and CIMS for COVID-19 vaccinations—linked to sociodemographic and socioeconomic information from Statistics Netherlands (CBS) [37]. This approach allows for a comprehensive analysis of how individual and household characteristics are associated with vaccination coverage, and enables the identification of at-risk groups and localised clusters of under-vaccination. The approach taken in these studies aligns with step 1—the situation analysis—of the Tailoring Immunisation Programmes (TIP) method developed by the WHO [38].

The TIP method is part of the broader Tailoring Health Programmes (THP) framework [39], as illustrated in Figure 2. This systematic framework, based on the theory of change, is designed to identify barriers and drivers of vaccination within specific subgroups and consists of four key steps. Following the initial situation analysis,

Chapter 1

in which possible geographical and sociodemographic patterns are revealed, the subsequent steps include formative research to further explore the underlying reasons for under-vaccination in risk groups, and the development, implementation, and evaluation of tailored interventions aimed at increasing immunisation uptake and reducing inequalities. By applying the TIP method within the context of the THP framework, the findings in this thesis can contribute to evidence-based strategies that support equitable vaccination coverage.

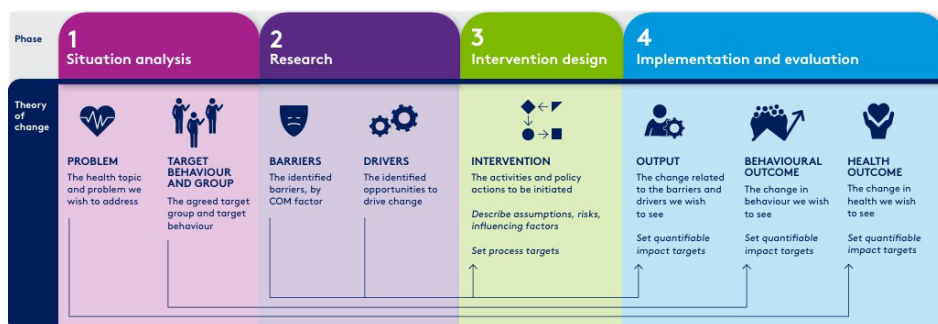


Figure 3. WHO Tailoring Health Programmes steps. Retrieved from [39]

This thesis is divided in two main sections. **Part I** focuses on developments in routine childhood vaccination coverage. In **Chapter 2**, trends in MMR and DTaP-IPV vaccination coverage among infants from birth cohorts 2008 to 2020 are analysed, with attention to associations with sociodemographic factors and changes in vaccine uptake. In **Chapter 3**, differences in vaccination coverage among primary schools of various denominations are examined, highlighting which school types have lower coverage and discussing the implications for disease outbreaks and public health. **Chapter 4** includes an assessment of the impact of the COVID-19 pandemic on routine childhood vaccination, with changes in uptake during and after the pandemic investigated at both the population and family level.

Part II turns to COVID-19 vaccination coverage. In **Chapter 5**, sociodemographic determinants of COVID-19 vaccine uptake among adults in the Netherlands are investigated, identifying subgroups with lower coverage and associated factors. In **Chapter 6**, the effectiveness of mobile vaccination units in increasing COVID-19 vaccine uptake in neighbourhoods with relatively low coverage is evaluated, illustrating how targeted public health interventions can help address identified disparities and support efforts to promote equitable vaccine access.

The main findings from both parts of the thesis are summarised and discussed in **Chapter 7**, including a reflection on public health implications and future perspectives.

References

1. Shattock AJ, Johnson HC, Sim SY, Carter A, Lambach P, Hutubessy RCW, et al. Contribution of vaccination to improved survival and health: modelling 50 years of the Expanded Programme on Immunization. *Lancet*. 2024;403(10441):2307–16 doi:10.1016/S0140-6736(24)00850-X.
2. United Nations (UN). The 17 goals 2025 [Available from: <https://sdgs.un.org/goals>.
3. Hahné S, Bollaerts K, Farrington P. Vaccination Programmes. Epidemiology, Monitoring, Evaluation.: Routledge; 2022.
4. Chen RT, Orenstein WA. Epidemiologic methods in immunization programs. *Epidemiol Rev*. 1996;18(2):99–117 doi:10.1093/oxfordjournals.epirev.a017931.
5. Horton R, Das P. The vaccine paradox. *Lancet*. 2011;378(9788):296–8 doi:10.1016/S0140-6736(11)60765-4.
6. van Wijhe M, McDonald SA, de Melker HE, Postma MJ, Wallinga J. Effect of vaccination programmes on mortality burden among children and young adults in the Netherlands during the 20th century: a historical analysis. *Lancet Infect Dis*. 2016;16(5):592–8 doi:10.1016/S1473-3099(16)00027-X.
7. van Wijhe M, McDonald SA, de Melker HE, Postma MJ, Wallinga J. Estimating the Population-Level Effectiveness of Vaccination Programs in the Netherlands. *Epidemiology*. 2018;29(2):215–23 doi:10.1097/EDE.0000000000000778.
8. van Wijhe M, Tulen AD, Korthals Altes H, McDonald SA, de Melker HE, Postma MJ, et al. Quantifying the impact of mass vaccination programmes on notified cases in the Netherlands. *Epidemiol Infect*. 2018;146(6):716–22 doi:10.1017/S0950268818000481.
9. Rijksinstituut voor Volksgezondheid en Milieu (RIVM). What is the National Immunisation Programme? 2025 [Available from: <https://rijksvaccinatieprogramma.nl/en/what-is-the-national-immunisation-programme>.
10. van Roon A, Lanooij S, de Melker H. The National Immunisation Programme in the Netherlands. Surveillance and developments in 2023-2024. RIVM. 2024.
11. World Health Organization. Immunization Agenda 2030: A global strategy to leave no one behind. Geneva, Switzerland; 2020.
12. van Lier A, Oomen P, de Hoogh P, Drijfhout I, Elsinghorst B, Kemmeren J, et al. Praeventis, the immunisation register of the Netherlands: a tool to evaluate the National Immunisation Programme. *Euro Surveill*. 2012;17(17) doi:10.2807/ese.17.17.20153-en.
13. van Lier A, Hament J, Holwerda M, Westra M, Giebers H, Maas Nvd, et al. Vaccinatiegraad Rijksvaccinatieprogramma Nederland. Verslagjaar 2025.: RIVM; 2025.
14. Albers CJ, van der Loeff MF, Hazeveld Y, de Melker HE, van der Wal MF, Nielsen A, et al. A longitudinal study on determinants of HPV vaccination uptake in parents/guardians from different ethnic backgrounds in Amsterdam, the Netherlands. *BMC Public Health*. 2017;17(1):220 doi:10.1186/s12889-017-4091-4.
15. de Munter AC, Klooster T, van Lier A, Akkermans R, de Melker HE, Ruijs WLM. Determinants of HPV-vaccination uptake and subgroups with a lower uptake in the Netherlands. *BMC Public Health*. 2021;21(1):1848 doi:10.1186/s12889-021-11897-0.
16. de Oliveira Bressane Lima P, van Lier A, de Melker H, Ferreira JA, van Vliet H, Knol MJ. MenACWY vaccination campaign for adolescents in the Netherlands: Uptake and its determinants. *Vaccine*. 2020;38(34):5516–24 doi:10.1016/j.vaccine.2020.05.087.
17. Rondy M, van Lier A, van de Kasstele J, Rust L, de Melker H. Determinants for HPV

Chapter 1

- vaccine uptake in the Netherlands: A multilevel study. *Vaccine*. 2010;28(9):2070–5 doi:10.1016/j.vaccine.2009.12.042.
18. van Lier A, van de Kasstelee J, de Hoogh P, Drijfhout I, de Melker H. Vaccine uptake determinants in The Netherlands. *Eur J Public Health*. 2014;24(2):304–9 doi:10.1093/eurpub/ckt042.
19. Ruijs WL, Hautvast JL, van der Velden K, de Vos S, Knippenberg H, Hulscher ME. Religious subgroups influencing vaccination coverage in the Dutch Bible belt: an ecological study. *BMC Public Health*. 2011;11:102 doi:10.1186/1471-2458-11-102.
20. Woudenberg T, van Binnendijk RS, Sanders EAM, Wallinga J, de Melker HE, Ruijs WLM, et al. Large measles epidemic in the Netherlands, May 2013 to March 2014: changing epidemiology. *Eurosurveillance*. 2017;22(3):30443 doi: 10.2807/1560-7917.ES.2017.22.3.30443
21. Hahne S, Macey J, van Binnendijk R, Kohl R, Dolman S, van der Veen Y, et al. Rubella outbreak in the Netherlands, 2004–2005: high burden of congenital infection and spread to Canada. *Pediatr Infect Dis J*. 2009;28(9):795–800 doi:10.1097/INF.0b013e3181a3e2d5.
22. Conyn-van Spaendonck MA, Oostvogel PM, van Loon AM, van Wijngaarden JK, Kromhout D. Circulation of poliovirus during the poliomyelitis outbreak in The Netherlands in 1992–1993. *Am J Epidemiol*. 1996;143(9):929–35 doi:10.1093/oxfordjournals.aje.a008836.
23. Oostvogel PM, Rumke HC, Conyn-Van Spaendonck MA, van der Avoort HG, Leeuwenburg J, van Loon AM. Poliovirus circulation among schoolchildren during the early phase of the 1992–1993 poliomyelitis outbreak in The Netherlands. *J Infect Dis*. 2001;184(11):1451–5 doi:10.1086/324327.
24. Ruijs WL, Hautvast JL, Akkermans RP, Hulscher ME, van der Velden K. The role of schools in the spread of mumps among unvaccinated children: a retrospective cohort study. *BMC Infect Dis*. 2011;11:227 doi:10.1186/1471-2334-11-227.
25. World Health Organization. Measles and rubella monthly update - WHO European Region - September 2024. WHO; 2024.
26. European Region reports highest number of measles cases in more than 25 years – UNICEF, WHO/Europe [press release]. WHO2025.
27. European Centers for Disease Control and Prevention (ECDC). Increase of pertussis cases in the EU/EEA, 8 May 2024. Stockholm: ECDC; 2024.
28. Watson OJ, Barnsley G, Toor J, Hogan AB, Winskill P, Ghani AC. Global impact of the first year of COVID-19 vaccination: a mathematical modelling study. *Lancet Infect Dis*. 2022;22(9):1293–302 doi:10.1016/S1473-3099(22)00320-6.
29. Valk A, Meijeren D, Smorenburg N, Neppelenbroek N, van Iersel S, de Bruijn S, et al. Vaccinatiegraad COVID-19 vaccinatie Nederland, 2021. 2022.
30. Middeldorp M, van Lier A, van der Maas N, Veldhuijzen I, Freudenburg W, van Sorge NM, et al. Short term impact of the COVID-19 pandemic on incidence of vaccine preventable diseases and participation in routine infant vaccinations in the Netherlands in the period March–September 2020. *Vaccine*. 2021;39(7):1039–43 doi:10.1016/j.vaccine.2020.12.080.
31. Unicef. The State of the World's Children 2023: For every child, vaccination. Florence: UNICEF Innocenti – Global Office of Research and Foresight; 2023 April 2023.
32. Wilkinson R, Pickett K. The spirit level: Why greater equality makes societies stronger.: Bloomsbury Publishing USA; 2011.
33. Wilkinson R, Pickett K. The spirit level: Why greater equality makes societies stronger.: Bloomsbury Publishing USA; 2011.
34. Lanza-Leon P, Cantarero-Prieto D, Pascual-Saez M. Exploring trends and determinants

- of basic childhood vaccination coverage: Empirical evidence over 41 years. *PLoS One*. 2024;19(3):e0300404 doi:10.1371/journal.pone.0300404.
- 35.Varbanova V, Verelst F, Hens N, Beutels P. Determinants of basic childhood vaccination coverage in European and OECD countries. *Hum Vaccin Immunother*. 2022;18(6):2123883 doi:10.1080/21645515.2022.2123883.
 - 36.Moore HC, Fathima P, Gidding HF, de Klerk N, Liu B, Sheppard V, et al. Assessment of on-time vaccination coverage in population subgroups: A record linkage cohort study. *Vaccine*. 2018;36(28):4062–9 doi:10.1016/j.vaccine.2018.05.084.
 - 37.B.F.M. Bakker, J. van Rooijen, Toor Lv. The System of social statistical datasets of Statistics Netherlands: An integral approach to the production of register-based social statistics. *Statistical Journal of the IAOS*. 2014;30(4):411–24 doi:10.3233/SJI-140803.
 - 38.World Health Organization. TIP Tailoring Immunization Programmes. WHO; 2019.
 - 39.World Health Organization. A guide to tailoring health programmes. 2023.

Part I

Routine childhood
vaccination coverage

Chapter 2

The decrease in childhood vaccination coverage and its sociodemographic determinants, the Netherlands, birth cohorts 2008 to 2020

Joyce Pijpers, Annika van Roon, Maarten Schipper, Marijn Stok, Susan van den Hof, Ruben van Gaalen, Susan Hahné, Hester de Melker

Eurosurveillance, 2025

DOI: [10.2807/1560-7917.ES.2025.30.39.2500251](https://doi.org/10.2807/1560-7917.ES.2025.30.39.2500251)

Chapter 2

ABSTRACT

INTRODUCTION: Childhood vaccination coverage has declined in recent years in many countries, including the Netherlands.

AIM: To understand differences in coverage between population subgroups in the Netherlands over time, we studied sociodemographic factors associated with measles-mumps-rubella (MMR) and diphtheria-tetanus-pertussis-poliomyelitis (DTaP-IPV) vaccination.

METHODS: We conducted a national retrospective database study including children born between 2008 and 2020. Individual-level data linkage allowed examination of associations of sociodemographic variables with MMR and DTaP-IPV vaccination status at age 2 years. We calculated coverage for each variable, stratified by birth cohort. Multivariable Poisson regression assessed independent associations and changes in coverage over time.

RESULTS: MMR coverage decreased in all population subgroups (overall 95% in cohort 2008 and 89% in cohort 2020), more substantially in some. In multivariable analysis, children of non-Dutch origin, particularly Moroccan and Turkish origin, showed more pronounced declines (respectively –25% and –12% as children of Dutch origin in cohort 2020). Among children not attending daycare and children living in larger families (≥ 4 children), coverage declined faster than in those attending daycare and living in smaller families (both –12% in cohort 2020). Coverage among children of self-employed mothers and children in the lowest income households was lower than among children of mothers in employment and the highest income households (respectively –8% and –7% in cohort 2020). Trends for DTaP-IPV vaccination were nearly identical.

CONCLUSION: Childhood vaccination coverage in the Netherlands declined substantially, with increasing disparities between sociodemographic groups. Vaccination efforts should be prioritised to protect public health equitably.

Introduction

Childhood vaccination programmes are the single most effective intervention to protect children's health. The Expanded Programme on Immunisation is estimated to have averted 154 million deaths globally between 1974 and 2024, the majority in children younger than 5 years [1]. Since 1957, the Netherlands' National Immunisation Programme (NIP) has provided free, voluntary vaccinations against 13 severe infectious diseases and has significantly reduced child and young adult mortality [2]. Despite its success and historically high coverage, childhood vaccination coverage has declined in recent years in many countries, including in the Netherlands [3]. Coverage for diphtheria-tetanus-pertussis-poliomyelitis vaccination (DTaP-IPV) and measles-mumps-rubella vaccination (MMR) in newborns dropped from 95% in the birth cohort 2008 to 2010 to 93% in cohorts 2015 and 2016 and further to 88% and 89%, respectively, in the 2020 cohort in the Netherlands [4]. Historically, NIP vaccine coverage has been relatively low in Dutch regions where orthodox reformed individuals live (Bible Belt region) [5,6]. However, in recent years a decline in coverage of all childhood vaccinations has occurred also outside of the Bible Belt region, specifically in large cities [4].

(Inter)national research has summarised sociodemographic factors associated with childhood vaccination coverage. Lower (maternal) education level and lower socioeconomic status were associated with lower routine childhood vaccination coverage [7,8]. Similarly, lower parental income, lower parental education level and not being the first-born child were independently associated with lower MMR vaccination uptake [9]. A Dutch study among infants born in 2005 found that parental country of birth and religious objections to vaccination were significant determinants of vaccination uptake [10]. Children with at least one parent born abroad, particularly those with both parents born in Türkiye or Morocco, had 20–30% lower odds of being fully vaccinated [10]. This lower uptake aligns with more recent Dutch studies on HPV and meningococcal (ACWY) vaccination [11–13]. In these studies, data on country of origin were available at individual level, while socioeconomic status (SES) variables and proxy variables for religion (voting proportions for religious political parties) were available at an aggregated level.

The aim of this study was to identify socio-demographic factors associated with changes in vaccination coverage over time, aligning with the 'situation analysis' phase of the World Health Organization (WHO) Tailoring Immunization Programmes (TIP) approach, using novel and detailed individual-level data. The WHO TIP model is a structured framework for improving immunisation coverage, consisting of four main phases: situation analysis (review existing data and define target groups), research (gain deeper insight into underlying factors), intervention design (developing targeted strategies) and implementation and evaluation (implementing interventions in real-world settings and systematically evaluating their effectiveness) [14–16]. Insights from this research can inform targeted interventions to improve MMR and DTaP-IPV

Chapter 2

vaccination coverage, reduce disparities and promote equitable access to vaccination and information.

Methods

Study design and population

For this retrospective cohort study, we linked multiple data sources using a unique identifier to assess determinants of MMR and DTaP-IPV vaccination coverage in the Netherlands of children born between 2008 and 2020. In that period, sociodemographic registries maintained consistent variables and data collection methods. Data linkage was done in the secured remote access environment of Statistics the Netherlands (CBS).

The study population included all children born 2008 to 2020 and was selected from the Personal Records Database (BRP). We used national registries on mortality and migration to determine whether the children had been eligible for routine vaccinations. Specifically, we excluded children who had died or emigrated before becoming eligible for the first dose of MMR (scheduled at age 14 months) or for the DTaP-IPV booster dose (scheduled at age 11 months), as well as children who immigrated to the Netherlands after these respective ages. In addition, we linked children to their parents using the BRP-based register for child–parent relations from Statistics the Netherlands. Children for whom no parent could be identified in the national registries were excluded from the analyses.

Outcome measure

The binary outcome measures in this study were uptake before the second birthday of (i) at least one dose of MMR vaccine and (ii) at least three doses of DTaP-IPV vaccine (scheduled at 2 and/or 3 months of age, at 5 months and 11 months), as recommended in the Dutch NIP. An overview of the national vaccination schedule can be found in Supplementary Table S1. We calculated age at time of vaccination based on birth date (month-year) and date of vaccine administration. Vaccination data was available from Praeventis, the register of the Dutch NIP [17]. The vaccination dataset including MMR and DTaP-IPV vaccinations was linked to the study population based on the same unique identifier. Children without a vaccination record in Praeventis were classified as unvaccinated.

Covariates

We included the following individual-level variables provided by CBS [18] as potential determinants for MMR1 and DTaP-IPV booster vaccination: year of birth, maternal education level (high vs not high (including intermediate, low and unknown), household disposable income, mother's income source (employed, self-employed, benefit recipient, pension recipient or student), family size (1–3 children, ≥ 4 children

or institutional household), urbanisation level, daycare attendance (yes or no), migration status and country of origin. Maternal education level was determined based on the highest completed education. The category 'high' education level is relatively well registered, as the registers are older, whereas information on 'low' and 'middle' education more often is incomplete. Therefore, we dichotomised education as high vs not high. Standardised household disposable income reflects the disposable income, corrected for household size and composition by CBS, and divided into quartiles based on the entire Dutch population. Urbanisation level was defined based on the average address density per square kilometre: extremely urbanised ($\geq 2,500$ addresses/km²), strongly urbanised (1,500–2,499 addresses/km²), moderately urbanised (1,000–1,499 addresses/km²), hardly urbanised (500–999 addresses/km²) and not urbanised (≤ 500 addresses/km²). Migration status contained the following categories: Dutch origin (all parents and grandparents born in the Netherlands), migrant or child of at least one first-generation migrant, and child of at least one second-generation migrant. Migrant children and children of first-generation migrants were grouped due to low numbers. Country of origin was categorised as the Netherlands, Europe (excluding the Netherlands), Morocco, Türkiye, Suriname, Dutch Caribbean, Indonesia, Other: America/Oceania, Other: Africa, Other: Asia). Indonesia; Other (Africa, Asia, America/Oceania). Country of origin was primarily defined by the country of birth (CoB) of the child itself. If the child was born in the Netherlands, country of origin was first determined by the parents' country of birth (CoB). If both parents were born in the Netherlands, the grandparents' CoB was then considered. Within this definition, the mother's CoB was prioritised over the father's, and the grandmother's CoB was prioritised over the grandfather's. Foreign-born origins were given precedence over Dutch origin if present in the lineage.

Statistical analysis

Descriptive analysis summarised the sociodemographic characteristics of the vaccinated and unvaccinated children. Vaccination coverage was calculated as the number of children vaccinated before their second birthday divided by the total population eligible for each category of the sociodemographic variables.

We used a multivariable Poisson regression model to assess the independent association between vaccination and the sociodemographic variables. The results are reported as adjusted rate ratios (RRs) with 95% confidence interval levels (CI) and p values. The level of significance was set at 5%. Since the proportion of missing categorical values was small ($\leq 3\%$), they were excluded from the multivariable regression analysis. To account for potential nonlinearity of the trend of vaccination coverage over time, we included the variable birth cohort in the model as a categorical variable. The variable migration status was excluded from the multivariable analysis, given its complete overlap with the variable country of origin. To assess changes in the associations over time, we included interaction terms between the variable birth

Chapter 2

cohort and each determinant in the multivariable model. We report the adjusted RRs (aRR) for each category within the sociodemographic variables per birth cohort and subsequently, we calculated the adjusted relative change in vaccination coverage $((aRR - 1) \times 100)$, based on the aRR of the total effect (main effect birth year + main effect socio-demographic variable + interaction effect). We calculated the number of unvaccinated children in each category for the most recent birth cohort to pinpoint where interventions could have the greatest impact on vaccination coverage; these calculations are appended in Supplementary Table S7.

All analyses were performed in R version 4.4.0 [19]. This manuscript was prepared in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [20].

Results

Descriptive analysis

The total population of the 13 included birth cohorts for MMR and DTaP-IPV included 2,323,838 and 2,331,199 children, respectively (Table). Overall, by the age of 2 years, 2,174,229 children (94%) were vaccinated for MMR, and 2,172,402 children (93%) were vaccinated for DTaP-IPV. The distribution of sociodemographic groups in both the MMR and DTaP-IPV population are described in Table. Of children eligible for both MMR and DTaP-IPV vaccination ($n = 2,319,001$), 97.2% had the same vaccination status for both vaccines (either vaccinated or unvaccinated), 1.4% only received the MMR vaccination and 1.3% only received the DTaP-IPV vaccination. Supplementary Table S2 additionally provides the distribution of the sociodemographic variables per birth cohort.

Determinants of Childhood Vaccination Coverage

Table 1. MMR and DTaP-IPV vaccination uptake at age 2 years, by sociodemographic characteristics, the Netherlands, children born 2008–2020 (n = 2,323,838 for MMR; n = 2,331,199 for DTaP-IPV)

	MMR				DTaP-IPV			
	Population		Vaccinated		Population		Vaccinated	
	N	%	N	%	N	%	N	%
Education level mother								
High	879,390	38	841,000	96	878,790	38	842,050	96
Not high ^a	1,444,450	62	1,333,230	92	1,452,410	62	1,330,350	92
Intermediate	708,950	31	663,840	94	708,600	30	666,340	94
Low	256,880	11	241,910	94	256,550	11	241,980	94
Unknown	478,620	21	427,480	89	487,270	21	422,030	87
Household standardised disposable income^b								
First quartile	316,700	14	289,380	91	315,930	14	288,750	91
Second quartile	645,820	28	602,760	93	645,450	28	603,710	94
Third quartile	758,400	33	725,150	96	757,760	33	725,960	96
Fourth quartile	535,960	23	515,700	96	535,130	23	514,710	96
Unknown	66,970	3	41,240	62	76,930	3	39,280	51
Income source mother								
Job in employment	1,554,150	67	1,494,390	96	1,552,980	67	1,495,390	96
Self-employed	178,250	8	161,340	91	178,090	8	161,780	91
Benefit recipient	273,210	12	253,600	93	272,400	12	253,710	93
Pension recipient	10,580	<1	9,830	93	10,560	<1	9,840	93
Student	35,430	2	33,050	93	35,320	2	33,060	94
Other	205,780	9	181,710	88	205,060	9	180,020	88

Chapter 2

	MMR				DTaP-IPV			
	Population		Vaccinated		Population		Vaccinated	
	N	%	N	%	N	%	N	%
Unknown	66,450	3	40,310	61	76,800	3	38,600	50
Migration status								
Dutch origin	1,407,980	61	1,337,740	95	1,385,260	59	1,318,650	95
Migrant or child of first generation migrant(s)	648,100	28	586,510	90	654,160	28	580,040	89
Child of second generation migrant(s)	267,760	12	249,990	93	291,790	13	273,710	94
Country of origin ^c								
The Netherlands	1,407,970	61	1,337,740	95	1,385,260	59	1,318,660	95
Europe (excl, The Netherlands)	266,380	11	237,350	89	276,730	12	239,190	87
Morocco	104,630	5	93,230	89	107,290	5	96,160	90
Türkiye	85,260	4	79,480	93	88,040	4	82,300	93
Suriname	71,860	3	67,940	95	75,310	3	71,160	94
The Dutch Caribbean	45,030	2	41,480	92	46,460	2	42,930	92
Indonesia	74,320	3	70,960	95	78,880	3	75,510	96
Other, America/ Oceania	61,340	3	55,770	91	63,430	3	55,600	88
Other, Africa	78,060	3	72,120	92	79,180	3	73,170	92
Other, Asia	129,000	6	118,170	92	130,630	6	117,730	90
Level of urbanisation								
Extremely urbanised	501,210	22	471,400	94	500,170	21	470,200	94

Determinants of Childhood Vaccination Coverage

	MMR				DTaP-IPV			
	Population		Vaccinated		Population		Vaccinated	
	N	%	N	%	N	%	N	%
Strongly urbanised	579,000	25	550,330	95	578,190	25	550,390	95
Moderately urbanised	440,560	19	419,740	95	440,110	19	419,760	95
Hardly urbanised	396,580	17	375,890	95	396,290	17	376,180	95
Not urbanised	344,940	15	320,720	93	344,840	15	321,030	93
Unknown	61,540	3	36,150	59	71,610	3	34,840	49
Family-size								
1-3 children	2,119,770	91	2,017,780	95	2,117,000	91	2,016,800	95
≥ 4 children	138,590	6	117,210	85	138,410	6	117,520	85
Institutional household	4,260	<1	3,360	79	4,260	<1	3,310	78
Unknown	61,224	3	35,878	59	71,530	3	34,777	50
Day care attendance								
Yes	1,389,670	60	1,342,800	97	1,388,140	60	1,343,320	97
No	934,030	40	831,290	89	942,910	40	828,940	88
Unknown	140	<1	140	>95	150	<1	140	>95

MMR: Measles-mumps-rubella; DTaP-IPV: diphtheria, tetanus, pertussis, poliomyelitis.

a) The category 'not high' included intermediate, low and unknown education level.

b) If parents of children were living in separate households, the average SDI of the two households was taken. Quartiles (percentiles) were calculated by Statistics the Netherlands based on the complete Dutch population.

c) The country of origin was determined based on the country of birth of the child included in the study, and the countries of birth of its parents and grandparents.

All tables exclude frequencies < 10 and all numbers are rounded to the nearest ten, to avoid personally identifiable information. Therefore, the totals in the table may differ slightly from the total number of children in the study population.

Chapter 2

Sociodemographic factors associated with vaccination coverage over time

Overall, crude MMR vaccination coverage declined from 95% in cohort 2008 to 89% in cohort 2020, and a decrease was observed across all sociodemographic groups (Figure 1).

The MMR vaccination coverage was not associated with maternal educational level in 2008 (97%), but this changed over time: children of mothers who had higher education levels maintained relatively high coverage over time (94% in cohort 2020) while it decreased to 85% in cohort 2020 for children of mothers with low educational level. Lower vaccination coverage was consistently present among children in the lowest (first) income quartile households (94% in cohort 2008 and 82% in cohort 2020) and those with self-employed mothers (94% in cohort 2008 and 85% in cohort 2020). In the 2008 cohort, children of second-generation migrants (at least one grandparent born abroad) had higher coverage compared with the combined group of migrant children (born abroad themselves) and children of first-generation migrant (at least one parent born abroad), 97% and 81%, respectively. Coverage declined faster over time in children of second-generation migrants, so that in cohort 2020, coverage (84%) was lower than the combined group of migrant children and children of first-generation migrants (86%). Children of Dutch origin had relatively high vaccination coverage (96% in cohorts 2008 to 2012 and 93% in cohort 2020) compared with Dutch children of non-Dutch origin. Specifically Dutch children of Moroccan and Turkish origin had a 1–2% higher coverage in birth cohorts 2008 to 2012 compared with children of Dutch origin, but experienced a steeper decline in coverage from cohort 2014 onwards (from 92% in cohort 2014 to 65% in cohort 2020 and from 96% in cohort 2014 to 79% in cohort 2020, for Dutch children of, respectively, Moroccan and Turkish origin). Within the group of Dutch children of Moroccan origin, coverage since cohort 2013 has been lower for children of second-generation migrants compared with the combined group of migrant children and children of first-generation migrants (58% and 71% in cohort 2020, respectively). Within the group of Dutch children of Turkish origin, coverage was only in cohort 2020 slightly lower for children of second-generation migrants compared with the combined group of migrant children and children of first-generation migrants (84% and 86%, respectively). Geographical factors also played a role, with children living in non-urbanised areas consistently showing lowest coverage until cohort 2019, whereafter coverage of children in extremely urbanised areas was lowest (87% in cohort 2020). Moreover, coverage was consistently lower in children living in large families (76% in cohort 2020), children living in institutional households (70% in cohort 2020) and children not attending daycare (78% in cohort 2020).

DTaP-IPV vaccination coverage decreased from 95% in cohort 2008 to 90% in cohort 2020. The DTap-IPV coverage by country of origin showed some slight differences compared with MMR coverage, with Dutch children from European origin (excluding the Netherlands), 'Other, America/Oceania' and 'Other, Asia' having lower coverage

Determinants of Childhood Vaccination Coverage

in earlier cohorts (2008–2014). Aside from this, similar trends were observed in the crude DTaP-IPV vaccination coverage over time; for a detailed overview of DTaP-IPV coverage by sociodemographic variables see Supplementary Figure S3.

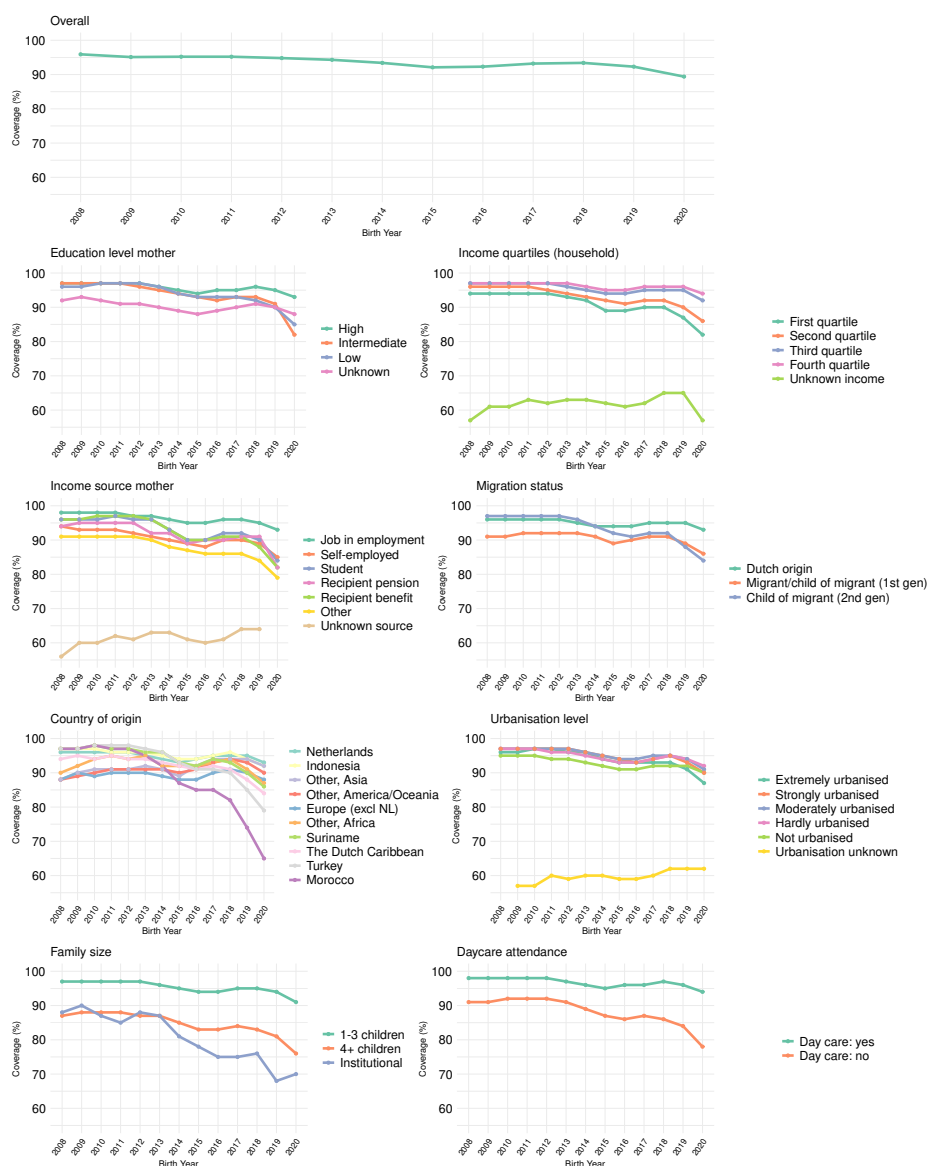


Figure 1. Unadjusted measles-mumps-rubella vaccination coverage at age 2 years, per birth cohort, the Netherlands, children born 2008–2020 (n = 2,323,838) gen: generation; NL: the Netherlands.

The vaccination coverage for cohort 2020 may be underestimated due to informed consent.

Chapter 2

Sociodemographic factors associated with vaccination coverage

Figure 2 shows the univariable and multivariable regression analysis for MMR vaccination and corresponding RR (unadjusted and adjusted). The figure shows variations in the RR across different sociodemographic groups. Overall, the strongest associations with lower vaccination coverage in adjusted analyses were related to larger family size (≥ 4 children; aRR = 0.91), living in an institutional household (aRR = 0.95) and not-attending daycare (aRR = 0.96). Maternal education level overall showed a nuanced effect: while lower education was associated with lower vaccination coverage in the unadjusted model (RR = 0.97), the adjusted model indicated minimal difference between children of mothers with high education level and children of mothers without high education level (aRR = 1.00). With regard to the economic variables: lower standardised disposable income of the household was associated with lower vaccination coverage in the adjusted model, particularly in the first quartile (aRR = 0.98) as was having a self-employed mother or a mother with 'other' income (aRR = 0.95 or aRR = 0.96, respectively). The association between country of origin and vaccine coverage varied: Dutch children of Moroccan origin had lower coverage than children of Dutch origin (aRR = 0.97), while Dutch children of Turkish, African and Asian origin showed higher coverage than children of Dutch origin (aRR = 1.01 for Türkiye, aRR = 1.02 for Africa and aRR = 1.03 for Asia). Living in hardly to extremely urbanised areas, compared with non-urbanised areas, was positively associated with MMR vaccination coverage (aRR = 1.02 for strongly urbanised areas).

With regard to DTaP-IPV vaccination coverage, we found similar results; these are appended in Supplementary Figure S4.

Determinants of Childhood Vaccination Coverage

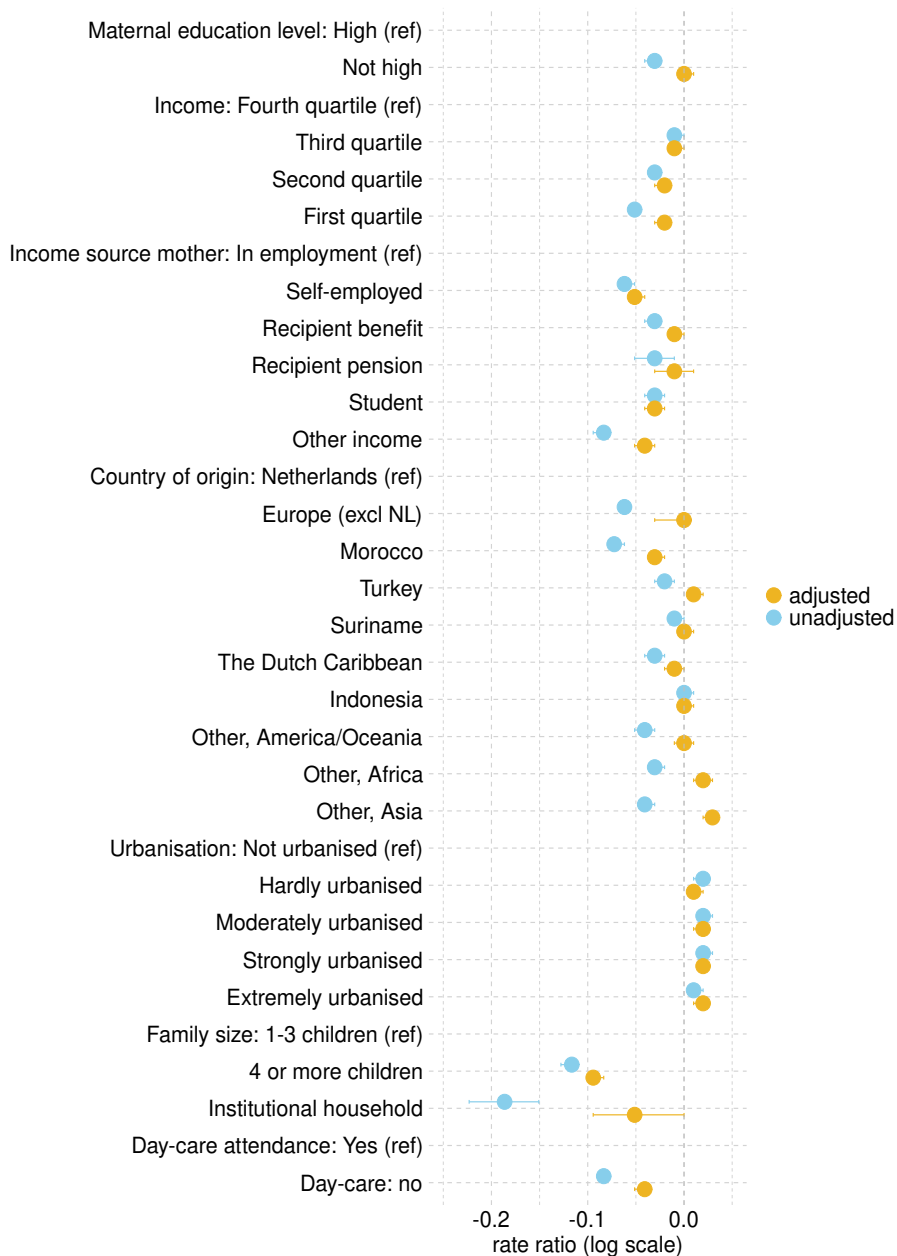


Figure 2. Unadjusted and adjusted rate ratios for measles-mumps-rubella vaccination coverage by sociodemographic factors, the Netherlands, children born 2008–2020 (n = 2,242,990)

ref: reference.

In addition to all the variables listed, the RRs are also adjusted for birth cohort.

Chapter 2

Changes in sociodemographic factors associated with vaccination coverage over time

The multivariable regression model including interaction terms for birth cohort revealed significant variations in MMR vaccination coverage over time; the extensive model can be found in Supplementary Table S5. Figure 3 presents the relative changes in vaccination coverage across sociodemographic groups relative to cohort 2008, calculated based on the estimates from the model and adjusted for baseline coverage and all sociodemographic variables. Country of origin played a significant role, with Dutch children of Moroccan origin having the most pronounced decline in coverage compared with Dutch children of Dutch origin, starting from a 4% higher coverage in cohort 2009 to a 25% lower coverage in cohort 2020. Dutch children of Turkish origin also showed a substantial decrease in coverage, with a 4% higher coverage in cohort 2009 and a 12% lower coverage in cohort 2020, compared with Dutch children of Dutch origin. Other notable declines were observed among Dutch children of Dutch Caribbean origin (–9% in cohort 2020) and Dutch children of Surinamese origin (–7% in cohort 2020). Daycare attendance and family size were also significantly associated with differential changes in vaccination coverage. Children not attending daycare had increasingly lower coverage compared with children attending daycare (–3% in cohort 2009 and –12% in cohort 2020). No significant differential changes in vaccination coverage over time were found for maternal educational level, urbanisation level and household size. Children living in families with four or more children, however, consistently had a lower vaccination coverage than children living in smaller families, with the largest difference in cohort 2020 (–12%). However, these differences have remained stable over time. Socioeconomic disparities were observed and became slightly wider in cohort 2020, with consistently lower coverage among children of self-employed mothers compared with children of mothers with a job in employment (–8% in cohort 2020) and lower coverage among children in the lowest income households compared with the highest income households (–7% in cohort 2020).

We append in Supplementary Table S5 a sensitivity analysis including missing values, which showed minimal changes in the model estimates. Regarding DTaP-IPV vaccination, similar trends were observed; the multivariable model for this can be found in Supplementary Table S4 and the adjusted relative changes in DTaP-IPV vaccination over time in Supplementary Table S6.

Determinants of Childhood Vaccination Coverage

Birth cohort	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Education level mother (reference: high)												
Not high	0.13	0.29	0.05	-0.38	-0.41	-1.01	-1.51	-1.34	-1.02	-1.10	-0.42	-2.69
Household standardised disposable income quartiles (reference: fourth quartile)												
First	-1.64	-1.80	-2.33	-2.42	-3.20	-4.02	-5.32	-5.57*	-4.65	-4.30	-5.11*	-7.20*
Second	-1.00	-1.46	-1.80	-2.14	-2.99	-4.03	-5.05	-5.02*	-4.12*	-4.14*	-3.97*	-5.92*
Third	-0.33	-0.68	-0.88	-1.27	-1.76	-2.61	-3.67	-3.15	-2.36	-2.16	-1.61	-2.87
Income source mother (reference: job in employment)												
Self-employed	-4.04	-4.21	-4.42	-5.05	-5.92	-7.31	-8.11	-7.84*	-5.84	-6.22	-5.80	-8.05*
Benefit recipient	-0.76	-0.13	-0.72	-0.74	-1.32	-3.06	-4.75	-2.94	-1.38	-0.95	-0.35	-2.15
Pension recipient	-1.26	-1.22	-2.05	-2.66	-4.70	-4.62	-7.23	-3.77	-3.59	-2.61	0.11	-5.63
Student	-2.31	-1.82	-2.30	-2.83	-2.81	-5.07	-7.95	-6.78	-4.40	-4.39	-4.52	-7.95
Other	-5.15	-5.05	-5.10	-5.55	-5.71	-6.57	-6.80	-5.34	-4.82	-4.80	-2.64	-2.10*
Country of origin (reference: the Netherlands)												
Europe excl. Netherlands	-0.57	-0.61	-0.80	-1.12	-1.61	-2.25	-2.99	-2.79	-1.92	-1.84	-1.36	-3.16
Indonesia	0.37	0.36	-0.30	-0.20	-0.59	-1.43	-2.03	-1.65	-0.66	-1.00	-1.24	-2.62
Morocco	4.05	4.78	3.73	3.33	1.90	-0.58	-5.11*	-7.04*	-7.25*	-10.05*	-17.74*	-25.41*
Other, Africa	0.18	1.15	2.03	1.15	1.86	-0.33	0.20	0.63	1.00	1.35	1.00	-1.56
Other, America/Oceania	-1.25	-0.69	-1.14	-1.75	-1.52	-2.49	-3.06	-2.04	-1.19	-1.23	-1.07	-2.61
Other, Asia	1.32	2.42	2.03	1.55	1.42	0.14	-1.87	0.46	2.23	2.28	3.30	2.03
Suriname	1.15	1.44	1.02	1.03	0.52	0.21	-1.59	-2.57	-1.23	-2.66	-3.83*	-7.05*
The Dutch Caribbean	0.84	0.51	0.56	-0.07	-0.08	-0.77	-1.87	-3.35	-2.11	-3.82	-5.02	-8.70*
Türkiye	3.68	4.31	3.77	3.66	3.61	2.56	0.40	-1.17	-1.48	-2.47*	-7.19*	-11.55*
Level of urbanisation (reference: not urbanised)												
Extremely	0.74	0.65	0.67	0.52	0.58	-0.22	-0.18	0.51	0.71	1.18	1.28	-0.51
Strongly	1.19	1.25	1.14	0.91	0.44	0.00	-0.24	0.35	0.93	1.68	1.67	0.66
Moderately	1.06	1.23	1.01	0.91	0.51	-0.04	-0.36	0.44	0.65	0.90	1.31	0.24
Hardly	1.04	0.91	0.67	0.32	-0.49	-1.05	-1.91	-1.00	-0.25	0.55	1.05	-0.37
Family size (reference: 1-3 children)												
≥ 4 children	-8.73	-8.84	-8.70	-9.66	-9.15	-10.78	-11.30	-10.09	-8.78	-9.77	-9.12	-12.00
Institutional	-0.73	-4.21	-5.76	-2.33	-3.31	-8.66	-8.66	-7.51	-6.31	-3.97	-9.21	-3.99
Daycare attendance (reference: daycare yes)												
Daycare no	-2.61	-2.91	-3.18	-3.70	-4.38	-5.67	-6.55*	-7.13*	-7.20*	-8.11*	-8.60*	-11.98*

Figure 3. Adjusted relative change in measles-mumps-rubella vaccination coverage compared with the reference cohort 2008 for each stratum of the covariates, based on the rate ratios derived from the multivariable regression model with interaction terms for birth cohort, the Netherlands, children born 2008-2020 (n = 2,242,990)

* Significant values ($p < 0.05$).

Chapter 2

Discussion

Our study revealed a substantial decline in MMR and DTaP-IPV vaccination coverage in the Netherlands from birth cohort 2008 to 2020, with a more pronounced and faster decline observed in specific sociodemographic subgroups. This trend increases the risk for outbreaks of vaccine preventable diseases and indicates rising inequity in vaccination coverage. This study presents an application of the situation analysis phase of the WHO TIP framework [14-16]. Further research within the SocioVax programme will explore barriers and drivers of vaccination in subgroups with lower coverage [21].

The general decline in vaccination coverage in the Netherlands is consistent with trends reported in other countries [3,22]. The coverage for the first dose of measles-containing vaccine in the European Union and European Economic Area decreased from 95% in 2018 to 92% in 2022 [23]. Widening inequities in childhood vaccination have also been reported in the United Kingdom, particularly with regards to ethnicity and deprivation level [24-26].

General explanations for the decline in vaccination coverage include distrust in vaccines and governmental organisations, misinformation, and the influence of social media [27-29]. Studies link reduced vaccination uptake to scepticism towards governmental policies and lack of confidence in vaccines [29]. The COVID-19 pandemic may have exacerbated these issues, and targeted strategies may be required to promote vaccination uptake in the post-pandemic era [30,31]. Trust in governmental institutions among people in the Netherlands in 2022 was below the pre-pandemic level, especially among individuals with a lower education level, and was associated with lower COVID-19 vaccine uptake [32]. Parental perceptions about childhood vaccination also became slightly more negative after the pandemic [33], although coverage had already been declining earlier. Social media also play a role in the spread of misinformation. Research on Dutch Twitter activity in 2019 showed how anti-vaccine narratives gained attention and influenced public opinion [28]. Because of selective exposure, individuals with more sceptical attitudes towards vaccination are more likely to encounter negative messages about vaccination, reinforcing their views [28]. The anti-vaccination message on the Internet is much less restrained than on other media, which makes it more likely that the public takes uninformed decisions about vaccination [27].

Crucially, our findings indicate that specific sociodemographic groups experience a more pronounced and faster decrease in vaccination coverage. The most substantial relative declines were observed among Dutch children of non-Dutch origin, children not attending daycare, those with self-employed mothers and children in the lowest income households. Vaccination coverage declined notably among Dutch children with a migration background, specifically children of Moroccan, Turkish, Dutch-Caribbean and Surinamese origin, also after adjusting for other variables. These findings are

consistent with earlier studies in the Netherlands on NIP coverage at national and municipal levels [10,13]. The potential social clustering of unvaccinated children within these populations poses public health risks by increasing outbreak potential [34]. Several qualitative studies have been conducted to provide further insights in reasons behind lower vaccination coverage among Dutch children with a migration background. The results of a focus group study among parents of Moroccan and Turkish origin in 2015 indicated difficulty in understanding information about the NIP and in reaching vaccination locations (i.e. child welfare centres) as important practical barriers to vaccination [35]. In the same study, some parents mentioned that limited consultation time restricted their opportunity to ask questions about vaccinations [35]. Other reasons may be equally or more important given that Morocco currently is experiencing a large measles epidemic, following declining vaccination rates after the COVID-19 pandemic [36]. Unlike objections in the Orthodox Reformed population [5], no clear Islamic religious objection to vaccination has been identified [35,37,38]. While some studies mention violation of dietary laws (e.g. non-halal-based vaccines), we found no difference between MMR (where one of the two widely used vaccine contains porcine gelatine and is therefore non-halal) and DTaP-IPV (halal vaccines) coverage.

Moreover, children not attending daycare showed lower vaccination coverage. A Canadian systematic review found varying associations between daycare attendance and infant vaccination uptake [39]. In the Dutch context, even though vaccination is not required for daycare attendance, parents are often asked about their child's vaccination status, which may influence their vaccination decision. As daycare attendance is likely to be associated with other sociodemographic variables, there may be residual confounding after adjusting for available information. Because of close contacts among children, daycare centres can be significant hotspots for infectious disease transmission, thus the higher vaccination coverage in these settings is advantageous for preventing outbreaks.

Children living in larger families (≥ 4 children) had lower vaccination coverage than those in smaller families. This may partly be explained by the higher prevalence of large households within the Orthodox Protestant communities, where vaccine hesitancy is more common [5,40]. Furthermore, our data showed larger families are more common in Dutch children of Moroccan origin and in lower income groups, both associated with lower vaccine coverage. Statistics the Netherlands reports Dutch women of Moroccan origin have, on average, two children, compared with 1.5 among Dutch women of Dutch origin [41]. Although lower income was historically associated with larger family size, recent trends suggest higher income is becoming an increasingly important factor for having more children, specifically for mothers [42].

The socioeconomic disparities observed in our study are consistent with findings

Chapter 2

from previous research. Systematic reviews reported persisting lower routine childhood vaccination coverage among children with lower parental socioeconomic status [43,44]. Contrary to low- and middle-income countries where (financial) access is often a barrier to vaccine uptake in lower socioeconomic groups, economic disparities in high-income countries may be more related to issues of perceived risks (both of the diseases against which vaccines protect as well as of the vaccines themselves), trust in the government and in healthcare professionals, and vaccine confidence [43,44]. However, to address these disparities, the effects of factors on vaccine uptake among people from lower socioeconomic positions need further research to investigate underlying causes.

While we described some findings about underlying factors from research in the general population it is unclear whether, and to what extent, these same factors play a role in the vaccination uptake of people from these specific subgroups. To address this, future studies within the SocioVax programme will involve members of target groups in the design and implementation phases to jointly develop research that investigates barriers and drivers of vaccination in subgroups with lower coverage [21].

Low coverage becomes a notable problem especially when unvaccinated individuals cluster. For example, children with similar migration backgrounds may cluster within households, families, schools and geographically (e.g. larger cities). This social clustering potentially creates environments where infections spread more easily. Therefore, further research to investigate networks of unvaccinated and nonimmune individuals is needed to assess the risk of spread of vaccine-preventable diseases.

A strength of our study is the use of nationwide registry data and the possibility to link vaccination data at individual level, avoiding ecological fallacies that may result from aggregated data. The results provide a comprehensive understanding of factors influencing changes in vaccination coverage and help identify potential risk groups for disease outbreaks. A limitation is the requirement for informed consent for registration in the national immunisation register for a subset of children born in 2020. Children who could not be linked to the vaccination database were categorised as unvaccinated. This may be differential between subgroups (data on characteristics of parents not providing consent are not available). However, the effect is limited. For MMR vaccination, only children born in November and December (approximately one sixth of the 2020 cohort) were scheduled for vaccination after the introduction of the informed consent in January 2022. For the DTaP-IPV vaccination, all children born in 2020 were scheduled for vaccination before the introduction of the informed consent. The percentage of parents not providing informed consent for vaccination was 3.1% for DTaP-IPV and 4.5% for MMR in 2022 [45]. Another limitation is that children with unknown sociodemographic information, often born abroad, had much lower registered vaccination coverage, possibly due to unrecorded vaccinations

Determinants of Childhood Vaccination Coverage

received outside the Netherlands. However, missing values were below 3%, and a sensitivity analysis including these unknown categories showed no impact on the results. Finally, the 2019 and 2020 cohorts were the first to be vaccinated during the COVID-19 pandemic, which may have caused delays. Nonetheless, when vaccination status was assessed at age 3 years instead of 2 years, overall coverage for these cohorts remained unchanged. Another limitation of this study is that our findings are based on the Dutch NIP and national context, which may limit their direct applicability to other countries. Nevertheless, as countries are facing similar challenges with declining vaccination coverage and persisting health inequalities, our analytical approach and the sociodemographic determinants identified in this may offer valuable insights.

2

Conclusion

We found a substantial decline in MMR and DTaP-IPV childhood vaccination coverage in the Netherlands, with increasing disparities between sociodemographic strata. The potential social clustering of these unvaccinated children increases the risk of localised outbreaks. Future research should focus on understanding the underlying reasons for non-uptake of childhood vaccinations, focusing on populations with lower uptake, according to the WHO TIP framework. Social science research can inform interventions with the aim to increase childhood vaccination coverage.

References

1. Shattock AJ, Johnson HC, Sim SY, Carter A, Lambach P, Hutubessy RCW, et al. Contribution of vaccination to improved survival and health: modelling 50 years of the Expanded Programme on Immunization. *Lancet*. 2024;403(10441):2307-16. [https://doi.org/10.1016/S0140-6736\(24\)00850-X](https://doi.org/10.1016/S0140-6736(24)00850-X) PMID: 38705159
2. van Wijhe M, McDonald SA, de Melker HE, Postma MJ, Wallinga J. Effect of vaccination programmes on mortality burden among children and young adults in the Netherlands during the 20th century: a historical analysis. *Lancet Infect Dis*. 2016;16(5):592-8. [https://doi.org/10.1016/S1473-3099\(16\)00027-X](https://doi.org/10.1016/S1473-3099(16)00027-X) PMID: 26873665
3. Alexander C, Cabrera M, Moore M, Lomazzi M. Driving paediatric vaccine recovery in Europe. *Vaccines (Basel)*. 2023;11(1):184. <https://doi.org/10.3390/vaccines11010184> PMID: 36680028
4. van Lier A, Hament J-M, Knijff M, Westra M, Giesbers H, Drijfhout I, et al. Vaccinatiegraad en jaarverslag Rijksvaccinatieprogramma Nederland 2023. [Vaccination coverage and annual report of the National Immunisation Programme in the Netherlands, 2023]. Bilthoven: Rijksinstituut voor Volksgezondheid en Milieu; 2024. Dutch.
5. Ruijs WL, Hautvast JL, van der Velden K, de Vos S, Knippenberg H, Hulscher ME. Religious subgroups influencing vaccination coverage in the Dutch Bible belt: an ecological study. *BMC Public Health*. 2011;11(1):102. <https://doi.org/10.1186/1471-2458-11-102> PMID: 21320348
6. Ruijs WLM, Hautvast JLA, van Ijzendoorn G, van Ansem WJC, van der Velden K, Hulscher MEJL. How orthodox protestant parents decide on the vaccination of their children: a qualitative study. *BMC Public Health*. 2012;12(1):408. <https://doi.org/10.1186/1471-2458-12-408> PMID: 22672710
7. Lanza-León P, Cantarero-Prieto D, Pascual-Sáez M. Exploring trends and determinants of basic childhood vaccination coverage: Empirical evidence over 41 years. *PLoS One*. 2024;19(3):e0300404. <https://doi.org/10.1371/journal.pone.0300404> PMID: 38512892
8. Tauil MC, Sato AP, Waldman EA. Factors associated with incomplete or delayed vaccination across countries: A systematic review. *Vaccine*. 2016;34(24):2635-43. <https://doi.org/10.1016/j.vaccine.2016.04.016> PMID: 27109562
9. Brown KF, Kroll JS, Hudson MJ, Ramsay M, Green J, Long SJ, et al. Factors underlying parental decisions about combination childhood vaccinations including MMR: a systematic review. *Vaccine*. 2010;28(26):4235-48. <https://doi.org/10.1016/j.vaccine.2010.04.052> PMID: 20438879
10. van Lier A, van de Kasstelee J, de Hoogh P, Drijfhout I, de Melker H. Vaccine uptake determinants in The Netherlands. *Eur J Public Health*. 2014;24(2):304-9. <https://doi.org/10.1093/eurpub/ckt042> PMID: 23531526
11. de Munter AC, Klooster TMST, van Lier A, Akkermans R, de Melker HE, Ruijs WLM. Determinants of HPV-vaccination uptake and subgroups with a lower uptake in the Netherlands. *BMC Public Health*. 2021;21(1):1848. <https://doi.org/10.1186/s12889-021-11897-0> PMID: 34641851
12. Rondy M, van Lier A, van de Kasstelee J, Rust L, de Melker H. Determinants for HPV vaccine uptake in the Netherlands: A multilevel study. *Vaccine*. 2010;28(9):2070-5. <https://doi.org/10.1016/j.vaccine.2009.12.042> PMID: 20045095
13. de Oliveira Bressane Lima P, van Lier A, de Melker H, Ferreira JA, van Vliet H, Knol MJ. MenACWY vaccination campaign for adolescents in the Netherlands: Uptake and its de-

- terminants. *Vaccine*. 2020;38(34):5516-24. <https://doi.org/10.1016/j.vaccine.2020.05.087> PMID: 32593605
14. World Health Organization Office for Europe (WHO/Europe). TIP: tailoring immunization programmes. Copenhagen: WHO/Europe; 2019. Available from: <https://www.who.int/europe/publications/i/item/9789289054492>
15. World Health Organization Office for Europe (WHO/Europe). A guide to tailoring health programmes : using behavioural and cultural insights to tailor health policies, services and communications to the needs and circumstances of people and communities. Copenhagen: WHO/Europe; 2023. Available from: <https://www.who.int/europe/publications/i/item/9789289058919>
16. World Health Organization Office for Europe (WHO/Europe). A practical guide to identifying, addressing and tracking inequities in immunization. Copenhagen: WHO/Europe; 2024. Available from: <https://www.who.int/europe/publications/i/item/WHO-EURO-2024-9917-49689-74446>
17. van Lier A, Oomen P, de Hoogh P, Drijfhout I, Elsinghorst B, Kemmeren J, et al. *Præventis*, the immunisation register of the Netherlands: a tool to evaluate the National Immunisation Programme. *Euro Surveill*. 2012;17(17):20153. <https://doi.org/10.2807/ese.17.17.20153-en> PMID: 22551495
18. Bakker BFM, van Rooijen J, Toor L. The system of social statistical datasets of Statistics Netherlands: An integral approach to the production of register-based social statistics. *Stat J IAOS*. 2014;30(4):411-24. <https://doi.org/10.3233/SJI-140803>
19. R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2020. Available from: <https://www.R-project.org>
20. Cuschieri S. The STROBE guidelines. *Saudi J Anaesth*. 2019;13(5) Suppl 1:S31-4. https://doi.org/10.4103/sja.SJA_543_18 PMID: 30930717
21. Rijksinstituut voor Volksgezondheid en Milieu (RIVM). SocioVax: social science research on vaccination. Bilthoven: RIVM. [Accessed: 28 Feb 2025]. Available from: <https://www.rivm.nl/en/behavioural-science/sociovox>
22. Montalti M, Kawalec A, Leoni E, Dallolio L. Measles Immunization Policies and Vaccination Coverage in EU/EEA Countries over the Last Decade. *Vaccines (Basel)*. 2020;8(1):86. <https://doi.org/10.3390/vaccines8010086> PMID: 32075206
23. European Centre for Disease Prevention and Control (ECDC). Threat assessment brief: Measles on the rise in the EU/EEA: considerations for public health response. Stockholm: ECDC; 2024. Available from: <https://www.ecdc.europa.eu/en/publications-data/threat-assessment-brief-measles-rise-eueea-considerations-public-health-response>
24. Zhang CX, Bankhead C, Quigley MA, Kwok CH, Carson C. Ethnic inequities in routine childhood vaccinations in England 2006-2021: an observational cohort study using electronic health records. *EClinicalMedicine*. 2023;65:102281. <https://doi.org/10.1016/j.eclinm.2023.102281> PMID: 37965428
25. Flatt A, Vivancos R, French N, Quinn S, Ashton M, Decraene V, et al. Inequalities in uptake of childhood vaccination in England, 2019-23: longitudinal study. *BMJ*. 2024;387:e079550. <https://doi.org/10.1136/bmj-2024-079550> PMID: 39662974
26. Perry M, Cottrell S, Gravenor MB, Griffiths L. Determinants of equity in coverage of measles-containing vaccines in Wales, UK, during the elimination era. *Vaccines (Basel)*. 2023;11(3):680. <https://doi.org/10.3390/vaccines11030680> PMID: 36992264
27. Larson HJ, Gakidou E, Murray CJL. The Vaccine-Hesitant Moment. *N Engl J Med*.

Chapter 2

- 2022;387(1):58-65. <https://doi.org/10.1056/NEJMra2106441> PMID: 35767527
28. Lutkenhaus RO, Jansz J, Bouman MPA. Mapping the Dutch vaccination debate on Twitter: Identifying communities, narratives, and interactions. *Vaccine X*. 2019;1:100019. <https://doi.org/10.1016/j.jvax.2019.100019> PMID: 31485580
29. Wiegand M, Eagan RL, Karimov R, Lin L, Larson HJ, de Figueiredo A. Global declines in vaccine confidence from 2015 to 2022: a large-scale retrospective analysis. *SSRN*. 2023;4438003 <http://dx.doi.org/> <https://doi.org/10.2139/ssrn.4438003>
30. Pennisi F, Genovese C, Gianfredi V. Lessons from the COVID-19 pandemic: promoting vaccination and public health resilience, a narrative review. *Vaccines (Basel)*. 2024;12(8):891. <https://doi.org/10.3390/vaccines12080891> PMID: 39204017
31. Omar M, Shibli H, Edelstein M. Comparative impact of the COVID-19 pandemic on parental behaviour towards childhood vaccination in Israel and the United Kingdom: A self-controlled matched cross-sectional study. *Vaccine*. 2025;61:127385. <https://doi.org/10.1016/j.vaccine.2025.127385> PMID: 40499347
32. Derksen E, Janssen L, Tummers-van der Aa M. COVID-19-vaccinatiegedrag. [COVID-19 vaccination behaviour]. The Hague: Centraal Bureau voor de Statistiek; 2023. Dutch. Available from: <https://www.cbs.nl/nl-nl/longread/rapportages/2023/covid-19-vaccinatiegedrag>
33. Knijff M, van Lier A, Boer M, de Vries M, Hament J-M, de Melker HE. Parental intention, attitudes, beliefs, trust and deliberation towards childhood vaccination in the Netherlands in 2022: Indications of change compared to 2013. *Vaccine*. 2024;42(4):801-11. <https://doi.org/10.1016/j.vaccine.2023.12.080> PMID: 38216441
34. Scholtes A. Raadsinformatiebrief. Stand van zaken uitvoering Rijksvaccinatieprogramma (RVP) Amsterdam. [Council information letter. Status of the implementation of the national vaccination programme in Amsterdam]. Amsterdam: Gemeente Amsterdam; 2023. Dutch. Available from: <https://amsterdam.raadsinformatie.nl/document/12813205/1#-search=%22rijksvaccinatieprogramma%20uitvoering%22>
35. Harmsen IA, Bos H, Ruiter RAC, Paulussen TGW, Kok G, de Melker HE, et al. Vaccination decision-making of immigrant parents in the Netherlands; a focus group study. *BMC Public Health*. 2015;15(1):1229. <https://doi.org/10.1186/s12889-015-2572-x> PMID: 26654538
36. Naim F. Measles crisis in Morocco: 19,000+ cases and 107 deaths recorded since 2023. Rabat: Morocco World News. 2024. Available from: <https://www.moroccoworldnews.com/2024/12/166569/measles-crisis-in-morocco-19-000-cases-and-107-deaths-recorded-since-2023>
37. Global Polio Eradication Initiative. Islamic advisory group supports final push for polio eradication. Geneva: World Health Organization; 2016 . Available from: <https://polioeradication.org/news/islamic-advisory-group-supports-final-push-for-polio-eradication>
38. Alsuwaidi AR, Hammad HAA, Elbarazi I, Sheek-Hussein M. Vaccine hesitancy within the Muslim community: Islamic faith and public health perspectives. *Hum Vaccin Immunother*. 2023;19(1):2190716. <https://doi.org/10.1080/21645515.2023.2190716> PMID: 36914409
39. Schellenberg N, Crizzle AM. Vaccine hesitancy among parents of preschoolers in Canada: a systematic literature review. *Can J Public Health*. 2020;111(4):562-84. <https://doi.org/10.17269/s41997-020-00390-7> PMID: 32783144
40. Woudenberg T, van Binnendijk RS, Sanders EAM, Wallinga J, de Melker HE, Ruijs WLM, et al. Large measles epidemic in the Netherlands, May 2013 to March 2014: changing epidemiology. *Euro Surveill*. 2017;22(3):30443. <https://doi.org/10.2807/1560-7917.ES.2017.22.3.30443> PMID: 28128092

Determinants of Childhood Vaccination Coverage

41. Centraal Bureau voor de Statistiek (CBS). Integratie en samenleven 2024. [Integration and coexistence report 2024]. The Hague: CBS; 2024. Dutch. Available from: <https://www.cbs.nl/nl-nl/publicatie/2024/47/rapportage-integratie-en-samenleven-2024>
42. Van Wijk D, Billari FC. Fertility postponement, economic uncertainty, and the increasing income prerequisites of parenthood. *Popul Dev Rev.* 2024;50(2):287-322. <https://doi.org/10.1111/padr.12624>
43. Bocquier A, Ward J, Raude J, Peretti-Watel P, Verger P. Socioeconomic differences in childhood vaccination in developed countries: a systematic review of quantitative studies. *Expert Rev Vaccines.* 2017;16(11):1107-18. <https://doi.org/10.1080/14760584.2017.1381020> PMID: 28914112
44. de Figueiredo A, Johnston IG, Smith DM, Agarwal S, Larson HJ, Jones NS. Forecasted trends in vaccination coverage and correlations with socioeconomic factors: a global time-series analysis over 30 years. *Lancet Glob Health.* 2016;4(10):e726-35. [https://doi.org/10.1016/S2214-109X\(16\)30167-X](https://doi.org/10.1016/S2214-109X(16)30167-X) PMID: 27569362
45. van Lier A, Hament J-M, Knijff M, Westra M, Ernst A, Giesbers H, et al. Vaccinatiegraad en jaarverslag Rijksvaccinatieprogramma Nederland 2022. [Vaccination coverage and annual report of the National Immunisation Programme in the Netherlands, 2022]. Bilthoven: Rijksinstituut voor Volksgezondheid en Milieu; 2023. Dutch. Available from: <https://www.rivm.nl/publicaties/vaccinatiegraad-en-jaarverslag-rijksvaccinatieprogramma-nederland-2022>

Supplementary material

Supplementary Table S1. MMR and DTaP-IPV vaccination schedule in the Netherlands in 2022

	Age	Vaccine	Vaccination status	Schedule changes
Phase 1 – Infants	2 months	DTaP-IPV	Primary series	Since the introduction of maternal pertussis vaccination in 2019, this vaccination can be skipped in case the mother is vaccinated.
	3 months	DTaP-IPV	Primary series	-
	5 months	DTaP-IPV	Primary series	-
	11 months	DTaP-IPV booster	Basic immunity	-
	14 months	MMR	Basic immunity	-
Phase 2 – Pre-school	4 years	DTaP-IPV booster	Revaccinated	-
Phase 3 – School age	9 years	DT-IPV	Fully vaccinated	-
	9 years	MMR	Fully vaccinated	-

Abbreviations: MMR Measles-Mumps-Rubella, DTaP-IPV Diphtheria-Tetanus-Pertussis-Poliomyelitis

Source: National Immunisation Programme | RIVM

Determinants of Childhood Vaccination Coverage

Supplementary Table S2. Distribution sociodemographic variables and MMR and DTaP-IPV vaccination coverage per birth cohort

Category	MMR popu- lation	Vaccinated		DTaP- IPV popu- lation	Vaccinated		Category	MMR popu- lation	Vaccinated		DTaP- IPV popu- lation	Vaccinated	
	N	N	%	N	N	%		N	N	%	N	N	%
Education level mother													
High							Intermediate						
Cohort 2008	55314	53742	97	55265	53619	97	Cohort 2008	40155	38877	97	40120	38698	96
Cohort 2009	58417	56784	97	58371	56674	97	Cohort 2009	43837	42431	97	43810	42223	96
Cohort 2010	60797	59028	97	60762	58905	97	Cohort 2010	47775	46229	97	47745	46018	96
Cohort 2011	67581	65501	97	67542	65440	97	Cohort 2011	51776	50083	97	51752	49919	96
Cohort 2012	67717	65440	97	67658	65372	97	Cohort 2012	53284	51260	96	53251	51121	96
Cohort 2013	67827	65115	96	67780	65335	96	Cohort 2013	54219	51701	95	54197	51920	96
Cohort 2014	70118	66677	95	70060	67062	96	Cohort 2014	58034	54628	94	58004	55115	95
Cohort 2015	69658	65574	94	69604	66144	95	Cohort 2015	58154	53904	93	58121	54522	94
Cohort 2016	71439	67530	95	71381	67673	95	Cohort 2016	60073	55373	92	60042	55760	93
Cohort 2017	71475	68213	95	71430	68078	95	Cohort 2017	60144	55808	93	60118	55836	93
Cohort 2018	72076	68993	96	72031	68821	96	Cohort 2018	59755	55305	93	59730	55458	93
Cohort 2019	73178	69616	95	73148	69522	95	Cohort 2019	60875	55291	91	60863	55713	92
Cohort 2020	73790	68789	93	73753	69406	94	Cohort 2020	60872	52946	87	60851	54039	89
Low							Unknown						
Cohort 2008	19495	18777	96	19472	18591	95	Cohort 2008	75891	69672	92	76539	68438	89
Cohort 2009	20538	19802	96	20521	19545	95	Cohort 2009	67652	62153	92	68390	61023	89
Cohort 2010	20951	20266	97	20921	20042	96	Cohort 2010	60169	55002	91	60865	54063	89
Cohort 2011	23765	23033	97	23742	22866	96	Cohort 2011	41636	37316	90	42393	36575	86
Cohort 2012	23175	22427	97	23166	22281	96	Cohort 2012	36309	32047	88	37116	31496	85
Cohort 2013	21683	20822	96	21647	20815	96	Cohort 2013	31681	27854	88	32409	27446	85
Cohort 2014	21883	20686	95	21812	20838	96	Cohort 2014	28867	25043	87	29633	24780	84
Cohort 2015	20424	18911	93	20374	19123	94	Cohort 2015	25951	22096	85	26586	21947	83
Cohort 2016	19764	18302	93	19747	18456	93	Cohort 2016	24170	20749	86	24851	20624	83
Cohort 2017	17925	16641	93	17898	16648	93	Cohort 2017	22840	19960	87	23482	19801	84
Cohort 2018	17291	15999	93	17279	16040	93	Cohort 2018	21636	19147	88	22196	19036	86
Cohort 2019	15621	14069	90	15612	14239	91	Cohort 2019	21345	18841	88	21912	18891	86
Cohort 2020	14364	12173	85	14354	12500	87	Cohort 2020	20472	17603	86	20893	17905	86
Standardised disposable income household													
First quartile							Second quartile						
Cohort 2008	29025	27353	94	28978	27030	93	Cohort 2008	58480	56286	96	58438	55989	96
Cohort 2009	28916	27197	94	28844	26831	93	Cohort 2009	57046	54864	96	57025	54642	96
Cohort 2010	28991	27382	94	28925	27075	94	Cohort 2010	54402	52197	96	54365	51910	95
Cohort 2011	27754	26167	94	27697	26002	94	Cohort 2011	51616	49462	96	51598	49257	95
Cohort 2012	26877	25271	94	26838	25112	94	Cohort 2012	49035	46768	95	49003	46585	95
Cohort 2013	25035	23304	93	24969	23263	93	Cohort 2013	46153	43581	94	46137	43705	95

Chapter 2

Category	MMR popu- lation			DTaP- IPV popu- lation			Category	MMR popu- lation			DTaP- IPV popu- lation		
	N	N	%	N	N	%		N	N	%	N	N	%
Cohort 2014	24806	22720	92	24730	22820	92	Cohort 2014	47911	44643	93	47889	45000	94
Cohort 2015	22868	20455	89	22782	20626	91	Cohort 2015	47018	43119	92	46980	43578	93
Cohort 2016	22806	20298	89	22735	20382	90	Cohort 2016	48674	44501	91	48645	44747	92
Cohort 2017	21171	18963	90	21096	18817	89	Cohort 2017	47119	43384	92	47074	43362	92
Cohort 2018	20718	18549	90	20673	18540	90	Cohort 2018	46632	42836	92	46594	42773	92
Cohort 2019	19229	16641	87	19223	16834	88	Cohort 2019	46870	42352	90	46879	42575	91
Cohort 2020	18502	15082	82	18442	15414	84	Cohort 2020	44864	38765	86	44827	39585	88
Third quartile							Fourth quartile						
Cohort 2008	56445	54740	97	56385	54556	97	Cohort 2008	39762	38652	97	39717	38368	97
Cohort 2009	57012	55494	97	56981	55253	97	Cohort 2009	40547	39409	97	40504	39149	97
Cohort 2010	57237	55666	97	57196	55467	97	Cohort 2010	42067	41001	97	42027	40773	97
Cohort 2011	57771	56244	97	57755	56122	97	Cohort 2011	41049	39943	97	41008	39755	97
Cohort 2012	57084	55284	97	57062	55153	97	Cohort 2012	41087	39862	97	41026	39689	97
Cohort 2013	56781	54708	96	56762	54872	97	Cohort 2013	41634	40244	97	41556	40214	97
Cohort 2014	58602	55909	95	58520	56206	96	Cohort 2014	42141	40325	96	42071	40450	96
Cohort 2015	58006	54571	94	57902	55017	95	Cohort 2015	41288	39221	95	41197	39410	96
Cohort 2016	58542	55297	94	58464	55447	95	Cohort 2016	41122	39226	95	41056	39220	96
Cohort 2017	59987	57072	95	59938	56987	95	Cohort 2017	40424	38902	96	40373	38764	96
Cohort 2018	59755	57031	95	59691	57015	96	Cohort 2018	40354	38880	96	40254	38722	96
Cohort 2019	60585	57331	95	60553	57396	95	Cohort 2019	41085	39390	96	41029	39255	96
Cohort 2020	60592	55798	92	60547	56468	93	Cohort 2020	43395	40645	94	43314	40942	95
Unknown													
Cohort 2008	7143	4037	57	7878	3403	43							
Cohort 2009	6923	4206	61	7738	3590	46							
Cohort 2010	6995	4279	61	7780	3803	49							
Cohort 2011	6568	4117	63	7371	3664	50							
Cohort 2012	6402	3989	62	7262	3731	51							
Cohort 2013	5807	3655	63	6609	3462	52							
Cohort 2014	5442	3437	63	6299	3319	53							
Cohort 2015	5007	3119	62	5824	3105	53							
Cohort 2016	4302	2632	61	5121	2717	53							
Cohort 2017	3683	2301	62	4447	2433	55							
Cohort 2018	3299	2148	65	4024	2305	57							
Cohort 2019	3250	2103	65	3851	2305	60							
Cohort 2020	2145	1221	57	2721	1441	53							
Income source mother													
Job in employment							Self-employed						
Cohort 2008	126454	123593	98	126369	123045	97	Cohort 2008	13017	12196	94	12997	12202	94
Cohort 2009	126154	123321	98	126070	122821	97	Cohort 2009	13026	12134	93	13014	12126	93
Cohort 2010	123131	120277	98	123051	119800	97	Cohort 2010	13209	12289	93	13198	12289	93
Cohort 2011	118906	116056	98	118860	115783	97	Cohort 2011	13170	12257	93	13161	12250	93

Determinants of Childhood Vaccination Coverage

Category	MMR			DTaP-IPV			Category	MMR			DTaP-IPV		
	popu- lation	Vaccinated		popu- lation	Vaccinated			popu- lation	Vaccinated		popu- lation	Vaccinated	
	N	N	%	N	N	%		N	N	%	N	N	%
Cohort 2012	115778	112628	97	115696	112363	97	Cohort 2012	13485	12462	92	13470	12434	92
Cohort 2013	113800	110078	97	113734	110342	97	Cohort 2013	13553	12389	91	13541	12430	92
Cohort 2014	118000	113223	96	117904	113830	97	Cohort 2014	14195	12769	90	14180	12880	91
Cohort 2015	116902	110997	95	116815	111859	96	Cohort 2015	14146	12555	89	14125	12695	90
Cohort 2016	119594	113604	95	119476	113932	95	Cohort 2016	14234	12583	88	14227	12642	89
Cohort 2017	117271	112132	96	117171	112008	96	Cohort 2017	13898	12553	90	13895	12515	90
Cohort 2018	116973	112118	96	116832	111932	96	Cohort 2018	14209	12776	90	14198	12742	90
Cohort 2019	119930	114012	95	119855	114016	95	Cohort 2019	14451	12807	89	14447	12835	89
Cohort 2020	121259	112354	93	121142	113663	94	Cohort 2020	13657	11567	85	13638	11739	86
Recipient benefit						Student							
Cohort 2008	1415	1334	94	1413	1334	94	Cohort 2008	3125	2990	96	3116	2964	95
Cohort 2009	1590	1505	95	1586	1511	95	Cohort 2009	3337	3200	96	3328	3146	95
Cohort 2010	1370	1304	95	1369	1302	95	Cohort 2010	3222	3109	96	3211	3072	96
Cohort 2011	1038	985	95	1037	978	94	Cohort 2011	3228	3119	97	3220	3091	96
Cohort 2012	780	738	95	779	730	94	Cohort 2012	3046	2926	96	3040	2895	95
Cohort 2013	897	827	92	897	841	94	Cohort 2013	2808	2690	96	2802	2701	96
Cohort 2014	846	777	92	844	782	93	Cohort 2014	2619	2446	93	2610	2471	95
Cohort 2015	604	536	89	601	544	91	Cohort 2015	2352	2111	90	2342	2147	92
Cohort 2016	533	481	90	531	478	90	Cohort 2016	2328	2087	90	2320	2110	91
Cohort 2017	473	428	90	470	425	90	Cohort 2017	2361	2177	92	2353	2185	93
Cohort 2018	456	417	91	456	416	91	Cohort 2018	2365	2182	92	2358	2175	92
Cohort 2019	306	277	91	306	278	91	Cohort 2019	2187	1958	90	2185	1980	91
Cohort 2020	267	218	82	267	222	83	Cohort 2020	2452	2058	84	2437	2118	87
Other						Unknown							
Cohort 2008	7235	4051	56	7986	3421	43	Cohort 2008	6682	3590	54	7444	3024	41
Cohort 2009	6944	4135	60	7771	3535	45	Cohort 2009	6344	3647	57	7191	3106	43
Cohort 2010	7005	4205	60	7802	3760	48	Cohort 2010	6344	3640	57	7161	3246	45
Cohort 2011	6732	4183	62	7553	3751	50	Cohort 2011	6098	3649	60	6941	3267	47
Cohort 2012	6529	4000	61	7413	3788	51	Cohort 2012	5960	3511	59	6858	3335	49
Cohort 2013	5906	3703	63	6735	3511	52	Cohort 2013	5324	3187	60	6164	3044	49
Cohort 2014	5454	3414	63	6344	3299	52	Cohort 2014	4899	2929	60	5798	2852	49
Cohort 2015	4965	3021	61	5818	3049	52	Cohort 2015	4510	2672	59	5381	2718	51
Cohort 2016	4277	2580	60	5138	2702	53	Cohort 2016	3877	2277	59	4742	2423	51
Cohort 2017	3616	2219	61	4407	2365	54	Cohort 2017	3294	1967	60	4110	2137	52
Cohort 2018	3185	2031	64	3957	2212	56	Cohort 2018	2836	1751	62	3621	1972	54
Cohort 2019	2993	1907	64	3636	2142	59	Cohort 2019	2680	1672	62	3317	1912	58
Cohort 2020	1606	860	54	2236	1068	48	Cohort 2020	2688	1660	62	2881	1802	63
Country of origin													
The Netherlands						Europe (excl NL)							
Cohort 2008	118975	114700	96	118968	114613	96	Cohort 2008	20717	18316	88	21108	17658	84
Cohort 2009	118260	114019	96	118263	113889	96	Cohort 2009	21197	18990	90	21613	18304	85

Chapter 2

Category	MMR			DTaP-IPV			Category	MMR			DTaP-IPV		
	popu- lation	Vaccinated		popu- lation	Vaccinated			popu- lation	Vaccinated		popu- lation	Vaccinated	
	N	N	%	N	N	%		N	N	%	N	N	%
Cohort 2010	116353	112059	96	116365	111827	96	Cohort 2010	21609	19320	89	21978	18815	86
Cohort 2011	112850	108601	96	112844	108497	96	Cohort 2011	20861	18709	90	21243	18206	86
Cohort 2012	108811	104285	96	108804	104218	96	Cohort 2012	20764	18593	90	21172	18151	86
Cohort 2013	105450	100399	95	105445	100864	96	Cohort 2013	20453	18306	90	20827	17994	86
Cohort 2014	106602	100614	94	106617	101408	95	Cohort 2014	21000	18696	89	21422	18495	86
Cohort 2015	102457	95762	93	102444	96678	94	Cohort 2015	20800	18378	88	21171	18306	86
Cohort 2016	102144	95820	94	102136	96169	94	Cohort 2016	21007	18574	88	21432	18570	87
Cohort 2017	100069	94617	95	100063	94538	94	Cohort 2017	20897	18703	90	21245	18540	87
Cohort 2018	97802	92814	95	97783	92759	95	Cohort 2018	20863	18915	91	21211	18764	88
Cohort 2019	97499	92343	95	97475	92208	95	Cohort 2019	20862	18804	90	21203	18859	89
Cohort 2020	97023	89821	93	96990	90830	94	Cohort 2020	20832	18267	88	21108	18531	88
Indonesia							Morocco						
Cohort 2008	7741	7483	97	7738	7466	96	Cohort 2008	8591	8366	97	8587	8279	96
Cohort 2009	7664	7420	97	7665	7424	97	Cohort 2009	8519	8274	97	8518	8199	96
Cohort 2010	7316	7075	97	7321	7086	97	Cohort 2010	8487	8278	98	8484	8216	97
Cohort 2011	6953	6703	96	6952	6689	96	Cohort 2011	8438	8216	97	8451	8190	97
Cohort 2012	6601	6356	96	6610	6364	96	Cohort 2012	8366	8095	97	8380	8091	97
Cohort 2013	6248	5976	96	6250	6002	96	Cohort 2013	8142	7749	95	8147	7802	96
Cohort 2014	6094	5767	95	6100	5825	95	Cohort 2014	8330	7658	92	8342	7815	94
Cohort 2015	5842	5466	94	5849	5518	94	Cohort 2015	8201	7160	87	8197	7324	89
Cohort 2016	5420	5120	94	5423	5148	95	Cohort 2016	8255	7015	85	8261	7133	86
Cohort 2017	5170	4927	95	5178	4938	95	Cohort 2017	8014	6826	85	8015	6858	86
Cohort 2018	4905	4693	96	4907	4690	96	Cohort 2018	7830	6460	83	7830	6534	83
Cohort 2019	4608	4349	94	4617	4389	95	Cohort 2019	8074	5990	74	8071	6237	77
Cohort 2020	4260	3927	92	4267	3971	93	Cohort 2020	8007	5239	65	8006	5480	68
Türkiye							Suriname						
Cohort 2008	6806	6589	97	6821	6504	95	Cohort 2008	6074	5915	97	6077	5812	96
Cohort 2009	6552	6363	97	6559	6302	96	Cohort 2009	6187	6015	97	6188	5933	96
Cohort 2010	6789	6640	98	6793	6571	97	Cohort 2010	6236	6080	97	6237	6018	96
Cohort 2011	6668	6533	98	6682	6502	97	Cohort 2011	6029	5869	97	6038	5846	97
Cohort 2012	6750	6596	98	6765	6584	97	Cohort 2012	5846	5680	97	5857	5653	97
Cohort 2013	6501	6317	97	6505	6307	97	Cohort 2013	5758	5545	96	5760	5552	96
Cohort 2014	6994	6688	96	6997	6713	96	Cohort 2014	5678	5436	96	5681	5452	96
Cohort 2015	6803	6330	93	6784	6402	94	Cohort 2015	5708	5338	94	5711	5408	95
Cohort 2016	7112	6504	91	7097	6556	92	Cohort 2016	5721	5281	92	5730	5321	93
Cohort 2017	6895	6288	91	6883	6308	92	Cohort 2017	5557	5213	94	5564	5227	94
Cohort 2018	6839	6181	90	6828	6233	91	Cohort 2018	5468	5070	93	5472	5088	93
Cohort 2019	6812	5780	85	6813	5955	87	Cohort 2019	5485	4955	90	5492	5022	91
Cohort 2020	6527	5174	79	6512	5363	82	Cohort 2020	5490	4705	86	5498	4830	88
The Dutch Caribbean							Other, Africa						

Determinants of Childhood Vaccination Coverage

Category	MMR			DTaP-IPV			Category	MMR			DTaP-IPV		
	popu- lation	Vaccinated		popu- lation	Vaccinated			popu- lation	Vaccinated		popu- lation	Vaccinated	
	N	N	%	N	N	%		N	N	%	N	N	%
Cohort 2008	3597	3362	93	3604	3325	92	Cohort 2008	5522	4981	90	5532	4897	89
Cohort 2009	3498	3326	95	3508	3301	94	Cohort 2009	5615	5169	92	5630	5060	90
Cohort 2010	3591	3390	94	3596	3370	94	Cohort 2010	5860	5490	94	5881	5426	92
Cohort 2011	3457	3288	95	3482	3294	95	Cohort 2011	5864	5564	95	5887	5554	94
Cohort 2012	3460	3265	94	3483	3266	94	Cohort 2012	5941	5608	94	5964	5605	94
Cohort 2013	3439	3246	94	3459	3282	95	Cohort 2013	5794	5499	95	5821	5480	94
Cohort 2014	3642	3405	93	3652	3449	94	Cohort 2014	5954	5488	92	5953	5552	93
Cohort 2015	3527	3248	92	3526	3296	93	Cohort 2015	5789	5304	92	5797	5377	93
Cohort 2016	3667	3326	91	3681	3365	91	Cohort 2016	6031	5573	92	6060	5626	93
Cohort 2017	3505	3230	92	3514	3237	92	Cohort 2017	6163	5748	93	6148	5754	94
Cohort 2018	3629	3300	91	3634	3313	91	Cohort 2018	6721	6297	94	6711	6301	94
Cohort 2019	3576	3164	88	3585	3207	89	Cohort 2019	7015	6409	91	7023	6462	92
Cohort 2020	3738	3125	84	3733	3224	86	Cohort 2020	6784	5908	87	6774	6076	90
Other, America/Oceania							Other, Asia						
Cohort 2008	4524	4007	89	4559	3739	82	Cohort 2008	8308	7349	88	8330	7046	85
Cohort 2009	4566	4086	89	4613	3827	83	Cohort 2009	8386	7508	90	8448	7215	85
Cohort 2010	4636	4179	90	4670	3939	84	Cohort 2010	8815	8014	91	8888	7753	87
Cohort 2011	4724	4308	91	4782	4100	86	Cohort 2011	8914	8142	91	9005	7909	88
Cohort 2012	4642	4217	91	4703	4006	85	Cohort 2012	9304	8479	91	9374	8319	89
Cohort 2013	4641	4215	91	4704	4079	87	Cohort 2013	8984	8240	92	9039	8141	90
Cohort 2014	5002	4550	91	5037	4433	88	Cohort 2014	9606	8732	91	9635	8645	90
Cohort 2015	4944	4460	90	5002	4402	88	Cohort 2015	10116	9039	89	10106	9008	89
Cohort 2016	4892	4475	91	4929	4421	90	Cohort 2016	11197	10266	92	11191	10191	91
Cohort 2017	4988	4626	93	5036	4549	90	Cohort 2017	11126	10444	94	11196	10403	93
Cohort 2018	4977	4652	93	5012	4620	92	Cohort 2018	11724	11062	94	11763	11044	94
Cohort 2019	5195	4816	93	5220	4800	92	Cohort 2019	11893	11207	94	11943	11213	94
Cohort 2020	5147	4640	90	5164	4683	91	Cohort 2020	11690	10705	92	11716	10842	93
Generation													
Dutch origin							Migrant or child of migrant(s)						
Cohort 2008	118975	114700	96	118970	114615	96	Cohort 2008	51981	47029	90	52448	45470	87
Cohort 2009	118260	114019	96	118265	113891	96	Cohort 2009	51511	47036	91	52052	45526	87
Cohort 2010	116353	112059	96	116368	111830	96	Cohort 2010	52194	47890	92	52684	46676	89
Cohort 2011	112850	108601	96	112850	108502	96	Cohort 2011	51078	47107	92	51667	46090	89
Cohort 2012	108811	104285	96	108810	104224	96	Cohort 2012	50467	46355	92	51082	45506	89
Cohort 2013	105450	100399	95	105451	100870	96	Cohort 2013	48420	44413	92	48963	43835	90
Cohort 2014	106602	100614	94	106619	101410	95	Cohort 2014	49846	45238	91	50338	44933	89
Cohort 2015	102457	95762	93	102447	96681	94	Cohort 2015	48906	43659	89	49296	43634	89
Cohort 2016	102144	95820	94	102140	96173	94	Cohort 2016	49557	44413	90	50030	44389	89
Cohort 2017	100069	94617	95	100064	94539	94	Cohort 2017	48639	44122	91	49069	43869	89
Cohort 2018	97802	92814	95	97785	92759	95	Cohort 2018	48802	44463	91	49168	44279	90
Cohort 2019	97499	92343	95	97476	92209	95	Cohort 2019	48973	43782	89	49387	44108	89

Chapter 2

Category	MMR popu- lation	Vaccinated	DTaP- IPV popu- lation	Vaccinated	Category	MMR popu- lation	Vaccinated	DTaP- IPV popu- lation	Vaccinated
	N	N	%	N		N	N	%	N
Cohort 2020	97023	89821	93	96991	Cohort 2020	47729	40998	86	47969
Child of second generation migrant(s)									
Cohort 2008	19899	19339	97	19908	19256	97			
Cohort 2009	20673	20115	97	20690	20039	97			
Cohort 2010	21145	20576	97	21164	20518	97			
Cohort 2011	20830	20225	97	20855	20200	97			
Cohort 2012	21207	20534	97	21226	20533	97			
Cohort 2013	21540	20680	96	21549	20804	97			
Cohort 2014	22454	21182	94	22482	21446	95			
Cohort 2015	22824	21064	92	22847	21407	94			
Cohort 2016	23745	21721	91	23774	21942	92			
Cohort 2017	23676	21883	92	23710	21945	93			
Cohort 2018	24154	22167	92	24200	22308	92			
Cohort 2019	24547	21692	88	24580	22036	90			
Cohort 2020	24746	20692	84	24809	21277	86			
Level of urbanisation									
Not urbanised					Hardly urbanised				
Cohort 2008	30407	28842	95	30380	28741	95	Cohort 2008	35156	33954
Cohort 2009	29830	28262	95	29809	28184	95	Cohort 2009	33737	32645
Cohort 2010	28743	27173	95	28717	27038	94	Cohort 2010	32816	31682
Cohort 2011	27401	25862	94	27385	25765	94	Cohort 2011	32141	31009
Cohort 2012	26170	24584	94	26157	24505	94	Cohort 2012	31172	29899
Cohort 2013	24684	23067	93	24672	23144	94	Cohort 2013	28701	27229
Cohort 2014	25185	23260	92	25166	23437	93	Cohort 2014	30067	28274
Cohort 2015	25053	22900	91	25028	23138	92	Cohort 2015	29083	26919
Cohort 2016	25256	23109	91	25235	23178	92	Cohort 2016	29354	27287
Cohort 2017	25079	23189	92	25070	23161	92	Cohort 2017	29048	27290
Cohort 2018	25503	23526	92	25487	23498	92	Cohort 2018	28487	26938
Cohort 2019	25696	23661	92	25691	23615	92	Cohort 2019	28388	26730
Cohort 2020	25935	23283	90	26043	23626	91	Cohort 2020	28431	26032
Moderately urbanised					Strongly urbanised				
Cohort 2008	37879	36662	97	37859	36512	96	Cohort 2008	45514	44160
Cohort 2009	38302	37100	97	38265	36884	96	Cohort 2009	45542	44147
Cohort 2010	37074	35978	97	37041	35752	97	Cohort 2010	46811	45433
Cohort 2011	35596	34490	97	35577	34401	97	Cohort 2011	44261	42967
Cohort 2012	34224	33076	97	34180	32933	96	Cohort 2012	44469	43021
Cohort 2013	32598	31297	96	32554	31358	96	Cohort 2013	43881	42094
Cohort 2014	33089	31443	95	33038	31643	96	Cohort 2014	45047	42750
Cohort 2015	32237	30252	94	32174	30429	95	Cohort 2015	44263	41417
Cohort 2016	32520	30608	94	32477	30698	95	Cohort 2016	44851	41931
Cohort 2017	31883	30169	95	31848	30099	95	Cohort 2017	44638	42143

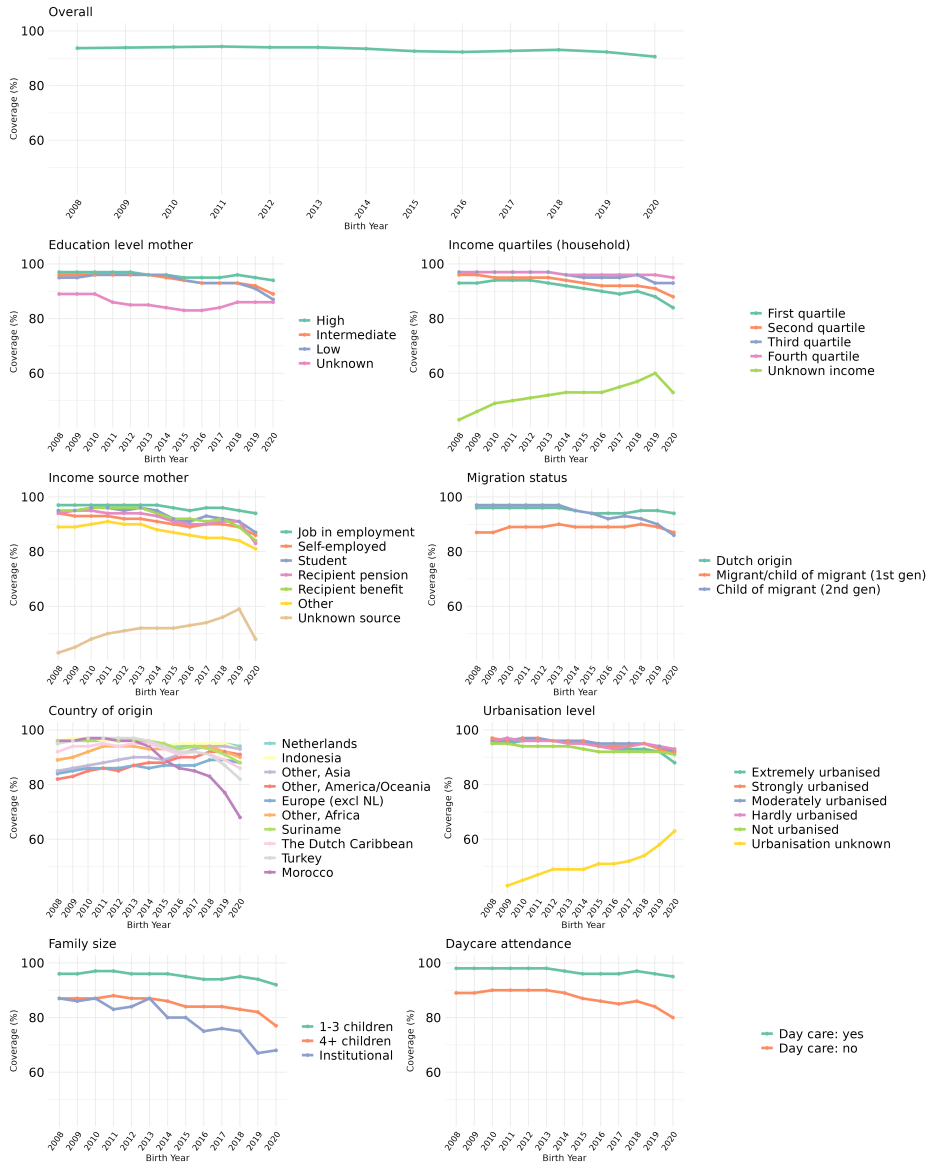
Determinants of Childhood Vaccination Coverage

Category	MMR			DTaP-IPV			Category	MMR			DTaP-IPV		
	popu- lation	Vaccinated		popu- lation	Vaccinated			popu- lation	Vaccinated		popu- lation	Vaccinated	
	N	N	%	N	N	%		N	N	%	N	N	%
Cohort 2018	31504	29796	95	31444	29763	95	Cohort 2018	43655	41331	95	43560	41244	95
Cohort 2019	31718	29740	94	31690	29728	94	Cohort 2019	43668	40646	93	43620	40773	93
Cohort 2020	31940	29132	91	31960	29559	92	Cohort 2020	42402	38288	90	42430	38855	92
Extremely urbanised							Urbanisation unknown						
Cohort 2008	35217	33860	96	35137	33365	95	Cohort 2008	6682	3590	54	7444	3024	41
Cohort 2009	36689	35369	96	36632	34899	95	Cohort 2009	6344	3647	57	7191	3106	43
Cohort 2010	37904	36619	97	37836	36279	96	Cohort 2010	6344	3640	57	7161	3246	45
Cohort 2011	39261	37956	97	39192	37661	96	Cohort 2011	6098	3649	60	6941	3267	47
Cohort 2012	38490	37083	96	38412	36789	96	Cohort 2012	5960	3511	59	6858	3335	49
Cohort 2013	40222	38618	96	40142	38505	96	Cohort 2013	5324	3187	60	6164	3044	49
Cohort 2014	40615	38378	94	40506	38470	95	Cohort 2014	4899	2929	60	5798	2852	49
Cohort 2015	39041	36325	93	38904	36535	94	Cohort 2015	4510	2672	59	5381	2718	51
Cohort 2016	39588	36742	93	39504	36792	93	Cohort 2016	3877	2277	59	4742	2423	51
Cohort 2017	38442	35864	93	38333	35687	93	Cohort 2017	3294	1967	60	4110	2137	52
Cohort 2018	38773	36102	93	38662	35978	93	Cohort 2018	2836	1751	62	3621	1972	54
Cohort 2019	38869	35368	91	38843	35617	92	Cohort 2019	2680	1672	62	3317	1912	58
Cohort 2020	38102	33116	87	38062	33624	88	Cohort 2020	2688	1660	62	2881	1802	63
Family size													
1-3 children							4 or more children						
Cohort 2008	172545	167376	97	172331	166275	96	Cohort 2008	11358	9893	87	11350	9853	87
Cohort 2009	172826	167650	97	172634	166559	96	Cohort 2009	11032	9655	88	11026	9594	87
Cohort 2010	172303	167205	97	172089	166132	97	Cohort 2010	10722	9397	88	10713	9359	87
Cohort 2011	167861	162776	97	167683	162026	97	Cohort 2011	10492	9249	88	10491	9246	88
Cohort 2012	164117	158579	97	163922	157936	96	Cohort 2012	10109	8820	87	10106	8744	87
Cohort 2013	159857	153400	96	159633	153537	96	Cohort 2013	9949	8662	87	9941	8680	87
Cohort 2014	163176	154938	95	162898	155677	96	Cohort 2014	10496	8902	85	10469	8992	86
Cohort 2015	159037	148994	94	158693	150077	95	Cohort 2015	10356	8599	83	10318	8706	84
Cohort 2016	160491	150498	94	160217	150847	94	Cohort 2016	10776	8960	83	10739	9003	84
Cohort 2017	158065	149396	95	157800	148990	94	Cohort 2017	10708	9025	84	10683	8982	84
Cohort 2018	156588	148292	95	156281	147957	95	Cohort 2018	10975	9128	83	10961	9147	83
Cohort 2019	157085	147094	94	156945	147294	94	Cohort 2019	10880	8810	81	10872	8896	82
Cohort 2020	155815	141583	91	155870	143489	92	Cohort 2020	10736	8108	76	10743	8315	77
Institutional							Unknown						
Cohort 2008	265	202	76	261	182	70	Cohort 2008	6687	3597	54	7454	3036	41
Cohort 2009	241	218	90	238	204	86	Cohort 2009	6345	3647	57	7194	3108	43
Cohort 2010	330	288	87	330	288	87	Cohort 2010	6337	3635	57	7161	3249	45
Cohort 2011	317	269	85	317	264	83	Cohort 2011	6088	3639	60	6938	3264	47
Cohort 2012	312	275	88	311	261	84	Cohort 2012	5947	3500	59	6852	3329	49
Cohort 2013	292	255	87	297	257	87	Cohort 2013	5312	3175	60	6162	3042	49
Cohort 2014	347	280	81	347	277	80	Cohort 2014	4883	2914	60	5795	2849	49
Cohort 2015	298	231	78	295	236	80	Cohort 2015	4496	2661	59	5379	2717	51

Chapter 2

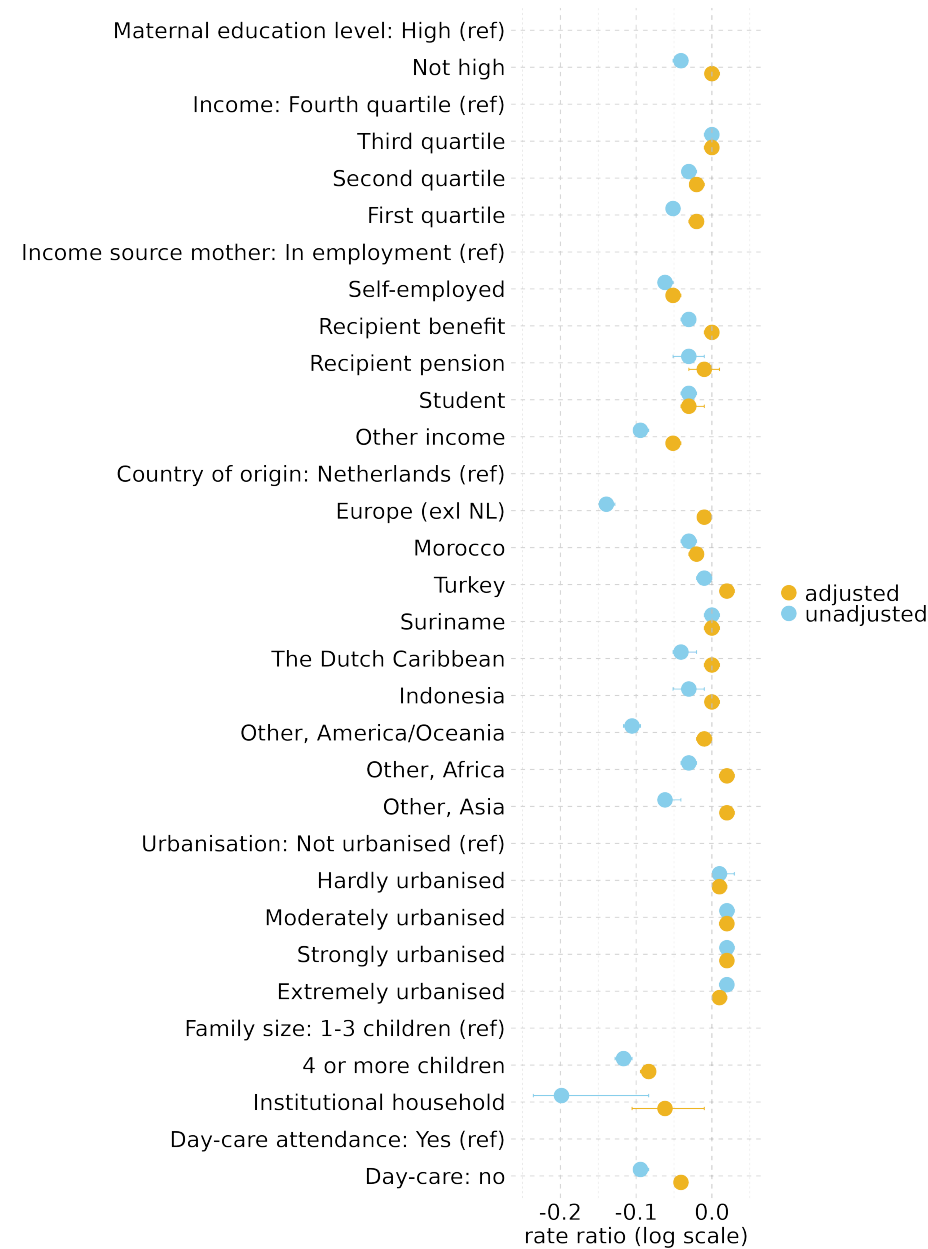
Category	MMR popu- lation	Vaccinated		DTaP- IPV popu- lation	Vaccinated		Category	MMR popu- lation	Vaccinated		DTaP- IPV popu- lation	Vaccinated	
	N	N	%	N	N	%		N	N	%	N	N	%
Cohort 2016	334	250	75	340	256	75	Cohort 2016	3845	2246	58	4725	2407	51
Cohort 2017	337	253	75	342	260	76	Cohort 2017	3274	1948	59	4103	2131	52
Cohort 2018	383	291	76	383	286	75	Cohort 2018	2812	1733	62	3611	1965	54
Cohort 2019	425	287	68	424	284	67	Cohort 2019	2629	1626	62	3294	1891	57
Cohort 2020	378	263	70	376	257	68	Cohort 2020	2569	1557	61	2862	1789	63
Day care attendance													
Yes							No						
Cohort 2008	102713	100753	98	102617	100258	98	Cohort 2008	88086	80259	91	88723	79035	89
Cohort 2009	105331	103355	98	105241	102842	98	Cohort 2009	85088	77790	91	85826	76598	89
Cohort 2010	102713	100853	98	102632	100456	98	Cohort 2010	86964	79657	92	87645	78557	90
Cohort 2011	94513	92776	98	94453	92555	98	Cohort 2011	90229	83143	92	90960	82231	90
Cohort 2012	91568	89602	98	91491	89408	98	Cohort 2012	88910	81565	92	89693	80855	90
Cohort 2013	91365	88928	97	91286	89092	98	Cohort 2013	84040	76559	91	84742	76419	90
Cohort 2014	101346	97749	96	101183	98229	97	Cohort 2014	77555	69284	89	78325	69565	89
Cohort 2015	105899	100944	95	105715	101707	96	Cohort 2015	68283	59536	87	68965	60024	87
Cohort 2016	114749	109611	96	114586	109879	96	Cohort 2016	60695	52341	86	61433	52632	86
Cohort 2017	117822	113425	96	117688	113256	96	Cohort 2017	54559	47194	87	55237	47104	85
Cohort 2018	117585	113612	97	117437	113348	97	Cohort 2018	53172	45831	86	53798	46007	86
Cohort 2019	120547	115672	96	120456	115621	96	Cohort 2019	50469	42142	84	51076	42741	84
Cohort 2020	123517	115518	94	123353	116671	95	Cohort 2020	45981	35993	78	46490	37171	80

Determinants of Childhood Vaccination Coverage



Supplementary Figure S3. Crude DTaP-IPV vaccination coverage by sociodemographic determinants

Chapter 2



Supplementary Figure S4. DTaP-IPV univariable and multivariable Poisson regression model – unadjusted and adjusted RRs

In addition to all the variables listed, the RRs are also adjusted for birth cohort.

Determinants of Childhood Vaccination Coverage

Supplementary Table S5. Multivariable Poisson regression model with interaction terms for birth cohort * sociodemographic variable for both MMR and DTaP-IPV vaccination

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2009	1.00 (0.97 - 1.02)	0.807	1.00 (0.97 - 1.02)	1.00 (0.98 - 1.02)	0.980	1.00 (0.98 -1.02)
Birth_year2010	1.00 (0.97 - 1.02)	0.767	1.00 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.742	1.00 (0.97 -1.02)
Birth_year2011	0.99 (0.97 - 1.02)	0.542	0.99 (0.97 - 1.02)	0.99 (0.97 - 1.02)	0.598	0.99 (0.97 -1.02)
Birth_year2012	0.99 (0.97 - 1.01)	0.374	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.483	0.99 (0.97 -1.01)
Birth_year2013	0.99 (0.96 - 1.01)	0.256	0.99 (0.96 - 1.01)	0.99 (0.97 - 1.02)	0.517	0.99 (0.97 -1.01)
Birth_year2014	0.98 (0.96 - 1.00)	0.074	0.98 (0.95 - 1.00)	0.99 (0.97 - 1.01)	0.293	0.99 (0.96 -1.01)
Birth_year2015	0.97 (0.95 - 1.00)	0.027	0.97 (0.95 - 1.00)	0.98 (0.96 - 1.01)	0.186	0.98 (0.96 -1.01)
Birth_year2016	0.98 (0.96 - 1.00)	0.083	0.98 (0.96 - 1.00)	0.98 (0.96 - 1.01)	0.141	0.98 (0.96 -1.00)
Birth_year2017	0.99 (0.96 - 1.01)	0.237	0.99 (0.96 - 1.01)	0.99 (0.96 - 1.01)	0.272	0.98 (0.96 -1.01)
Birth_year2018	0.99 (0.96 - 1.01)	0.228	0.98 (0.96 - 1.01)	0.99 (0.96 - 1.01)	0.219	0.98 (0.96 -1.01)
Birth_year2019	0.99 (0.97 - 1.02)	0.598	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.324	0.99 (0.96 -1.01)
Birth_year2020	0.98 (0.96 - 1.00)	0.094	0.98 (0.96 - 1.00)	0.99 (0.96 - 1.01)	0.253	0.98 (0.96 -1.01)
High_education_motherNo	1.00 (0.99 - 1.02)	0.475	1.00 (0.99 - 1.02)	1.00 (0.99 - 1.01)	0.977	1.00 (0.99 -1.01)
Household_incomeFirst quartile	0.99 (0.97 - 1.01)	0.222	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.264	0.99 (0.97 -1.01)
Household_incomeSecond quartile	0.99 (0.98 - 1.01)	0.335	0.99 (0.98 - 1.01)	1.00 (0.98 - 1.01)	0.645	1.00 (0.98 -1.01)
Household_incomeThird quartile	1.00 (0.98 - 1.01)	0.525	1.00 (0.98 - 1.01)	1.00 (0.99 - 1.01)	0.996	1.00 (0.99 -1.01)
Household_incomeUnknown	NA	NA	0.87 (0.81 - 0.93)	NA	NA	0.79 (0.72 -0.85)
Country_originEurope (excl NL)	1.00 (0.98 - 1.01)	0.593	0.99 (0.97 - 1.00)	0.99 (0.97 - 1.00)	0.157	0.97 (0.95 -0.98)
Country_originIndonesia	1.00 (0.98 - 1.03)	0.694	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.830	1.00 (0.98 -1.03)
Country_originMorocco	1.05 (1.02 - 1.07)	<0.001	1.05 (1.02 - 1.07)	1.04 (1.02 - 1.07)	0.001	1.04 (1.02 -1.07)
Country_originOther, Africa	1.00 (0.97 - 1.03)	0.787	0.98 (0.95 - 1.01)	0.98 (0.95 - 1.01)	0.226	0.98 (0.95 -1.01)
Country_originOther, America/Oceania	0.99 (0.96 - 1.03)	0.699	1.01 (0.98 - 1.04)	0.98 (0.95 - 1.02)	0.387	0.97 (0.93 -1.00)
Country_originOther, Asia	1.01 (0.99 - 1.04)	0.308	1.00 (0.98 - 1.03)	1.00 (0.97 - 1.02)	0.781	0.99 (0.96 -1.01)
Country_originSuriname	1.01 (0.99 - 1.04)	0.295	1.02 (0.99 - 1.04)	1.00 (0.98 - 1.03)	0.848	1.00 (0.98 -1.03)
Country_originThe Dutch Caribbean	1.00 (0.97 - 1.04)	0.846	1.01 (0.97 - 1.04)	0.99 (0.96 - 1.03)	0.772	1.01 (0.97 -1.05)
Country_originTürkiye	1.03 (1.01 - 1.06)	0.011	1.03 (1.01 - 1.06)	1.03 (1.00 - 1.05)	0.057	1.03 (1.00 -1.05)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Income_source_mother-Self-employed	0.97 (0.95 - 0.99)	0.001	0.97 (0.95 - 0.99)	0.97 (0.96 - 0.99)	0.007	0.98 (0.96 -0.99)
Income_source_mother-Recipient benefit	0.99 (0.97 - 1.01)	0.229	0.99 (0.98 - 1.01)	0.99 (0.97 - 1.01)	0.178	0.99 (0.97 -1.01)
Income_source_mother-Recipient benefit	0.98 (0.93 - 1.04)	0.504	0.98 (0.93 - 1.04)	0.99 (0.94 - 1.04)	0.677	0.99 (0.94 -1.05)
Income_source_mother-Child/student	0.98 (0.94 - 1.02)	0.261	0.98 (0.94 - 1.02)	0.98 (0.95 - 1.02)	0.386	0.98 (0.95 -1.02)
Income_source_mother-Other	0.95 (0.93 - 0.97)	<0.001	0.95 (0.94 - 0.97)	0.95 (0.93 - 0.96)	<0.001	0.95 (0.93 -0.97)
Income_source_mother-Unknown	NA	NA	0.87 (0.79 - 0.94)	NA	NA	0.81 (0.72 -0.89)
UrbanisationExtremely urbanised	1.01 (0.99 - 1.02)	0.469	1.01 (0.99 - 1.02)	1.00 (0.99 - 1.02)	0.806	1.00 (0.99 -1.02)
UrbanisationHardly urbanised	1.01 (0.99 - 1.03)	0.199	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.03)	0.266	1.01 (0.99 -1.02)
UrbanisationModerately urbanised	1.01 (1.00 - 1.03)	0.151	1.01 (1.00 - 1.03)	1.01 (1.00 - 1.03)	0.125	1.01 (1.00 -1.03)
UrbanisationStrongly urbanised	1.01 (1.00 - 1.03)	0.068	1.01 (1.00 - 1.03)	1.02 (1.00 - 1.03)	0.040	1.02 (1.00 -1.03)
UrbanisationUnknown	NA	NA	0.74 (0.32 - 1.16)	NA	NA	0.61 (0.15 -1.07)
family_size4 or more children	0.91 (0.89 - 0.93)	<0.001	0.91 (0.89 - 0.93)	0.91 (0.90 - 0.93)	<0.001	0.91 (0.89 -0.94)
family_sizeInstitutional	0.90 (0.75 - 1.06)	0.206	0.86 (0.72 - 1.00)	0.86 (0.72 - 1.03)	0.097	0.83 (0.68 -0.97)
Family_sizeUnknown	NA	NA	0.99 (0.58 - 1.41)	NA	NA	1.10 (0.64 -1.55)
Daycare2No daycare	0.98 (0.97 - 0.99)	<0.001	0.97 (0.96 - 0.98)	0.98 (0.97 - 0.99)	<0.001	0.97 (0.96 -0.98)
Birth_year2009:High_education_motherNo	1.00 (0.98 - 1.02)	0.997	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.965	1.00 (0.98 -1.02)
Birth_year2010:High_education_motherNo	1.00 (0.99 - 1.02)	0.781	1.00 (0.99 - 1.02)	1.00 (0.99 - 1.02)	0.698	1.00 (0.99 -1.02)
Birth_year2011:High_education_motherNo	1.00 (0.99 - 1.02)	0.660	1.00 (0.99 - 1.02)	1.00 (0.99 - 1.02)	0.630	1.00 (0.99 -1.02)
Birth_year2012:High_education_motherNo	1.00 (0.99 - 1.02)	0.754	1.00 (0.99 - 1.02)	1.00 (0.99 - 1.02)	0.702	1.00 (0.99 -1.02)
Birth_year2013:High_education_motherNo	1.01 (0.99 - 1.02)	0.520	1.01 (0.99 - 1.02)	1.01 (0.99 - 1.02)	0.432	1.01 (0.99 -1.02)
Birth_year2014:High_education_motherNo	1.01 (0.99 - 1.02)	0.404	1.01 (0.99 - 1.02)	1.01 (0.99 - 1.03)	0.240	1.01 (0.99 -1.03)
Birth_year2015:High_education_motherNo	1.01 (0.99 - 1.02)	0.407	1.01 (0.99 - 1.02)	1.01 (0.99 - 1.03)	0.271	1.01 (0.99 -1.02)
Birth_year2016:High_education_motherNo	1.00 (0.99 - 1.02)	0.736	1.00 (0.99 - 1.02)	1.01 (0.99 - 1.02)	0.352	1.01 (0.99 -1.02)
Birth_year2017:High_education_motherNo	1.00 (0.98 - 1.02)	0.948	1.00 (0.98 - 1.02)	1.00 (0.99 - 1.02)	0.621	1.00 (0.99 -1.02)
Birth_year2018:High_education_motherNo	1.00 (0.98 - 1.01)	0.896	1.00 (0.98 - 1.01)	1.01 (0.99 - 1.02)	0.508	1.01 (0.99 -1.02)
Birth_year2019:High_education_motherNo	1.00 (0.98 - 1.01)	0.793	1.00 (0.98 - 1.01)	1.00 (0.99 - 1.02)	0.646	1.00 (0.99 -1.02)
Birth_year2020:High_education_motherNo	0.99 (0.97 - 1.00)	0.148	0.99 (0.97 - 1.01)	1.00 (0.98 - 1.01)	0.624	1.00 (0.98 -1.01)

Determinants of Childhood Vaccination Coverage

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2009:Housh-old_incomeFirst quartile	1.00 (0.97 - 1.02)	0.791	1.00 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.701	1.00 (0.97 -1.02)
Birth_year2010:Housh-old_incomeFirst quartile	1.00 (0.97 - 1.02)	0.724	1.00 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.681	1.00 (0.97 -1.02)
Birth_year2011:Housh-old_incomeFirst quartile	0.99 (0.97 - 1.02)	0.622	0.99 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.758	1.00 (0.97 -1.02)
Birth_year2012:Housh-old_incomeFirst quartile	1.00 (0.97 - 1.02)	0.768	1.00 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.858	1.00 (0.97 -1.02)
Birth_year2013:Housh-old_incomeFirst quartile	0.99 (0.97 - 1.02)	0.490	0.99 (0.97 - 1.02)	0.99 (0.97 - 1.02)	0.497	0.99 (0.97 -1.02)
Birth_year2014:Housh-old_incomeFirst quartile	0.99 (0.97 - 1.02)	0.444	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.02)	0.505	0.99 (0.97 -1.02)
Birth_year2015:Housh-old_incomeFirst quartile	0.98 (0.96 - 1.01)	0.156	0.98 (0.96 - 1.01)	0.98 (0.96 - 1.01)	0.212	0.99 (0.96 -1.01)
Birth_year2016:Housh-old_incomeFirst quartile	0.97 (0.95 - 1.00)	0.037	0.97 (0.95 - 1.00)	0.98 (0.95 - 1.00)	0.076	0.98 (0.95 -1.00)
Birth_year2017:Housh-old_incomeFirst quartile	0.98 (0.95 - 1.00)	0.072	0.98 (0.95 - 1.00)	0.98 (0.95 - 1.00)	0.053	0.98 (0.95 -1.00)
Birth_year2018:Housh-old_incomeFirst quartile	0.98 (0.96 - 1.01)	0.134	0.98 (0.96 - 1.01)	0.98 (0.96 - 1.01)	0.128	0.98 (0.96 -1.01)
Birth_year2019:Housh-old_incomeFirst quartile	0.96 (0.94 - 0.99)	0.007	0.97 (0.94 - 0.99)	0.97 (0.95 - 1.00)	0.027	0.97 (0.95 -1.00)
Birth_year2020:Housh-old_incomeFirst quartile	0.96 (0.93 - 0.98)	0.001	0.96 (0.93 - 0.98)	0.96 (0.94 - 0.99)	0.003	0.96 (0.93 -0.99)
Birth_year2009:Housh-old_incomeSecond quartile	1.00 (0.98 - 1.02)	0.962	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.946	1.00 (0.98 -1.02)
Birth_year2010:Housh-old_incomeSecond quartile	1.00 (0.98 - 1.01)	0.643	1.00 (0.98 - 1.01)	0.99 (0.97 - 1.01)	0.500	0.99 (0.97 -1.01)
Birth_year2011:Housh-old_incomeSecond quartile	1.00 (0.98 - 1.02)	0.668	1.00 (0.98 - 1.02)	0.99 (0.97 - 1.01)	0.546	0.99 (0.97 -1.01)
Birth_year2012:Housh-old_incomeSecond quartile	1.00 (0.98 - 1.02)	0.652	1.00 (0.98 - 1.01)	0.99 (0.97 - 1.01)	0.505	0.99 (0.97 -1.01)
Birth_year2013:Housh-old_incomeSecond quartile	0.99 (0.97 - 1.01)	0.311	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.277	0.99 (0.97 -1.01)
Birth_year2014:Housh-old_incomeSecond quartile	0.99 (0.97 - 1.01)	0.184	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.185	0.99 (0.97 -1.01)
Birth_year2015:Housh-old_incomeSecond quartile	0.98 (0.96 - 1.00)	0.062	0.98 (0.96 - 1.00)	0.98 (0.96 - 1.00)	0.067	0.98 (0.96 -1.00)
Birth_year2016:Housh-old_incomeSecond quartile	0.98 (0.96 - 1.00)	0.016	0.98 (0.96 - 1.00)	0.98 (0.96 - 1.00)	0.014	0.98 (0.96 -1.00)
Birth_year2017:Housh-old_incomeSecond quartile	0.98 (0.96 - 1.00)	0.035	0.98 (0.96 - 1.00)	0.98 (0.96 - 1.00)	0.029	0.98 (0.96 -1.00)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2018:Housh-old_incomeSecond quartile	0.98 (0.96 - 1.00)	0.036	0.98 (0.96 - 1.00)	0.97 (0.95 - 0.99)	0.011	0.97 (0.95 -0.99)
Birth_year2019:Housh-old_incomeSecond quartile	0.97 (0.95 - 0.99)	0.007	0.97 (0.95 - 0.99)	0.97 (0.95 - 0.99)	0.008	0.97 (0.95 -0.99)
Birth_year2020:Housh-old_incomeSecond quartile	0.97 (0.95 - 0.99)	0.001	0.97 (0.94 - 0.99)	0.97 (0.95 - 0.99)	0.002	0.97 (0.95 -0.99)
Birth_year2009:Housh-old_incomeThird quartile	1.00 (0.99 - 1.02)	0.692	1.00 (0.99 - 1.02)	1.00 (0.98 - 1.02)	0.911	1.00 (0.98 -1.02)
Birth_year2010:Housh-old_incomeThird quartile	1.00 (0.98 - 1.02)	0.921	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.886	1.00 (0.98 -1.02)
Birth_year2011:Housh-old_incomeThird quartile	1.00 (0.98 - 1.02)	0.784	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.974	1.00 (0.98 -1.02)
Birth_year2012:Housh-old_incomeThird quartile	1.00 (0.98 - 1.02)	0.840	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.877	1.00 (0.98 -1.02)
Birth_year2013:Housh-old_incomeThird quartile	1.00 (0.98 - 1.02)	1.000	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.827	1.00 (0.98 -1.02)
Birth_year2014:Housh-old_incomeThird quartile	1.00 (0.98 - 1.02)	0.908	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.01)	0.686	1.00 (0.98 -1.02)
Birth_year2015:Housh-old_incomeThird quartile	0.99 (0.97 - 1.01)	0.460	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.353	0.99 (0.97 -1.01)
Birth_year2016:Housh-old_incomeThird quartile	0.99 (0.97 - 1.01)	0.440	0.99 (0.97 - 1.01)	0.99 (0.97 - 1.01)	0.290	0.99 (0.97 -1.01)
Birth_year2017:Housh-old_incomeThird quartile	0.99 (0.98 - 1.01)	0.548	0.99 (0.98 - 1.01)	0.99 (0.97 - 1.01)	0.352	0.99 (0.97 -1.01)
Birth_year2018:Housh-old_incomeThird quartile	1.00 (0.98 - 1.02)	0.721	1.00 (0.98 - 1.02)	0.99 (0.98 - 1.01)	0.503	0.99 (0.98 -1.01)
Birth_year2019:Housh-old_incomeThird quartile	0.99 (0.98 - 1.01)	0.541	0.99 (0.98 - 1.01)	0.99 (0.97 - 1.01)	0.451	0.99 (0.97 -1.01)
Birth_year2020:Housh-old_incomeThird quartile	0.99 (0.98 - 1.01)	0.577	0.99 (0.98 - 1.01)	0.99 (0.97 - 1.01)	0.415	0.99 (0.97 -1.01)
Birth_year2009:Housh-old_incomeUnknown	NA	NA	1.03 (0.94 - 1.11)	NA	NA	1.03 (0.94 -1.12)
Birth_year2010:Housh-old_incomeUnknown	NA	NA	1.04 (0.95 - 1.12)	NA	NA	1.04 (0.95 -1.13)
Birth_year2011:Housh-old_incomeUnknown	NA	NA	1.03 (0.95 - 1.12)	NA	NA	1.03 (0.94 -1.12)
Birth_year2012:Housh-old_incomeUnknown	NA	NA	1.06 (0.97 - 1.14)	NA	NA	1.06 (0.97 -1.15)
Birth_year2013:Housh-old_incomeUnknown	NA	NA	1.02 (0.93 - 1.11)	NA	NA	1.06 (0.96 -1.15)
Birth_year2014:Housh-old_incomeUnknown	NA	NA	1.03 (0.94 - 1.12)	NA	NA	1.07 (0.98 -1.17)
Birth_year2015:Housh-old_incomeUnknown	NA	NA	1.03 (0.94 - 1.12)	NA	NA	1.06 (0.96 -1.15)
Birth_year2016:Housh-old_incomeUnknown	NA	NA	1.00 (0.91 - 1.10)	NA	NA	1.03 (0.94 -1.13)
Birth_year2017:Housh-old_incomeUnknown	NA	NA	1.02 (0.92 - 1.11)	NA	NA	1.08 (0.98 -1.17)
Birth_year2018:Housh-old_incomeUnknown	NA	NA	1.04 (0.94 - 1.13)	NA	NA	1.09 (0.99 -1.19)

Determinants of Childhood Vaccination Coverage

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2019:Housh-old_incomeUnknown	NA	NA	1.02 (0.93 - 1.12)	NA	NA	1.09 (0.99 -1.18)
Birth_year2020:Housh-old_incomeUnknown	NA	NA	0.93 (0.84 - 1.03)	NA	NA	1.03 (0.93 -1.12)
Birth_year2009:Country_originEurope (excl NL)	1.00 (0.98 - 1.03)	0.893	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.02)	0.944	1.00 (0.98 -1.03)
Birth_year2010:Country_originEurope (excl NL)	1.00 (0.98 - 1.03)	0.873	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.678	1.01 (0.98 -1.03)
Birth_year2011:Country_originEurope (excl NL)	1.00 (0.98 - 1.03)	0.758	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.689	1.01 (0.98 -1.03)
Birth_year2012:Country_originEurope (excl NL)	1.00 (0.98 - 1.03)	0.758	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.774	1.01 (0.98 -1.03)
Birth_year2013:Country_originEurope (excl NL)	1.00 (0.98 - 1.03)	0.884	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.755	1.01 (0.98 -1.03)
Birth_year2014:Country_originEurope (excl NL)	1.00 (0.98 - 1.03)	0.816	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.719	1.01 (0.98 -1.03)
Birth_year2015:Country_originEurope (excl NL)	1.00 (0.98 - 1.02)	0.983	1.00 (0.98 - 1.02)	1.01 (0.98 - 1.03)	0.646	1.01 (0.99 -1.03)
Birth_year2016:Country_originEurope (excl NL)	1.00 (0.97 - 1.02)	0.780	1.00 (0.97 - 1.02)	1.00 (0.98 - 1.03)	0.745	1.01 (0.99 -1.03)
Birth_year2017:Country_originEurope (excl NL)	1.00 (0.98 - 1.02)	0.935	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.831	1.01 (0.99 -1.03)
Birth_year2018:Country_originEurope (excl NL)	1.00 (0.98 - 1.02)	0.999	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.872	1.01 (0.99 -1.04)
Birth_year2019:Country_originEurope (excl NL)	1.00 (0.97 - 1.02)	0.805	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.816	1.02 (0.99 -1.04)
Birth_year2020:Country_originEurope (excl NL)	0.99 (0.97 - 1.02)	0.503	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.954	1.01 (0.99 -1.04)
Birth_year2009:Country_originIndonesia	1.00 (0.97 - 1.04)	0.915	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.704	1.01 (0.97 -1.04)
Birth_year2010:Country_originIndonesia	1.00 (0.97 - 1.04)	0.894	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.685	1.01 (0.97 -1.04)
Birth_year2011:Country_originIndonesia	1.00 (0.97 - 1.03)	0.971	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.04)	0.994	1.00 (0.97 -1.03)
Birth_year2012:Country_originIndonesia	1.00 (0.97 - 1.04)	0.834	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.683	1.01 (0.97 -1.04)
Birth_year2013:Country_originIndonesia	1.00 (0.97 - 1.04)	0.877	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.771	1.00 (0.97 -1.04)
Birth_year2014:Country_originIndonesia	1.00 (0.97 - 1.04)	0.917	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.737	1.00 (0.97 -1.04)
Birth_year2015:Country_originIndonesia	1.00 (0.97 - 1.04)	0.965	1.00 (0.96 - 1.03)	1.00 (0.97 - 1.04)	0.941	1.00 (0.96 -1.03)
Birth_year2016:Country_originIndonesia	1.00 (0.96 - 1.04)	0.956	1.00 (0.96 - 1.04)	1.00 (0.97 - 1.04)	0.882	1.00 (0.97 -1.04)
Birth_year2017:Country_originIndonesia	1.00 (0.97 - 1.04)	0.896	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.787	1.01 (0.97 -1.04)
Birth_year2018:Country_originIndonesia	1.00 (0.96 - 1.04)	0.970	1.00 (0.96 - 1.04)	1.00 (0.96 - 1.04)	0.929	1.00 (0.97 -1.04)
Birth_year2019:Country_originIndonesia	0.99 (0.95 - 1.03)	0.576	0.99 (0.95 - 1.03)	1.00 (0.96 - 1.04)	0.973	1.00 (0.96 -1.04)
Birth_year2020:Country_originIndonesia	0.99 (0.95 - 1.03)	0.563	0.99 (0.95 - 1.03)	0.99 (0.95 - 1.03)	0.582	0.99 (0.95 -1.03)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2009:Country_originMorocco	1.00 (0.96 - 1.03)	0.800	1.00 (0.96 - 1.03)	1.00 (0.96 - 1.03)	0.889	1.00 (0.97 -1.03)
Birth_year2010:Country_originMorocco	1.00 (0.97 - 1.04)	0.853	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.04)	0.728	1.01 (0.97 -1.04)
Birth_year2011:Country_originMorocco	1.00 (0.96 - 1.03)	0.855	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.04)	0.877	1.00 (0.97 -1.04)
Birth_year2012:Country_originMorocco	1.00 (0.96 - 1.03)	0.829	1.00 (0.96 - 1.03)	1.00 (0.97 - 1.04)	0.840	1.01 (0.97 -1.04)
Birth_year2013:Country_originMorocco	0.99 (0.95 - 1.02)	0.403	0.99 (0.95 - 1.02)	0.99 (0.96 - 1.03)	0.726	1.00 (0.96 -1.03)
Birth_year2014:Country_originMorocco	0.97 (0.94 - 1.00)	0.071	0.97 (0.93 - 1.00)	0.98 (0.95 - 1.02)	0.348	0.99 (0.95 -1.02)
Birth_year2015:Country_originMorocco	0.93 (0.90 - 0.96)	<0.001	0.93 (0.90 - 0.97)	0.95 (0.92 - 0.98)	0.003	0.95 (0.92 -0.98)
Birth_year2016:Country_originMorocco	0.91 (0.87 - 0.94)	<0.001	0.90 (0.87 - 0.94)	0.92 (0.89 - 0.95)	<0.001	0.92 (0.89 -0.96)
Birth_year2017:Country_originMorocco	0.90 (0.87 - 0.93)	<0.001	0.90 (0.87 - 0.94)	0.91 (0.88 - 0.94)	<0.001	0.91 (0.88 -0.95)
Birth_year2018:Country_originMorocco	0.87 (0.84 - 0.90)	<0.001	0.87 (0.84 - 0.91)	0.88 (0.85 - 0.92)	<0.001	0.89 (0.85 -0.92)
Birth_year2019:Country_originMorocco	0.79 (0.76 - 0.82)	<0.001	0.79 (0.76 - 0.83)	0.83 (0.80 - 0.86)	<0.001	0.83 (0.79 -0.86)
Birth_year2020:Country_originMorocco	0.73 (0.70 - 0.75)	<0.001	0.73 (0.69 - 0.77)	0.75 (0.72 - 0.78)	<0.001	0.75 (0.71 -0.79)
Birth_year2009:Country_originOther, Africa	1.01 (0.97 - 1.05)	0.684	1.01 (0.97 - 1.05)	1.01 (0.97 - 1.06)	0.586	1.01 (0.96 -1.05)
Birth_year2010:Country_originOther, Africa	1.02 (0.98 - 1.06)	0.373	1.03 (0.99 - 1.07)	1.03 (0.99 - 1.07)	0.202	1.03 (0.99 -1.07)
Birth_year2011:Country_originOther, Africa	1.03 (0.99 - 1.08)	0.142	1.04 (1.00 - 1.08)	1.05 (1.00 - 1.09)	0.032	1.05 (1.01 -1.10)
Birth_year2012:Country_originOther, Africa	1.03 (0.98 - 1.07)	0.222	1.04 (1.00 - 1.08)	1.04 (1.00 - 1.09)	0.057	1.05 (1.01 -1.09)
Birth_year2013:Country_originOther, Africa	1.04 (0.99 - 1.08)	0.093	1.05 (1.01 - 1.09)	1.04 (1.00 - 1.09)	0.042	1.05 (1.01 -1.09)
Birth_year2014:Country_originOther, Africa	1.02 (0.98 - 1.07)	0.306	1.04 (1.00 - 1.08)	1.04 (1.00 - 1.09)	0.054	1.05 (1.01 -1.09)
Birth_year2015:Country_originOther, Africa	1.03 (0.99 - 1.08)	0.134	1.04 (1.00 - 1.08)	1.05 (1.01 - 1.10)	0.022	1.05 (1.01 -1.09)
Birth_year2016:Country_originOther, Africa	1.03 (0.99 - 1.08)	0.146	1.04 (1.00 - 1.08)	1.05 (1.01 - 1.09)	0.025	1.05 (1.01 -1.09)
Birth_year2017:Country_originOther, Africa	1.03 (0.99 - 1.07)	0.183	1.04 (1.00 - 1.08)	1.05 (1.01 - 1.09)	0.021	1.05 (1.01 -1.09)
Birth_year2018:Country_originOther, Africa	1.03 (0.99 - 1.07)	0.126	1.04 (1.00 - 1.08)	1.05 (1.01 - 1.09)	0.020	1.05 (1.01 -1.09)
Birth_year2019:Country_originOther, Africa	1.02 (0.98 - 1.06)	0.325	1.03 (0.99 - 1.07)	1.04 (1.00 - 1.08)	0.050	1.04 (1.00 -1.08)
Birth_year2020:Country_originOther, Africa	1.01 (0.97 - 1.05)	0.707	1.02 (0.98 - 1.06)	1.04 (1.00 - 1.08)	0.071	1.03 (0.99 -1.07)
Birth_year2009:Country_originOther, America/ Oceania	1.00 (0.95 - 1.05)	0.907	1.00 (0.95 - 1.04)	0.99 (0.94 - 1.04)	0.694	1.00 (0.95 -1.05)

Determinants of Childhood Vaccination Coverage

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2010:Country_originOther, America/Oceania	1.00 (0.96 - 1.05)	0.892	1.00 (0.95 - 1.04)	1.00 (0.95 - 1.05)	0.944	1.00 (0.96 -1.05)
Birth_year2011:Country_originOther, America/Oceania	1.00 (0.96 - 1.05)	0.920	1.00 (0.96 - 1.05)	1.00 (0.96 - 1.05)	0.882	1.01 (0.97 -1.06)
Birth_year2012:Country_originOther, America/Oceania	1.00 (0.95 - 1.05)	0.988	1.00 (0.95 - 1.04)	0.99 (0.95 - 1.04)	0.794	1.00 (0.95 -1.04)
Birth_year2013:Country_originOther, America/Oceania	1.00 (0.96 - 1.05)	0.839	1.00 (0.95 - 1.04)	1.00 (0.96 - 1.05)	0.918	1.01 (0.96 -1.06)
Birth_year2014:Country_originOther, America/Oceania	1.00 (0.96 - 1.05)	0.912	1.00 (0.96 - 1.04)	1.00 (0.96 - 1.05)	0.855	1.02 (0.97 -1.06)
Birth_year2015:Country_originOther, America/Oceania	1.00 (0.96 - 1.05)	0.938	1.00 (0.95 - 1.04)	1.01 (0.96 - 1.05)	0.828	1.02 (0.97 -1.06)
Birth_year2016:Country_originOther, America/Oceania	1.01 (0.96 - 1.06)	0.782	1.00 (0.96 - 1.04)	1.01 (0.96 - 1.06)	0.654	1.03 (0.99 -1.08)
Birth_year2017:Country_originOther, America/Oceania	1.01 (0.96 - 1.06)	0.711	1.00 (0.96 - 1.05)	1.01 (0.96 - 1.05)	0.806	1.03 (0.98 -1.07)
Birth_year2018:Country_originOther, America/Oceania	1.01 (0.96 - 1.06)	0.717	1.00 (0.96 - 1.04)	1.01 (0.97 - 1.06)	0.578	1.04 (0.99 -1.08)
Birth_year2019:Country_originOther, America/Oceania	1.00 (0.96 - 1.05)	0.921	0.99 (0.95 - 1.04)	1.01 (0.96 - 1.05)	0.777	1.03 (0.99 -1.07)
Birth_year2020:Country_originOther, America/Oceania	1.00 (0.95 - 1.05)	0.997	0.99 (0.95 - 1.04)	1.00 (0.96 - 1.05)	0.874	1.03 (0.99 -1.07)
Birth_year2009:Country_originOther, Asia	1.00 (0.97 - 1.04)	0.887	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.05)	0.623	1.00 (0.97 -1.04)
Birth_year2010:Country_originOther, Asia	1.01 (0.98 - 1.05)	0.443	1.02 (0.98 - 1.05)	1.02 (0.98 - 1.06)	0.285	1.02 (0.99 -1.06)
Birth_year2011:Country_originOther, Asia	1.01 (0.98 - 1.05)	0.445	1.02 (0.98 - 1.05)	1.02 (0.99 - 1.06)	0.180	1.02 (0.99 -1.06)
Birth_year2012:Country_originOther, Asia	1.01 (0.98 - 1.05)	0.487	1.02 (0.98 - 1.05)	1.03 (0.99 - 1.06)	0.150	1.03 (1.00 -1.06)
Birth_year2013:Country_originOther, Asia	1.01 (0.98 - 1.05)	0.434	1.02 (0.99 - 1.06)	1.03 (0.99 - 1.06)	0.137	1.03 (1.00 -1.07)
Birth_year2014:Country_originOther, Asia	1.01 (0.97 - 1.04)	0.611	1.02 (0.98 - 1.05)	1.02 (0.99 - 1.06)	0.188	1.03 (1.00 -1.06)
Birth_year2015:Country_originOther, Asia	0.99 (0.96 - 1.03)	0.726	1.01 (0.97 - 1.04)	1.01 (0.98 - 1.05)	0.495	1.02 (0.99 -1.06)
Birth_year2016:Country_originOther, Asia	1.01 (0.98 - 1.05)	0.499	1.02 (0.99 - 1.05)	1.03 (0.99 - 1.06)	0.105	1.03 (1.00 -1.07)
Birth_year2017:Country_originOther, Asia	1.02 (0.99 - 1.06)	0.186	1.03 (1.00 - 1.07)	1.04 (1.01 - 1.08)	0.020	1.05 (1.02 -1.08)
Birth_year2018:Country_originOther, Asia	1.02 (0.99 - 1.06)	0.169	1.03 (1.00 - 1.07)	1.04 (1.01 - 1.08)	0.017	1.05 (1.02 -1.08)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2019:Country_originOther, Asia	1.03 (0.99 - 1.06)	0.134	1.04 (1.01 - 1.07)	1.04 (1.01 - 1.08)	0.014	1.05 (1.02 -1.08)
Birth_year2020:Country_originOther, Asia	1.03 (0.99 - 1.06)	0.123	1.04 (1.01 - 1.07)	1.04 (1.01 - 1.08)	0.014	1.05 (1.02 -1.08)
Birth_year2009:Country_originSuriname	1.00 (0.96 - 1.04)	0.992	1.00 (0.96 - 1.04)	1.00 (0.97 - 1.04)	0.863	1.01 (0.97 -1.04)
Birth_year2010:Country_originSuriname	1.00 (0.97 - 1.04)	0.866	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.05)	0.633	1.01 (0.97 -1.05)
Birth_year2011:Country_originSuriname	1.00 (0.96 - 1.04)	0.887	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.05)	0.546	1.02 (0.98 -1.05)
Birth_year2012:Country_originSuriname	1.01 (0.97 - 1.05)	0.754	1.01 (0.97 - 1.04)	1.01 (0.98 - 1.06)	0.458	1.02 (0.98 -1.06)
Birth_year2013:Country_originSuriname	1.00 (0.97 - 1.04)	0.835	1.00 (0.96 - 1.04)	1.01 (0.97 - 1.05)	0.514	1.02 (0.98 -1.05)
Birth_year2014:Country_originSuriname	1.01 (0.97 - 1.05)	0.665	1.01 (0.97 - 1.05)	1.02 (0.98 - 1.06)	0.420	1.02 (0.98 -1.06)
Birth_year2015:Country_originSuriname	1.00 (0.96 - 1.04)	0.826	1.00 (0.96 - 1.03)	1.01 (0.97 - 1.05)	0.570	1.01 (0.97 -1.05)
Birth_year2016:Country_originSuriname	0.98 (0.94 - 1.02)	0.313	0.98 (0.94 - 1.02)	0.99 (0.96 - 1.03)	0.739	0.99 (0.95 -1.03)
Birth_year2017:Country_originSuriname	0.99 (0.95 - 1.03)	0.517	0.99 (0.95 - 1.03)	1.00 (0.96 - 1.04)	0.912	1.00 (0.96 -1.04)
Birth_year2018:Country_originSuriname	0.97 (0.94 - 1.01)	0.177	0.97 (0.93 - 1.01)	0.99 (0.95 - 1.03)	0.515	0.99 (0.95 -1.03)
Birth_year2019:Country_originSuriname	0.95 (0.92 - 0.99)	0.020	0.95 (0.91 - 0.99)	0.98 (0.94 - 1.01)	0.216	0.97 (0.93 -1.01)
Birth_year2020:Country_originSuriname	0.93 (0.90 - 0.97)	0.001	0.93 (0.89 - 0.97)	0.95 (0.92 - 0.99)	0.024	0.95 (0.91 -0.99)
Birth_year2009:Country_originThe Dutch Caribbean	1.01 (0.96 - 1.06)	0.772	1.01 (0.96 - 1.06)	1.01 (0.96 - 1.07)	0.596	1.02 (0.97 -1.07)
Birth_year2010:Country_originThe Dutch Caribbean	1.00 (0.95 - 1.06)	0.852	1.01 (0.96 - 1.06)	1.01 (0.96 - 1.06)	0.704	1.01 (0.96 -1.06)
Birth_year2011:Country_originThe Dutch Caribbean	1.01 (0.96 - 1.06)	0.727	1.01 (0.96 - 1.06)	1.01 (0.96 - 1.07)	0.595	1.02 (0.97 -1.07)
Birth_year2012:Country_originThe Dutch Caribbean	1.01 (0.96 - 1.06)	0.817	1.01 (0.96 - 1.06)	1.01 (0.96 - 1.07)	0.642	1.01 (0.96 -1.06)
Birth_year2013:Country_originThe Dutch Caribbean	1.01 (0.96 - 1.06)	0.733	1.01 (0.96 - 1.06)	1.02 (0.97 - 1.08)	0.431	1.02 (0.97 -1.07)
Birth_year2014:Country_originThe Dutch Caribbean	1.01 (0.96 - 1.06)	0.708	1.01 (0.96 - 1.06)	1.02 (0.97 - 1.08)	0.387	1.01 (0.96 -1.06)
Birth_year2015:Country_originThe Dutch Caribbean	1.00 (0.95 - 1.06)	0.892	1.00 (0.95 - 1.05)	1.02 (0.97 - 1.07)	0.499	1.01 (0.96 -1.06)
Birth_year2016:Country_originThe Dutch Caribbean	0.98 (0.93 - 1.03)	0.506	0.98 (0.93 - 1.03)	1.00 (0.95 - 1.05)	0.937	0.99 (0.94 -1.04)

Determinants of Childhood Vaccination Coverage

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2017:Country_originThe Dutch Caribbean	0.99 (0.94 - 1.04)	0.673	0.99 (0.94 - 1.04)	1.00 (0.95 - 1.05)	0.980	0.99 (0.94 -1.04)
Birth_year2018:Country_originThe Dutch Caribbean	0.97 (0.92 - 1.02)	0.273	0.97 (0.92 - 1.02)	0.98 (0.94 - 1.04)	0.555	0.97 (0.92 -1.02)
Birth_year2019:Country_originThe Dutch Caribbean	0.95 (0.90 - 1.00)	0.062	0.95 (0.90 - 1.00)	0.97 (0.92 - 1.02)	0.268	0.96 (0.91 -1.01)
Birth_year2020:Country_originThe Dutch Caribbean	0.93 (0.88 - 0.98)	0.004	0.93 (0.88 - 0.98)	0.95 (0.91 - 1.00)	0.071	0.94 (0.89 -0.99)
Birth_year2009:Country_originTürkiye	1.01 (0.97 - 1.04)	0.787	1.00 (0.97 - 1.04)	1.01 (0.97 - 1.05)	0.617	1.01 (0.97 -1.05)
Birth_year2010:Country_originTürkiye	1.01 (0.98 - 1.05)	0.532	1.01 (0.98 - 1.05)	1.02 (0.98 - 1.06)	0.385	1.02 (0.98 -1.05)
Birth_year2011:Country_originTürkiye	1.01 (0.97 - 1.05)	0.585	1.01 (0.98 - 1.05)	1.02 (0.98 - 1.05)	0.394	1.02 (0.98 -1.06)
Birth_year2012:Country_originTürkiye	1.01 (0.98 - 1.05)	0.509	1.02 (0.98 - 1.05)	1.02 (0.98 - 1.06)	0.290	1.03 (0.99 -1.07)
Birth_year2013:Country_originTürkiye	1.02 (0.98 - 1.05)	0.431	1.02 (0.98 - 1.05)	1.02 (0.98 - 1.06)	0.304	1.02 (0.99 -1.06)
Birth_year2014:Country_originTürkiye	1.01 (0.98 - 1.05)	0.510	1.01 (0.98 - 1.05)	1.02 (0.98 - 1.06)	0.345	1.02 (0.98 -1.06)
Birth_year2015:Country_originTürkiye	1.00 (0.96 - 1.03)	0.844	1.00 (0.96 - 1.03)	1.01 (0.97 - 1.05)	0.611	1.01 (0.98 -1.05)
Birth_year2016:Country_originTürkiye	0.98 (0.94 - 1.01)	0.182	0.98 (0.94 - 1.01)	0.99 (0.96 - 1.03)	0.656	0.99 (0.96 -1.03)
Birth_year2017:Country_originTürkiye	0.97 (0.93 - 1.00)	0.067	0.97 (0.93 - 1.00)	0.98 (0.95 - 1.02)	0.336	0.98 (0.94 -1.02)
Birth_year2018:Country_originTürkiye	0.96 (0.92 - 0.99)	0.019	0.96 (0.92 - 0.99)	0.97 (0.94 - 1.01)	0.173	0.97 (0.94 -1.01)
Birth_year2019:Country_originTürkiye	0.90 (0.87 - 0.94)	<0.001	0.90 (0.87 - 0.94)	0.94 (0.90 - 0.97)	0.001	0.94 (0.90 -0.97)
Birth_year2020:Country_originTürkiye	0.87 (0.84 - 0.91)	<0.001	0.87 (0.83 - 0.91)	0.90 (0.86 - 0.93)	<0.001	0.90 (0.86 -0.94)
Birth_year2009:Income_source_motherSelf-employed	0.99 (0.97 - 1.02)	0.667	0.99 (0.97 - 1.02)	0.99 (0.97 - 1.02)	0.564	0.99 (0.97 -1.02)
Birth_year2010:Income_source_motherSelf-employed	0.99 (0.97 - 1.02)	0.607	0.99 (0.97 - 1.02)	0.99 (0.97 - 1.02)	0.511	0.99 (0.96 -1.02)
Birth_year2011:Income_source_motherSelf-employed	0.99 (0.97 - 1.02)	0.688	0.99 (0.97 - 1.02)	0.99 (0.96 - 1.02)	0.478	0.99 (0.96 -1.02)
Birth_year2012:Income_source_motherSelf-employed	0.99 (0.97 - 1.02)	0.515	0.99 (0.96 - 1.02)	0.99 (0.96 - 1.01)	0.286	0.99 (0.96 -1.01)
Birth_year2013:Income_source_motherSelf-employed	0.99 (0.96 - 1.01)	0.269	0.98 (0.96 - 1.01)	0.98 (0.95 - 1.01)	0.140	0.98 (0.95 -1.01)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2014:Income_source_motherSelf-employed	0.98 (0.95 - 1.00)	0.097	0.98 (0.95 - 1.00)	0.97 (0.95 - 1.00)	0.059	0.97 (0.95 -1.00)
Birth_year2015:Income_source_motherSelf-employed	0.97 (0.95 - 1.00)	0.055	0.97 (0.95 - 1.00)	0.97 (0.95 - 1.00)	0.034	0.97 (0.95 -1.00)
Birth_year2016:Income_source_motherSelf-employed	0.97 (0.95 - 1.00)	0.033	0.97 (0.95 - 1.00)	0.97 (0.94 - 0.99)	0.012	0.97 (0.94 -0.99)
Birth_year2017:Income_source_motherSelf-employed	0.99 (0.96 - 1.01)	0.312	0.99 (0.96 - 1.01)	0.98 (0.95 - 1.00)	0.097	0.98 (0.95 -1.00)
Birth_year2018:Income_source_motherSelf-employed	0.98 (0.96 - 1.01)	0.193	0.98 (0.96 - 1.01)	0.97 (0.95 - 1.00)	0.057	0.97 (0.95 -1.00)
Birth_year2019:Income_source_motherSelf-employed	0.98 (0.95 - 1.01)	0.118	0.98 (0.95 - 1.01)	0.97 (0.95 - 1.00)	0.046	0.97 (0.95 -1.00)
Birth_year2020:Income_source_motherSelf-employed	0.97 (0.94 - 1.00)	0.021	0.97 (0.94 - 1.00)	0.96 (0.94 - 0.99)	0.006	0.96 (0.94 -0.99)
Birth_year2009:Income_source_motherRecipient benefit	1.01 (0.98 - 1.03)	0.645	1.01 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.770	1.00 (0.98 -1.03)
Birth_year2010:Income_source_motherRecipient benefit	1.01 (0.99 - 1.04)	0.291	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.03)	0.382	1.01 (0.99 -1.03)
Birth_year2011:Income_source_motherRecipient benefit	1.01 (0.99 - 1.03)	0.388	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.512	1.01 (0.98 -1.03)
Birth_year2012:Income_source_motherRecipient benefit	1.01 (0.99 - 1.04)	0.265	1.01 (0.99 - 1.04)	1.01 (0.99 - 1.04)	0.258	1.01 (0.99 -1.04)
Birth_year2013:Income_source_motherRecipient benefit	1.01 (0.99 - 1.03)	0.390	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.04)	0.312	1.01 (0.99 -1.03)
Birth_year2014:Income_source_motherRecipient benefit	1.00 (0.98 - 1.02)	0.988	1.00 (0.98 - 1.02)	1.01 (0.98 - 1.03)	0.508	1.01 (0.98 -1.03)
Birth_year2015:Income_source_motherRecipient benefit	0.99 (0.96 - 1.01)	0.323	0.99 (0.96 - 1.01)	1.00 (0.97 - 1.02)	0.897	1.00 (0.97 -1.02)
Birth_year2016:Income_source_motherRecipient benefit	1.00 (0.98 - 1.03)	0.950	1.00 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.537	1.01 (0.98 -1.03)
Birth_year2017:Income_source_motherRecipient benefit	1.01 (0.99 - 1.04)	0.404	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.04)	0.383	1.01 (0.99 -1.04)
Birth_year2018:Income_source_motherRecipient benefit	1.01 (0.99 - 1.04)	0.234	1.02 (0.99 - 1.04)	1.02 (0.99 - 1.04)	0.136	1.02 (0.99 -1.04)

Determinants of Childhood Vaccination Coverage

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2019:Income_source_motherRecipient benefit	1.01 (0.99 - 1.04)	0.315	1.01 (0.99 - 1.04)	1.02 (0.99 - 1.05)	0.120	1.02 (1.00 -1.05)
Birth_year2020:Income_source_motherRecipient benefit	1.01 (0.98 - 1.03)	0.548	1.01 (0.98 - 1.03)	1.01 (0.99 - 1.04)	0.342	1.01 (0.99 -1.04)
Birth_year2009:Income_source_motherRecipient benefit	1.01 (0.94 - 1.09)	0.820	1.01 (0.93 - 1.08)	1.01 (0.94 - 1.09)	0.719	1.01 (0.94 -1.09)
Birth_year2010:Income_source_motherRecipient benefit	1.01 (0.93 - 1.09)	0.807	1.01 (0.93 - 1.09)	1.01 (0.93 - 1.09)	0.872	1.01 (0.93 -1.08)
Birth_year2011:Income_source_motherRecipient benefit	1.00 (0.92 - 1.09)	0.907	1.00 (0.92 - 1.09)	0.99 (0.92 - 1.08)	0.906	1.00 (0.91 -1.08)
Birth_year2012:Income_source_motherRecipient benefit	1.00 (0.92 - 1.10)	0.966	1.00 (0.91 - 1.09)	0.99 (0.90 - 1.08)	0.820	0.99 (0.90 -1.08)
Birth_year2013:Income_source_motherRecipient benefit	0.98 (0.90 - 1.07)	0.718	0.98 (0.90 - 1.07)	0.99 (0.91 - 1.08)	0.844	0.99 (0.90 -1.08)
Birth_year2014:Income_source_motherRecipient benefit	0.99 (0.91 - 1.08)	0.864	0.99 (0.90 - 1.08)	0.99 (0.90 - 1.08)	0.783	0.99 (0.90 -1.08)
Birth_year2015:Income_source_motherRecipient benefit	0.97 (0.88 - 1.07)	0.555	0.97 (0.87 - 1.07)	0.97 (0.88 - 1.08)	0.610	0.97 (0.87 -1.07)
Birth_year2016:Income_source_motherRecipient benefit	1.00 (0.90 - 1.11)	0.994	1.00 (0.89 - 1.10)	0.99 (0.89 - 1.10)	0.791	0.98 (0.88 -1.09)
Birth_year2017:Income_source_motherRecipient benefit	1.00 (0.89 - 1.11)	0.941	0.99 (0.88 - 1.10)	0.99 (0.89 - 1.10)	0.844	0.98 (0.87 -1.09)
Birth_year2018:Income_source_motherRecipient benefit	1.01 (0.90 - 1.12)	0.913	1.01 (0.90 - 1.12)	1.00 (0.89 - 1.11)	0.935	1.00 (0.88 -1.11)
Birth_year2019:Income_source_motherRecipient benefit	1.03 (0.90 - 1.17)	0.697	1.03 (0.90 - 1.16)	1.02 (0.89 - 1.16)	0.801	1.02 (0.89 -1.15)
Birth_year2020:Income_source_motherRecipient benefit	0.98 (0.85 - 1.13)	0.786	0.98 (0.83 - 1.12)	0.97 (0.84 - 1.12)	0.639	0.97 (0.82 -1.11)
Birth_year2009:Income_source_motherChild/student	1.00 (0.95 - 1.05)	0.977	1.00 (0.95 - 1.05)	0.99 (0.94 - 1.04)	0.735	0.99 (0.94 -1.04)
Birth_year2010:Income_source_motherChild/student	1.01 (0.96 - 1.06)	0.810	1.00 (0.95 - 1.06)	1.00 (0.95 - 1.05)	0.982	1.00 (0.95 -1.05)
Birth_year2011:Income_source_motherChild/student	1.01 (0.95 - 1.06)	0.846	1.00 (0.95 - 1.06)	1.00 (0.95 - 1.05)	0.945	1.00 (0.94 -1.05)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2012:Income_source_motherChild/student	1.00 (0.95 - 1.06)	0.910	1.00 (0.95 - 1.05)	0.99 (0.94 - 1.05)	0.803	0.99 (0.94 -1.05)
Birth_year2013:Income_source_motherChild/student	1.01 (0.95 - 1.06)	0.824	1.00 (0.95 - 1.06)	1.01 (0.95 - 1.06)	0.791	1.01 (0.95 -1.06)
Birth_year2014:Income_source_motherChild/student	0.99 (0.94 - 1.05)	0.731	0.99 (0.93 - 1.04)	0.99 (0.94 - 1.05)	0.795	0.99 (0.94 -1.05)
Birth_year2015:Income_source_motherChild/student	0.97 (0.91 - 1.02)	0.227	0.96 (0.91 - 1.02)	0.97 (0.92 - 1.03)	0.318	0.97 (0.91 -1.03)
Birth_year2016:Income_source_motherChild/student	0.97 (0.92 - 1.03)	0.333	0.97 (0.91 - 1.03)	0.97 (0.92 - 1.03)	0.378	0.97 (0.92 -1.03)
Birth_year2017:Income_source_motherChild/student	0.99 (0.94 - 1.05)	0.737	0.99 (0.93 - 1.05)	0.99 (0.94 - 1.05)	0.792	0.99 (0.94 -1.05)
Birth_year2018:Income_source_motherChild/student	0.99 (0.94 - 1.05)	0.744	0.99 (0.93 - 1.05)	0.98 (0.93 - 1.04)	0.598	0.99 (0.93 -1.04)
Birth_year2019:Income_source_motherChild/student	0.98 (0.93 - 1.04)	0.531	0.98 (0.92 - 1.04)	0.98 (0.93 - 1.04)	0.548	0.98 (0.93 -1.04)
Birth_year2020:Income_source_motherChild/student	0.96 (0.90 - 1.02)	0.157	0.96 (0.90 - 1.02)	0.97 (0.91 - 1.03)	0.274	0.97 (0.91 -1.03)
Birth_year2009:Income_source_motherOther	1.00 (0.97 - 1.03)	0.973	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.03)	0.941	1.00 (0.97 -1.02)
Birth_year2010:Income_source_motherOther	1.00 (0.98 - 1.03)	0.926	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.935	1.00 (0.98 -1.03)
Birth_year2011:Income_source_motherOther	1.00 (0.98 - 1.03)	0.739	1.00 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.607	1.01 (0.98 -1.03)
Birth_year2012:Income_source_motherOther	1.00 (0.98 - 1.03)	0.824	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.841	1.00 (0.98 -1.03)
Birth_year2013:Income_source_motherOther	1.00 (0.98 - 1.03)	0.757	1.00 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.639	1.00 (0.98 -1.03)
Birth_year2014:Income_source_motherOther	1.00 (0.98 - 1.03)	0.848	1.00 (0.97 - 1.03)	1.00 (0.98 - 1.03)	0.871	1.00 (0.97 -1.03)
Birth_year2015:Income_source_motherOther	1.01 (0.98 - 1.03)	0.710	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.774	1.00 (0.98 -1.03)
Birth_year2016:Income_source_motherOther	1.02 (0.99 - 1.04)	0.293	1.01 (0.99 - 1.04)	1.01 (0.98 - 1.04)	0.488	1.01 (0.98 -1.04)
Birth_year2017:Income_source_motherOther	1.01 (0.99 - 1.04)	0.338	1.01 (0.98 - 1.04)	1.01 (0.98 - 1.04)	0.519	1.01 (0.98 -1.04)
Birth_year2018:Income_source_motherOther	1.01 (0.99 - 1.04)	0.332	1.01 (0.98 - 1.04)	1.02 (0.99 - 1.05)	0.318	1.01 (0.98 -1.04)
Birth_year2019:Income_source_motherOther	1.03 (1.00 - 1.06)	0.056	1.03 (1.00 - 1.06)	1.03 (1.00 - 1.06)	0.064	1.03 (1.00 -1.06)
Birth_year2020:Income_source_motherOther	1.05 (1.02 - 1.08)	0.003	1.04 (1.01 - 1.08)	1.05 (1.01 - 1.08)	0.005	1.04 (1.01 -1.07)
Birth_year2009:Income_source_motherUnknown	NA	NA	0.99 (0.88 - 1.09)	NA	NA	1.01 (0.89 -1.12)

Determinants of Childhood Vaccination Coverage

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2010:Income_source_motherUnknown	NA	NA	1.02 (0.91 - 1.12)	NA	NA	1.06 (0.95 -1.17)
Birth_year2011:Income_source_motherUnknown	NA	NA	1.02 (0.91 - 1.13)	NA	NA	1.07 (0.95 -1.18)
Birth_year2012:Income_source_motherUnknown	NA	NA	1.02 (0.91 - 1.13)	NA	NA	1.08 (0.96 -1.19)
Birth_year2013:Income_source_motherUnknown	NA	NA	1.06 (0.95 - 1.17)	NA	NA	1.08 (0.96 -1.19)
Birth_year2014:Income_source_motherUnknown	NA	NA	1.06 (0.95 - 1.17)	NA	NA	1.08 (0.96 -1.19)
Birth_year2015:Income_source_motherUnknown	NA	NA	0.98 (0.86 - 1.10)	NA	NA	1.05 (0.93 -1.17)
Birth_year2016:Income_source_motherUnknown	NA	NA	1.00 (0.88 - 1.12)	NA	NA	1.03 (0.90 -1.15)
Birth_year2017:Income_source_motherUnknown	NA	NA	1.01 (0.89 - 1.14)	NA	NA	1.06 (0.93 -1.19)
Birth_year2018:Income_source_motherUnknown	NA	NA	1.02 (0.90 - 1.15)	NA	NA	1.03 (0.90 -1.16)
Birth_year2019:Income_source_motherUnknown	NA	NA	1.03 (0.90 - 1.15)	NA	NA	1.07 (0.94 -1.20)
Birth_year2020:Income_source_motherUnknown	NA	NA	0.95 (0.84 - 1.07)	NA	NA	0.86 (0.74 -0.98)
Birth_year2009:UrbanisationExtremely urbanised	1.00 (0.98 - 1.03)	0.744	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.783	1.00 (0.98 -1.03)
Birth_year2010:UrbanisationExtremely urbanised	1.00 (0.98 - 1.03)	0.761	1.00 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.490	1.01 (0.98 -1.03)
Birth_year2011:UrbanisationExtremely urbanised	1.01 (0.98 - 1.03)	0.533	1.01 (0.98 - 1.03)	1.01 (0.99 - 1.04)	0.377	1.01 (0.99 -1.03)
Birth_year2012:UrbanisationExtremely urbanised	1.01 (0.99 - 1.03)	0.445	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.04)	0.305	1.01 (0.99 -1.04)
Birth_year2013:UrbanisationExtremely urbanised	1.01 (0.99 - 1.04)	0.296	1.01 (0.99 - 1.04)	1.01 (0.99 - 1.04)	0.261	1.01 (0.99 -1.04)
Birth_year2014:UrbanisationExtremely urbanised	1.01 (0.99 - 1.04)	0.307	1.01 (0.99 - 1.04)	1.01 (0.99 - 1.04)	0.270	1.01 (0.99 -1.04)
Birth_year2015:UrbanisationExtremely urbanised	1.02 (0.99 - 1.04)	0.148	1.02 (0.99 - 1.04)	1.02 (0.99 - 1.04)	0.144	1.02 (0.99 -1.04)
Birth_year2016:UrbanisationExtremely urbanised	1.02 (0.99 - 1.04)	0.121	1.02 (1.00 - 1.05)	1.02 (1.00 - 1.05)	0.084	1.02 (1.00 -1.05)
Birth_year2017:UrbanisationExtremely urbanised	1.01 (0.99 - 1.04)	0.236	1.02 (0.99 - 1.04)	1.02 (0.99 - 1.04)	0.172	1.02 (0.99 -1.04)
Birth_year2018:UrbanisationExtremely urbanised	1.02 (1.00 - 1.04)	0.114	1.02 (1.00 - 1.05)	1.02 (1.00 - 1.05)	0.070	1.02 (1.00 -1.05)
Birth_year2019:UrbanisationExtremely urbanised	1.01 (0.99 - 1.04)	0.309	1.01 (0.99 - 1.04)	1.02 (1.00 - 1.04)	0.115	1.02 (1.00 -1.05)
Birth_year2020:UrbanisationExtremely urbanised	1.01 (0.98 - 1.03)	0.517	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.04)	0.367	1.01 (0.99 -1.04)
Birth_year2009:UrbanisationHardly urbanised	1.00 (0.98 - 1.03)	0.808	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.737	1.00 (0.98 -1.03)
Birth_year2010:UrbanisationHardly urbanised	1.00 (0.98 - 1.03)	0.856	1.00 (0.98 - 1.02)	1.01 (0.98 - 1.03)	0.649	1.01 (0.98 -1.03)
Birth_year2011:UrbanisationHardly urbanised	1.00 (0.98 - 1.03)	0.768	1.00 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.616	1.01 (0.98 -1.03)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2012:UrbanisationHardly urbanised	1.00 (0.98 - 1.03)	0.783	1.00 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.600	1.01 (0.98 -1.03)
Birth_year2013:UrbanisationHardly urbanised	1.00 (0.97 - 1.02)	0.876	1.00 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.890	1.00 (0.97 -1.02)
Birth_year2014:UrbanisationHardly urbanised	1.00 (0.98 - 1.02)	0.992	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.991	1.00 (0.98 -1.02)
Birth_year2015:UrbanisationHardly urbanised	1.00 (0.97 - 1.02)	0.766	1.00 (0.97 - 1.02)	1.00 (0.97 - 1.02)	0.887	1.00 (0.98 -1.02)
Birth_year2016:UrbanisationHardly urbanised	1.00 (0.98 - 1.02)	0.998	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.874	1.00 (0.98 -1.03)
Birth_year2017:UrbanisationHardly urbanised	1.00 (0.98 - 1.02)	0.936	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	0.853	1.00 (0.98 -1.03)
Birth_year2018:UrbanisationHardly urbanised	1.01 (0.99 - 1.03)	0.446	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.03)	0.405	1.01 (0.99 -1.03)
Birth_year2019:UrbanisationHardly urbanised	1.01 (0.98 - 1.03)	0.606	1.01 (0.98 - 1.03)	1.01 (0.99 - 1.03)	0.477	1.01 (0.99 -1.03)
Birth_year2020:UrbanisationHardly urbanised	1.01 (0.98 - 1.03)	0.655	1.01 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.546	1.01 (0.98 -1.03)
Birth_year2009:UrbanisationModerately urbanised	1.00 (0.98 - 1.02)	0.868	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.950	1.00 (0.98 -1.02)
Birth_year2010:UrbanisationModerately urbanised	1.00 (0.98 - 1.03)	0.718	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.786	1.00 (0.98 -1.03)
Birth_year2011:UrbanisationModerately urbanised	1.01 (0.98 - 1.03)	0.622	1.01 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.586	1.01 (0.98 -1.03)
Birth_year2012:UrbanisationModerately urbanised	1.01 (0.99 - 1.03)	0.492	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.533	1.01 (0.98 -1.03)
Birth_year2013:UrbanisationModerately urbanised	1.01 (0.98 - 1.03)	0.555	1.01 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.613	1.01 (0.98 -1.03)
Birth_year2014:UrbanisationModerately urbanised	1.01 (0.99 - 1.03)	0.442	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.516	1.01 (0.99 -1.03)
Birth_year2015:UrbanisationModerately urbanised	1.01 (0.99 - 1.03)	0.357	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.602	1.01 (0.98 -1.03)
Birth_year2016:UrbanisationModerately urbanised	1.01 (0.99 - 1.04)	0.264	1.01 (0.99 - 1.04)	1.01 (0.99 - 1.04)	0.311	1.01 (0.99 -1.04)
Birth_year2017:UrbanisationModerately urbanised	1.01 (0.99 - 1.03)	0.455	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.550	1.01 (0.98 -1.03)
Birth_year2018:UrbanisationModerately urbanised	1.01 (0.99 - 1.04)	0.329	1.01 (0.99 - 1.04)	1.01 (0.99 - 1.04)	0.343	1.01 (0.99 -1.04)
Birth_year2019:UrbanisationModerately urbanised	1.01 (0.98 - 1.03)	0.517	1.01 (0.98 - 1.03)	1.01 (0.98 - 1.03)	0.560	1.01 (0.98 -1.03)

Determinants of Childhood Vaccination Coverage

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2020:UrbanisationModerately urbanised	1.01 (0.99 - 1.03)	0.386	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.03)	0.390	1.01 (0.99 -1.04)
Birth_year2009:UrbanisationStrongly urbanised	1.00 (0.98 - 1.02)	0.972	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.832	1.00 (0.98 -1.02)
Birth_year2010:UrbanisationStrongly urbanised	1.00 (0.98 - 1.02)	0.885	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.02)	0.924	1.00 (0.98 -1.02)
Birth_year2011:UrbanisationStrongly urbanised	1.00 (0.98 - 1.03)	0.709	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.770	1.00 (0.98 -1.03)
Birth_year2012:UrbanisationStrongly urbanised	1.01 (0.98 - 1.03)	0.645	1.01 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.704	1.00 (0.98 -1.03)
Birth_year2013:UrbanisationStrongly urbanised	1.00 (0.98 - 1.03)	0.754	1.00 (0.98 - 1.03)	1.00 (0.98 - 1.03)	0.824	1.00 (0.98 -1.02)
Birth_year2014:UrbanisationStrongly urbanised	1.01 (0.98 - 1.03)	0.553	1.01 (0.99 - 1.03)	1.00 (0.98 - 1.03)	0.791	1.00 (0.98 -1.03)
Birth_year2015:UrbanisationStrongly urbanised	1.01 (0.99 - 1.03)	0.414	1.01 (0.99 - 1.03)	1.00 (0.98 - 1.03)	0.671	1.00 (0.98 -1.03)
Birth_year2016:UrbanisationStrongly urbanised	1.01 (0.99 - 1.03)	0.401	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.526	1.01 (0.99 -1.03)
Birth_year2017:UrbanisationStrongly urbanised	1.01 (0.99 - 1.03)	0.439	1.01 (0.99 - 1.03)	1.01 (0.98 - 1.03)	0.569	1.01 (0.98 -1.03)
Birth_year2018:UrbanisationStrongly urbanised	1.02 (0.99 - 1.04)	0.150	1.02 (0.99 - 1.04)	1.01 (0.99 - 1.04)	0.219	1.01 (0.99 -1.04)
Birth_year2019:UrbanisationStrongly urbanised	1.01 (0.99 - 1.03)	0.461	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.03)	0.438	1.01 (0.99 -1.03)
Birth_year2020:UrbanisationStrongly urbanised	1.01 (0.99 - 1.04)	0.307	1.01 (0.99 - 1.03)	1.01 (0.99 - 1.03)	0.439	1.01 (0.99 -1.03)
Birth_year2009:UrbanisationUnknown	NA	NA	1.15 (0.60 - 1.70)	NA	NA	1.25 (0.65 -1.86)
Birth_year2010:UrbanisationUnknown	NA	NA	1.10 (0.53 - 1.68)	NA	NA	1.08 (0.42 -1.73)
Birth_year2011:UrbanisationUnknown	NA	NA	1.32 (0.72 - 1.93)	NA	NA	1.48 (0.76 -2.19)
Birth_year2012:UrbanisationUnknown	NA	NA	1.24 (0.52 - 1.96)	NA	NA	1.92 (1.00 -2.85)
Birth_year2013:UrbanisationUnknown	NA	NA	1.46 (0.75 - 2.16)	NA	NA	1.71 (0.25 -3.17)
Birth_year2014:UrbanisationUnknown	NA	NA	1.33 (0.69 - 1.97)	NA	NA	1.54 (0.47 -2.61)
Birth_year2015:UrbanisationUnknown	NA	NA	1.18 (0.45 - 1.90)	NA	NA	0.97 (-1.04 -2.98)
Birth_year2016:UrbanisationUnknown	NA	NA	1.41 (0.87 - 1.95)	NA	NA	1.63 (0.97 -2.29)
Birth_year2017:UrbanisationUnknown	NA	NA	1.40 (0.79 - 2.02)	NA	NA	1.60 (0.68 -2.53)
Birth_year2018:UrbanisationUnknown	NA	NA	1.15 (0.53 - 1.77)	NA	NA	1.32 (0.45 -2.19)
Birth_year2019:UrbanisationUnknown	NA	NA	1.36 (0.85 - 1.87)	NA	NA	1.70 (1.07 -2.33)
Birth_year2020:UrbanisationUnknown	NA	NA	1.33 (0.87 - 1.79)	NA	NA	1.40 (0.69 -2.11)
Birth_year2009:family_size4 or more children	1.01 (0.98 - 1.04)	0.708	1.01 (0.98 - 1.03)	1.00 (0.97 - 1.03)	0.875	1.00 (0.97 -1.03)

Chapter 2

	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
Category	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2010:family_size4 or more children	1.01 (0.98 - 1.04)	0.740	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.04)	0.775	1.00 (0.97 -1.03)
Birth_year2011:family_size4 or more children	1.01 (0.98 - 1.04)	0.500	1.01 (0.98 - 1.04)	1.01 (0.98 - 1.04)	0.510	1.01 (0.98 -1.04)
Birth_year2012:family_size4 or more children	1.00 (0.97 - 1.03)	0.840	1.00 (0.97 - 1.03)	0.99 (0.96 - 1.02)	0.702	0.99 (0.96 -1.02)
Birth_year2013:family_size4 or more children	1.01 (0.98 - 1.04)	0.453	1.01 (0.98 - 1.04)	1.01 (0.98 - 1.04)	0.641	1.01 (0.98 -1.04)
Birth_year2014:family_size4 or more children	1.00 (0.97 - 1.03)	0.940	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.03)	0.999	1.00 (0.97 -1.03)
Birth_year2015:family_size4 or more children	1.00 (0.97 - 1.03)	0.977	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.03)	0.986	1.00 (0.97 -1.03)
Birth_year2016:family_size4 or more children	1.01 (0.98 - 1.04)	0.596	1.01 (0.98 - 1.04)	1.01 (0.98 - 1.04)	0.706	1.01 (0.98 -1.04)
Birth_year2017:family_size4 or more children	1.02 (0.99 - 1.05)	0.295	1.02 (0.99 - 1.05)	1.01 (0.98 - 1.04)	0.526	1.01 (0.98 -1.04)
Birth_year2018:family_size4 or more children	1.01 (0.98 - 1.04)	0.722	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.03)	0.927	1.00 (0.97 -1.03)
Birth_year2019:family_size4 or more children	1.00 (0.97 - 1.04)	0.759	1.00 (0.97 - 1.03)	1.00 (0.97 - 1.03)	0.876	1.00 (0.97 -1.03)
Birth_year2020:family_size4 or more children	0.99 (0.96 - 1.02)	0.375	0.99 (0.95 - 1.02)	0.98 (0.95 - 1.01)	0.287	0.98 (0.95 -1.02)
Birth_year2009:family_sizeInstitutional	1.11 (0.87 - 1.42)	0.393	1.17 (0.98 - 1.37)	1.13 (0.88 - 1.45)	0.334	1.22 (1.01 -1.42)
Birth_year2010:family_sizeInstitutional	1.07 (0.85 - 1.35)	0.548	1.13 (0.95 - 1.31)	1.12 (0.88 - 1.42)	0.343	1.24 (1.05 -1.43)
Birth_year2011:family_sizeInstitutional	1.06 (0.83 - 1.36)	0.641	1.10 (0.92 - 1.29)	1.10 (0.85 - 1.41)	0.472	1.20 (1.00 -1.39)
Birth_year2012:family_sizeInstitutional	1.10 (0.86 - 1.41)	0.435	1.14 (0.95 - 1.33)	1.11 (0.86 - 1.43)	0.425	1.20 (1.00 -1.39)
Birth_year2013:family_sizeInstitutional	1.09 (0.86 - 1.39)	0.457	1.13 (0.94 - 1.32)	1.13 (0.89 - 1.44)	0.314	1.20 (1.01 -1.39)
Birth_year2014:family_sizeInstitutional	1.04 (0.82 - 1.32)	0.737	1.07 (0.89 - 1.26)	1.05 (0.82 - 1.34)	0.712	1.13 (0.94 -1.32)
Birth_year2015:family_sizeInstitutional	1.05 (0.82 - 1.35)	0.718	1.05 (0.86 - 1.24)	1.12 (0.87 - 1.44)	0.387	1.15 (0.95 -1.35)
Birth_year2016:family_sizeInstitutional	1.05 (0.82 - 1.35)	0.673	1.03 (0.84 - 1.22)	1.11 (0.87 - 1.42)	0.391	1.10 (0.91 -1.30)
Birth_year2017:family_sizeInstitutional	1.06 (0.82 - 1.37)	0.644	1.03 (0.83 - 1.22)	1.12 (0.87 - 1.44)	0.377	1.11 (0.91 -1.30)
Birth_year2018:family_sizeInstitutional	1.09 (0.85 - 1.39)	0.498	1.03 (0.84 - 1.21)	1.11 (0.87 - 1.42)	0.386	1.08 (0.89 -1.27)
Birth_year2019:family_sizeInstitutional	1.02 (0.79 - 1.32)	0.878	0.95 (0.76 - 1.14)	1.05 (0.81 - 1.35)	0.729	1.00 (0.80 -1.19)
Birth_year2020:family_sizeInstitutional	1.09 (0.86 - 1.40)	0.475	1.08 (0.89 - 1.27)	1.16 (0.90 - 1.48)	0.250	1.11 (0.91 -1.30)
Birth_year2009:family_sizeUnknown	NA	NA	0.92 (0.36 - 1.47)	NA	NA	0.82 (0.22 -1.43)
Birth_year2010:family_sizeUnknown	NA	NA	0.92 (0.34 - 1.50)	NA	NA	0.95 (0.29 -1.60)
Birth_year2011:family_sizeUnknown	NA	NA	0.80 (0.19 - 1.41)	NA	NA	0.71 (0.00 -1.43)

Determinants of Childhood Vaccination Coverage

Category	MMR vaccination model		Sensitivity analysis*:	DTaP-IPV vaccination model		Sensitivity analysis*:
	aRR (95% CI)	p-value	aRR (95% CI)	aRR (95% CI)	p-value	aRR (95% CI)
Birth_year2012:family_sizeUnknown	NA	NA	0.83 (0.10 - 1.56)	NA	NA	0.55 (-0.38 -1.47)
Birth_year2013:family_sizeUnknown	NA	NA	0.71 (0.01 - 1.42)	NA	NA	0.63 (-0.84 -2.09)
Birth_year2014:family_sizeUnknown	NA	NA	0.78 (0.13 - 1.43)	NA	NA	0.69 (-0.39 -1.77)
Birth_year2015:family_sizeUnknown	NA	NA	0.96 (0.23 - 1.69)	NA	NA	1.18 (-0.83 -3.20)
Birth_year2016:family_sizeUnknown	NA	NA	0.80 (0.25 - 1.35)	NA	NA	0.75 (0.08 -1.41)
Birth_year2017:family_sizeUnknown	NA	NA	0.80 (0.18 - 1.42)	NA	NA	0.73 (-0.20 -1.66)
Birth_year2018:family_sizeUnknown	NA	NA	0.99 (0.36 - 1.62)	NA	NA	0.95 (0.08 -1.83)
Birth_year2019:family_sizeUnknown	NA	NA	0.86 (0.34 - 1.37)	NA	NA	0.76 (0.13 -1.40)
Birth_year2020:family_sizeUnknown	NA	NA	0.86 (0.40 - 1.32)	NA	NA	1.00 (0.29 -1.71)
Birth_year2009:Daycare-2No daycare	1.00 (0.98 - 1.01)	0.792	1.00 (0.98 - 1.01)	1.00 (0.98 - 1.01)	0.783	1.00 (0.98 -1.01)
Birth_year2010:Daycare-2No daycare	1.00 (0.98 - 1.01)	0.564	1.00 (0.98 - 1.01)	0.99 (0.98 - 1.01)	0.469	0.99 (0.98 -1.01)
Birth_year2011:Daycare-2No daycare	1.00 (0.98 - 1.01)	0.642	1.00 (0.98 - 1.01)	0.99 (0.98 - 1.01)	0.499	1.00 (0.98 -1.01)
Birth_year2012:Daycare-2No daycare	0.99 (0.98 - 1.01)	0.473	1.00 (0.98 - 1.01)	0.99 (0.98 - 1.01)	0.380	0.99 (0.98 -1.01)
Birth_year2013:Daycare-2No daycare	0.99 (0.97 - 1.01)	0.227	0.99 (0.98 - 1.01)	0.99 (0.98 - 1.01)	0.262	0.99 (0.98 -1.01)
Birth_year2014:Daycare-2No daycare	0.98 (0.97 - 1.00)	0.054	0.99 (0.97 - 1.00)	0.98 (0.97 - 1.00)	0.051	0.98 (0.97 -1.00)
Birth_year2015:Daycare-2No daycare	0.98 (0.96 - 1.00)	0.017	0.98 (0.96 - 1.00)	0.98 (0.96 - 1.00)	0.015	0.98 (0.96 -1.00)
Birth_year2016:Daycare-2No daycare	0.97 (0.95 - 0.98)	<0.001	0.97 (0.95 - 0.98)	0.97 (0.95 - 0.98)	<0.001	0.97 (0.95 -0.98)
Birth_year2017:Daycare-2No daycare	0.96 (0.94 - 0.98)	<0.001	0.96 (0.94 - 0.98)	0.96 (0.94 - 0.98)	<0.001	0.96 (0.94 -0.98)
Birth_year2018:Daycare-2No daycare	0.95 (0.94 - 0.97)	<0.001	0.95 (0.93 - 0.97)	0.95 (0.94 - 0.97)	<0.001	0.95 (0.94 -0.97)
Birth_year2019:Daycare-2No daycare	0.94 (0.92 - 0.96)	<0.001	0.94 (0.92 - 0.96)	0.94 (0.92 - 0.96)	<0.001	0.94 (0.92 -0.96)
Birth_year2020:Daycare-2No daycare	0.92 (0.90 - 0.93)	<0.001	0.92 (0.90 - 0.94)	0.93 (0.91 - 0.94)	<0.001	0.93 (0.91 -0.95)

Chapter 2

Supplementary Table S6. Adjusted relative change in DTaP-IPV vaccination coverage

Birth cohort												
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Education level mother (ref: high)												
Not high	-0,05	-0,05	-0,21	-0,50	-0,11	-0,27	-0,65	-0,95	-0,87	-0,88	-0,76	-1,7
Household standardised disposable income quartiles (ref: fourth quartile)												
First	-1,45	-1,83	-1,94	-1,99	-2,54	-2,99	-4,03	-4,83	-4,65	-4,29	-4,90	-6,13
Second	-0,42	-1,36	-1,53	-1,80	-2,17	-2,85	-3,67	-4,44	-3,78	-4,27	-4,09	-4,67
Third	0,08	-0,51	-0,58	-0,96	-0,96	-1,60	-2,41	-2,70	-2,15	-2,05	-1,85	-2,08
Income source mother (ref: job in employment)												
Self-employed	-3,35	-3,79	-4,09	-4,75	-5,21	-6,17	-6,76	-7,43	-5,94	-6,39	-6,23	-7,39
Benefit recipient	-0,83	-0,50	-1,00	-0,63	-0,70	-1,57	-2,84	-2,1	-1,36	-0,73	-0,31	-1,21
Recipient benefit	0,19	-0,90	-2,25	-2,99	-2,76	-3,58	-5,19	-4,21	-3,49	-3,01	-0,63	-5,74
Student	-2,55	-1,95	-2,42	-3,10	-1,67	-3,55	-5,95	-5,80	-3,64	-4,53	-4,50	-6,02
Other	-5,40	-5,54	-5,23	-5,81	-5,40	-6,23	-6,37	-5,97	-5,60	-5,22	-3,70	-2,31
Country of origin (ref: The Netherlands)												
Europe excl NL	-1,32	-1,09	-1,34	-1,67	-1,59	-1,99	-2,19	-2,52	-2,22	-2,43	-2,06	-2,44
Indonesia	0,88	0,58	-0,34	0,16	0,02	-0,36	-1,15	-1,18	-0,52	-1,00	-0,82	-2,16
Morocco	3,85	4,36	3,77	3,64	2,70	1,17	-2,81	-5,74	-6,26	-9,18	-15,03	-22,83
Other, Africa	-0,73	0,48	2,11	1,37	1,74	1,01	1,50	1,15	1,73	1,51	1,03	0,57
Other, America/ Oceania	-2,54	-2,08	-1,78	-2,97	-2,04	-2,31	-2,55	-2,17	-2,23	-1,65	-2,01	-2,47
Other, Asia	0,52	1,22	1,48	1,43	1,58	0,76	-0,71	0,71	2,39	2,27	2,69	2,55
Suriname	0,58	0,82	0,84	0,92	0,81	0,65	-0,15	-2,10	-0,80	-2,46	-3,34	-5,54
The Dutch Caribbean	0,83	0,08	0,25	-0,14	0,78	0,48	-0,32	-2,44	-1,75	-3,46	-4,50	-6,39
Türkiye	3,54	3,89	3,62	3,81	3,83	3,15	1,99	-0,02	-0,58	-1,49	-5,03	-9,07
Level of urbanization (ref: not urbanized)												
Extremely	0,52	0,68	0,68	0,66	0,84	0,34	0,47	0,63	0,62	1,03	1,02	0,01
Strongly	1,35	1,34	1,33	1,22	1,10	0,68	0,54	0,61	0,97	1,59	1,35	1,18
Moderately	1,13	1,16	1,25	1,14	1,07	0,77	0,29	0,71	0,65	0,92	0,77	0,93
Hardly	1,26	1,05	0,87	0,70	-0,03	-0,35	-0,83	-0,64	-0,17	0,46	0,61	0,30
Family size (ref: 1-3 children)												
≥ 4 children	-8,35	-8,49	-8,18	-9,84	-8,58	-9,66	-9,98	-9,58	-8,83	-9,72	-9,37	-11,26
Institutional	-2,65	-3,86	-6,27	-5,44	-3,34	-11,01	-5,28	-5,95	-4,86	-5,51	-11,0	-1,90
Day-care attendance (ref: day-care yes)												
Day-care no	-2,32	-3,01	-3,20	-3,56	-3,71	-4,81	-5,55	-6,84	-7,27	-7,92	-8,87	-10,39

Determinants of Childhood Vaccination Coverage

Supplementary Table S7. Distribution of sociodemographic groups and number of unvaccinated children in birth cohort 2020

Category	Population (N)	Total population (%)	Unvaccinated N	Unvaccinated population (%)
Total	169500	100%	17990	100%
Education level mother				
High	73790	43,5%	5000	27,8%
Not high	95710	56,5%	12990	72,2%
Income household				
First quartile	18500	10,9%	3420	19,0%
Second quartile	44860	26,5%	6100	33,9%
Third quartile	60590	35,7%	4790	26,6%
Fourth quartile	43400	25,6%	2750	15,3%
Income source mother				
Job in employment	121260	71,5%	8910	49,5%
Self-employed	13660	8,1%	2090	11,6%
Benefit recipient	18510	10,9%	3380	18,8%
Recipient benefit	270	0,2%	50	0,3%
Student	2450	1,4%	390	2,2%
Other	11750	6,9%	2420	13,5%
Country of origin				
The Netherlands	97260	57,4%	7230	40,2%
Europe (excl. The Netherlands)	20650	12,2%	2540	14,1%
Morocco	8020	4,7%	2770	15,4%
Türkiye	6530	3,9%	1350	7,5%
Suriname	5500	3,2%	790	4,4%
The Dutch Caribbean	3720	2,2%	610	3,4%
Indonesia	4270	2,5%	340	1,9%
Other, America/Oceania	5090	3,0%	500	2,8%
Other, Africa	6790	4,0%	880	4,9%
Other, Asia	11670	6,9%	980	5,4%
Level of urbanisation				
Extremely urbanised	38100	22,5%	4990	27,7%
Strongly urbanised	42400	25,0%	4110	22,8%
Moderately urbanised	31940	18,8%	2810	15,6%
Hardly urbanised	28430	16,8%	2400	13,3%
Not urbanised	25940	15,3%	2650	14,7%
Family-size				
1-3 children	155820	91,9%	14230	79,1%
≥ 4 children	10740	6,3%	2630	14,6%
Institutional household	380	0,2%	120	0,7%
Day care attendance				
Yes	123520	72,9%	8000	44,5%
No	45980	27,1%	9990	55,5%

Chapter 3

Large differences in MMR and DTaP-IPV vaccination coverage among primary schools of various denominations, The Netherlands, 2024

Joyce Pijpers, Annika van Roon, Susan van den Hof, Ruben van Gaalen, Hester de Melker, Susan Hahné

Vaccine, 2026

DOI: [10.1016/j.vaccine.2025.128137](https://doi.org/10.1016/j.vaccine.2025.128137)

ABSTRACT

BACKGROUND: Recently, the number of measles and pertussis cases increased worldwide, including in the Netherlands. As schools are important in transmission of several vaccine-preventable diseases, we systematically assessed childhood vaccination coverage in the Netherlands among primary school children by birth cohort for all school denominations.

METHODS: We linked nationwide vaccination data with sociodemographic registries for children born 2013–2020 attending primary school on 01-10-2024. Vaccination status for MMR (at 14 months), DTaP-IPV (at (2)3-5-11 months), and DTaP-booster (at 4 years) was retrieved from the immunisation register. Vaccination coverage was stratified by school denomination, birth year and sociodemographic characteristics. Poisson regression assessed independent associations between denomination and vaccination uptake.

RESULTS: MMR and DTaP-IPV coverage was high (>94%) in general, Catholic, Protestant, collaborative, and other schools, but lower in Anthroposophical (78% MMR, 77% DTaP-IPV), Islamic (74% MMR, 75% DTaP-IPV), and Orthodox Protestant schools (57% MMR, 58% DTaP-IPV). DTaP-IPV booster coverage was lower than the primary series, ranging from 50% (Orthodox Protestant) to 88% (Catholic/Protestant). Primary coverage remained stable for most denominations (overall 95%) but declined at Islamic schools (MMR: 87% to 59%, DTaP-IPV: 88% to 60%) and moderately at Orthodox Protestant schools (MMR: 60% to 54%, DTaP-IPV: 60% to 55%), while coverage at Anthroposophical schools fluctuated (MMR: range 76–81%, DTaP-IPV: range 74–79%). Adjusting for sociodemographic variables had little impact.

CONCLUSIONS: Although most unvaccinated children attend schools with high coverage, clustering at Orthodox Protestant, Anthroposophical, and increasingly Islamic schools poses ongoing outbreak risks. Further research on vaccination barriers, drivers, and the role of social networks is needed to better understand vaccination decisions.

Introduction

In recent years, many countries in Europe and beyond have experienced a resurgence of vaccine-preventable diseases (VPDs) such as measles and pertussis, largely due to declining vaccination coverage and the clustering of unvaccinated individuals in the case of measles, and in addition waning immunity following vaccination in the case of pertussis. For example, large measles outbreaks have occurred in several European countries, with over 128,352 cases reported in the World Health Organization (WHO) European Region in 2024, the highest number since 1997 [1, 2]. Pertussis cases have also increased in Europe and other regions [3]. Additionally, the recent detection of vaccine-derived poliovirus (VDPV) in the European Union highlights ongoing threats, even in areas previously considered polio-free [4]. The WHO and the European Centre for Disease Prevention and Control (ECDC) have expressed concern that vaccination coverage below herd immunity thresholds with consequent outbreaks threaten progress towards disease elimination [1, 5].

Unfortunately, The Netherlands, with a longstanding childhood vaccination programme offering free and non-mandatory measles-mumps-rubella (MMR) and diphtheria-tetanus-acellular pertussis-inactivated poliovirus (DTaP-IPV) vaccines, has not been immune to these trends. Recently, the number of measles, mumps and pertussis cases increased, coinciding with a gradual decline in childhood vaccination coverage. In 2024, estimated one-dose MMR and $\geq$ three-dose DTaP-IPV vaccination coverage at 2 years of age (birth year 2021) was 88.3% and 85.4%, respectively [6]. The estimated second-dose MMR and booster DT-IPV vaccination coverage among school children (10 years of age) was 78.5% and 80.1% respectively [6]—well below the WHO goal of 95% set to eliminate endemic measles [7].

Schools are key settings for infectious disease transmission, especially as vaccination coverage declines. High-density settings and close interactions among children facilitate pathogen spread, particularly among unvaccinated populations. In the Netherlands, the clustering of unvaccinated children is enhanced by a school system, rooted in Article 23 of the Dutch Constitution, which guarantees freedom of education. This allows parents to choose schools that reflect their beliefs, philosophies or convictions, creating a spectrum of denominations. In some, including Orthodox Protestant and Anthroposophical schools, hesitancy toward vaccination is more common. Orthodox Protestant individuals relatively frequently refuse vaccination based on religious objections, viewing it as interference with God's plan [8, 9], while Anthroposophy, inspired by Steiner's philosophy, tends to believe experiencing diseases such as measles is important for children's development [10, 11]. The consequences of this clustering of unvaccinated individuals within certain networks are reflected in the outbreak patterns observed in the Netherlands over recent decades.

Historically, outbreaks of several major VPDs in the Netherlands have been strongly

Chapter 3

associated with specific communities and networks. Major measles outbreaks occurred in Orthodox Protestant communities in 1992–1994, 1999–2000, and 2013–2014 [12], while a measles outbreak in 2008 affected the Anthroposophical community [13]. Rubella saw a notable outbreak in 2004–2005, also largely confined to Orthodox Protestant groups [14]. Mumps outbreaks occurred in these communities in 2007–2008 [15], and more recently, in the beginning of 2024 [16]. A significant polio outbreak in 1992–1993 was again largely restricted to Orthodox Protestant communities [17, 18]. Of note, major vaccine preventable disease outbreaks in the Dutch Orthodox Reformed community spread to a related community in Canada, and sometimes to the US [12, 14, 19]. Notably, while such clustering of VPD outbreaks was previously limited to Anthroposophical and Orthodox-Protestant groups, more recent evidence suggests that similar clusters of unvaccinated children are now also emerging in some urban areas [6, 16].

Previous research has shown that school identity and associated social networks play a key role in the clustering of unvaccinated children in the Netherlands. For example, Klinkenberg et al. [20] found significantly lower MMR uptake among Orthodox Protestant and Anthroposophical schools, and Munday et al. [21, 22] highlighted how extensive primary and secondary school-household networks, particularly in Orthodox Protestant communities, contribute to clusters of unvaccinated children and elevate outbreak risk. However, previous studies on school-level vaccination coverage have mostly relied on aggregated and older data. Therefore, we aim to estimate MMR and DTaP-IPV vaccination coverage among primary school children by school denomination, using recent, individual-level data that link vaccination status to school enrolment. These findings can inform social scientific research on vaccination barriers and drivers, and the role of social networks to better understand vaccination decisions.

Methods

Study population

For this retrospective database study, several national data registers were linked using a unique person identifier. Based on the Dutch personal records database, all children born between 1 January 2013 and 1 October 2020 were selected, i.e. those of primary school age. In the Netherlands, education is compulsory from the age of five years, but the vast majority of children (94% in 2022) begins primary school when they turn four. Data on primary school enrolment were obtained from Statistics Netherlands (CBS). Children attending primary school on 01-10-2024 were selected. The school enrolment register does not include enrolments in private education, however, 98% of schools in the Netherlands are government-funded (public) schools. Furthermore, the register does not contain information on foreign schools, resulting in the omission of children living near the German or Belgian borders who attend schools outside the Netherlands.

Outcome measure

An overview of the complete DTaP-IPV and MMR vaccination schedule within the National Immunization Programme (NIP) can be found in table 1. Three binary outcomes were used: having received a primary MMR vaccination, having received at least 3 doses of DTaP-IPV primary series ((2), 3, 5 and 11 months), and having received a DTaP-IPV booster vaccination (4 years), by 1-10-2024. The 9-year DT-IPV booster and second-dose MMR vaccinations were excluded from the analyses as not all children in the study population had reached the eligible age. Vaccination status was measured at this single time point to assess the current vaccination coverage among primary school children, rather than timeliness of vaccination. Vaccination data was retrieved from Praeventis, the Dutch national immunisation register [23]. Children for whom the defined vaccinations were not registered in Praeventis were classified as unvaccinated. Since January 2022, parental informed consent is needed to register vaccinations in Praeventis. As a consequence, some children from the 2018-2020 cohorts who were classified as unvaccinated in our data may have actually received vaccinations, leading to an underestimation of the vaccination coverage. This is relatively uncommon for primary DTaP-IPV and MMR vaccination, since the majority of children (everyone for DTaP-IPV and all children born before November 2020 for MMR) were scheduled to receive these vaccines before the consent requirement was implemented. However, for DTaP-IPV booster vaccination this issue is more substantial because children born from January 2018 onwards were scheduled to receive the booster after the introduction of the informed consent policy. The percentage of parents not providing informed consent for vaccination was 2.4% for MMR and 2.6% for DTaP-IPV vaccination in 2024 [6].

Table 1. DTaP-IPV and MMR vaccination schedule of the Dutch National Immunisation Programme in 2024

	Age	Vaccine	Type
Phase 1 – Infants	2 months*	DTaP-IPV*	Primary series*
	3 months	DTaP-IPV	Primary series
	5 months	DTaP-IPV	Primary series
	11 months	DTaP-IPV	Primary series
	14 months	MMR	First dose
Phase 2 – Pre-school	4 years	DTaP-IPV	Booster
Phase 3 – School age	9 years	DT-IPV	Booster
		MMR	Second dose

Abbreviations: MMR measles-mumps-rubella, DTaP-IPV diphtheria-tetanus-pertussis-poliomyelitis.

* Since the introduction of the maternal pertussis vaccination in 2019, the 2 month DTaP-IPV vaccination can be omitted in case the mother received the maternal vaccine during pregnancy.

Chapter 3

Covariates

Additional CBS datasets were used to link primary school-level characteristics: primary school denomination, number of primary schools and urbanisation level of the school's municipality. The denomination variable originally contained 40 categories, which were merged into eight main school categories: general non-denominational (hereafter referred to as general), Catholic, Protestant, Orthodox Protestant, Islamic, Anthroposophical, collaborative (i.e. combination of denominations), and other. A complete list of the denominations and aggregated levels can be found in supplementary table S1. On individual (child) level, migration status (i.e. whether children or their (grand)parents were born in the Netherlands or abroad), country of origin (based on the child's, parents' and grandparents country of birth) and household standardised disposable income (quartiles based on the entire Dutch population) were linked. A detailed description of the definition of urbanisation level, household income, migration status and country of origin can be found in supplementary table S2.

Data analysis

Descriptive analysis

Vaccination coverage was calculated as the number of children vaccinated divided by the total number of children, by primary school denomination. Additionally, vaccination coverage by primary school denomination was stratified by birth cohort, to analyse trends over time. We also examined the variation in vaccination coverage within denominations. We describe vaccination coverage by school- and child-level sociodemographic characteristics.

Statistical analysis

Multilevel Poisson regression models were used to assess whether differences in vaccination coverage between school denominations could, in part, be explained by sociodemographic variables, including birth year, migration status, household income, and urbanisation level. To account for potential non-linearity of the trend of vaccination coverage over time, the variable birth year was included in the model as a categorical variable. To account for clustering of children within schools, initially a random intercept at the school level was included. Preliminary analysis showed that the estimated variance for the school-level random effect was essentially zero in models where school denomination was the only covariate, indicating that school-level variability was fully explained by denomination. In models that included additional covariates, school-level variance remained negligible. Therefore, we deemed random effects at the school level unnecessary, and the final analyses utilised fixed-effect Poisson regression models. We report both unadjusted and adjusted rate ratios, with corresponding 95% confidence intervals, for the association between school denomination and primary MMR vaccination coverage. Models for primary DTaP-IPV

and DTaP-IPV booster vaccination coverage can be found in supplementary table S5.

All analyses were performed in R version 4.4.0 [24]. The manuscript was prepared in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [25].

Results

The study population contained 1,295,958 children residing in the Netherlands, born between 2013 and 2020, who were enrolled in 6,388 unique elementary schools on 1 October 2024. Of these, 1,212,457 (94%) received a primary MMR vaccination, 1,207,916 (93%) received at least 3 doses of DTaP-IPV vaccination and 1,102,956 (85%) received the DTaP-IPV booster vaccination. Table 2 presents the vaccination coverage stratified by denomination. The coverages for the primary vaccinations were relatively high (>94%) in General, Catholic, Protestant, collaborative schools and other schools. The primary vaccination coverage was lower in Anthroposophical, Islamic and Orthodox Protestant schools (78%, 74% and 57% respectively for MMR and 77%, 75% and 58% respectively for DTaP-IPV). The DTaP-IPV booster coverage was lower compared to the primary series, ranging from 50% in Orthodox Protestant schools to 88% in Catholic and Protestant schools.

Table 2. MMR primary, DTaP-IPV primary and DTaP-IPV booster vaccination coverage among elementary school children on 1 October 2024 in The Netherlands (n = 1,295,958) stratified by school denomination.

			MMR first dose	DTaP-IPV primary	DTaP-IPV booster
Denomination	Schools	Children	Vaccinated	Vaccinated	Vaccinated
	N (%)	N (%)	N (%)	N (%)	N (%)
General schools	2,351 (37)	461,610 (36)	435,930 (94)	433,366 (94)	392,844 (85)
Catholic schools	1,909 (30)	418,331 (32)	400,841 (96)	399,499 (95)	369,807 (88)
Protestant schools	1,695 (27)	318,387 (25)	303,406 (95)	302,664 (95)	278,631 (88)
Orthodox Protestant	169 (3)	36,038 (3)	20,614 (57)	20,784 (58)	18,175 (50)
Islamic schools	80 (1)	19,400 (1)	14,337 (74)	14,560 (75)	10,720 (55)
Anthroposophical schools	78 (1)	17,342 (1)	13,611 (78)	13,434 (77)	11,212 (65)
Collaborative schools	75 (1)	17,862 (1)	17,028 (95)	16,951 (95)	15,525 (87)
Other schools	30 (0)	6,988 (1)	6,690 (96)	6,658 (95)	6,042 (86)

Abbreviations: MMR measles-mumps-rubella, DTaP-IPV Diphtheria-tetanus-pertussis-poliomyelitis.

Figure 1 shows the vaccination coverage per vaccine, stratified by school denomination and birth cohort. Coverage for primary MMR and DTaP-IPV vaccination remained stable over time for all denominations except for Islamic, Orthodox Protestant and Anthroposophical schools. Vaccination coverage declined considerably at Islamic schools (from 87% birth year 2013 to 59% in birth year 2020 for MMR, and from 88% in birth year 2013 to 60% in birth year 2020 for DTaP-IPV). There was a moderate decline at Orthodox Protestant schools (from 60% in birth year 2013 to 54% in birth year 2020 for MMR, and from 60% in birth year 2013 to 55% in birth year 2020 for DTaP-IPV). In contrast, coverage at Anthroposophical schools fluctuated for MMR (range 76-81%) and for DTaP-IPV (range 74-80%). For the DTaP-IPV booster vaccination, a decrease is seen in most denominations which is partly explained by the lack of consent for some children born in 2018 onwards, as well as to the fact that some children born in 2020 may not yet have received their booster vaccination by 01-10-2024, if administered a few months later than the recommended schedule.

School Vaccination Coverage

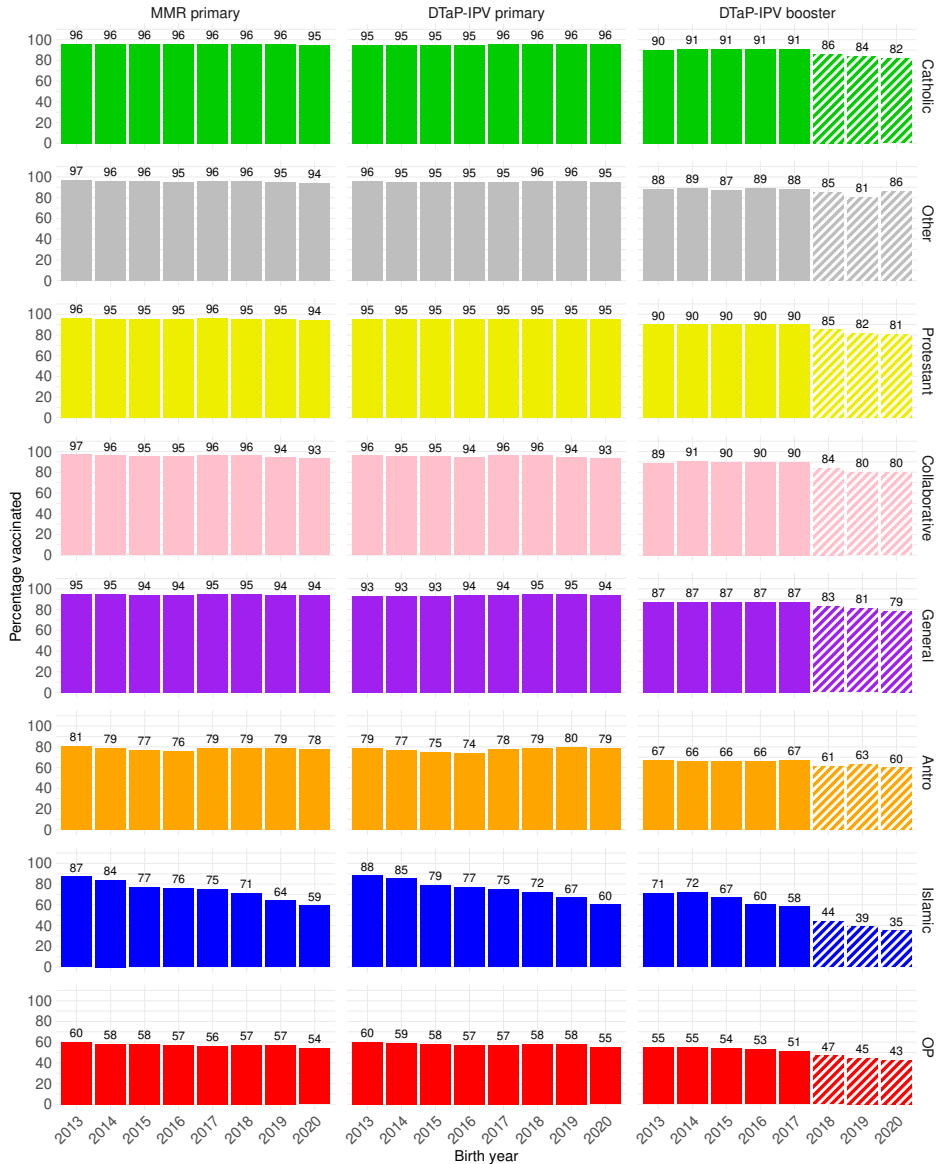


Figure 1. MMR primary, DTap-IPV primary and DTap-IPV booster vaccination coverage among elementary school children in The Netherlands on 1-10-2024 (n = 1,295,958) stratified by school denomination and birth cohort.

Abbreviations: Antro Anthroposophical MMR Measles mumps rubella, DTap Diphtheria, tetanus, pertussis, poliomyelitis. OP Orthodox Protestant. The reported vaccination coverage for the DTap-IPV booster for birth cohort 2018-2020 (dashed bars) is underestimated due to the informed consent since 01-01-2022.

Chapter 3

The majority of children attend general, Catholic or Protestant schools (36%, 32% and 25%, respectively) whilst 3% attend Orthodox Protestant schools, 1% Islamic schools, 1% Anthroposophical schools, 1% collaborative schools, and <1% to schools of other denominations (Table 2). Figure 2 shows the distribution of children per school denomination over time and the proportion of unvaccinated children per school denomination over time. The number of Islamic schools increased from 53 (0.8% of all schools) in 2017 to 80 (1.3%) in 2024, and therefore, the proportion of children attending these schools also rose slightly (1.2% for birth year 2013 to 1.7% for birth year 2020). The proportion of children attending the other denomination schools remained relatively stable over time. Of all children not vaccinated for MMR (n= 83,501), the largest proportion is attending general schools (32% for birth year 2013, 29% for 2020) and Catholic schools (22% for birth year 2013, 20% for 2020) and Protestant schools (18% for birth year 2013, 19% for 2020). Although only a small proportion of all children attend Orthodox Protestant schools, a relatively high, but decreasing, proportion of unvaccinated children attend these schools (20% for birth year 2013, 17% for 2020). An increasing proportion of all unvaccinated children attend Islamic schools (3% for birth year 2013, 9% for 2020). Similarly for Anthroposophical schools, the proportion of unvaccinated children was higher than the proportion of total children attending these schools but remained rather stable (4% for birth year 2013 and 2020). Nearly identical results were found for DTaP-IPV primary and booster vaccination (supplementary figures S3 and S4).

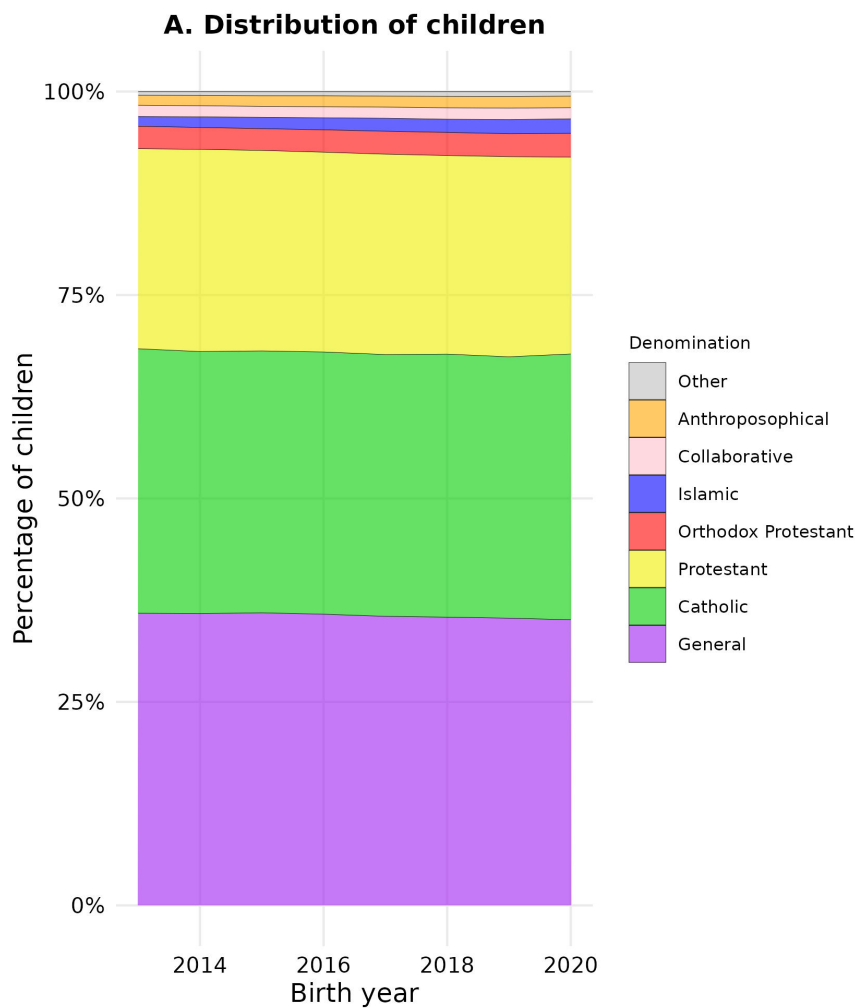


Figure 2. Distribution of children (A) and MMR unvaccinated children (B) by school denomination and birth year (2013-2020).

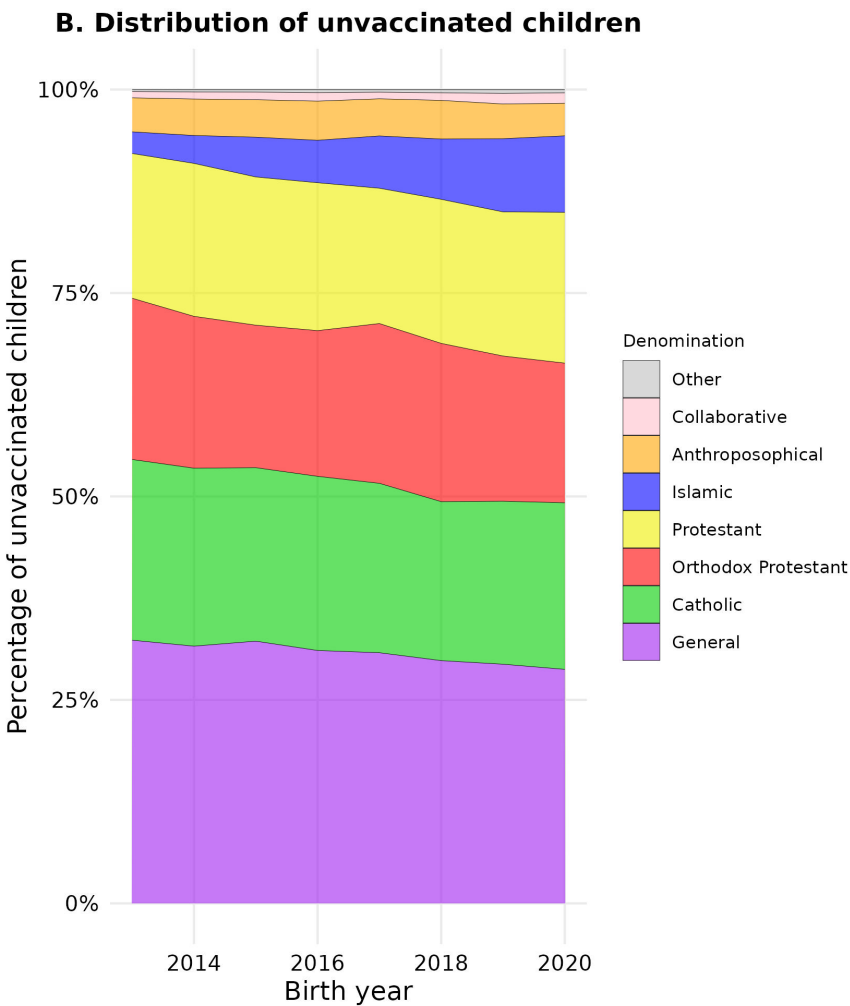


Figure 2. (Continued)

Variation in vaccination coverage

Figure 3 shows the variation in vaccination coverage per school, by school denomination. While most denominations (general, Protestant, catholic, collaborative and other) show relatively little variation between schools, substantial heterogeneity was seen between Orthodox Protestant schools. For example, the median primary MMR coverage in Orthodox Protestant schools was 66%, but the interquartile range (IQR) was wide (46%-81%). Less variation was observed between Anthroposophical schools (median: 65%, IQR 59-71%) and Islamic schools (median: 74% and IQR: 70%-78%). For all denominations there was more variation in the DTaP-IPV booster coverage compared to the primary series.

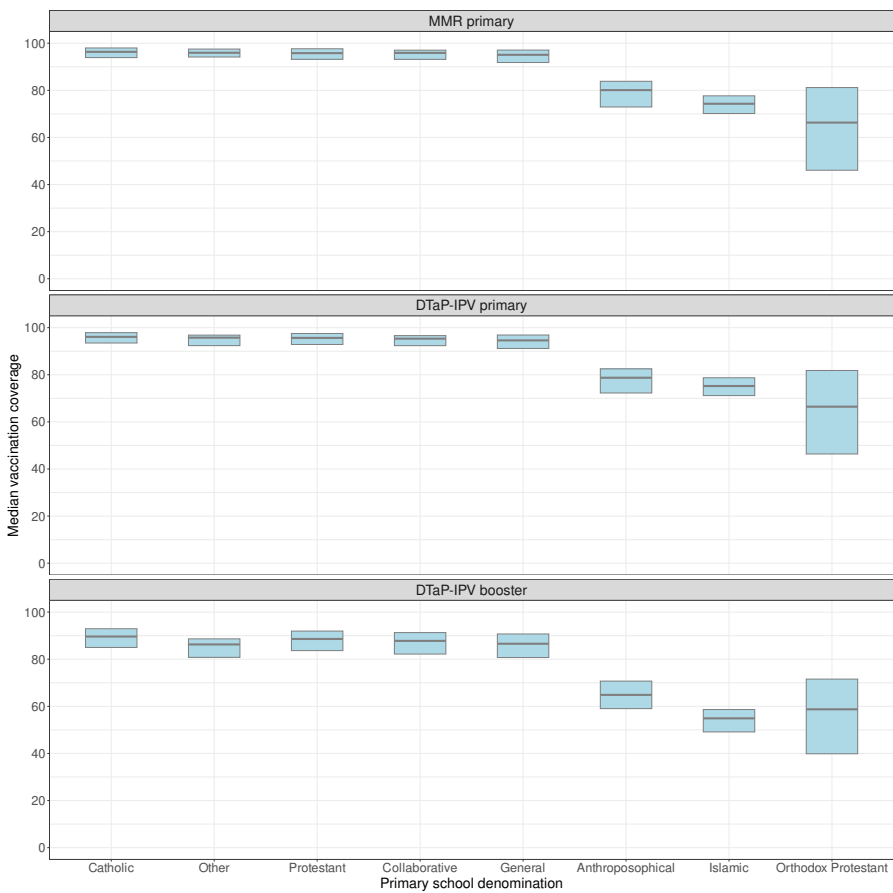


Figure 3. Median vaccination coverage for MMR primary, DTaP-IPV primary and DTaP-IPV booster, grouped by school denominations. Displayed are medians with interquartile range (IQR). Minimum and maximum values and outliers were removed from the graph to avoid school-level identifiable information.

Chapter 3

Vaccination coverage by school- and child-level sociodemographic characteristics

Urbanisation

General, Catholic and Protestant schools were well represented across all levels of urbanisation. In contrast, Orthodox Protestant schools were mostly located in hardly urbanised (31%) and non-urbanised areas (19%), while Islamic schools were predominantly located in extremely (57%) and strongly (36%) urbanised environments (table 3). In Orthodox Protestant schools, the coverage was higher in extremely urbanised areas (74% for MMR) compared to non-urbanised areas (53% for MMR). In Anthroposophical schools, coverage of all vaccinations was higher in extremely urbanised areas (82% for MMR), compared to less urbanised areas (71% hardly urbanised areas for MMR). Vaccination coverage for primary MMR and DTaP-IPV and DTaP-IPV booster was relatively high in general, Catholic and Protestant schools across all urbanisation levels (94-96%) and lower for DTaP-IPV booster vaccination in general and Catholic schools in extremely urbanised areas (82-84%, compared to 88-91% in non-urbanised areas) (table 4). In Islamic schools, the coverage was similar in moderate-, strongly-, and extremely urbanised areas (75%, 74% and 74% for MMR respectively).

Household income

The distribution of children by household income quartile differed by school denomination. Islamic schools had over half (54%) of children from households in the lowest income quartile, while other denominations had more evenly distributed income backgrounds (table 3). Vaccination coverage increased with higher income within all school denominations, with particularly lower coverage in the first income quartile (table 4). For example, in general schools, MMR coverage ranged from 88% in the lowest quartile to 98% in the highest. The same pattern was seen in Anthroposophical, Islamic and Orthodox Protestant schools, although coverage was substantially lower (65-87%, 74-78% and 46-76% for Anthroposophical, Islamic and Orthodox Protestant schools respectively).

Migration status and country of origin

The majority of children at Orthodox Protestant, Catholic and Protestant schools were of Dutch origin (93%, 61%, and 64%, respectively). Islamic schools had the highest proportion of children of non-Dutch origin: 64% were children of first-generation migrants and 28% were children of second-generation migrants. Most children at Islamic schools were of Moroccan (53%) or Turkish (19%) origin. In contrast, General, Catholic and Protestant schools had a more diverse but generally lower proportion of non-Dutch origin pupils. Vaccination coverage was highest among children of Dutch origin across all denominations, except for Orthodox Protestant schools (59% MMR coverage for children of Dutch origin compared to 66-89% for other countries of origin). The MMR vaccination coverage was 70% among Dutch children of Moroccan origin attending Islamic schools, compared to 90% among Dutch children of Moroccan origin attending general schools.

Table 3. School-level and child-level descriptive characteristics by school denomination

School denomination																	
General		Catholic		Protestant		Orthodox-Protestant		Islamic		Anthroposophical		Collaboration		Other			
School-level																	
Urbanisation	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
non-urbanised	280	12	122	6	227	13	32	19	<3	<1	<3	<1	9	12	<3	<1	
hardly urbanised	542	23	569	30	508	30	53	31	<3	<1	4	5	18	24	3	10	
moderately urbanised	380	16	404	21	265	16	28	17	4	5	10	13	5	7	3	10	
strongly urbanised	622	26	513	27	420	25	42	25	29	36	39	50	29	39	14	47	
extremely urbanised	520	22	299	16	273	16	14	8	46	57	24	31	14	19	10	33	
Unknown	<3	<1	<3	<1	<3	<1	<3	<1	<3	<1	<3	<1	<3	<1	<3	<1	
schools in G4 cities ^a	229	10	103	5	117	7	<3	<1	25	31	8	10	8	11	6	20	
Child-level																	
Household income ^b	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
first quartile	97,228	21	73,207	17	57,529	18	5,664	16	10,387	54	3,057	18	3,525	20	1,066	15	
second quartile	103,407	22	95,385	23	84,199	26	14,384	40	4,662	24	4,449	26	4,227	24	1,331	20	
third quartile	133,708	29	140,519	34	104,354	33	10,081	28	2,282	15	5,527	32	5,746	32	2,231	33	
fourth quartile	114,245	25	11,723	24	66,692	21	5,595	16	1,051	5	4,015	23	4,016	22	2,088	30	
unknown	11,080	2	6,515	2	4,797	2	224	1	429	2	130	1	252	1	136	2	



School denomination																
	General	Catholic	Protestant	Orthodox-Protestant	Islamic	Anthroposophical	Collaboration	Other								
Migration status																
Dutch origin	234,061	51	253,216	61	204,435	64	33,643	93	54	<1	10,308	59	9,179	51	2,863	41
first generation migrant	43,141	9	26,849	6	17,380	5	456	1	1,544	8	643	4	1,107	6	539	8
child of first generation migrant(s)	117,626	25	85,422	20	60,707	19	1,269	4	12,425	64	3,334	19	4,681	26	2,138	31
child of second generation migrant(s)	66,775	14	52,836	13	35,953	11	669	2	5,377	28	3,057	18	2,894	16	1,448	21
Country of origin ^c																
Total ^d	461,113	417,895	317,683	34,685	17,232	14,439	17,103	6,520								
The Netherlands	233,753	51	252,898	61	203,903	64	32,414	93	47	<1	8,436	58	8,754	51	2,792	43
Europe (excl The Netherlands)	62,588	14	53,153	13	29,851	9	629	2	792	5	2,457	17	1,983	12	813	12
Morocco	22,773	5	14,333	3	9,621	3	36	<1	9,130	53	147	1	458	3	200	3
Türkiye	23,218	5	15,395	4	9,717	3	44	<1	3,251	19	193	1	665	4	372	6
Suriname	17,441	4	10,532	3	9,659	3	131	<1	213	1	367	3	1,469	9	991	15
The Dutch Caribbean	10,724	2	8,024	2	6,754	2	128	<1	48	<1	255	2	431	3	122	2
Indonesia	15,247	3	12,681	3	9,061	3	102	<1	133	1	820	6	576	3	20	4
Other, America/Oceania	15,309	3	10,506	3	8,275	3	393	1	45	<1	755	5	566	3	183	3

School denomination																
	General	Catholic	Protestant	Orthodox-Protestant	Islamic	Anthroposophical	Collaboration	Other								
Other, Africa	18,697	4	12,781	3	11,922	4	439	1	1,657	10	350	2	905	5	219	3
Other, Asia	41,363	9	27,592	7	18,920	6	369	1	1,916	11	659	5	1,269	7	183	9

a)The four largest cities (>250,000 inhabitants) in The Netherlands: Amsterdam, Rotterdam, The Hague, Utrecht.

b)Household income reflects standardised disposable income of the household the child is living in. Quartiles (percentiles) were calculated by CBS based on the complete Dutch population.

c)Country of origin is determined based on the country of birth of the child and the country/countries of birth of its parents and grandparents.

For calculating the number of children from each country of origin by denomination, per denomination we only included children that live in a municipality that has at least one school of this denomination.

All reported tables exclude frequencies below ten, and percentages are rounded to zero decimals, to avoid personally identifiable (school-level) information.

	MMR	DTaP	MMR	DTaP	MMR	DTaP	MMR	DTaP
	First dose	Primary	Booster	First dose	Primary	Booster	First dose	Primary
	General schools	Catholic schools	Protestant schools	Orthodox-Protestant schools				
unknown	70	62	33	71	64	37	73	66
MMR								
Dutch origin	98	98	93	98	98	94	97	97
migrants	72	65	36	71	64	36	71	64
children of first generation migrants	96	96	87	96	97	88	96	96
children of second generation migrants	94	95	85	96	96	88	95	96
Country of origin c								
The Netherlands	98	98	93	98	88	94	97	97
Europe (excl The Netherlands)	93	91	76	94	92	80	93	91
Morocco	90	91	75	90	91	76	91	92

	MMR	DTaP	MMR	DTaP	MMR	DTaP	MMR	DTaP
	First dose	Primary	Booster	First dose	Primary	Booster	First dose	Primary
	Booster	DTaP	Booster	DTaP	Booster	DTaP	Booster	DTaP
	Other schools	Collaboration schools	Other schools	Collaboration schools	Other schools	Collaboration schools	Other schools	Collaboration schools
strongly urbanised	74	76	57	77	76	62	96	95
extremely urbanised	74	75	54	82	80	67	94	93
G4 cities a								
Household income b								
first quartile	74	75	55	65	64	49	90	90
second quartile	74	75	55	75	73	60	96	96
third quartile	77	79	59	83	82	71	98	98
fourth quartile	78	79	60	87	87	76	97	97
unknown	55	54	32	65	60	36	73	65
Migration								
Dutch origin	65	65	37	79	78	66	98	98
migrants	52	50	29	75	69	41	75	67
children of first generation migrants	81	83	65	78	77	65	96	96

Abbreviations: MMR Measles mumps rubella, DTaP Diphtheria, tetanus, pertussis, poliomyelitis.

- a) The four largest cities (>250,000 inhabitants) in The Netherlands: Amsterdam, Rotterdam, The Hague, Utrecht.*
 - b) Household income reflects standardised disposable income of the household the child is living in. Quartiles (percentiles) were calculated by CBS based on the complete Dutch population.*
 - c) Country of origin is determined based on the country of birth of the child and the country/countries of birth of its parents and grandparents.*
- Values are suppressed (x) in case of there were less than 3 schools in the category or the difference between the total number of children and the number of vaccinated children was less than 10.*

Chapter 3

Regression analysis

Regression analysis showed that primary school denomination was independently associated with vaccination uptake. Adjustment for birth year, country of origin, household income, and urbanisation level only slightly changed estimates. In both the unadjusted and the adjusted model, children attending Orthodox Protestant (aRR 0.60), Islamic (aRR 0.83) and Anthroposophical (aRR 0.81) schools had significantly lower MMR vaccination coverage compared to general schools (which served as the reference category; see table 5). The largest change in RR after adjustment was observed for Islamic schools, where the RR increased from 0.78 to 0.83, primarily after adjustment for country of origin; further adjustment for household income and urbanisation had little additional effect. This suggests the lower coverage in Islamic schools is only, to a small extent, explained by country of origin of the children. The full models, including primary DTaP-IPV and DTaP-IPV booster vaccination can be found in supplementary table S5.

Table 5. Univariable and multivariable Poisson regression models for primary MMR vaccination uptake among primary school children (n = 1,293,919).

Denomination	Univariable model			Multivariable model*		
	RR	95% CI	P-value	RR	95% CI	P-value
General schools (reference)	ref	ref	ref	ref	ref	ref
Catholic schools	1.01	1.01-1.02	<0.001	1.01	1.00-1.01	0.003
Protestant schools	1.01	1.00-1.01	<0.001	1.00	1.00-1.01	0.849
Orthodox protestant schools	0.61	0.60-0.61	<0.001	0.60	0.59-0.60	<0.001
Islamic schools	0.78	0.77-0.80	<0.001	0.83	0.82-0.85	<0.001
Anthroposophical schools	0.83	0.82-0.85	<0.001	0.81	0.80-0.83	<0.001
Collaboration schools	1.01	0.99-1.03	0.228	1.00	0.99-1.02	0.461
Other schools	1.01	0.99-1.04	0.268	1.01	0.98-1.03	0.651

Abbreviations: RR Rate Ratio

* Multivariable model: adjusted for birth year, country of origin, household income and school urbanisation level.

Discussion

We found that vaccination coverage among primary school children in the Netherlands varies substantially by school denomination. Both primary series (MMR and DTaP-IPV) and booster (DTaP-IPV) vaccination uptake was notably lower in Orthodox-Protestant, Anthroposophical and Islamic schools compared to other denominations. The majority of all children, including the majority of unvaccinated children, attend schools with relatively high vaccination coverage. However, our findings of lower coverage in schools with Orthodox Protestant, Anthroposophical and Islamic denomination, indicate an increased risk of outbreaks due to clustering of unvaccinated children in these schools.

Our findings confirm that vaccination coverage in Orthodox Protestant schools remains substantially lower than in other school denominations, consistent with previous studies and outbreak reports. The spatial clustering of Orthodox Protestant communities, often in the so-called “Bible Belt” stretching from the South-West to the North-East of the Netherlands, has historically contributed to recurrent outbreaks of VPDs. While some children in these communities may have acquired natural immunity against measles during the 2013–2014 epidemic, ongoing introduction of unvaccinated cohorts maintains the risk of future epidemics [21]. Interestingly, we found considerable variation within these schools. Previous research indicates that this variation is partly explained by differences between sub-denominations within the Orthodox Protestant tradition, as these groups differ in their theological perspectives on vaccination [8, 26]. While Orthodox Protestant schools are not formally linked to specific churches, there is an indirect association: the most conservative parents tend to choose the most conservative schools, which in turn have the lowest vaccination coverage (personal communication with H. Ruijs, RIVM). Although our data did not allow us to distinguish between specific sub-denominations, we observed that Orthodox Protestant schools located within the Bible Belt tend to have lower vaccination coverage than those situated outside this region.

Vaccination coverage in Anthroposophical schools was also found to be consistently lower than in most other school denominations, which aligns with previous research and the documented history of outbreaks within these communities. Outbreaks of VPDs have been reported in Anthroposophical communities and Waldorf (Steiner) schools in various countries, including Germany, Switzerland, and the United States [27]. Recent literature highlights that mistrust in health authorities, a preference for individualized care, and stigma around vaccine choices contribute to selective or delayed vaccination among Anthroposophical parents, rather than complete refusal [27]. To address these challenges, further research into underlying motivations and concerns is needed and vaccination efforts should prioritize building trust and

Chapter 3

engaging in respectful, tailored dialogue.

A notable finding of this study is the strongly declining vaccination coverage observed in Islamic schools, a trend that has not been observed in previous studies. Within these schools, the decline was most pronounced among Dutch children of Moroccan and Turkish origin, affecting both first- and second-generation migrants, with a larger decrease in the second generation (data not shown), consistent with patterns previously seen in the general population [28]. Reasons for reduced uptake in Islamic schools are less well understood. Notably, there is no known religious objection to vaccination in these communities [29]. Qualitative studies indicate that practical barriers, such as difficulty understanding information about the NIP, limited consultation time, and challenges in accessing vaccination locations, play an important role in vaccination decisions among parents of Moroccan and Turkish origin [30]. Research into the COVID-19 vaccination decision-making process among Dutch adults of Moroccan origin indicated that it was a personal risk-benefit assessment rather than a social responsibility, and that religious beliefs and values acted both facilitating and hindering in their decision to be vaccinated against COVID-19 [31]. The school-based findings are in line with our previous research where we found decreasing MMR and DTaP-IPV vaccination coverage in Dutch children of Moroccan and Turkish origin [28]. Interestingly, our current results show that Dutch children of Moroccan origin attending Islamic schools have lower coverage than Dutch children of Moroccan origin in schools of other denominations, suggesting that social networks, with relation to the school environment, may play a role in vaccination decisions. Recent outbreaks and increasing numbers of unvaccinated children in urban areas with Islamic schools highlight the importance of further research into vaccination barriers, drivers, and the role of social networks to better understand NIP vaccination decisions in these communities.

Another interesting finding is that variation in DTaP-IPV booster coverage was greater than in the primary series, particularly among school denominations with generally high vaccination coverage. Although both the primary series and booster are offered through well-baby clinics, regional differences in how informed consent is obtained, and percentage of parents providing consent, may contribute to this increased heterogeneity. However, our study did not identify a clear explanation for these patterns, highlighting the need for further research into regional and organisational factors affecting registered booster uptake.

A key strength of our study is the use of large, linked national datasets, which allowed for comprehensive analysis of vaccination coverage across all primary schools in the Netherlands and enabled adjustment for important sociodemographic factors. However, several limitations should be considered. First, some children born in 2020 may not yet have received their DTaP-IPV booster vaccination at the time of assessment, if it was administered a few months later than the recommended

schedule. This may have led to an underestimation of the DTaP-IPV booster vaccination coverage. Also, since January 2022, parental informed consent has been required to register vaccinations in the national immunisation register. As a result, some children, particularly those eligible for the DTaP-IPV booster after this policy change (i.e. children born from 2018 onwards), may have received vaccinations that were not captured in our data, leading to an underestimation of coverage for this dose. This issue is less pronounced for the primary DTaP-IPV and MMR vaccinations, as most children (everyone for DTaP-IPV and all children born before November 2020 for MMR) were scheduled to receive these vaccinations before 2022. Furthermore, our analysis focused on primary schools only. Vaccination patterns in secondary schools may differ from those at the primary level, as there are fewer secondary schools and students are therefore more likely to come from a mix of backgrounds. Lastly, the data on school enrolment did not include private education or foreign schools; however, as 98% of children attend public schools and only a very small proportion of children in the Netherlands attend school across the border, the impact of this limitation is minimal.

Conclusion

Even though the majority of unvaccinated children in the Netherlands attend schools with relatively high vaccination coverage, our findings indicate a continued risk of outbreaks due to clustering of unvaccinated children at Orthodox Protestant and Anthroposophical schools and a more recent increased risk at Islamic schools. Identifying and monitoring pockets with low vaccination coverage is important to inform future efforts to reduce the risk of VPD outbreaks. Our results provide a foundation for further research - especially among parents of children attending schools with lower uptake, but also more broadly given the overall increase in vaccine hesitancy - into the specific beliefs, barriers, and the role of social networks to better understand vaccination decisions. School-level interventions, such as providing information and engaging parents through schools, may be explored as strategies to support informed decision-making and address clusters of low vaccination coverage.

Chapter 3

References

1. Unicef. Media brief. European region reports highest number of measles cases in more than 25 years. 2025.
2. World Health Organization. Measles and rubella monthly update - WHO European Region - September 2024. WHO 2024. <https://www.who.int/europe/publications/m/item/measles-and-rubella-monthly-update---who-european-region---september-2024> [Accesses 18 December 2025]
3. European Center for Disease Control. Increase of pertussis cases in the EU/EEA, 8 May 2024. Stockholm: ECDC 2024.
4. Bottcher S, Kreibich J, Wilton T, Saliba V, Blomqvist S, Al-Hello H, et al. Detection of circulating vaccine-derived poliovirus type 2 (cVDPV2) in wastewater samples: a wake-up call, Finland, Germany, Poland, Spain, the United Kingdom, 2024. *Euro Surveill.* 2025;30(3) doi:10.2807/1560-7917.ES.2025.30.3.2500037.
5. European Center for Disease Control. Tools and methods for promoting vaccination acceptance and uptake: a social and behavioural science approach. Stockholm 2025.
6. Van Lier A, Hament J, Holwerda M, Westra M, Giebers H, van der Maas N, et al. Vaccinatiegraad Rijksvaccinatieprogramma Nederland. Verslagjaar 2025.: RIVM; 2025.
7. World Health Organization. Immunization Agenda 2030: A global strategy to leave no one behind. Geneva, Switzerland; 2020.
8. Ruijs WLM, Hautvast JLA, van der Velden K, de Vos S, Knippenberg H, Hulscher MEJL. Religious subgroups influencing vaccination coverage in the Dutch Bible belt: an ecological study. *BMC Public Health.* 2011;11:102 doi:10.1186/1471-2458-11-102.
9. Ruijs WLM, Hautvast JLA, van Ijzendoorn G, van Ansem WJC, van der Velden K, Hulscher MEJL. How orthodox protestant parents decide on the vaccination of their children: a qualitative study. *BMC Public Health.* 2012;12(1):408 doi:10.1186/1471-2458-12-408.
10. Harmsen IA, Ruiter RA, Paulussen TG, Mollema L, Kok G, de Melker HE. Factors that influence vaccination decision-making by parents who visit an anthroposophical child welfare center: a focus group study. *Adv Prev Med.* 2012;2012:175694 doi:10.1155/2012/175694.
11. Rijksinstituut voor Volksgezondheid en Milieu. Bezwaren tegen vaccinaties. Het perspectief van de weigeraar. In: RIVM, editor. 2010.
12. Woudenberg T, van Binnendijk RS, Sanders EAM, Wallinga J, de Melker HE, Ruijs WLM, et al. Large measles epidemic in the Netherlands, May 2013 to March 2014: changing epidemiology. *Eurosurveillance.* 2017;22(3):30443. doi: 10.2807/1560-7917.ES.2017.22.3.30443
13. van Velzen E, de Coster E, van Binnendijk R, Hahne S. Measles outbreak in an anthroposophic community in The Hague, The Netherlands, June-July 2008. *Eurosurveillance.* 2008;13(31).
14. Hahne S, Macey J, van Binnendijk R, Kohl R, Dolman S, van der Veen Y, et al. Rubella outbreak in the Netherlands, 2004-2005: high burden of congenital infection and spread to Canada. *Pediatr Infect Dis J.* 2009;28(9):795-800 doi:10.1097/INF.0b013e3181a3e2d5.
15. Ruijs WLM, Hautvast JLA, Akkermans RP, Hulscher MEJL, van der Velden K. The role of schools in the spread of mumps among unvaccinated children: a retrospective cohort study. *BMC Infectious Diseases.* 2011;11(1):227 doi:10.1186/1471-2334-11-227.
16. Roon AM, Lanooij SJ, de Melker HE. The National Immunisation Programme in the Netherlands. Surveillance and developments in 2023-2024. RIVM 2025.
17. Conyn-van Spaendonck MA, Oostvogel PM, van Loon AM, van Wijngaarden JK, Kromhout

- D. Circulation of poliovirus during the poliomyelitis outbreak in The Netherlands in 1992-1993. *Am J Epidemiol.* 1996;143(9):929-35 doi:10.1093/oxfordjournals.aje.a008836.
- 18.Oostvogel PM, Rumke HC, Conyn-Van Spaendonck MA, van der Avoort HG, Leeuwenburg J, van Loon AM. Poliovirus circulation among schoolchildren during the early phase of the 1992-1993 poliomyelitis outbreak in The Netherlands. *J Infect Dis.* 2001;184(11):1451-5 doi:10.1086/324327
- 19.European Center for Disease Control. Morbidity and Mortality Weekly Report. Epidemiologic Notes and Reports Follow-Up on Poliomyelitis -- United States, Canada, Netherlands. 1997.
- 20.Klinkenberg D, van Hoek AJ, Veldhuijzen I, Hahné S, Wallinga J. Social clustering of unvaccinated children in schools in the Netherlands. *Epidemiology and Infection.* 2022;150:e200 doi:10.1017/S0950268822001455.
- 21.Munday JD, Atkins KE, Klinkenberg D, Meurs M, Fleur E, Hahne S, et al. Anticipating the risk and spatial spread of measles in populations with high MMR uptake: Using school-household networks to understand the 2013 to 2014 outbreak in the Netherlands. *PLoS medicine.* 2024 Oct 8;21 (10):e1004466
- 22.Munday JD. Projected increase in risk of large measles outbreaks in the Netherlands as susceptible children enter secondary school in 2025/26. *Int J Infect Dis.* 2025;108240 doi:10.1016/j.ijid.2025.108240.
- 23.van Lier A, Oomen P, de Hoogh P, Drijfhout I, Elsinghorst B, Kemmeren J, et al. Praeventis, the immunisation register of the Netherlands: a tool to evaluate the National Immunisation Programme. *Euro Surveill.* 2012;17(17) doi:10.2807/ese.17.17.20153-en.
- 24.R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2020.
- 25.Cuschieri S. The STROBE guidelines. *Saudi J Anaesth.* 2019;13(Suppl 1):S31-S4 doi:10.4103/sja.SJA_543_18.
- 26.Ruijs WL, Hautvast JL, van Ansem WJ, Akkermans RP, van't Spijker K, Hulscher ME, et al. Measuring vaccination coverage in a hard to reach minority. *Eur J Public Health.* 2012;22(3):359-64 doi:10.1093/eurpub/ckr081.
- 27.Herzig van Wees S, Abunnaja K, Mounier-Jack S. Understanding and explaining the link between anthroposophy and vaccine hesitancy: a systematic review. *BMC Public Health.* 2023;23(1):2238 doi:10.1186/s12889-023-17081-w.
- 28.Pijpers J, van Roon A, Schipper M, Stok M, van den Hof S, van Gaalen R, et al. The decrease in childhood vaccination coverage and its sociodemographic determinants, the Netherlands, birth cohorts 2008 to 2020. *Euro Surveill.* 2025;30(39) doi:10.2807/1560-7917.ES.2025.30.39.2500251.
- 29.Alsuwaidi AR, Hammad HAA, Elbarazi I, Sheek-Hussein M. Vaccine hesitancy within the Muslim community: Islamic faith and public health perspectives. *Hum Vaccin Immunother.* 2023;19(1):2190716 doi:10.1080/21645515.2023.2190716.
- 30.Harmsen IA, Bos H, Ruiter RAC, Paulussen TGW, Kok G, de Melker HE, et al. Vaccination decision-making of immigrant parents in the Netherlands; a focus group study. *BMC Public Health.* 2015;15(1):1229 doi:10.1186/s12889-015-2572-x.
- 31.Hamdiui N, de Vries M, Stein ML, Crutzen R, Hintaran P, van den Muijsenbergh M, et al. How did Moroccan immigrants in the Netherlands decide with regard to their COVID-19 vaccine uptake? An exploratory qualitative study. *BMC Infect Dis.* 2025;25(1):602 doi:10.1186/s12879-025-11003-4.

Chapter 3

Supplementary material

Supplementary table S1. Aggregation of school denomination

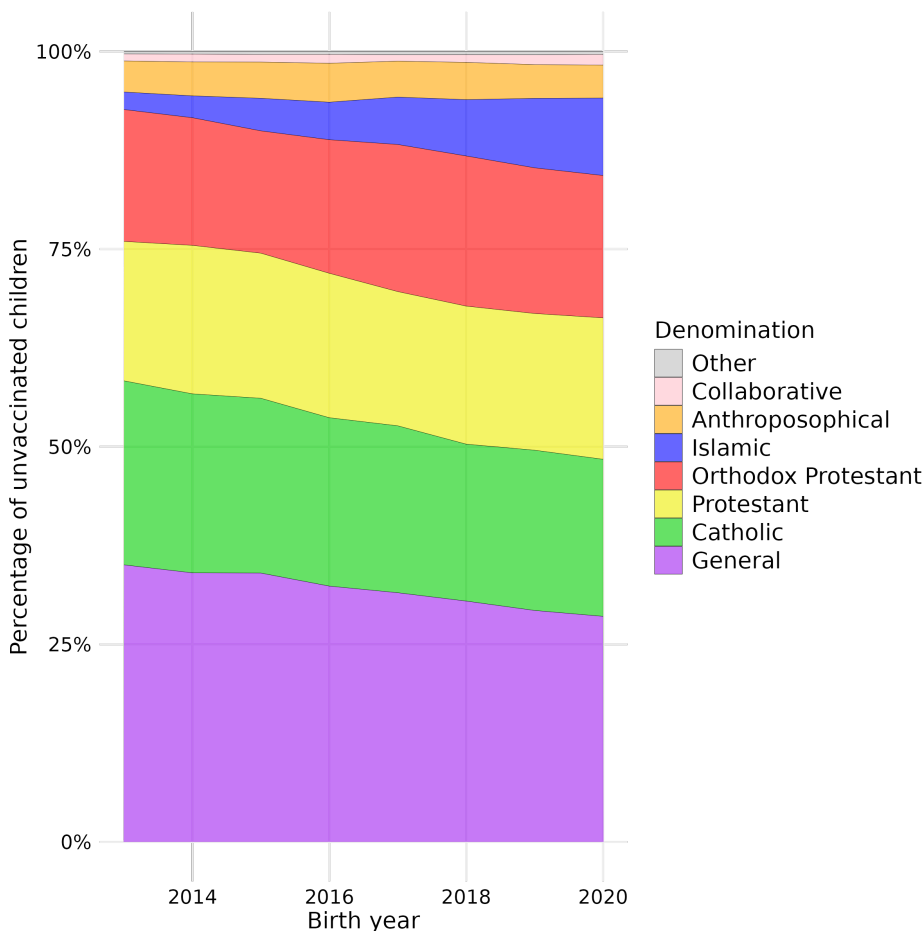
Aggregated denomination	Denomination in Dutch
General-Public	Algemeen bijzonder (ABZ)
	Openbaar (OPB)
Catholic	Oud-Katholiek (OKA)
	Rooms-Katholiek (RK)
Orthodox Protestant	Reformatorisch (REF)
Protestant	Baptistisch (BAP)
	Evangelisch (EVA)
	Evangelische Broedergemeenschap (EVB)
	Evangelisch-Luthers (EVL)
	Nederlands Hervormd (NH)
	Protestants-Christelijk (PC)
	Protestants-Christelijk/Evangelisch (PCE)
	Remonstrants (REM)
	Gereformeerd (GER)
	Gereformeerd vrijgemaakt (GEV)
	Protestants-Christelijk/Reformatorisch (PCR)
Islamic	Islamitisch (ISL)
Anthroposophical	Antroposofisch (ASF)
Other	Hindoeïstisch (HIN)
	Humanistisch (HUM)
	Interconfessioneel (IC)
	Joods liberaal (JOL)
	Joods (JOO)
	Joods Orthodox (JOR)
	Nederlands-Israëlitisch (NIS)
	Overige (RST)
	Rijks (RYK)
Combination	Samenwerking PC, RK, ABZ (SCA)
	Samenwerking OPB, PC, RK, ABZ (SCH)
	Samenwerking OPB, ABZ (SOA)
	Samenwerking OPB, PC, RK (SOC)
	Samenwerking OPB, PC (SOP)
	Samenwerking OPB, RK (SOR)
	Samenwerking PC, ABZ (SPA)
	Samenwerking OPB, PC, ABZ (SPH)
	Samenwerking PC, RK (SPR)
	Samenwerking RK, ABZ (SRA)
	Samenwerking OPB, RK, ABZ (SRH)

Source: [file:///N:/Documents/Downloads/brinwpowectab%20\(13\).pdf](file:///N:/Documents/Downloads/brinwpowectab%20(13).pdf)

Supplementary table S2. Overview covariate definitions

Variable	Definition	Levels
Migration status	Migrations status based on whether: 1) children were born in the Netherlands, 2) parents were born in the Netherlands and 3) grandparents were born in the Netherlands	Dutch origin; first-generation migrant; child of first-generation migrant; child of second-generation migrants
Country of origin	Country of origin was primarily defined by the country of birth (CoB) of the child itself. If the child was born in the Netherlands, country of origin was first determined by the parents' country of birth (CoB). If both parents were born in the Netherlands, the grandparents' CoB was then considered. Within this definition, the mother's CoB was prioritized over the father's, and the grandmother's CoB was prioritized over the grandfather's. Foreign-born origins were given precedence over Dutch origin if present in the lineage.	The Netherlands; Europe (excluding the Netherlands); Morocco; Turkey; Suriname; Dutch Caribbean; Indonesia; Other, America/Oceania; Other, Africa; Other, Asia). Indonesia; Other (Africa, Asia, America/Oceania)
Household standardised disposable income	Disposable income of the household taking into account differences in household size and household composition, divided into quartiles based on the entire Dutch population.	First quartile; second quartile; third quartile; fourth quartile; unknown
Level of Urbanisation	Urbanisation level was defined based on the average address density per square kilometre: extremely urbanised (≥ 2500 addresses/ km^2), strongly urbanised (1500-2499 addresses/ km^2), moderately urbanised (1000-1499 addresses/ km^2), hardly urbanised (500-999 addresses/ km^2) and not urbanised (≤ 500 addresses/ km^2).	Non-urbanised; hardly urbanised; moderately urbanised; strongly urbanised; extremely urbanised; unknown

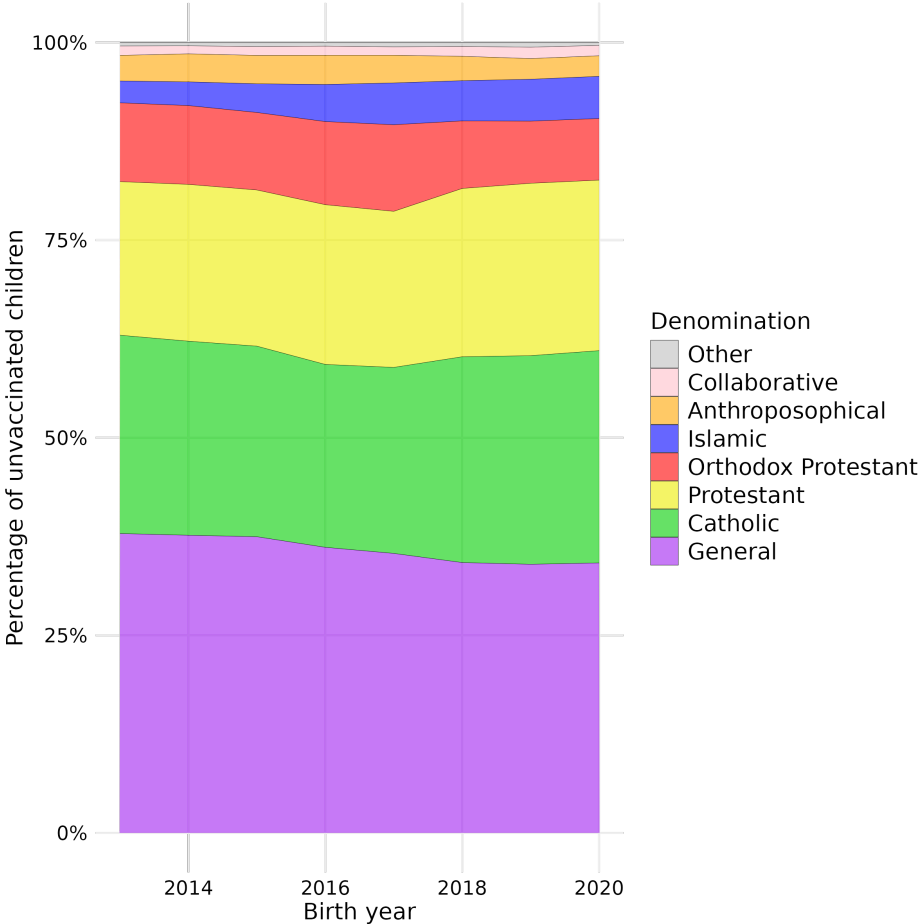
Chapter 3



Supplementary figure S3. Distribution of primary DTaP-IPV unvaccinated children (n = 88,042) by school denomination and birth year

DTaP-IPV diphtheria-tetanus-acellular pertussis-inactivated poliovirus vaccination

School Vaccination Coverage



Supplementary figure S4. Distribution of DTaP-IPV booster unvaccinated children (n = 193,002) by school denomination and birth year

DTaP-IPV diphtheria-tetanus-acellular pertussis-inactivated poliovirus vaccination

3

Supplementary table S5. Univariable and multivariable Poisson regression models for first dose MMR, primary DTaP-IPV and DTP-IPV booster vaccination

Variable	First dose MMR vaccination		Primary DTaP-IPV vaccination		Booster DTaP-IPV vaccination	
	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Denomination	ref	ref	ref	ref	ref	ref
General-public	ref	ref	ref	ref	ref	ref
Catholic	1.01 (1.00-1.01)	1.01 (1.01-1.00)	1.02 (1.01-1.02)	1.01 (1.00-1.01)	1.03 (1.03-1.04)	1.02 (1.01-1.02)
Protestant	1.01 (1.00-1.01)	1.00 (1.00-1.01)	1.01 (1.01-1.02)	1.00 (1.00-1.01)	1.03 (1.02-1.03)	1.00 (1.00-1.01)
Orthodox Protestant	0.61 (0.60-0.61)	0.60 (0.59-0.60)	0.61 (0.61-0.62)	0.60 (0.59-0.61)	0.59 (0.58-0.60)	0.56 (0.55-0.57)
Islamic	0.78 (0.77-0.80)	0.83 (0.82-0.85)	0.80 (0.79-0.81)	0.84 (0.83-0.86)	0.65 (0.64-0.66)	0.75 (0.74-0.77)
Anthroposophical	0.83 (0.82-0.85)	0.81 (0.80-0.83)	0.83 (0.81-0.84)	0.81 (0.79-0.82)	0.76 (0.75-0.77)	0.74 (0.73-0.75)
Collaboration schools	1.01 (0.99-1.03)	1.00 (0.99-1.02)	1.00 (1.00-1.03)	1.00 (0.99-1.02)	1.02 (1.01-1.04)	1.01 (0.99-1.02)
Other schools	1.01 (0.99-1.04)	1.01 (0.98-1.03)	1.01 (0.99-1.04)	1.01 (0.98-1.03)	1.02 (0.99-1.04)	1.01 (0.98-1.03)
Birth year						
2013	-	ref	-	ref	-	ref
2014	-	1.00 (0.99-1.00)	-	1.00 (0.99-1.01)	-	1.00 (1.00-1.01)
2015	-	0.99 (0.99-1.00)	-	1.00 (0.99-1.00)	-	1.00 (0.99-1.01)
2016	-	0.99 (0.98-1.00)	-	1.00 (0.99-1.01)	-	1.00 (1.00-1.01)
2017	-	1.00 (0.99-1.00)	-	1.00 (1.00-1.01)	-	1.00 (1.00-1.01)
2018	-	1.00 (0.99-1.00)	-	1.01 (1.00-1.02)	-	0.95 (0.94-0.95)
2019	-	0.99 (0.98-1.00)	-	1.01 (1.00-1.01)	-	0.92 (0.91-0.93)
2020	-	0.98 (0.97-0.99)	-	0.99 (0.99-1.00)	-	0.90 (0.89-0.90)
Country of origin						
The Netherlands	-	ref	-	ref	-	ref
Europe (excl NL)	-	0.97 (0.96-0.98)	-	0.96 (0.95-0.96)	-	0.87 (0.87-0.88)
Indonesia	-	0.99 (0.98-1.00)	-	0.99 (0.98-1.00)	-	0.98 (0.97-0.99)

Variable	First dose MMR vaccination		Primary DTaP-IPV vaccination		Booster DTaP-IPV vaccination	
	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Morocco	-	0.93 (0.93-0.94)	-	0.95 (0.94-0.96)	-	0.85 (0.84-0.86)
Other, Africa	-	0.97 (0.96-0.98)	-	0.96 (0.95-0.96)	-	0.90 (0.89-0.91)
Other, America/ Oceania	-	0.99 (0.98-1.00)	-	0.98 (0.97-0.99)	-	0.92 (0.91-0.93)
Other, Asia	-	0.90 (0.90-0.91)	-	0.89 (0.88-0.90)	-	0.84 (0.84-0.85)
Surinam	-	0.98 (0.97-0.99)	-	0.99 (0.98-1.00)	-	0.94 (0.93-0.95)
The Dutch Caribbean	-	0.98 (0.97-0.99)	-	0.98 (0.97-1.00)	-	0.92 (0.91-0.93)
Turkey	-	0.94 (0.93-0.95)	-	0.95 (0.94-0.95)	-	0.88 (0.87-0.89)
Household income	-	-	-	-	-	-
Fourth quartile	-	ref	-	ref	-	ref
Third quartile	-	1.00 (0.99-1.00)	-	1.00 (0.99-1.00)	-	0.99 (0.98-0.99)
Second quartile	-	0.98 (0.97-0.98)	-	0.98 (0.97-0.98)	-	0.95 (0.94-0.95)
First quartile	-	0.92 (0.91-0.92)	-	0.91 (0.91-0.92)	-	0.84 (0.84-0.85)
Urbanisation level	-	-	-	-	-	-
Non-urbanised	-	ref	-	ref	-	ref
Hardly urbanised	-	1.00 (0.99-1.01)	-	1.00 (0.99-1.01)	-	1.00 (0.99-1.01)
Moderately urbanised	-	1.01 (1.00-1.02)	-	1.01 (1.00-1.02)	-	1.00 (0.99-1.01)
Strongly urbanised	-	1.02 (1.01-1.03)	-	1.02 (1.01-1.03)	-	1.01 (1.01-1.02)
Extremely urbanised	-	1.03 (1.02-1.04)	-	1.03 (1.02-1.04)	-	1.00 (1.00-1.01)

DTaP-IPV diphtheria-tetanus-acellular pertussis-inactivated poliovirus vaccination MMR measles-mumps-rubella vaccination

Chapter 4

Assessing the impact of the COVID-19 pandemic on routine childhood vaccination uptake in the Netherlands

Joyce Pijpers, Manon Haverkate, Ruben van Gaalen,
Susan Hahné, Hester de Melker, Susan van den Hof

Submitted

Preprint available at medRxiv: doi.org/10.64898/2026.02.19.26346601

ABSTRACT

BACKGROUND: Initial reports from the Netherlands indicate a decline in routine childhood vaccination uptake during and after the COVID-19 pandemic, with emerging evidence of reduced parental vaccine confidence. This study aimed to evaluate the long-term impact of the COVID-19 pandemic on routine childhood vaccination uptake.

METHODS: We conducted a retrospective nationwide cohort study including all children born in the Netherlands in 2016-2024. First-dose DTaP-IPV vaccination status by age six months was obtained from the national immunisation register. National trends in vaccination uptake across pre-pandemic, pandemic, and post-pandemic periods were assessed using interrupted time series analyses. To further assess the independent effect of the pandemic, a matched-sibling analysis compared vaccination uptake within families before, during and after the pandemic.

RESULTS: Interrupted time series analyses showed significant immediate decreases in vaccination uptake both at the start and end of the pandemic, accompanied by a continuing downward trend during the pandemic (OR 0.984, 95%CI 0.982-0.985) that further declined after its end (OR 0.995, 95%CI 0.994-0.997). In the matched-sibling analysis children eligible during and after the pandemic had lower odds of being vaccinated (pandemic: OR 0.66, 95%CI 0.55-0.80; post-pandemic: OR 0.20, 95%CI 0.17-0.25) compared to their pre-pandemic siblings. Also, later birth order was associated with lower odds compared to first-born siblings (second-born: OR 0.42, 95%CI 0.37-0.48).

CONCLUSIONS: Both analyses indicate a negative impact of the COVID-19 pandemic on parental vaccination decisions, which may reflect lingering pandemic effects or new post-pandemic factors, highlighting the need for further research into the drivers of vaccination uptake changes in the post-pandemic era.

Introduction

The COVID-19 pandemic has had major impact on all aspects of healthcare worldwide [1]. In the Netherlands, the emergence of COVID-19 in February 2020 led to the rapid implementation of widespread public health measures. The Dutch government introduced a lockdown mid-March 2020, which included closures of schools, restaurants, and non-essential shops. Alternating periods of stricter and more relaxed restrictions followed, before most measures were lifted early 2022 [2].

Although infant vaccination schedules were largely maintained, appointments for older children and adolescents were occasionally postponed or rescheduled. Despite catch-up campaigns, early data from the Netherlands indicated that the vaccination coverage for infants scheduled to receive their first measles, mumps, rubella (MMR1) vaccination between March and September 2020, was estimated to be 1-2 percentage points lower compared to the coverage among children born one year earlier [3]. Importantly, a decreasing trend in first-dose MMR and ≥ 3 -dose DTaP-IPV vaccination coverage (by age 2 years) was already apparent before the pandemic. Coverage, which had been consistently above 95% for the 2005–2011 birth cohorts, dropped to 92.6% for DTaP-IPV and 92.9% for MMR in cohort 2015. After a slight recovery to 93.1% (DTaP-IPV) and 93.3% (MMR) for the 2018 birth cohort, coverage declined again, reaching 87.9% and 87.7% for MMR and DTaP-IPV, respectively, in the 2022 birth cohort [4] (see supplementary Figure S1). Notably, from 2022 onwards, a new policy requiring explicit parental informed consent for vaccination registration was implemented in the Netherlands. Consequently, children vaccinated without parental consent for registration are recorded as unvaccinated, leading to an underestimation of coverage in recent years.

In addition to logistical barriers, the pandemic coincided with an unprecedented spread of mis- and disinformation and scepticism surrounding the SARS-CoV-2 virus, the public health measures and vaccines, particularly during the COVID-19 vaccine rollout [5]. Emerging evidence suggests that this infodemic has undermined trust not only in COVID-19 vaccines, but also in established childhood immunisation programmes. For example, UNICEF reported a worldwide decline in confidence in the importance of childhood vaccination, including the Netherlands (-10 percentage points in 2022 compared to 2019) [6]. Similarly, surveys in 2022 and 2023 indicated that Dutch parents have become slightly more negative towards routine childhood vaccines compared to a decade earlier [7, 8]. These findings suggest the pandemic's impact may extend beyond temporary service disruptions towards a sustained decrease in vaccine uptake.

Therefore, this study aimed to assess this impact by using two complementary approaches. First, we performed an interrupted time series analysis (ITS) to assess changes in population level vaccination trends and to determine whether the rate of decline in vaccine uptake changed at the start and at the end of the pandemic.

Chapter 4

Second, we use a matched-sibling analysis to compare siblings within the same family, thereby assessing the effect of the pandemic while controlling for family-specific factors that may influence vaccination decisions. Together, these analyses provide a comprehensive assessment of the pandemic’s impact on routine childhood vaccination in the Netherlands.

Methods

Study setting and population

This retrospective registry study was conducted using linked national data within the secure remote access environment of Statistics Netherlands (Centraal Bureau voor de Statistiek, CBS). We included children born 2016–2024, residing in the Netherlands on 31-12-2024, as registered in the personal records database. Using national registries on migration, we excluded children who were not living in the Netherlands during the pre-defined age window for eligibility for first-dose DTaP-IPV vaccination (2-6 months of age). Children were assigned to one of three pandemic periods based on their date of birth and the corresponding age of eligibility for their first-dose DTaP-IPV vaccination (Table 1). Pandemic periods were defined based on COVID-19-related public health measures in the Netherlands. The relaxation of pandemic measures coincided in time with the introduction of informed consent of registration of vaccination in the national vaccination register Praeventis [9]. National data indicate that on average 1.7% of parents did not provide consent for primary series DTaP-IPV vaccination registration.

Table 1. Definitions of pandemic periods and corresponding birth cohorts

Period	Definition	Birth cohort
Pre-pandemic	Eligible for first-dose DTaP-IPV before implementation of pandemic response measures in March 2020	1 January 2016 – 31 December 2019
Pandemic	Eligible for vaccination during the period of COVID-19 measures and prior to the introduction of informed consent for national vaccination registration (March 2020 – January 2022)	1 January 2020 – 30 September 2021
Post-pandemic	Eligible for vaccination after the relaxation of pandemic measures and following the introduction of the informed consent policy in January 2022	1 October 2021 – 31 December 2024

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

Outcome measure

The primary outcome was having received the first-dose DTaP-IPV vaccination at the age of 6 months. The first dose is scheduled at 2 months of age for children born before 2020. In 2020 maternal pertussis vaccination was introduced, and children of vaccinated mothers are scheduled to receive the first dose at 3 months. Otherwise, the first dose is given at 2 months of age. Individual level vaccination status at 6 months of age was retrieved from Praeventis on 28 August 2025.

Interrupted time series analysis

We used an interrupted time series (ITS) design to assess changes in first-dose DTaP-IPV vaccination uptake. Two interruptions were defined, corresponding to the transitions between the previously defined 'pandemic periods.' ITS is a quasi-experimental method for evaluating changes in outcomes following distinct intervention points or events [10]. We used individual-level data and segmented regression models to estimate changes in the probability of receiving the first scheduled DTaP-IPV vaccination associated with each interruption, capturing both immediate (level) and gradual (slope) changes over time. A binomial logistic regression model was used. Results are presented as odds ratios with 95% confidence intervals, where each period is compared to the immediately preceding period (i.e., the pandemic period is compared to the pre-pandemic period, and the post-pandemic period is compared to the pandemic period). Average monthly model predictions were used to calculate the absolute level changes (i.e., percentage point changes in vaccination uptake).

First, a simple model was created, including birth year and month, interruption 1 and 2 (level changes) and time since interruption 1 and 2 (slope changes). In the second model we extended the first model by adjusting for sociodemographic variables, including birth order, migration status, maternal education level, household income, and urbanisation level based on the residential neighbourhood. For descriptive statistics, we also included the variable country of origin. Because some categories of 'country of origin' and 'migration status' (e.g. 'Dutch origin' and 'country of origin: The Netherlands') overlapped completely, including both variables in the model would result in multicollinearity. The reference year for all sociodemographic variables was 2024. A more detailed description of the sociodemographic variables can be found in supplementary Table S2.

Matched-sibling analysis

We performed a matched-sibling analysis to improve the possibilities for causal inference by accounting for unmeasured family-level confounders. We included families with at least two children, with all children born in 2016-2024. Families in which any child was living outside the Netherlands at the time of first-dose DTaP-IPV vaccination eligibility were excluded. In the case of multiples, we included only the first child in the register, as vaccination decisions for multiples are typically made

Chapter 4

collectively and reflect a single family-level decision.

We employed conditional logistic regression to compare vaccination uptake among siblings within the same family, effectively matching on shared family-level factors. Birth order was included as an independent variable, as previous studies have shown that later-born children are at higher risk of incomplete or delayed vaccination [11]. We aimed to investigate whether this association persisted or changed during and after the pandemic. Therefore, we first constructed a model that included birth order and pandemic period as independent variables. In a second model, we added an interaction term between pandemic period and birth order to assess whether the effect of birth order on vaccination uptake differed before, during, and after the pandemic. In accordance with the principles of conditional logistic regression, only discordant families - those in which siblings differed in outcome - contributed to the estimation of model parameters. Furthermore, for the estimation of the effect of 'pandemic period,' only discordant families in which siblings were eligible for vaccination in different pandemic periods (i.e., before, during, or after the pandemic) contributed information to these parameter estimates [12]. Descriptive family-level characteristics were reported to provide context for generalizability of the findings.

Sensitivity analysis

As a sensitivity analysis, we repeated the conditional logistic regression analysis restricted to families with two children to assess consistency and generalizability across different family sizes. This approach allows for a straightforward comparison between first- and second-born siblings and reduces potential heterogeneity associated with larger family sizes, which may differ in parental characteristics or vaccination behaviours [13]. In this subgroup, by definition, first-born children were always eligible pre-pandemic and second-born children during or after the pandemic. As a result, birth order and pandemic period were perfectly overlapping, and only the main effects model (model 1) was estimated, as independent estimation of interaction effects was not possible.

To assess the potential impact of misclassification due to incomplete parental consent for national vaccination registration after January 2022, we conducted a sensitivity analysis in which we reclassified a proportion of unvaccinated children eligible in the post-pandemic/informed consent period (2021–2024) as vaccinated. Specifically, since the 1.7% non-consent rate refers to the vaccinated population, we calculated the number of unvaccinated children to be reclassified as vaccinated using the formula: $(\text{number of vaccinated children in the subset} / 98.3) \times 1.7$. For the ITS analysis, we did not apply this correction, as adjusting for non-consent would only shift the absolute coverage level in the post-pandemic period upward, without affecting the underlying slope over time. Therefore, the potential impact of incomplete consent on the ITS results is addressed in the interpretation of our findings rather than through direct adjustment of the estimates.

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

All analyses were performed in R version 4.4.3[14].

Results

The total study population included 1,375,514 children of whom 1,284,440 (93%) had received a first-dose DTaP-IPV vaccination at 6 months of age (Table 2). Vaccination coverage was highest in the pre-pandemic period and declined slightly during and after the pandemic. Uptake was generally higher among first- and second-born children compared to later born children, those with Dutch origin compared to non-Dutch origin, higher maternal education level and higher household income versus lower maternal education level and lower household income. Coverage also varied by country of origin and level of urbanisation.

Table 2. First-dose DTaP-IPV vaccination uptake at age 6 months by descriptive sociodemographic characteristics, The Netherlands, children born 2016-2024 (n = 1,375,514)

Characteristics	Total population		Vaccinated population	
	N	Column %	N	Row %
Total number of children	1,375,514	100	1,284,440	93
Pandemic period				
Pre-pandemic	589,003	43	562,205	95
Pandemic	277,223	20	260,742	94
Post-pandemic	509,288	37	461,493	91
Birth order				
First born	660,026	48	624,849	95
Second born	523,562	38	491,982	94
Third born	156,408	11	140,233	90
Fourth or later born	35,518	3	27,376	77
Year of birth				
2016	144,177	10	137,232	95
2017	145,791	11	139,035	95
2018	147,766	11	141,065	95
2019	151,269	11	144,873	96
2020	153,090	11	144,413	94
2021	165,515	12	154,694	93

Chapter 4

Characteristics	Total population		Vaccinated population	
	N	Column %	N	Row %
2022	155,927	11	142,905	92
2023	154,422	11	139,444	90
2024	157,557	11	140,779	89
Family size				
One child	324,162	24	303,861	94
Two children	700,061	51	666,334	95
Three children	275,127	20	252,911	92
Four or more children	76,164	6	61,334	81
Migration status				
Dutch origin	830,040	60	786,450	95
Migrant or child of first generation migrant(s)	336,263	24	312,183	93
Child of second generation migrant(s)	209,211	15	185,807	89
Country of origin ^a				
The Netherlands	830,040	60	786,450	95
Europe (excl. The Netherlands)	152,629	11	143,539	94
Morocco	59,793	4	44,198	74
Turkey	51,613	4	44,796	87
Suriname	41,732	3	38,607	93
The Dutch Caribbean	26,725	2	24,514	92
Indonesia	35,855	3	34,120	95
Other, America/Oceania	39,738	3	37,548	94
Other, Africa	47,652	3	44,793	94
Other, Asia	89,737	7	85,875	96
Maternal education level				
High	658,273	48	624,970	95
Not high	717,241	52	659,470	92

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

Characteristics	Total population		Vaccinated population	
	N	Column %	N	Row %
Household income ^b				
First quartile	148,969	11	131,572	88
Second quartile	343,537	25	310,967	91
Third quartile	502,183	37	476,197	95
Fourth quartile	375,579	27	361,292	96
Unknown	5,246	<1	4,412	84
Level of urbanisation				
Not urbanised	216,838	16	200,647	93
Hardly urbanised	242,206	18	228,561	94
Moderately urbanised	264,172	19	249,176	94
Strongly urbanised	351,509	26	329,207	94
Extremely urbanised	300,313	22	276,409	92
Unknown	476	<1	440	92

a) The country of origin is determined based on the country of birth of the child included in the study, and the countries/countries of birth of its parents and grandparents.

b) Standardised disposable income of the household. If parents of children were living in separate households, the average SDI of the two households was taken. Quartiles (percentiles) were calculated by CBS based on the complete Dutch population.

All reported tables exclude frequencies below ten to avoid personally identifiable information.

Interrupted time series analysis

The basic ITS model just taking into account year and month of birth showed an initial significant drop in vaccination uptake after the start of the pandemic with an OR of 0.777 (95% CI 0.746–0.809). This corresponds to an absolute level change of -1.12 percent points. Simultaneously, the slightly increasing trend in vaccination uptake that was visible from 2016-2019 (OR 1.004, 95% CI 1.003–1.004), significantly decreased after the start of the pandemic (OR 0.985, 95% CI 0.983–0.988). At the end of the pandemic, a significant level change was observed (OR 0.868, 95% CI 0.836–0.900), corresponding to an absolute level change of -1.00 percent points. No significant post-pandemic slope change was found compared to the pandemic period (OR 0.999, 95% CI 0.996–1.002).

After adjusting for sociodemographic factors, similar statistically significant decreases

Chapter 4

in vaccination uptake were seen directly after both interruptions (OR 0.765 [95% CI 0.735–0.798] and -0.896 [95% CI 0.863–0.930] at the start and end of the pandemic, as can be seen in Figure 1. These correspond to level changes of -1.15 and -0.66 percent points at the start and end of the pandemic, respectively. After the start of the pandemic, a significant slope change was found (OR 0.984, 95% CI 0.981–0.986) compared to pre-pandemic, indicating a decreasing trend in vaccination uptake. Opposed to model 1, in the adjusted model we did find a statistically significant slope change after the end of the pandemic compared to during the pandemic, with an OR of 0.995 (95% CI 0.993–0.998), indicating that the decreasing trend in vaccination uptake during the pandemic declined even faster after the end of the pandemic. Furthermore, when comparing the vaccination uptake as presented in Table 2 to the adjusted estimates of the covariates in model 2, similar trends in vaccination uptake are seen across specific subgroups. More details can be found in Table 3.

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

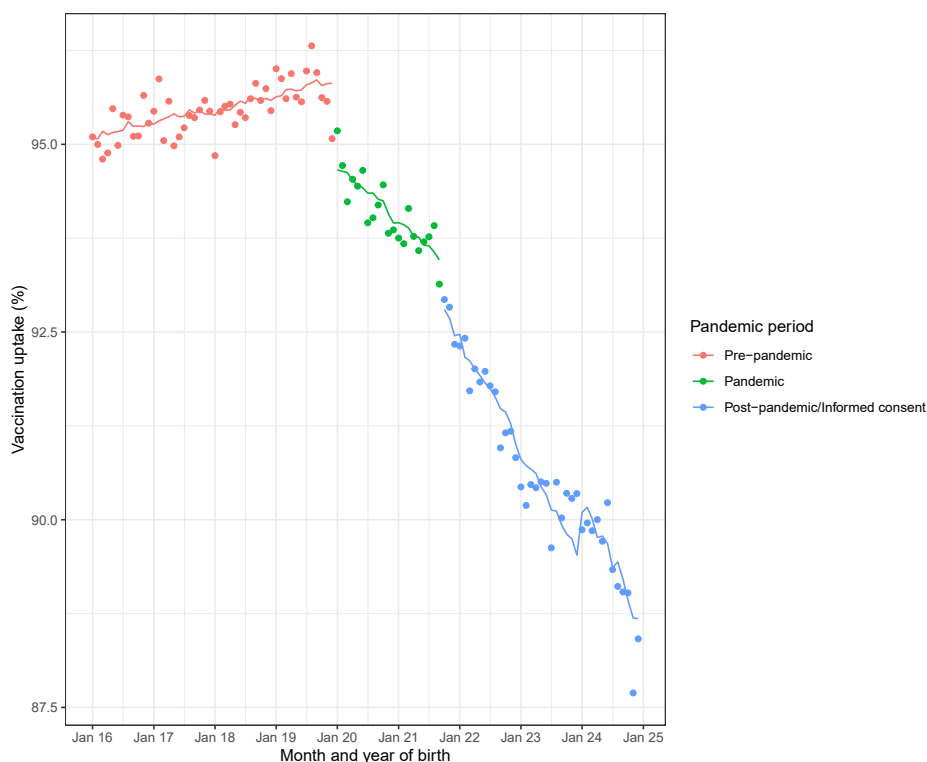


Figure 1. Vaccination coverage DTaP-IPV at age 6 months by month of birth and pandemic period, with fitted regression lines (model 2 - adjusted model)

The figure displays month and year of birth: children born in January 2020 were eligible for first dose DTaP-IPV vaccination in March 2020 (start of the pandemic), and children born in October 2021 were eligible in January 2022 (end of the pandemic/start of informed consent).

Points: observed data. Lines: model prediction.

N.B. the model predictions (lines) are not linear, as they are based on the average predicted vaccination uptake per month, e.g., predictions are made on an individual level, and then an average predicted vaccination uptake per month is calculated and shown in the Figure..

Chapter 4

Table 3. Interrupted time series model results for first-dose DTaP-IPV vaccination uptake at age 6 months: unadjusted (model 1, $n = 1,375,514$) and adjusted for sociodemographic factors (model 2, $n = 1,369,801$)

	Model 1 (unadjusted)			Model 2 (adjusted)		
	OR	95% CI	p value	OR	95% CI	p value
Slope (birth month)	1.004	1.003 - 1.004	<0.001	1.006	1.005 - 1.007	<0.001
Level change start pandemic ^a	0.777	0.746 - 0.809	<0.001	0.765	0.735 - 0.798	<0.001
Slope change start pandemic ^a	0.985	0.983 - 0.988	<0.001	0.984	0.981 - 0.986	<0.001
Level change end pandemic/start informed consent ^b	0.868	0.836 - 0.900	<0.001	0.896	0.863 - 0.930	<0.001
Slope change end pandemic/start informed consent ^b	0.999	0.996 - 1.002	0.558	0.995	0.993 - 0.998	0.001
Birth order						
First born				ref	ref	
Second born				0.907	0.892 - 0.921	<0.001
Third born				0.552	0.541 - 0.563	<0.001
Fourth born or later				0.256	0.249 - 0.264	<0.001
Migration status						
Dutch origin				ref	ref	
Child of first generation migrant(s)				0.926	0.909 - 0.943	<0.001
Child of second generation migrant(s)				0.467	0.459 - 0.475	<0.001
Migrant				0.306	0.278 - 0.336	<0.001
Maternal education level						
High				ref	ref	<0.001
Not high				0.864	0.850 - 0.877	<0.001
Household income ^c						
Fourth quartile				ref	ref	
Third quartile				0.700	0.685 - 0.715	<0.001
Second quartile				0.395	0.387 - 0.404	<0.001

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

	Model 1 (unadjusted)			Model 2 (adjusted)		
	OR	95% CI	P value	OR	95% CI	P value
First quartile				0.347	0.339 - 0.356	<0.001
Level of urbanisation						
Not urbanised				ref	ref	
Hardly urbanised				1.352	1.320 - 1.385	<0.001
Moderately urbanised				1.418	1.385 - 1.452	<0.001
Strongly urbanised				1.357	1.327 - 1.388	<0.001
Extremely urbanised				1.151	1.125 - 1.178	<0.001

a) Reference period: pre-pandemic.

b) Reference period: pandemic.

c) Standardised disposable income of the household. If parents of children were living in separate households, the average SDI of the two households was taken. Quartiles (percentiles) were calculated by CBS based on the complete Dutch population.

All reported tables exclude frequencies below ten to avoid personally identifiable information.

4

Matched-sibling analysis

Table 4 presents the descriptive characteristics of concordant and discordant families included in the matched-sibling analysis. The study population included 708,059 children within 326,981 families. The majority of families was concordant for vaccination status, with 301,465 families (92%) having all eligible children vaccinated and 13,164 families (4%) having all unvaccinated. The remaining 12,352 families (4%) were discordant, meaning siblings differed in vaccination status and thus contributed information to the conditional logistic regression. Most families had two children (86% of concordant-all-vaccinated, 74% of concordant-all-unvaccinated, and 68% of discordant families). Discordant families were more often of non-Dutch origin, had a lower maternal education level, and lived in more urbanised areas compared to concordant families, particularly compared to those in which all children were vaccinated.

Chapter 4

Table 4. Family-level characteristics by sibling vaccination concordance for first-dose DTaP-IPV vaccination uptake at age 6 months, families with at least two children born 2016-2024 (n = 326,981)

	Concordant families				Discordant families	
	All vaccinated		All unvaccinated			
	N	Column %	N	Column %	N	Column %
Total	301,465		13,164		12,352	
Family size						
Two children	259,145	86	9,695	74	8,408	68
Three children	39,573	13	2,780	21	3,341	27
Four or more children	2,747	1	689	5	603	5
Migration status						
Dutch origin	199,511	66	6,649	51	4,755	38
Migrant or child of first generation migrant(s)	58,756	19	2,939	22	3,782	31
Child of second generation migrant(s)	43,198	14	3,576	27	3,815	31
Country of origin ^a						
The Netherlands	199,511	66	6,649	51	4,755	38
Europe (excl. The Netherlands)	30,346	10	1,126	9	1,184	10
Morocco	8,142	3	2,454	19	2,419	20
Turkey	972	7	972	7	1,437	12
Suriname	7,752	3	343	3	516	4
The Dutch Caribbean	4,837	2	263	2	344	3
Indonesia	7,869	3	223	2	240	2
Other, America/Oceania	8,179	3	287	2	273	2
Other, Africa	8,825	3	347	3	527	4
Other, Asia	16,687	6	500	4	657	5
Maternal education level						
High	159,949	53	4,820	37	4,487	36
Not high	141,516	47	8,344	63	7,865	64
Household income ^b						

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

	Concordant families				Discordant families	
	All vaccinated		All unvaccinated			
	N	Column %	N	Column %	N	Column %
First quartile	24,580	8	2,441	19	2,260	18
Second quartile	70,417	23	4,930	37	4,269	35
Third quartile	121,283	40	3,877	29	3,836	31
Fourth quartile	84,624	28	1,831	14	1,913	15
Unknown	561	<1	85	<1	74	<1
Level of urbanisation						
Not urbanised	50,879	17	2,599	20	1,564	13
Hardly urbanised	57,642	19	2,080	16	1,685	14
Moderately urbanised	60,669	20	2,239	17	2,010	16
Strongly urbanised	75,398	25	3,121	24	3,340	27
Extremely urbanised	56,776	19	3,121	24	3,747	30
Unknown	101	<1	<10	<1	<10	<1

a) The country of origin is determined based on the country of birth of the child included in the study, and the countries/countries of birth of its parents and grandparents. This characteristics table provides context for understanding the analytic sample; however, by design, the within-family analysis controls for stable family-level factors, and thus these differences do not confound the estimated effects within discordant families.

All reported tables exclude frequencies below ten to avoid personally identifiable information.

Table 5 presents the results of the matched-sibling conditional logistic regression models. In Model 1, both pandemic period and birth order were independently associated with vaccination uptake within discordant families. Children who became eligible for vaccination during the pandemic had lower odds of receiving the first-dose DTaP-IPV vaccination compared to their siblings eligible before the pandemic (OR 0.50, 95% CI 0.44–0.55), and this effect was even more pronounced for those eligible after the pandemic (OR 0.15, 95% CI 0.13–0.18). Birth order also showed a strong association with vaccination uptake: compared to first-born siblings, the odds of vaccination were lower for second-born (OR 0.32, 95% CI 0.29–0.35), third-born (OR 0.14, 95% CI 0.12–0.16), and fourth or later-born children (OR 0.08, 95% CI 0.06–0.10).

In Model 2, the effect of birth order on vaccination uptake was modified by the pandemic period. For second-born children, the interaction terms were statistically significant, indicating lower odds of vaccination during and after the pandemic compared to first-borns (OR 0.53, 95% CI 0.42–0.68 and OR 0.66, 95% CI 0.55–0.79 for

Chapter 4

pandemic and post-pandemic, respectively). For third-born and fourth or later-born children, the interaction terms were not statistically significant. The total effects of birth order and pandemic period on vaccination uptake, calculated relative to first-born children eligible for vaccination pre-pandemic, are presented in Supplementary Table S3.

Table 5. Matched-sibling conditional logistic regression model for first-dose DTaP-IPV vaccination uptake at age 6 months, children born 2016-2024 within families with at least two children (n = 708,059)

	Model 1			Model 2		
	OR	95% CI	p value	OR	95% CI	p value
Pre-pandemic (ref)	ref	ref	Ref	ref	ref	ref
Pandemic	0.50	0.44-0.55	<0.001	0.66	0.55-0.80	<0.001
Post pandemic	0.15	0.13-0.18	<0.001	0.20	0.17-0.25	<0.001
First born (ref)	ref	ref	Ref	ref	ref	ref
Second born	0.32	0.29-0.35	<0.001	0.42	0.37-0.48	<0.001
Third born	0.14	0.12-0.16	<0.001	0.19	0.10-0.35	<0.001
Fourth or later born	0.08	0.06-0.10	<0.001	0.07	0.00-3.75	0.193
pandemic* second born				0.53	0.42-0.68	<0.001
post pandemic * second born				0.66	0.55-0.79	<0.001
pandemic * third born				0.64	0.33-1.24	0.182
post pandemic * third born				0.60	0.32-1.13	0.117
pandemic * fourth or later born				0.43	0.01-24.65	0.682
post pandemic * fourth or later born				0.94	0.02-47.86	0.973

Sensitivity analysis

We first repeated the matched-sibling conditional logistic regression analysis (model 1), restricting the sample to families with exactly two children (n = 554,496; see Supplementary Table S4). Results were nearly identical to those of the main analysis.

Additionally, we conducted a sensitivity analysis to address incomplete parental consent in the post-pandemic/informed consent period by reclassifying 16% of unvaccinated children as vaccinated. This proportion was calculated to reflect the estimated level of non-consent. The results remained broadly consistent with the primary analysis, although the effect sizes for birth order were smaller and the interaction between being second-born and the post-pandemic period was not statistically significant (see Supplementary Tables S5 and S6).

Discussion

This study assessed the impact of the COVID-19 pandemic on routine childhood vaccination uptake using two complementary approaches. The ITS showed that the slight increase in first-dose DTaP-IPV uptake (at age six months) in recent years before the pandemic shifted to a decreasing trend after the pandemic started, which accelerated slightly post-pandemic. Similarly, the matched-sibling analysis found significantly lower odds of vaccination for children eligible during and even more for children after the pandemic compared to their pre-pandemic siblings in households with both at least one vaccinated and an unvaccinated child. Both analyses indicate a negative effect of the pandemic on first-dose DTaP-IPV uptake, with a sustained decline post-pandemic. This sustained decrease may reflect lingering pandemic effects or new post-pandemic factors, and is concerning for increased risk of vaccine-preventable disease outbreaks and weakened herd immunity.

The ITS analysis also showed level changes at both predefined interruptions. The abrupt decline in vaccination uptake at the start of the pandemic is most likely due to disruptions because of the COVID-19 pandemic and the public health measures in place. This was previously reported for MMR1 vaccination in the Netherlands [3]. The second interruption at the end of the pandemic coincided with the introduction of informed consent for vaccination registration. Although the estimated level change from our model (-1.00 percentage points in the unadjusted model, -0.66 percentage points in the adjusted model) is a bit smaller than the estimated proportion of vaccinated individuals for whom informed consent for registration in Praeventis is lacking (1.7%), the abrupt decline at this timepoint is most likely explained by this policy change. The matched-sibling analysis offers important additional insights beyond the ITS approach, as it inherently controls for family-level characteristics that remain constant between siblings. By comparing siblings within the same family, this method helps to isolate the independent effect of the pandemic from other potential confounding factors, including trends in the composition of the population.

Our findings are consistent with evidence from other European countries that have reported reductions in childhood vaccination uptake during the pandemic, with coverage for key vaccines such as MMR and DTaP-IPV in several regions falling below the WHO target of 90% [15-18]. In most cases, only partial recovery has been observed post-pandemic, and persistent declines have been accompanied by widening socioeconomic disparities [17, 18]. These similarities suggest that the negative impact of the pandemic on vaccination uptake is a broader phenomenon within Europe. However, it should be noted that most studies were conducted relatively soon after the initial pandemic period, which limits abilities to draw conclusions about longer-term impact on vaccination uptake. Outside of Europe, similar effects have been reported, although local factors such as healthcare system disruptions may influence the magnitude and duration of impact [19, 20]. These findings underline the importance of ongoing monitoring of vaccination uptake and initiating efforts to

Chapter 4

further study and address lower vaccination rates post-pandemic.

The sustained decrease in vaccination uptake observed post-pandemic suggests that lingering pandemic effects play a role or there are new post-pandemic reasons. A frequently mentioned result of the pandemic is a decrease in vaccine confidence [6]. In Flanders (Belgium), a cross-sectional survey found that, although most parents remained confident in childhood vaccines, overall confidence declined over time [21]. UK-based studies reported that, while overall confidence in routine childhood vaccination remains relatively high, it has declined in the post-pandemic era [22-24]. Particularly among ethnic minority groups, parents had more questions about childhood vaccinations compared to pre-pandemically [22]. A systematic review further supports that the pandemic affected vaccine confidence in various countries, though the direction and extent of change are context-dependent and may evolve over time [25]. In the Netherlands, parental vaccine confidence appears to have slightly decreased after the pandemic [7], but more specific reasons remain insufficiently understood and require further research.

Several factors may have contributed to this observed decrease in vaccine confidence following the COVID-19 pandemic. The widespread circulation of misinformation and disinformation during the pandemic, particularly through social media and other online platforms, likely played a significant role in shaping negative attitudes towards vaccination [5, 26-28]. Furthermore, public trust in governmental institutions was affected by the rapidly evolving situation and restrictive measures, while the fast development and rollout of COVID-19 vaccines raised concerns about safety and regulation [5]. Together, these factors may have undermined overall confidence in established vaccination programmes and contributed to the sustained decline in routine childhood vaccine uptake, although further research is needed to confirm this.

Several studies have previously examined the association between birth order and childhood vaccine uptake, with evidence suggesting that later-born children are at increased risk of incomplete or delayed immunization compared to first-borns, possibly due to factors such as parental time constraints or changing perceptions with subsequent children [11, 29]. This is in line with our finding that second-born children are less likely to be vaccinated and is concerning because, if this pattern of declining vaccine uptake over time persists, vaccination coverage could decline even further in the future if families have more children.

A key strength of this study is the use of the two complementary methodological approaches, enhancing validity and interpretability of our findings by providing both a broad epidemiological perspective and a more refined within-family comparison. Notably, both analyses consistently indicated a negative effect since the pandemic on DTaP-IPV vaccine uptake, lending greater confidence to the observed association. Furthermore, the use of nationwide, registry-based data enabled a comprehensive

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

assessment of vaccination trends and adjustment for key sociodemographic factors. Lastly, by using recent data extending through 2025, we were able to evaluate both immediate and longer-term effects after the COVID-19 pandemic on childhood vaccination uptake, in contrast to earlier studies that have largely been limited to short-term outcomes.

Several limitations should be considered. First, post-pandemic vaccination coverage is likely underestimated due to incomplete registration following the introduction of informed consent; for primary DTaP-IPV, the average percentage of parents not providing consent is relatively low (1.7% compared to compared to over 3–10% for DTP booster and school-age vaccinations)[4]. Although sensitivity analyses continued to show a negative effect, variation in consent rates across subgroups may still have introduced bias, which we were unable to adjust for due to lack of data. Second, while the ITS controlled for pre-existing trends, unmeasured confounding remains possible given concurrent pandemic-related factors that may have influenced uptake. In addition, sociodemographic variables were measured at a single time point (2024) and may not reflect changes over the study period, though major shifts are unlikely. Third, children who died before 31 December 2024 were excluded, slightly underrepresenting the at-risk population, but the impact is minimal given low childhood mortality. Fourth, some children may have received their vaccination later than usual due to pandemic delays, but assessing vaccination status at 9 months of age showed only a minor increase in coverage (0.2 percentage points) and no differences between pandemic periods (data not shown). This confirms that although there was some delay as described earlier, this was not substantial [3]. Finally, the matched-sibling analysis estimates effects only within families where siblings differ in both vaccination status and pandemic period, rather than across the entire population, which may limit the generalizability of the findings [12]. Generalizability of covariates associated with lower vaccination coverage may not hold true for one-child families, and the results could be influenced by unmeasured confounding, such as changes in family circumstances (e.g., divorce or household composition). Nonetheless, only 5% of households in this analysis included siblings who did not share the same parents (0.4% different mother; 4.6% different father), and excluding these households yielded nearly identical results (data not shown). Similarly, restricting the analysis to families with exactly two children produced similar findings, further supporting the robustness of our results.

Chapter 4

Conclusion

This nationwide study demonstrates a sustained decline in routine childhood vaccination uptake in the Netherlands during the COVID-19 pandemic that continued after the pandemic. Both population-level and within-family analyses indicate that the pandemic has had a negative impact on parental vaccination decisions, which may reflect lingering pandemic effects or new post-pandemic factors. The observation that the downward trend in vaccination coverage continues, rather than stabilizes, is particularly concerning as it may increase the risk of outbreaks of vaccine-preventable diseases and undermine herd immunity. Therefore, continuous monitoring of vaccination uptake and further research is essential to understand changes in practical barriers to and attitudes towards vaccination, alongside continued efforts to manage mis- and disinformation and address vaccine hesitancy.

References

1. Watson OJ, Barnsley G, Toor J, Hogan AB, Winskill P, Ghani AC. Global impact of the first year of COVID-19 vaccination: a mathematical modelling study. *Lancet Infect Dis.* 2022;22(9):1293–302 doi:10.1016/S1473-3099(22)00320-6.
2. Rijksinstituut voor Volksgezondheid en Milieu (RIVM). Tijdenlijnen COVID-19. [Timelines COVID-19]. 2025 [Available from: <https://tijdlijnencovid19.rivm.nl/>].
3. Middeldorp M, van Lier A, van der Maas N, Veldhuijzen I, Freudenburg W, van Sorge NM, et al. Short term impact of the COVID-19 pandemic on incidence of vaccine preventable diseases and participation in routine infant vaccinations in the Netherlands in the period March-September 2020. *Vaccine.* 2021;39(7):1039–43 doi:10.1016/j.vaccine.2020.12.080.
4. van Lier A, Hament J, Holwerda M, Westra M, Giebers H, van der Maas N, et al. Vaccinatiegraad Rijksvaccinatieprogramma Nederland. Verslagjaar 2025.: RIVM; 2025.
5. Buijsen M. Public Reason in Times of Corona: Countering Disinformation in the Netherlands. *Camb Q Healthc Ethics.* 2025;1–13 doi:10.1017/S0963180125000027.
6. Unicef. The stat of the world's children 2023. For every child, vaccination.; 2023.
7. Knijff M, van Lier A, Boer M, de Vries M, Hament J-M, de Melker HE. Parental intention, attitudes, beliefs, trust and deliberation towards childhood vaccination in the Netherlands in 2022: Indications of change compared to 2013. *Vaccine.* 2024;42(4):801–11 doi:<https://doi.org/10.1016/j.vaccine.2023.12.080>.
8. van Lier A, Hament J-M, Knijff M, Westra M, Giesbers H, Drijfhout I, et al. Vaccinatiegraad en jaarverslag Rijksvaccinatieprogramma Nederland 2023. Vaccination coverage and annual report of the National Immunisation Programme in the Netherlands, 2023: Rijksinstituut voor Volksgezondheid en Milieu RIVM; 2024.
9. van Lier A, Oomen P, de Hoogh P, Drijfhout I, Elsinghorst B, Kemmeren J, et al. Praeventis, the immunisation register of the Netherlands: a tool to evaluate the National Immunisation Programme. *Euro Surveill.* 2012;17(17) doi:10.2807/ese.17.17.20153-en.
10. Bernal JL, Cummins S, Gasparrini A. Interrupted time series regression for the evaluation of public health interventions: a tutorial. *Int J Epidemiol.* 2017;46(1):348–55 doi:10.1093/ije/dyw098.
11. Scheepers ED, van Lier A, Drijfhout IH, Berbers G, van der Maas NAT, de Melker HE, et al. Dutch national immunization schedule: compliance and associated characteristics for the primary series. *Eur J Pediatr.* 2017;176(6):769–78 doi:10.1007/s00431-017-2904-1.
12. Petersen AH, Lange T. What Is the Causal Interpretation of Sibling Comparison Designs? *Epidemiology.* 2020;31(1):75–81 doi:10.1097/EDE.0000000000001108.
13. Pijpers J, van Roon A, Schipper M, Stok M, van den Hof S, van Gaalen R, et al. The decrease in childhood vaccination coverage and its sociodemographic determinants, the Netherlands, birth cohorts 2008 to 2020. *Euro Surveill.* 2025;30(39) doi:10.2807/1560-7917.ES.2025.30.39.2500251.
14. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2020.
15. Omar M, Shibli H, Edelstein M. Comparative impact of the COVID-19 pandemic on parental behaviour towards childhood vaccination in Israel and the United Kingdom: A self-controlled matched cross-sectional study. *Vaccine.* 2025;61:127385 doi:10.1016/j.vaccine.2025.127385.

Chapter 4

16. Pennisi F, Silenzi A, Mammone A, Siddu A, Odone A, Sabbatucci M, et al. Childhood Immunization Coverage Before, During and After the COVID-19 Pandemic in Italy. *Vaccines (Basel)*. 2025;13(7) doi:10.3390/vaccines13070683.
17. Sacre A, Sowden S, Bambra C, Bennett N, Todd A. COVID-19 and regional inequalities in childhood vaccination uptake in England: a spline regression. *BMC Public Health*. 2025;25(1):2913 doi:10.1186/s12889-025-24207-9.
18. Buck E, Burt J, Karampatsas K, Hsia Y, Whyte G, Amirthalingam G, et al. 'Unable to have a proper conversation over the phone about my concerns': a multimethods evaluation of the impact of COVID-19 on routine childhood vaccination services in London, UK. *Public Health*. 2023;225:229–36 doi:10.1016/j.puhe.2023.09.026.
19. Saavedra RC, Carvalho-Sauer R, Paixao ES, Ichihara MYT, Costa M, Teixeira MDG. Is Brazil Reversing the Decline in Childhood Immunization Coverage in the Post-COVID-19 Era? An Interrupted Time Series Analysis. *Vaccines (Basel)*. 2025;13(5) doi:10.3390/vaccines13050527.
20. Ngigi M, Moride Y, Castilloux AM, Clemens SAC. An Interrupted Time Series Analysis of the Impact of the COVID-19 Pandemic on Routine Vaccination Uptake in Kenya. *Vaccines (Basel)*. 2024;12(8) doi:10.3390/vaccines12080826.
21. Pattyn J, Hanning N, Valckx S, Claessens T, Karafillakis E, Jong V, et al. Investigating the state of vaccine confidence among the general public and parents with children up to 13 years in Flanders (Belgium). *Vaccine*. 2025;58:127250 doi:10.1016/j.vaccine.2025.127250.
22. Skirrow H, Lewis C, Haque H, Choudary-Salter L, Foley K, Whittaker E, et al. The impact of the COVID-19 pandemic on UK parents' attitudes towards routine childhood vaccines: A mixed-methods study. *PLoS One*. 2024;19(8):e0306484 doi:10.1371/journal.pone.0306484.
23. Kasstan-Dabush B, Chantler T, Bedford H. Decline in UK childhood vaccine uptake. *BMJ*. 2025;390:r1500 doi:10.1136/bmj.r1500.
24. Thompson S, Meyer JC, Burnett RJ, Campbell SM. Mitigating Vaccine Hesitancy and Building Trust to Prevent Future Measles Outbreaks in England. *Vaccines (Basel)*. 2023;11(2) doi:10.3390/vaccines11020288.
25. Vojtek I, van Wouw M, Thomson A. Impact of COVID-19 on vaccine confidence and uptake: A systematic literature review. *Hum Vaccin Immunother*. 2024;20(1):2384180 doi:10.1080/21645515.2024.2384180.
26. Loomba S, de Figueiredo A, Piatek SJ, de Graaf K, Larson HJ. Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. *Nat Hum Behav*. 2021;5(3):337–48 doi:10.1038/s41562-021-01056-1.
27. Brennen JS, Simon FM, Nielsen RK. Beyond (Mis)Representation: Visuals in COVID-19 Misinformation. *Int J Press Polit*. 2021;26(1):277–99 doi:10.1177/1940161220964780.
28. Pennisi F, Genovese C, Gianfredi V. Lessons from the COVID-19 Pandemic: Promoting Vaccination and Public Health Resilience, a Narrative Review. *Vaccines (Basel)*. 2024;12(8) doi:10.3390/vaccines12080891.
29. Gavrielov-Yusim N, Battat E, Neumann L, Friger M, Balicer RD. Birth order and private voluntary immunization--a study of 110,902 children. *Vaccine*. 2012;30(2):442–7 doi:10.1016/j.vaccine.2011.10.060.

Supplementary material

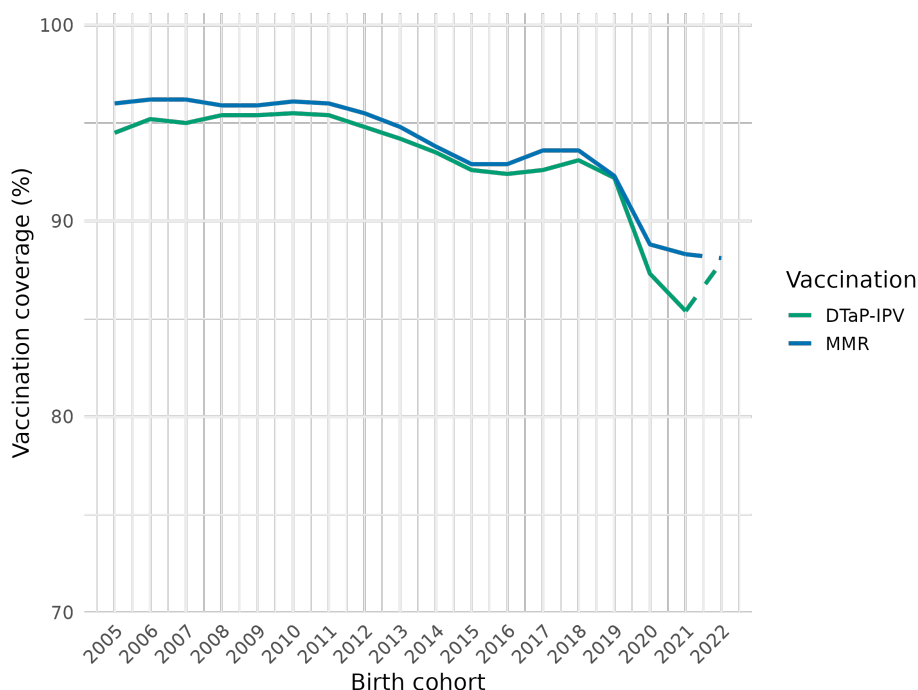


Figure S1. First-dose MMR and ≥ 3 dose DTaP-IPV vaccination coverage at age 2 years, birth cohort 2005-2022, The Netherlands. Data retrieved from the annual vaccination coverage report by the Dutch National Public Health Institute [4].

Abbreviations: DTaP-IPV diphtheria-tetanus-pertussis-polio, MMR measles-mumps-rubella

The dashed lines indicate the vaccination coverage is impacted by the informed consent. Note: changes in registered vaccination coverage in the most recent cohort do not necessarily reflect changes in actual coverage, as recent figures do not yet account for anonymous vaccinations or administrative corrections for missing JGZ indications. For DTaP-IPV, the apparent increase in coverage in cohort 2025 is due to such an administrative correction and does not indicate a true rise in uptake; actual coverage is likely slightly lower than the previous year.

Chapter 4

Table S2. Sociodemographic variables definitions

Variable	Definition	Levels	Reference year
Migration status	Migrations status based on whether: 1) children were born in the Netherlands, 2) parents were born in the Netherlands and 3) grandparents were born in the Netherlands	Dutch origin; first-generation migrant; child of first-generation migrant; child of second-generation migrants	2024
Country of origin	Country of origin was primarily defined by the country of birth (CoB) of the child itself. If the child was born in the Netherlands, country of origin was first determined by the parents' country of birth (CoB). If both parents were born in the Netherlands, the grandparents' CoB was then considered. Within this definition, the mother's CoB was prioritized over the father's, and the grandmother's CoB was prioritized over the grandfather's. Foreign-born origins were given precedence over Dutch origin if present in the lineage.	The Netherlands; Europe (excluding the Netherlands); Morocco; Turkey; Surinam; Dutch Caribbean; Indonesia; Other, America/Oceania; Other, Africa; Other, Asia). Indonesia; Other (Africa, Asia, America/Oceania)	2024

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

Variable	Definition	Levels	Reference year
Maternal education level	Highest level of completed education. High: HBO higher professional education; WO, University education Not high: primary education; VMBO, pre-vocational education; MBO1, entry-level secondary vocational education; HAVO, senior general secondary education WO, pre-university education	High; not high	2024
Household standardised disposable income	Disposable income of the household taking into account differences in household size and household composition, divided into quartiles based on the entire Dutch population.	First quartile; second quartile; third quartile; fourth quartile; unknown	2024
Level of Urbanisation	Urbanisation level was defined based on the average address density per square kilometre: extremely urbanised (≥ 2500 addresses/km ²), strongly urbanised (1500-2499 addresses/km ²), moderately urbanised (1000-1499 addresses/km ²), hardly urbanised (500-999 addresses/km ²) and not urbanised (≤ 500 addresses/km ²).	Non-urbanised; hardly urbanised; moderately urbanised; strongly urbanised; extremely urbanised; unknown	2024

Chapter 4

Table S3. Total effects of birth order and pandemic period on first-dose DTaP-IPV vaccination uptake among children in families with at least two children (reference group: first-born child, pre-pandemic period)

Group (ref: first child pre-pandemic)	OR	95% CI
Second child pandemic	0.15	0.11-0.21
Second child post pandemic	0.06	0.04-0.08
Third child pandemic	0.08	0.03-0.20
Third child post pandemic	0.02	0.01-0.06
Fourth or later child pandemic	0.02	0.00-5.94
Fourth or later child post pandemic	0.01	0.00-3.68

Table S4. Matched-sibling conditional logistic regression model for first-dose DTaP-IPV vaccination uptake at age 6 months, children born 2016-2024 within families with two children (n = 554,496)

	OR	95% CI	p value
Pre-pandemic (ref)	ref	ref	ref
Pandemic	0.50	0.43-0.58	<0.001
Post pandemic	0.14	0.12-0.18	<0.001
First born (ref)	ref	ref	ref
Second born	0.32	0.29-0.35	<0.001

COVID-19 Pandemic's Impact on Routine Childhood Vaccination Uptake

Table S5. Sensitivity analysis with 16% of unvaccinated children in the post-pandemic/informed consent period reclassified as vaccinated. Matched-sibling conditional logistic regression model for first-dose DTaP-IPV vaccination uptake at age 6 months, children born 2016–2024 within families with at least two children (n = 708,059)

	Model 1			Model 2		
	OR	95% CI	p value	OR	95% CI	p value
Pre-pandemic (ref)	ref	ref	ref	ref	ref	ref
Pandemic	0.43	0.40-0.47	<0.001	0.48	0.43-0.54	<0.001
Post pandemic	0.35	0.32-0.40	<0.001	0.36	0.32-0.41	<0.001
First born (ref)	ref	ref	ref	ref	ref	ref
Second born	0.49	0.46-0.52	<0.001	0.53	0.47-0.58	<0.001
Third born	0.34	0.30-0.39	<0.001	0.31	0.19-0.51	<0.001
Fourth or later born	0.40	0.32-0.50	<0.001	0.21	0.01-4.62	0.320
pandemic* second born				0.82	0.69-0.98	0.026
post pandemic * second born				0.96	0.84-1.11	0.584
pandemic * third born				0.90	0.53-1.51	0.683
post pandemic * third born				1.14	0.69-1.87	0.616
pandemic * fourth or later born				0.51	0.02-13.03	0.687
post pandemic * fourth or later born				2.01	0.09-45.14	0.661

Table S6. Total effects of birth order and pandemic period on first-dose DTaP-IPV vaccination uptake among children in families with at least two children (sensitivity analysis reclassifying 16% of unvaccinated children in the post-pandemic/informed consent period as vaccinated; reference group: first-born child, pre-pandemic period)

Group (ref: first child pre-pandemic)	OR	95%CI
Second child pandemic	0.21	0.11-0.21
Second child post pandemic	0.18	0.04-0.08
Third child pandemic	0.13	0.03-0.20
Third child post pandemic	0.13	0.01-0.06
Fourth or later child pandemic	0.05	0.00-5.94
Fourth or later child post pandemic	0.15	0.00-3.68



Part II

COVID-19
vaccination coverage
and interventions



Chapter 5

Determinants of COVID-19 vaccine uptake in the Netherlands: a nationwide registry-based study

Joyce Pijpers, Annika van Roon, Caren van Roekel,
Lisanne Labuschagne, Bente Smagge, José A Ferreira,
Hester de Melker, Susan Hahné

Vaccines, 2023

DOI: [10.3390/vaccines11091409](https://doi.org/10.3390/vaccines11091409)

ABSTRACT

By September 2022, the uptake of at least one dose of COVID-19 vaccine in the Dutch adult population was 84%. Ecological studies have indicated a lower uptake in certain population groups. We aimed to investigate determinants of COVID-19 vaccine uptake in the Netherlands at individual level to evaluate and optimize implementation of the vaccination program and generate hypotheses for research on drivers of, and barriers to, vaccination. A retrospective database study was performed including the entire Dutch population ≥ 18 . Vaccination data (5 January 2021–18 November 2021) were at individual levels linked to sociodemographic data. Random forest analyses ranked sociodemographic determinants of COVID-19 vaccine uptake. The most important determinant was age; uptake increased until the age of 80 (67% in 18–35 years, 92% in 67–79 years, and 88% in those > 80). Personal income and socioeconomic position ranked second and third, followed by migration status. Uptake was lower among individuals in the lowest income group (69%), those receiving social benefits (56%), and individuals with two parents born abroad (59%). Our finding that age is the most important determinant for uptake likely reflects the prioritisation of elderly in the programme and the general understanding of their increased vulnerability. However, our findings also reveal important other disparities in vaccine uptake. How to best address this inequity in future vaccination campaigns requires further research.

Introduction

The COVID-19 pandemic emerged in December 2019 and has caused high rates of illness and over 6-million deaths worldwide [1]. In the Netherlands, with a population of 17.7-million people, more than 8-million infected individuals and nearly 50,000 COVID-19- related deaths have been registered up to 2022 [2]. Safe and effective vaccines were available from late 2020. Studies have indicated the beneficial impact of COVID-19 vaccination on public health in terms of the large numbers of averted deaths and hospitalisations [3–5]. In the Netherlands, the COVID-19 vaccination programme was implemented from 6 January 2021 onwards. Equivalent to routine childhood immunisation, COVID-19 vaccination was offered free of charge and was non-mandatory. With the aim to reduce severe disease, the vaccination programme was prioritising older age groups, people with certain medical conditions, people living in institutions, and healthcare workers [6]. By September 2022, an uptake of at least one dose of COVID-19 vaccine in the Dutch population was 84% [7].

High-risk groups that are disproportionately affected by COVID-19 include older adults and individuals with underlying medical conditions [8,9]. People living in long-term care facilities are at a higher risk of contracting and spreading the disease. Other factors such as socioeconomic status and ethnicity were also found to be associated with increased risk of COVID-19 infection and poor outcomes, underpinning the importance of homogeneous high coverage to maximise the beneficial impact of vaccination [8,10]. However, an ecological study in the Netherlands showed that the uptake of COVID-19 vaccination differed between population subgroups. The findings indicated lower vaccine uptake in neighbourhoods with a higher percentage of residents with a non-Western migration background and whose residents were more likely to vote for right-wing Christian and right-wing conservative political parties [11]. In line with those results, an ecological study investigating spatiotemporal distributions of COVID-19 vaccine uptake found lower uptake in the main urban areas and in the most religiously conservative regions of the Netherlands [12].

To date, no studies using individual-level data have been conducted to study COVID-19 vaccine uptake in the Dutch population. As individual-level data could provide more robust evidence, we aimed to investigate determinants of COVID-19 vaccine uptake in the Netherlands by linking national vaccination registration data at the individual level to sociodemographic data. Results from this study can be used to evaluate and optimize the implementation of COVID-19 vaccination programmes to increase vaccination coverage and reduce mortality and morbidity, as well as minimize health inequality. Furthermore, the results can inform health promotion activities and generate hypotheses for further research on drivers of and barriers to vaccination.

Chapter 5

Methods

Study design and population

A retrospective database study was performed including the entire Dutch population of 18 years and older, as registered in the Personal Records Database (BRP) on 5 January 2021 (the day before the start of the COVID-19 vaccination campaign).

Vaccine uptake

The outcome variable in this study was vaccine uptake, defined as having received at least one COVID-19 vaccination between 6 January 2021 and 18 November 2021 (day before start of the booster campaign). The vaccination data were retrieved from the COVID-19- vaccination Information and Monitoring System (CIMS) on 4 October 2022. CIMS is a national vaccination registration system maintained by the Dutch National Institute for Public Health and the Environment (RIVM). CIMS only includes data of people who provided informed consent to register their vaccination data. For the primary series, 93% of the vaccinees provided informed consent [13]. Vaccinated individuals who did not give informed consent could not be distinguished from unvaccinated individuals and are thus included in this study as unvaccinated. In case an individual had been infected with SARS-CoV-2 six months prior to vaccination, one dose instead of two was recommended for the primary series. However, since the CIMS database does not contain information about previous infections, completion of the primary series could not be assessed for individuals with only one primary series dose. Therefore, we chose to study vaccine uptake, defined as having received (and having provided consent for) at least one COVID-19 vaccine.

Determinants of vaccination

The population database, including vaccination data, was linked to data available in the remote access environment at Statistics Netherlands (CBS). Data were linked on a person level after CBS converted citizen service numbers to a non-identifiable unique number, known as RIN (random identification number). An overview of the included determinants, and their definitions, is presented in Table 1. The majority data were most recently available for the year 2021, and some for 2020.

Determinants of COVID-19 Vaccination Uptake

Table 1. Characteristics of outcome variable and determinants: level of aggregation, measurement level, date of reference, and original database

Variable	Levels	Reference Date	Database
Individual level			
Vaccine uptake	At least one COVID-19 vaccination registered in CIMS; 1 = yes; 0 = no ^a	5 January 2021–18 November 2021 ^b	CIMS
Age ^c	Continuous	5 January 2021	CBS
Sex	0 = male; 1 = female	5 January 2021	CBS
Education level	Primary education; prevocational secondary education-basic vocational programme (VMBO-b/k), lower secondary vocational training and assistant's training (MBO-1); prevocational secondary education—theoretical and vocational programme (VMBO-g/t), the first three years of senior general secondary education (HAVO) and pre-university secondary education (VWO); basic vocational training (MBO-2) and vocational training (MBO-3); middle management and specialist education (MBO-4); upper secondary education (HAVO/VWO); Hbo-, wo-bachelor; Hbo-, wo-master, doctor; Unknown	5 January 2021	CBS

Chapter 5

Country of origin d	The Netherlands; Turkey; Morocco; Suriname; The Dutch Caribbean; Indonesia; Other Africa; Other Asia; Other America/Oceania; Middle and Eastern European countries within the EU; GIPS countries (Greece, Italy, Portugal, Spain); Former or associated member states of the Commonwealth of Independent States, other countries of the EU; Other European countries; Unknown	5 January 2021	CBS
Migration status e	Netherlands; Born in the Netherlands with one parent born abroad; Born in the Netherlands with two parents born abroad; Born abroad with one parent born abroad; Born abroad with two parents born abroad; Born abroad with two parents born in the Netherlands; Unknown	2021	CBS
Socioeconomic position	In employment; Self-employed; Unemployment benefits (WW); Social assistance benefit; Other benefits; Disability benefit; Pensioner; Student; Other/Unknown	2021	CBS
Personal income	Continuous (percentiles) f	2021	CBS
Household type	One-person household; Unmarried couple without children; Married couple without children; Unmarried couple with children; Married couple with children; One-parent family; Other households; Institutional household; Other	2021	CBS
Household car ownership	1 = yes; 0 = no	2021	CBS

Determinants of COVID-19 Vaccination Uptake

Employment sector	Agriculture, Forestry and fishery; Mining and quarrying; Industry; Electricity supply; Water supply, sewerage and waste management; Construction; Wholesale and retail trade; Transportation and storage; Accommodation and food service activities; Information and communication; Financial services; Real estate activities; Professional scientific and technical activities; Administrative and support service activities; Public administration and defence; Education; Human health and social work activities; Arts, entertainment and recreation; Other service activities; Activities of household as employer, undifferentiated goods- and service producing activities of households for own use; Activities of extraterritorial organisations and bodies; Other/unemployed/unknown	2021	CBS
Urbanisation level	Not urbanised; Hardly urbanised; Moderately urbanised; Strongly urbanised; Extremely urbanised; Unknown	2021	CBS
X-coordinate postal code	Numeric	2021	CBS
Y-coordinate postal code	Numeric	2021	CBS
Medical risk groups g	High medical risk; Intermediate medical risk; Low medical risk	2020	CBS
Long term care recipients, residential, nursing home	1 = yes; 0 = no	2020	CBS
Long term care recipients, residential, mentally impaired	1 = yes; 0 = no	2020	CBS

Chapter 5

Long term care recipients, non-residential, mentally impaired	1 = yes; 0 = no	2020 h	CBS
Neighbourhood (NBHD) level			
Voting proportions for political movements i		2021	Open State Foundation
Right-wing liberal	Percentage		
Progressive liberal	Percentage		
Christian middle	Percentage		
Right-wing Christian	Percentage		
Progressive left-wing	Percentage		
Right-wing conservative	Percentage		
Other parties	Percentage		

Abbreviations: CBS Centraal Bureau voor de Statistiek (Statistics Netherlands), CDA Christian Democratic Appeal, CU Christian Union, D66 Democrats 66, FvD Forum for Democracy, GL Green Left, JA21 Right Answer 2021, PvdA Labour party, PvdD Party for the Animals, PVV Party for Freedom, SP Socialist Party, Volt Volt Netherlands, SGP Reformed Political Party, VVD People's Party for Freedom and Democracy.

a) 0 = did not receive vaccination or did not provide informed consent for data to be registered in CIMS;

b) The extraction date was 4 October 2022;

c) Age was estimated as 2021, minus year of birth;

d) Both country of origin and migration status were included in the analysis, based on the new classification (Level 3) of population by origin by CBS. More information on the CBS 2022 classification of population by origin can be found at: New classification of population by origin www.cbs.nl/en-gb/news/2022/07/cbs-introducing-new-population-classification-by-origin (accessed on 1 August 2022);

e) If a person was born in the Netherlands and their mother was born abroad, country of origin was defined as the mother's country of birth. If only the father was born abroad, their father's country of birth was the person's country of origin.

Determinants of COVID-19 Vaccination Uptake

f) Percentiles are calculated by CBS Microdata based on personal income data, including the entire Dutch population in 2020;

g) Approximated based on healthcare utilisation and medication prescription data;

h) In case of rare medical conditions, data from 2016–2020 were included.

i) Based on information from the National Elections in March 2021 for political parties with at least two seats. Data available from the Open State Foundation URL: www.data.overheid.nl/community/organization/kiesraad (accessed on 15 June 2022).

Sociodemographic determinants

Included sociodemographic determinants were age, sex, origin (captured by the two variables “country of origin” and “migration status”), socioeconomic position, personal income, household type, household car ownership, employment sector, urbanisation level, and place of residence (expressed by XY coordinates of postal code).

Medical risk groups

Information on medical risk conditions was derived from Dutch national healthcare registry data. The database contained data from a claims database of outpatient specialist care utilisations and data on medication at ATC-4 code level. For selecting individuals with medical risk, we applied the method described by de Gier et al. [13]. Individuals were categorised as high, intermate, or low medical risk for severe COVID-19. The high-risk group was defined by having received care or medication for conditions associated with a high risk for severe COVID-19 [9]. People with these conditions were prioritised for the primary vaccination series. The intermediate risk group was defined by their eligibility for the annual influenza vaccination [9]. All remaining individuals were categorised as low medical risk. In addition to underlying medical conditions, living in a nursing home and having an intellectual disability (living in residential and non-residential care) were included as separate variables in the analyses. Data on long-term care utilisation were available within a national database comprising dates and types of long-term care use at individual level. More detailed information regarding the classification of long-term care recipients is included in Supplement S1.

Voting proportions for political movements

The voting proportions for political movements per neighbourhood were based on the National Elections in March 2021 in the Netherlands. We applied the classification used by Labuschagne et al. [11] that distinguished six political movements: Right-wing liberal, progressive liberal, Christian middle, right-wing Christian, progressive left wing, and right-wing conservative.

Chapter 5

Statistical analysis

Determinants were ranked according to their importance in predicting vaccine uptake at individual level using the random forest (RF) method [14]. The RF was applied to randomly selected sample of 400,000 individuals, equally divided into training and test datasets. This sample size was determined using a level at which the prediction accuracy and the ranking of the determinants stabilized, i.e., did not change visibly by taking a larger subset.

Two types of analyses were done. First, a standard RF predictor was constructed. This provided estimates of prediction accuracy, such as the PMC (probability of misclassification, i.e., the probability of predicting an individual's status incorrectly), the sensitivity and the specificity, and the ranking of the predictor variables according to their importance, which was measured as the average increase in (worsening of) the PMC that results from the replacement of the value of a variable by a randomly chosen value. As expected, the standard RF yielded a very high sensitivity and a comparatively low specificity because there were far more vaccinated (80%) than unvaccinated individuals and the default prediction rule aims at minimizing the PMC (as opposed to the sensitivity or specificity). For this reason, a second "refined" RF, meant to yield more balanced values of sensitivity or specificity, was built. This was done by creating a standard RF with the training data and adjusting its prediction rule in the direction of the desired target based on its ROC (receiver-operating characteristics) curve, as explained in more detail in Supplement S2. The performance characteristics and the variable importance of the new RF obtained by the adjusted rule were estimated by making predictions on the test data. These analyses were carried out with the R package "ranger" version 0.13.1 [15]. The results of the refined RF are presented in this paper. Since people aged 60 and above are at risk for severe outcomes of COVID-19, a second RF was performed for the population ≥ 60 years of age.

Results

On 5 January 2021, the Dutch population of 18 years and older included 14,175,650 people. The COVID-19 vaccine uptake in our dataset was 80%, with a much higher uptake in older age groups (88% in the oldest age group opposed to 67% in the youngest age group) and slightly higher among females (80% opposed to 79% in males). Lower uptake was found in individuals born abroad in the Netherlands with two parents born abroad (46%), lower income groups (69%), households with one-parent families (65%), households without a car (73% opposed to 82% with a car), individuals with low medical risk for severe COVID-19 (78% opposed to 87% in individuals with high medical risk), and individuals living in neighbourhoods with the highest voting proportions for right-wing Christian parties (40%). Uptake also varied between employment sectors (range 69–87%). A decreasing trend was observed in uptake from higher to lower education levels (range 69–85%), and from lower to

Determinants of COVID-19 Vaccination Uptake

higher levels of urbanisation degree (range 74–84%). Further information on uptake per variable by age group can be found in Supplement S3.

Ranking of determinants

Figure 1 shows the results of the refined RF. The performance of characteristics of the refined RF estimated from the predictions made on the test data agree with those targeted by the ROC analysis (Supplement S2), which are a PMC of 30% and both a sensitivity and specificity of 70%.

Age

The outstanding most important variable was age. The bivariate tables in Supplement S3 also show that uptake increases with age within the levels of every other variable. Only the highest age group (80+), for most variables, shows a slightly lower uptake than the age group 67–79.

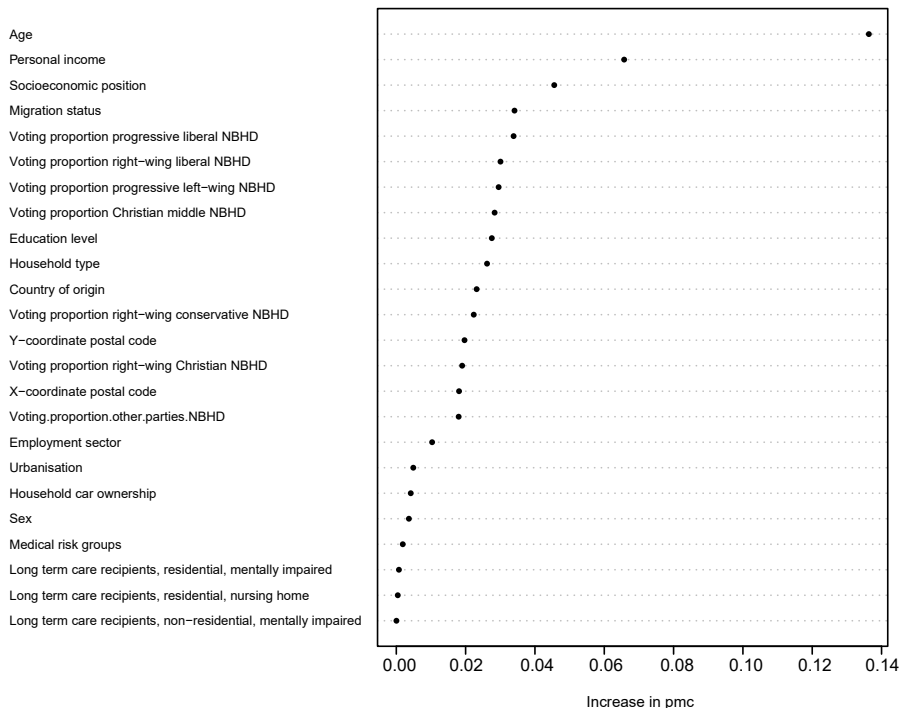


Figure 1. Ranking of variable importance for predicting COVID-19 vaccination status based on the refined RF. PMC = 0.30; sensitivity = 0.70; specificity = 0.70. Abbreviations: NBHD = neighbourhood

Chapter 5

Personal income and socioeconomic position

Personal income and socioeconomic position ranked second and third in the RF. Bivariate analyses noted that individuals with higher personal income had a higher uptake. In all percentage intervals of personal income, except for the lowest decile of 0–10%, the uptake was higher with increasing age (Supplement S3). Within decile 0–10%, individuals of 67 years and older had the lowest uptake. However, this group comprised relatively few individuals. With regard to socioeconomic position, uptake was highest for people in employment and pensioners, and lowest for people with social assistance benefits. The observation that higher uptake was seen with increasing age was less clear in the group with the “another or unknown” socioeconomic position. Figure 2 shows the vaccine uptake by personal income and socioeconomic position, per age group. In people below the age of 50, uptake was higher if they had a higher personal income and worked in employment, compared to people with higher personal income in the other socioeconomic position categories.

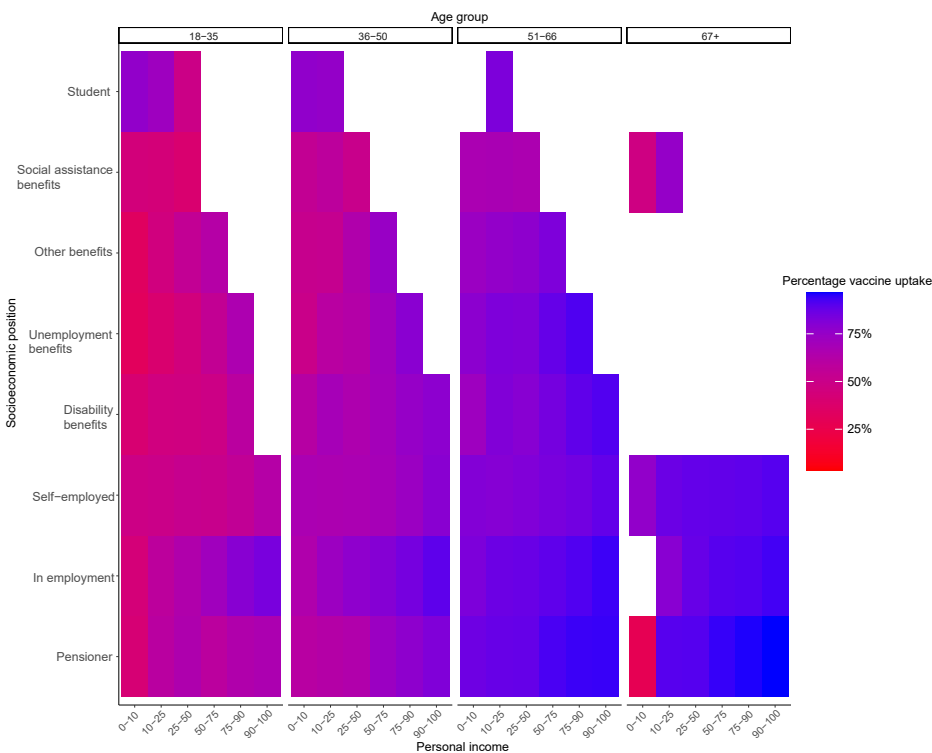


Figure 2. Vaccine uptake by personal income (deciles) and socioeconomic position per age group. Groups with frequencies <100 were excluded and coloured white.

Population by origin

The variable migration status ranked fourth in the RF and country of origin ranked 11th; however, in terms of an increase in PMC, their importance is comparable. Bivariate analyses (Supplement S3) showed that individuals with one or two parents born in the Netherlands had a higher uptake than individuals with both parents born abroad, regardless of whether the individual was a migrant. Within the youngest age group (18–35 years), uptake was lowest for individuals born in the Netherlands with two parents born abroad, followed by migrants with two parents born abroad. Within the oldest age group, uptake is similar for all categories, except migrants with two parents born abroad for whom uptake was lower. With regard to country of origin, people from Dutch origin had the highest vaccine uptake, while people from Morocco and Middle and Eastern European countries the lowest. Figure 3 shows the vaccine uptake by origin and migration status per age group. For most countries of origin, we see a higher uptake in the higher age groups, although the differences between the age groups in some countries of origin are less clear than in others. Whether one or two parents were born abroad seems to have more influence on vaccine uptake in the age groups <50.

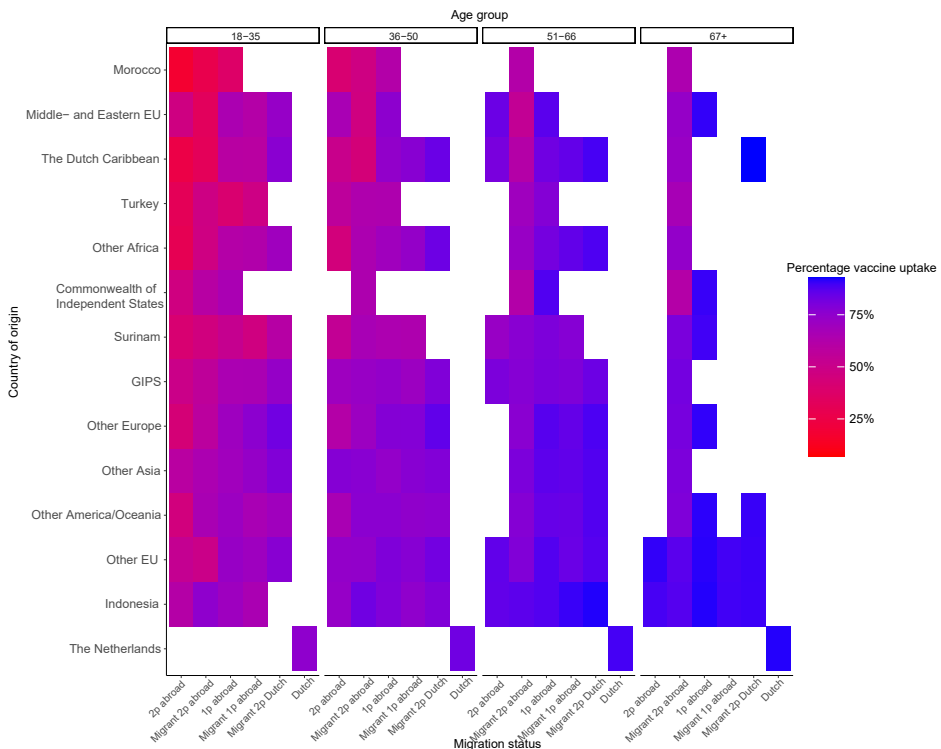


Figure 3. Vaccine uptake by country of origin and migration status per age group. Abbreviations: EU European Union, GIPS Greece, Italy, Portugal, Spain, 2p two parents, 1p one parent. Groups with frequencies <100 were excluded and coloured white.

Chapter 5

Personal income versus country of origin

Figure 4 shows the vaccine uptake by country of origin and personal income, per age group. Uptake was higher in higher income groups for all countries of origin. However, for some countries, this is less clear. Particularly in the 18–35 age group, there were only small differences in uptake between the personal income groups in Morocco, Turkey, the Middle and Eastern EU, and Suriname as country of origin.

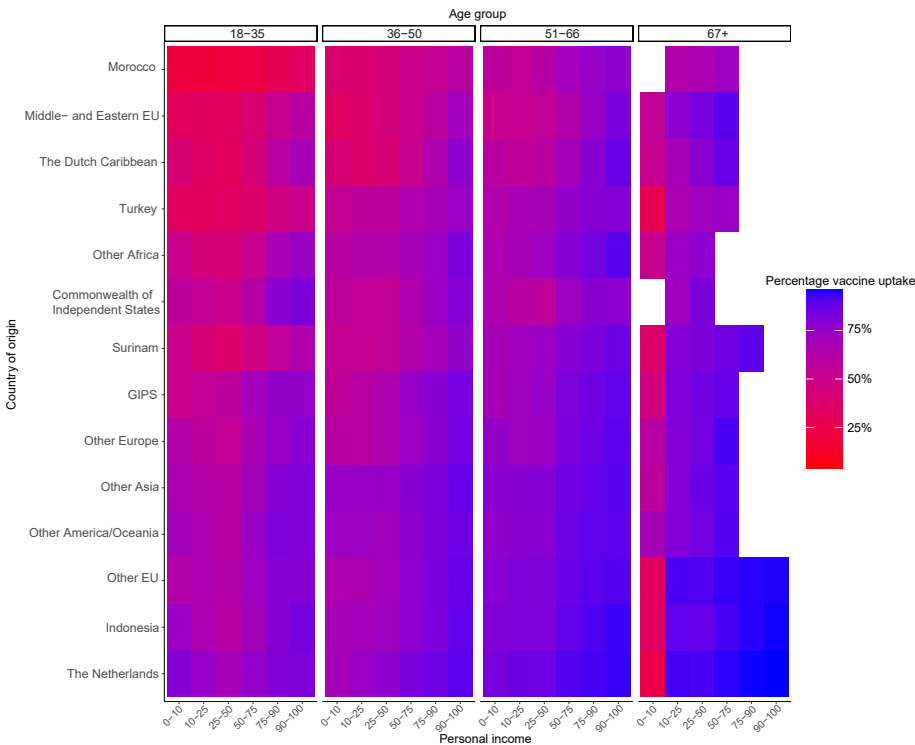


Figure 4. Vaccine uptake by country of origin and personal income (deciles) per age group. Abbreviations: EU European Union, GIPS Greece, Italy, Portugal, Spain. Groups with frequencies <100 were excluded and coloured white.

Voting proportions for political movements in national elections

Voting proportions for progressive liberal parties, right-wing liberal parties, progressive left-wing parties, and Christian middle parties ranked fourth to seventh in the RF, respectively. Figure 5 shows the vaccine uptake per age group for all political movements (the corresponding numbers can be found in Supplement S3). For progressive liberal, right-wing liberal, and Christian-middle movements, the uptake increased with higher proportions of votes, particularly in individuals aged < 50. The opposite was the case for the right-wing Christian movement, with a lower uptake in people living in neighbourhoods with a higher proportion of votes. Uptake

Determinants of COVID-19 Vaccination Uptake

also declined slightly with higher voting proportions for right-wing conservative parties. With regard to the progressive left-wing movement, uptake was lower in people living in neighbourhoods with either the lowest or the highest category of voting proportions. For all political movements, older age groups have higher uptake as opposed to younger age groups, except for 80+.

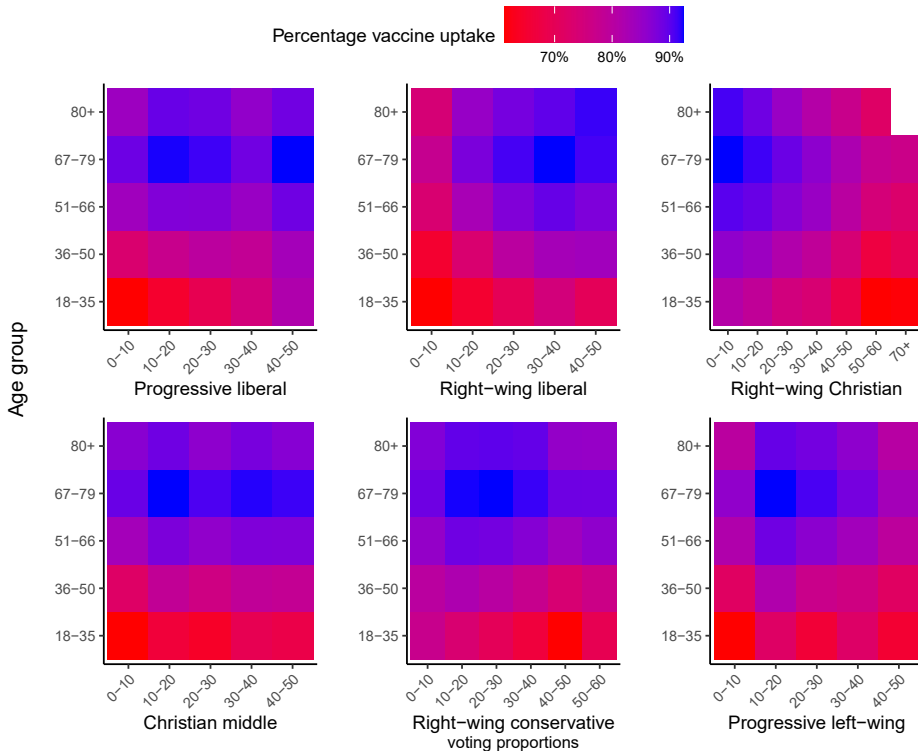


Figure 5. Vaccine uptake by voting proportions (%) for political movements in the 2021 national elections, per age group. Groups with frequencies <100 were excluded and coloured white.

Population of 60 years and older

On 5 January 2021, the Dutch population of 60 years and older included 4,610,000 individuals. The vaccine uptake for the 60+ population in our dataset was 90%. Compared to the general population, voting proportions for all political movements, as well as the XY coordinates of people's place of residence, ranked higher in the variable importance for predicting COVID-19 vaccination status (Figure 6). With regard to the XY coordinates, geographically, a low uptake in the 60+ population was mainly concentrated in the most religiously conservative regions of the Netherlands (Supplement S4). Although age still has predictive value on uptake in this population group, it is far less outstanding compared to the ranking of variables in the general population.

Chapter 5

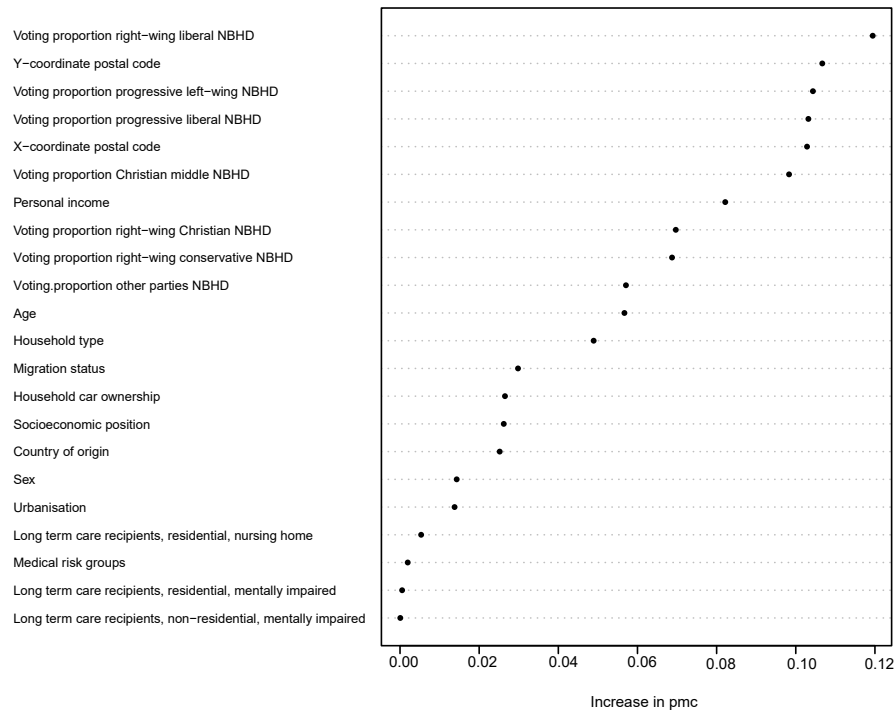


Figure 6. Ranking of variable importance for predicting COVID-19 vaccination status in people aged ≥ 60 years of age based on the refined RF. PMC = 0.30; sensitivity = 0.70; specificity = 0.70. Abbreviations: NBHD = neighbourhood. The variables education level (due to incomplete data in this age group) and employment sector were excluded from this analysis.

Discussion

This study presents important new insights into the determinants of COVID-19 vaccine uptake in the Netherlands. Among the adult population, the most important determinant was age. Uptake was higher in older individuals, which is consistent with previously published studies on COVID-19 vaccine uptake [7] and likely reflects the general understanding of their increased risk for severe disease. This underscores the success of prioritising elderly individuals to maximise the impact of vaccination programmes in reducing the burden of COVID-19.

After age, personal income, socioeconomic position, and origin ranked as the second-to-fourth-most important determinants of vaccine uptake. This is consistent with national registry-based studies from Norway, Sweden, and the United Kingdom, which found lower socioeconomic status and migration to be significantly associated with lower COVID-19 vaccine uptake [16–19]. Possible explanations for this are misinformation about the risks of disease due to COVID-19 and the effects of vaccination, as well as a lack of trust in authorities and the healthcare system. It is further hypothesised that factors such as language barriers, social and cultural beliefs, and religion are important [20,21]. The HELIUS study indicated that the belief that COVID-19 was exaggerated in the media was significantly associated with low vaccination intent in ethnic minority populations in Amsterdam [22]. This highlights the need for tailored communication and outreach strategies and trust [21]. Especially since it was shown that ethnic minority populations were at higher risk of SARS-CoV-2 infection and severe disease [23], further research to investigate reasons for lower vaccine uptake in those groups is important.

Voting proportions for political parties in the 2021 national elections were an important determinant for vaccine uptake as well. These findings were already reported in an ecological study on COVID-19 vaccine uptake in the Dutch population using the same data on voting proportions for political parties [11]. This study reported a positive association between vaccine uptake and higher voting proportions for right-wing liberal, progressive liberal, and Christian-middle political parties, and a negative association with higher voting proportions for right-wing Christian and right-wing conservative political parties. Voting proportions for right-wing Christian political parties have been well-described as a proxy for the Orthodox protestant religion, associated with the refusal of childhood vaccinations based on religious arguments [24,25]. Furthermore, previous studies found a positive association between higher voting proportions for right-wing conservative parties and HPV and MenACWY vaccine uptake and hypothesise these voters may have less confidence in the government, media, and social institutions [25,26].

Differences were identified in the determinants of vaccine uptake between the adult population and the 60+ group. Specifically, voting proportions for political movements ranked higher among the 60+ population, possibly reflecting generational differences

Chapter 5

in political engagement and political beliefs and values. For instance, a study by Krouwel et al. [27] revealed that individuals aged 65 and older had lower confidence in political institutions during the COVID-19 pandemic, compared to those aged 18–50. However, it is important to note that voting proportions were only available at neighbourhood level, yielding a regional effect possibly introducing ecological fallacy. Therefore, we must be cautious attributing the results directly to individual behaviour. Accordingly, we found that XY coordinates of people's place of residence also ranked higher in the 60+ population than in the 18+ population. Further analysis at the postal code level showed that low uptake among the 60+ population was mainly concentrated in the most religiously conservative areas (i.e., regions with a relatively high proportion of orthodox protestants) of the Netherlands, while uptake was relatively high in the rest of the country. In contrast, we observed more geographical variation among the 18+ population, suggesting that other determinants played a more critical role. These findings are consistent with previously published data at the municipal level that show uptake was low among individuals ≥ 65 in a limited number of municipalities, standing in stark contrast with the high uptake in the rest of the country [28].

Interestingly, having a medical risk condition and receiving long-term care did not seem to be an important factor for vaccine uptake in our study, despite the fact that people with certain underlying medical risk conditions were prioritised in the vaccination campaign. While some studies indicated that people with a high risk for severe disease and comorbidities are more likely to accept vaccination [29], others found no association between clinical vulnerability and vaccination intention [30], or even reported more hesitancy in those groups due to the fear of possible side effects [31]. Since our data on medical risk were most recently available for 2020, recently diagnosed individuals may have been misclassified as low risk, causing an underestimation of vaccine uptake in the intermediate and high medical risk group. Furthermore, not all relevant risk conditions could be adequately identified based on the data (e.g., Down syndrome and morbid obesity). Further research investigating determinants for vaccine uptake in this specific target group is needed.

The most important strength of our study was the use of a large set of individual level data, which has significant advantage over ecological analyses on determinants of vaccination, which may be affected by ecological fallacy. Only data on political voting behaviour were not available on individual level. Furthermore, we used vaccination registration data on actual vaccine uptake rather than data on the intention to vaccinate.

This study also has limitations that should be considered when interpreting the results. First, the vaccine uptake presented in this study is an underestimation of the true uptake, as individuals who did not provide informed consent for their data to be registered were included as unvaccinated. This may have led to bias in the estimates

Determinants of COVID-19 Vaccination Uptake

of the effect of the determinants of vaccine uptake in different ways. In case the non-consent group has similar characteristics to the individuals who did provide consent, the true effect of the determinants is larger than the observed effect. We know older individuals provide informed consent more often than younger individuals (personal communication S. McDonald), which is similar to the positive association between age and vaccine uptake (consent group). However, information on other individual characteristics of this group is unavailable. Without this information, the extent of the bias introduced due to the informed consent cannot be investigated. Secondly, the study had limitations in terms of data quality. Education level data were incomplete for older age groups and missing for individuals that received education abroad. For medical risk and long-term care variables, the reference date was earlier in time than the reference date of the population (and the start of the vaccination campaign), causing some inaccuracies in the data. However, since the determinants we found are largely consistent with previous studies, we believe that the inaccuracies caused by data quality issues are limited. Lastly, this study could not include other potential determinants of vaccine uptake, or consent, such as religion, beliefs, and values regarding vaccination, safety concerns, language barriers, trust in the government, or distance to vaccination location, since data on these variables were not available at population level. Previous studies have shown that these factors may play a role in vaccine acceptance [32].

Conclusion

This study presents a ranking of the importance of determinants for COVID-19 vaccine uptake in the Netherlands. Our finding that age is the most important determinant for uptake likely reflects the prioritisation of older people in the programme and the general understanding of their increased vulnerability. However, our findings also reveal other important disparities in COVID-19 vaccine uptake. Lower uptake was found in individuals with lower income, lower socioeconomic status, and non-Dutch origin. How to best address this inequity in future vaccination campaigns requires further research.

References

1. WHO. WHO Coronavirus (COVID-19) Dashboard: World Health Organization. 2022. Available online: <https://covid19.who.int/> (accessed on 1 May 2022).
2. Overledenen; Belangrijke Doorzaken (Korte Lijst), Leeftijd, Geslacht. CBS. 2023. Available online: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7052_95/table?ts=1640705218537 (accessed on 23 August 2023).
3. van Iersel, S.; McDonald, S.A.; de Gier, B.; Knol, M.J.; de Melker, H.E.; van Werkhoven, C.H.; Hahné, S.J. Number of COVID-19 hospitalisations averted by vaccination: Estimates for the Netherlands, January 6, 2021 through August 30, 2022. *Vaccine* 2023, 41, 3847–3854.
4. Watson, O.J.; Barnsley, G.; Toor, J.; Hogan, A.B.; Winskill, P.; Ghani, A.C. Global impact of the first year of COVID-19 vaccination: A mathematical modelling study. *Lancet Infect. Dis.* 2022, 22, 1293–1302.
5. Meslé, M.M.; Brown, J.; Mook, P.; Hagan, J.; Pastore, R.; Bundle, N.; Spiteri, G.; Ravasi, G.; Nicolay, N.; Andrews, N.; et al. Estimated number of deaths directly averted in people 60 years and older as a result of COVID-19 vaccination in the WHO European Region, December 2020 to November 2021. *Eurosurveillance* 2021, 26, 2101021.
6. Health Council. Alle Adviezen over COVID-19 Vaccinaties. 2021. Available online: <https://www.gezondheidsraad.nl/onderwerpen/vaccinaties/alle-adviezen-over-covid-19-vaccinaties> (accessed on 15 May 2022).
7. RIVM. Archief Wekelijkse Update Vaccinatiecijfers. 2022. Available online: <https://www.rivm.nl/covid-19-vaccinatie/archiefwekelijkse-update-vaccinatiecijfers-2022> (accessed on 1 May 2022).
8. ECDC. Guidance on the Provision of Support for Medically and Socially Vulnerable Populations in EU/EEA Countries and the United Kingdom during the COVID-19 Pandemic; European Centre for Disease Prevention and Control: Stockholm, Sweden, 2020.
9. RIVM. COVID-19-Vaccinatie Uitvoeringsrichtlijn: RIVM. 2022. Available online: <https://lci.rivm.nl/richtlijnen/covid-19-vaccinatie> (accessed on 15 May 2022).
10. Khanijahani, A.; Iezadi, S.; Gholipour, K.; Azami-Aghdash, S.; Naghibi, D. A systematic review of racial/ethnic and socioeconomic disparities in COVID-19. *Int. J. Equity Health* 2021, 20, 248.
11. Labuschagne, L.J.; Smorenburg, N.; van de Kasstelee, J.; Bom, B.; de Weerd, A.; de Melker, H.E.; Hahné, S. Determinants of COVID-19 vaccine uptake in the Netherlands: An ecological analysis. *medRxiv* 2023.
12. Wang, H.; Varol, T.; Gultzow, T.; Zimmermann, H.M.; Ruiter, R.A.; Jonas, K.J. Spatio-temporal distributions of COVID-19 vaccine doses uptake in the Netherlands: A Bayesian ecological modelling analysis. *medRxiv* 2023.
13. de Gier, B.; van Asten, L.; Boere, T.M.; van Roon, A.; van Roekel, C.; Pijpers, J.; van Werkhoven, C.H.; Ende, C.v.D.; Hahné, S.J.; de Melker, H.E.; et al. Effect of COVID-19 vaccination on mortality by COVID-19 and on mortality by other causes, the Netherlands, January 2021–January 2022. *Vaccine* 2023, 41, 4488–4496.
14. Breiman, L. Random Forests. *Mach. Learn.* 2001, 45, 5–32.
15. Wright, M.N.; Ziegler, A. Ranger: A fast implementation of random forests for high dimensional data in C++ and R. *J. Stat. Softw.* 2017, 77, 1–17.
16. Kraft, K.B.; Godoy, A.A.; Vinjerui, K.H.; Kour, P.; Kjøllesdal, M.K.R.; Indseth, T. COVID-19

Determinants of COVID-19 Vaccination Uptake

- vaccination coverage by immigrant background. *Tidsskr. Den Nor. Lægeforening* 2022, 141.
17. Hansen, B.T.; Labberton, A.S.; Kour, P.; Kraft, K.B. Coverage of primary and booster vaccination against COVID-19 by socioeconomic level: A nationwide cross-sectional registry study. *Hum. Vaccines Immunother.* 2023, 19, 2188857.
 18. Spetz, M.; Lundberg, L.; Nwaru, C.; Li, H.; Santosa, A.; Ng, N.; Leach, S.; Gisslén, M.; Hammar, N.; Nyberg, F.; et al. An intersectional analysis of sociodemographic disparities in COVID-19 vaccination: A nationwide register-based study in Sweden. *Vaccine* 2022, 40, 6640–6648.
 19. Dolby, T.; Finning, K.; Baker, A.; Fowler-Dowd, L.; Khunti, K.; Razieh, C.; Yates, T.; Nafilyan, V. Monitoring sociodemographic inequality in COVID-19 vaccination uptake in England: A national linked data study. *J. Epidemiol. Community Health* 2022, 76, 646–652.
 20. Crawshaw, A.F.; Farah, Y.; Deal, A.; Rustage, K.; Hayward, S.E.; Carter, J.; Knights, F.; Goldsmith, L.P.; Campos-Matos, I.; Wurie, F.; et al. Defining the determinants of vaccine uptake and undervaccination in migrant populations in Europe to improve routine and COVID-19 vaccine uptake: A systematic review. *Lancet Infect. Dis.* 2022, 22, e254–e266.
 21. Tankwanchi, A.S.; Bowman, B.; Garrison, M.; Larson, H.; Wiysonge, C.S. Vaccine hesitancy in migrant communities: A rapid review of latest evidence. *Curr. Opin. Immunol.* 2021, 71, 62–68.
 22. Campman, S.L.; van Rossem, G.; Boyd, A.; Coyer, L.; Schinkel, J.; Agyemang, C.; Galenkamp, H.; Koopman, A.D.; Leenstra, T.; van der Loeff, M.S.; et al. Intent to vaccinate against SARS-CoV-2 and its determinants across six ethnic groups living in Amsterdam, the Netherlands: A cross-sectional analysis of the HELIUS study. *Vaccine* 2023, 41, 2035–2045.
 23. Coyer, L.; Boyd, A.; Schinkel, J.; Agyemang, C.; Galenkamp, H.; Koopman, A.D.M.; Leenstra, T.; van Duijnhoven, Y.T.; van Charante, E.P.M.; van den Born, B.-J.H.; et al. Differences in SARS-CoV-2 infections during the first and second wave of SARS-CoV-2 between six ethnic groups in Amsterdam, the Netherlands: A population-based longitudinal serological study. *Lancet Reg. Health Eur.* 2022, 13, 100284.
 24. Ruijs, W.L.; Hautvast, J.L.; van der Velden, K.; de Vos, S.; Knippenberg, H.; Hulscher, M.E. Religious subgroups influencing vaccination coverage in the Dutch Bible belt: An ecological study. *BMC Public Health* 2011, 11, 102.
 25. de Munter, A.C.; Klooster, T.; van Lier, A.; Akkermans, R.; de Melker, H.E.; Ruijs, W.L.M. Determinants of HPV-vaccination uptake and subgroups with a lower uptake in the Netherlands. *BMC Public Health* 2021, 21, 1848.
 26. de Oliveira Bressane Lima, P.; van Lier, A.; de Melker, H.; Ferreira, J.A.; van Vliet, H.; Knol, M.J. MenACWY vaccination campaign for adolescents in the Netherlands: Uptake and its determinants. *Vaccine* 2020, 38, 5516–5524.
 27. Krouwel, A.; de Vries, O.; Van Heck, L.; Kutiyski, Y.; Étienne, T. COVID-19 en institutioneel vertrouwen. 2021. Impact corona. Available online: www.impactcorona.nl/wp-content/uploads/2021/10/Institutioneelvertrouwen_KL01.pdf (accessed on 5 March 2023).
 28. RIVM. Deelname COVID-19-Vaccinatie in Nederland. 2021. Available online: www.rivm.nl/sites/default/files/2023-05/Deelname-COVID-19-vaccinatie-in-Nederland_20230508_def.pdf (accessed on 5 March 2023).
 29. Biswas, M.R.; Alzubaidi, M.S.; Shah, U.; Abd-Alrazaq, A.A.; Shah, Z. A Scoping Review to Find Out Worldwide COVID-19 Vaccine Hesitancy and Its Underlying Determinants. *Vaccines* 2021, 9, 1243.

Chapter 5

30. Sherman, S.M.; Smith, L.E.; Sim, J.; Amlot, R.; Cutts, M.; Dasch, H.; Rubin, G.J.; Sevdalis, N. COVID-19 vaccination intention in the UK: Results from the COVID-19 vaccination acceptability study (CoVAccS), a nationally representative cross-sectional survey. *Hum. Vaccin. Immunother.* 2021, 17, 1612–1621.
31. Palamenghi, L.; Barello, S.; Boccia, S.; Graffigna, G. Mistrust in biomedical research and vaccine hesitancy: The forefront challenge in the battle against COVID-19 in Italy. *Eur. J. Epidemiol.* 2020, 35, 785–788.
32. De Vries, M.; Claassen, L.; Lambooj, M.; Leung, K.Y.; Boersma, K.; Timen, A. COVID-19 Vaccination intent and belief that vaccination will end the pandemic. *Emerg. Infect. Dis.* 2022, 28, 1642–1649.

Supplementary material

S1 Long-term care recipients

To identify individuals receiving long-term care (LTC), two data sources were used. Firstly, start and end dates and types of LTC use were available within CBS. This is data from the CAK and includes LTC that is covered by the Long-term care act (WLZ) for which the LTC receiver pays a personal contribution to the CAK. An elaborate description of the database can be found (in Dutch) using the following URL: [Gebwilztab: Personen Wlz-zorg \(cbs.nl\)](http://gebwilztab.personen.wlz-zorg.cbs.nl). Secondly, using the type of household variable in the personal records database (CBS) we were able to select individuals with 'institutional household' as type of household. A description of the personal records database and the variable type of household can be found (in Dutch) using the following URL: [Gbapersoontab: Persoonskenmerken van personen in de BRP \(cbs.nl\)](http://gbapersoontab.persoonskenmerken.van.personen.in.de.brp.cbs.nl)

In our analyses, we included three variables regarding LTC care distinguishing between residential and non-residential care and LTC for intellectual disabilities (residential and non-residential). For each variable, different selection methods were used:

1. LTC recipients, residential, nursing home: individuals were selected for this group if
 - a. they received LTC care with profile VV5-8 (nursing and caring level 5-8) LTC and type of care 'care in kind'
 - b. they lived in an institutional household according to the personal records database and received LTC with profile VV5-8
1. LTC recipients, residential, mentally impaired: individuals were selected for this group if
 - a. they received LTC care with profile 'VG' (intellectually disabled) or 'LVG' (mildly intellectually disabled) and type of care 'care in kind'
 - b. they lived in an institutional household according to the personal records database and received LTC with profile 'VG' or 'LVG'
2. LTC recipients, non-residential, mentally impaired: individuals were selected for this group if
 - a. they received LTC care with profile 'VG' or 'LVG' and any type of care other than 'care in kind'
 - b. they lived in any type of household other than institutional household according to the personal records database and received LTC with profile 'VG' or 'LVG'

Chapter 5

S2 Standard random forest and ROC analysis

The standard RF predictor was constructed and assessed using a dataset of 400,000 people. This provided estimates of prediction accuracy such as the PMC (probability of misclassification, i.e. the probability of predicting an individual's status incorrectly), the sensitivity (the probability of an individual's status being predicted as a '1', i.e. as vaccinated, when its status is indeed '1'), the specificity (the probability of an individual's status being predicted as a '0', i.e. as unvaccinated (or not having provided informed consent to share their status), when its status is indeed '0'), and the ranking of the predictor variables according to their importance, which was measured as the average increase in (worsening of) the PMC that results from the replacement of the value of a variable by a randomly chosen value. As expected, the standard RF yielded a very high sensitivity and a comparatively low specificity because there were far more vaccinated (80%) than unvaccinated people and the default prediction rule aims at minimizing the PMC (as opposed to the sensitivity or specificity).

Figure S2.1 shows the results of an ROC analysis based on the RF. The algorithm's ordinary prediction rule consists of predicting an individual's outcome as a 1 (vaccinated) if and only if the ratio of estimated probabilities of that individual being a 1 to it being a 0 conditionally on the predictor variables is ≥ 1 . If we replace this inequality by $> c$ and we vary the value of the 'threshold' c over positive values other than 1 we create a family of predictors, each with its own, adjusted prediction rule, and hence with its own performance characteristics. In particular, by varying the value of the threshold we get a varying pair of sensitivity and fpr (false positive rate = 1 minus specificity) estimates, which constitute the ROC curve, shown in the left panel of Fig. 2. By looking at the performance indicators obtained by varying the threshold, as shown on the right panel of Figure S3.1, we can pick the value which yields similar estimates of sensitivity and specificity; in this case this is a c of 3.55, with corresponding values of 70% sensitivity and specificity and an increased PMC of 30%, together with the area under the ROC curve, 0.76. The value of c was used to adjust the first RF, leading to the second, 'refined' RF, whose performance and variable importance were estimated by making predictions on the test data.

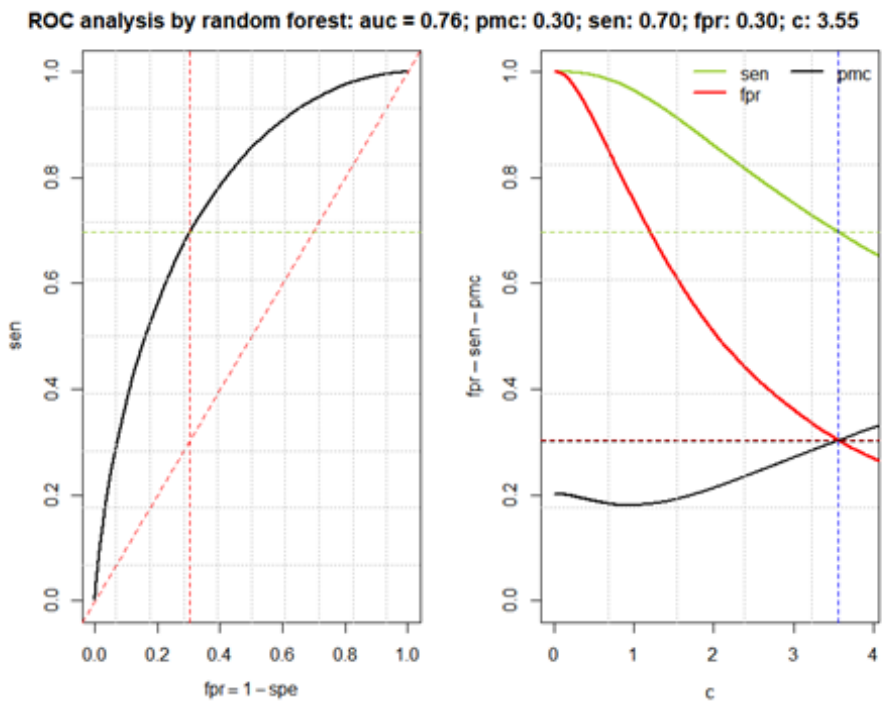


Figure S2.1 ROC analysis by random forest.

S3 Vaccine uptake – bivariate analyses

All reported tables exclude frequencies below ten and all numbers and percentages are rounded to the nearest ten, to avoid personally identifiable information.

Table S3.1 Vaccine uptake by age group

Age group	N	Uptake (N, %)
18-35	4.012.330	2.683.820 (67)
36-50	3.260.110	2.526.670 (78)
51-66	3.845.610	3.339.460 (87)
67-79	2.211.910	2.024.530 (92)
80+	845.690	748.310 (88)

Chapter 5

Table S3.2 Vaccine uptake per determinant by age group

	N Uptake (N, %)	
Sex		
Male	6.995.450	5.546.310 (79)
18-35	2.037.610	1.345.890 (66)
36-50	1.627.950	1.242.870 (76)
51-66	1.922.600	1.674.810 (87)
67-79	1.072.830	984.800 (92)
80+	334.460	297.950 (89)
Female	7.180.190	5.776.480 (80)
18-35	1.974.720	1.337.930 (68)
36-50	1.632.150	1.283.800 (79)
51-66	1.923.010	1.664.650 (87)
67-79	1.139.080	1.039.740 (91)
80+	511.230	450.370 (88)
Education level		
Primary education	680.660	482.560 (71)
18-35	115.660	59.860 (52)
36-50	165.170	102.470 (62)
51-66	243.680	185.030 (76)
67-79	140.210	120.700 (86)
80+	15.940	14.500 (91)
Prevocational secondary education - basic vocational programme (VMBO-b/k), lower secondary vocational training and assistant's training (MBO-1)	770.830	532.300 (69)
18-35	256.470	120.450 (47)
36-50	172.290	115.670 (67)
51-66	235.650	198.120 (84)
67-79	95.970	88.390 (92)
80+	10.460	9.670 (92)
Prevocational secondary education - theoretical and vocational programme (VMBO-g/t), the first three years of senior general secondary education (HAVO) and pre-university secondary education (VWO)	385.580	273.660 (71)
18-35	169.480	99.660 (59)
36-50	73.070	49.550 (68)
51-66	98.160	83.140 (85)
67-79	41.490	38.150 (92)
80+	3.370	3.150 (94)
Basic vocational training (MBO-2) and vocational training (MBO-3)	1.428.730	1.005.180 (70)
18-35	620.640	350.130 (56)
36-50	331.250	237.140 (72)

	N Uptake (N, %)	
51-66	354.030	303.730 (86)
67-79	113.790	105.750 (93)
80+	9.020	8.450 (94)
Middle management and specialist education (MBO-4)	1.470.350	1.094.650 (74)
18-35	710.230	464.700 (65)
36-50	379.970	293.240 (77)
51-66	313.830	275.090 (88)
67-79	63.620	59.100 (93)
80+	2.690	2.530 (94)
Upper secondary education (HAVO/VWO)	898.270	694.220 (77)
18-35	568.380	421.100 (74)
36-50	133.520	100.780 (75)
51-66	156.840	136.040 (87)
67-79	36.940	33.890 (92)
80+	2.590	2.420 (94)
Hbo-, wo-bachelor	2.055.220	1.700.130 (83)
18-35	825.060	637.910 (77)
36-50	674.610	561.610 (83)
51-66	450.710	402.610 (89)
67-79	98.960	92.460 (93)
80+	5.880	5.550 (94)
Hbo-, wo-master, doctor	1.204.530	1.067.060 (89)
18-35	416.170	358.120 (86)
36-50	438.950	387.290 (88)
51-66	292.430	268.120 (92)
67-79	53.690	50.400 (94)
80+	3.290	3.140 (95)
Unknown	5.281.490	4.473.030 (85)
18-35	330.230	171.900 (52)
36-50	891.270	678.930 (76)
51-66	1.700.280	1.487.580 (87)
67-79	1.567.240	1.435.700 (92)
80+	792.460	698.910 (88)
Country of origin		
The Netherlands	10.660.430	9.045.520 (85)
18-35	2.703.240	2.030.150 (75)
36-50	2.269.290	1.874.450 (83)
51-66	3.074.150	2.743.040 (89)
67-79	1.883.420	1.746.340 (93)
80+	730.340	651.540 (89)
Turkey	333.090	177.880 (53)
18-35	133.490	48.110 (36)
36-50	110.090	67.880 (62)
51-66	67.890	47.480 (70)
67-79	16.800	11.160 (66)
80+	4.830	3.250 (67)
Morocco	294.480	119.200 (40)
18-35	120.060	25.420 (21)
36-50	94.790	43.960 (46)
51-66	55.760	34.490 (62)
67-79	17.900	11.770 (66)

Determinants of COVID-19 Vaccination Uptake

	N	Uptake (N, %)
80+	5.980	3.560 (60)
Surinam	304.370	191.400 (63)
18-35	99.830	44.970 (45)
36-50	83.550	52.020 (62)
51-66	85.850	65.980 (77)
67-79	28.710	23.400 (81)
80+	6.420	5.020 (78)
The Dutch Caribbean	136.230	70.510 (52)
18-35	60.260	23.610 (39)
36-50	35.650	18.850 (53)
51-66	28.320	18.970 (67)
67-79	10.310	7.820 (76)
80+	1.690	1.270 (75)
Indonesia	353.070	293.860 (83)
18-35	42.620	29.610 (69)
36-50	83.840	65.540 (78)
51-66	131.790	114.410 (87)
67-79	69.640	62.480 (90)
80+	25.170	21.830 (87)
Other Africa	227.900	134.870 (59)
18-35	106.320	50.560 (48)
36-50	66.990	43.690 (65)
51-66	45.340	33.650 (74)
67-79	7.960	6.010 (76)
80+	1.290	970 (75)
Other Asia	501.590	362.270 (72)
18-35	230.590	149.920 (65)
36-50	156.200	120.030 (77)
51-66	88.910	71.410 (80)
67-79	21.830	17.830 (82)
80+	4.070	3.080 (76)
Other America/ Oceania	195.140	142.310 (73)
18-35	92.520	61.650 (67)
36-50	55.130	41.810 (76)
51-66	37.120	30.230 (81)
67-79	8.980	7.490 (83)
80+	1.400	1.140 (82)
Middle and eastern European countries within the EU	304.230	137.150 (45)
18-35	145.640	52.020 (36)
36-50	105.500	50.800 (48)
51-66	39.550	23.430 (59)
67-79	11.200	9.020 (80)
80+	2.340	1.890 (81)
GIPS countries	142.440	96.850 (68)
18-35	63.930	37.270 (58)
36-50	42.550	30.870 (73)
51-66	24.980	19.640 (79)
67-79	7.530	6.280 (83)
80+	3.450	2.800 (81)
Former or associated member states of the Commonwealth of Independent States	46.170	29.150 (63)
18-35	21.260	12.680 (60)
36-50	14.430	9.240 (64)

	N	Uptake (N, %)
51-66	7.270	4.730 (65)
67-79	2.710	2.170 (80)
80+	510	340 (66)
Other countries of the EU	516.720	408.360 (79)
18-35	133.000	81.470 (61)
36-50	97.580	75.350 (77)
51-66	121.580	102.720 (84)
67-79	109.180	99.540 (91)
80+	55.390	49.280 (89)
Other European countries	159.780	113.460 (71)
18-35	59.570	36.400 (61)
36-50	44.530	32.190 (72)
51-66	37.120	29.290 (79)
67-79	15.740	13.230 (84)
80+	2.820	2.360 (83)
Migration status		
Born in The Netherlands with both parents born in The Netherlands	10.660.430	9.045.520 (85)
18-35	2.703.240	2.030.150 (75)
36-50	2.269.290	1.874.450 (83)
51-66	3.074.150	2.743.040 (89)
67-79	1.883.420	1.746.340 (93)
80+	730.340	651.540 (89)
Born in the Netherlands with one parent born abroad	735.910	570.470 (78)
18-35	257.930	164.880 (64)
36-50	158.800	121.540 (77)
51-66	166.760	144.710 (87)
67-79	107.170	98.760 (92)
80+	45.260	40.590 (90)
Born in the Netherlands with two parents born abroad	527.880	241.560 (46)
18-35	337.560	113.810 (34)
36-50	124.550	71.370 (57)
51-66	48.760	41.090 (84)
67-79	13.000	11.730 (90)
80+	4.000	3.560 (89)
Born abroad with one parent born abroad	84.660	66.410 (78)
18-35	24.850	16.620 (67)
36-50	19.300	14.510 (75)
51-66	18.910	15.950 (84)
67-79	15.080	13.610 (90)
80+	6.520	5.720 (88)
Born abroad with two parents born abroad	2.053.270	1.305.630 (64)
18-35	653.310	331.700 (51)
36-50	657.390	420.250 (64)
51-66	508.020	369.170 (73)
67-79	181.470	143.370 (79)
80+	53.070	41.130 (78)

Chapter 5

	N	Uptake (N, %)
Born abroad with two parents born in the Netherlands	113.490	93.220 (82)
18-35	35.440	26.660 (75)
36-50	30.780	24.560 (80)
51-66	29.010	25.500 (88)
67-79	11.760	10.720 (91)
80+	6.500	5.780 (89)
Socioeconomic position		
In employment	6.984.360	5.618.950 (80)
18-35	2.470.560	1.735.130 (70)
36-50	2.324.820	1.911.280 (82)
51-66	2.161.520	1.947.610 (90)
67-79	26.030	23.650 (91)
80+	1.430	1.280 (90)
Self-employed	1.078.860	780.210 (72)
18-35	253.550	135.610 (53)
36-50	388.890	277.210 (71)
51-66	395.840	331.520 (84)
67-79	38.140	33.820 (89)
80+	2.440	2.070 (85)
Unemployment benefits (WW)	103.080	72.400 (70)
18-35	20.420	8.860 (43)
36-50	33.820	21.960 (65)
51-66	48.810	41.560 (85)
67-79	20	.
80+	.	.
Social assistance benefit	416.890	233.240 (56)
18-35	106.960	44.920 (42)
36-50	141.830	76.580 (54)
51-66	165.130	109.580 (66)
67-79	1.960	1.480 (76)
80+	1.020	680 (67)
Other benefits	266.950	178.090 (67)
18-35	117.520	68.330 (58)
36-50	70.180	46.990 (67)
51-66	78.100	61.820 (79)
67-79	380	320 (83)
80+	770	630 (82)
Disability benefit	521.330	387.210 (74)
18-35	55.310	25.850 (47)
36-50	140.340	94.440 (67)
51-66	325.650	266.890 (82)
67-79	30	.
80+	.	.
Pensioner	3.429.200	3.106.120 (91)
18-35	3.730	2.180 (59)
36-50	17.420	12.620 (72)
51-66	426.260	384.420 (90)
67-79	2.142.670	1.963.720 (92)
80+	839.120	743.180 (89)
Student	832.380	612.810 (74)
18-35	825.380	607.400 (74)
36-50	5.730	4.360 (76)
51-66	1.260	1.040 (82)

	N	Uptake (N, %)
67-79	20	.
80+	.	.
Other/unknown	542.590	333.770 (62)
18-35	158.910	55.550 (35)
36-50	137.080	81.240 (59)
51-66	243.030	195.030 (80)
67-79	2.660	1.480 (56)
80+	910	470 (52)
Personal income (percentiles)		
0 till 10	706.770	488.830 (69)
18-35	447.550	312.420 (70)
36-50	86.120	54.440 (63)
51-66	139.530	112.140 (80)
67-79	16.980	5.330 (31)
80+	16.590	4.510 (27)
10 till 25	2.033.890	1.582.610 (78)
18-35	644.150	414.500 (64)
36-50	240.810	161.310 (67)
51-66	366.730	300.720 (82)
67-79	603.840	548.200 (91)
80+	178.360	157.880 (89)
25 till 50	3.481.510	2.695.920 (77)
18-35	864.710	519.310 (60)
36-50	640.570	452.280 (71)
51-66	811.500	668.440 (82)
67-79	803.200	729.430 (91)
80+	361.540	326.450 (90)
50 till 75	3.485.790	2.836.700 (81)
18-35	1.073.340	747.850 (70)
36-50	832.310	654.310 (79)
51-66	933.650	825.990 (88)
67-79	501.880	473.180 (94)
80+	144.620	135.370 (94)
75 till 90	2.091.710	1.787.130 (85)
18-35	515.240	398.710 (77)
36-50	675.350	560.580 (83)
51-66	696.980	633.000 (91)
67-79	167.180	159.740 (96)
80+	36.960	35.100 (95)
90 till 100	1.533.870	1.365.600 (89)
18-35	201.730	158.650 (79)
36-50	616.310	538.930 (87)
51-66	618.540	574.880 (93)
67-79	82.640	79.150 (96)
80+	14.640	13.990 (96)
Unknown	842.090	566.020 (67)
18-35	265.620	132.380 (50)
36-50	168.650	104.820 (62)
51-66	278.670	224.290 (80)
67-79	36.190	29.510 (82)
80+	92.980	75.010 (81)
Household type		
One-person household	3.075.860	2.344.020 (76)
18-35	878.160	569.020 (65)
36-50	499.110	336.070 (67)
51-66	728.590	584.370 (80)

Determinants of COVID-19 Vaccination Uptake

	N	Uptake (N, %)
67-79	586.680	516.430 (88)
80+	383.320	338.140 (88)
Unmarried couple without children	1.257.950	988.890 (79)
18-35	665.210	493.520 (74)
36-50	209.100	157.400 (75)
51-66	272.620	236.400 (87)
67-79	94.100	86.260 (92)
80+	16.910	15.310 (91)
Married couple without children	3.372.970	3.059.750 (91)
18-35	188.300	128.090 (68)
36-50	190.400	153.840 (81)
51-66	1.330.510	1.218.040 (92)
67-79	1.350.010	1.270.760 (94)
80+	313.760	289.020 (92)
Unmarried couple with children	1.052.990	799.390 (76)
18-35	374.200	242.570 (65)
36-50	495.060	399.570 (81)
51-66	171.380	147.210 (86)
67-79	10.930	8.980 (82)
80+	1.430	1.060 (74)
Married couple with children	4.101.880	3.248.490 (79)
18-35	1.392.250	966.940 (69)
36-50	1.523.520	1.245.210 (82)
51-66	1.071.830	940.260 (88)
67-79	97.260	82.590 (85)
80+	17.020	13.490 (79)
One-parent family	965.810	628.550 (65)
18-35	400.760	214.350 (53)
36-50	295.490	202.700 (69)
51-66	219.070	171.700 (78)
67-79	32.920	26.080 (79)
80+	17.580	13.720 (78)
Other household	101.440	63.750 (63)
18-35	65.660	38.610 (59)
36-50	13.470	7.330 (54)
51-66	14.380	11.160 (78)
67-79	6.080	5.130 (84)
80+	1.840	1.520 (82)
Institutional household	246.740	189.960 (77)
18-35	47.780	30.710 (64)
36-50	33.960	24.570 (72)
51-66	37.220	30.330 (81)
67-79	33.930	28.290 (83)
80+	93.840	76.060 (81)
Household car ownership		
Yes	11.113.920	9.101.130 (82)
18-35	2.848.490	1.929.370 (68)
36-50	2.669.600	2.122.330 (79)
51-66	3.283.050	2.904.110 (88)
67-79	1.838.870	1.712.610 (93)
80+	473.900	432.710 (91)
No	3.061.720	2.221.670 (73)

	N	Uptake (N, %)
18-35	1.163.830	754.460 (65)
36-50	590.500	404.340 (68)
51-66	562.560	435.350 (77)
67-79	373.040	311.920 (84)
80+	371.790	315.600 (85)
Employment sector		
Activities of household as employer, undifferentiated goods and service producing activities of household for own use	31.030	21.420 (69)
18-35	6.320	2.730 (43)
36-50	9.150	6.050 (66)
51-66	11.360	8.960 (79)
67-79	3.790	3.320 (88)
80+	410	360 (90)
Agriculture, forestry and fishery	73.830	57.290 (78)
18-35	29.310	20.080 (69)
36-50	21.140	16.510 (78)
51-66	21.310	18.780 (88)
67-79	1.950	1.800 (93)
80+	130	.
Mining and quarrying	6.910	5.820 (84)
18-35	1.800	1.380 (77)
36-50	2.910	2.450 (84)
51-66	2.170	1.960 (90)
67-79	40	.
80+	.	.
Industry	717.940	586.020 (82)
18-35	205.920	145.140 (70)
36-50	240.560	196.370 (82)
51-66	265.370	238.770 (90)
67-79	5.850	5.520 (94)
80+	240	230 (94)
Electricity supply	29.730	25.260 (85)
18-35	8.870	6.780 (76)
36-50	10.960	9.300 (85)
51-66	9.610	8.910 (93)
67-79	280	260 (94)
80+	10	.
Water supply, sewage and waste management	35.770	28.660 (80)
18-35	9.270	6.130 (66)
36-50	12.390	9.890 (80)
51-66	13.900	12.440 (90)
67-79	200	190 (94)
80+	.	.
Construction	323.500	255.540 (79)
18-35	109.010	72.450 (66)
36-50	113.030	91.370 (81)
51-66	98.230	88.700 (90)
67-79	3.110	2.900 (93)
80+	130	.

Chapter 5

	N	Uptake (N, %)
Wholesale and retail trade	1.123.120	881.150 (78)
18-35	512.910	358.040 (70)
36-50	326.750	267.110 (82)
51-66	267.510	240.990 (90)
67-79	15.310	14.410 (94)
80+	640	600 (93)
Transportation and storage	363.240	280.800 (77)
18-35	113.780	71.740 (63)
36-50	111.120	86.260 (78)
51-66	128.980	113.990 (88)
67-79	9.180	8.640 (94)
80+	180	170 (94)
Accommodation and food services activities	261.770	198.610 (76)
18-35	163.730	116.810 (71)
36-50	54.940	43.730 (80)
51-66	40.580	35.700 (88)
67-79	2.420	2.280 (94)
80+	110	.
Information and communication	291.390	245.100 (84)
18-35	138.630	110.630 (80)
36-50	97.840	84.000 (86)
51-66	53.790	49.420 (92)
67-79	1.090	1.020 (93)
80+	40	.
Financial services	264.170	230.000 (87)
18-35	70.100	55.320 (79)
36-50	103.530	90.310 (87)
51-66	82.900	77.120 (93)
67-79	7.010	6.650 (95)
80+	620	590 (95)
Real estate activities	65.700	55.230 (84)
18-35	19.260	14.060 (73)
36-50	23.850	20.370 (85)
51-66	20.720	19.020 (92)
67-79	1.690	1.600 (94)
80+	190	180 (93)
Professional scientific and technical activities	515.870	440.230 (85)
18-35	223.000	179.200 (80)
36-50	166.110	143.960 (87)
51-66	119.250	109.970 (92)
67-79	7.230	6.850 (95)
80+	280	260 (93)
Administrative and support service activities	740.260	513.200 (69)
18-35	367.700	223.950 (61)
36-50	196.570	139.810 (71)
51-66	163.090	137.330 (84)
67-79	12.710	11.930 (94)
80+	190	180 (94)
Public administration and defence	529.030	455.280 (86)

	N	Uptake (N, %)
18-35	142.170	110.050 (77)
36-50	183.370	157.170 (86)
51-66	202.020	186.640 (92)
67-79	1.450	1.400 (97)
80+	20	.
Education	529.830	459.890 (87)
18-35	185.110	149.120 (81)
36-50	178.860	156.640 (88)
51-66	162.420	150.880 (93)
67-79	3.380	3.200 (95)
80+	60	.
Human health and social work activities	1.348.300	1.113.670 (83)
18-35	509.860	377.020 (74)
36-50	402.870	340.760 (85)
51-66	429.630	390.340 (91)
67-79	5.870	5.480 (93)
80+	80	.
Arts, entertainment and recreation	106.330	87.350 (82)
18-35	49.420	37.710 (76)
36-50	27.650	22.930 (83)
51-66	27.540	25.070 (91)
67-79	1.640	1.570 (96)
80+	90	80 (89)
Other service activities	116.860	94.510 (81)
18-35	45.700	32.260 (71)
36-50	35.600	29.780 (84)
51-66	33.460	30.520 (91)
67-79	2.000	1.880 (94)
80+	90	.
Activities of extraterritorial organisations and bodies	1.090	800 (73)
18-35	220	150 (68)
36-50	400	280 (71)
51-66	460	360 (77)
67-79	10	.
80+	.	.
Other/unemployed/unknown	6.699.980	5.286.970 (79)
18-35	1.100.270	593.090 (54)
36-50	940.520	611.630 (65)
51-66	1.691.310	1.393.600 (82)
67-79	2.125.700	1.943.610 (91)
80+	842.190	745.040 (88)
Urbanisation		
Not urbanised	2.267.080	1.869.340 (82)
18-35	534.040	373.250 (70)
36-50	494.820	392.120 (79)
51-66	721.400	632.820 (88)
67-79	390.800	359.620 (92)
80+	126.020	111.530 (88)
Hardly urbanised	2.243.130	1.882.930 (84)
18-35	538.900	384.790 (71)
36-50	522.880	428.280 (82)

Determinants of COVID-19 Vaccination Uptake

	N	Uptake (N, %)
51-66	648.070	578.700 (89)
67-79	386.890	359.970 (93)
80+	146.400	131.180 (90)
Moderately urbanised	2.553.650	2.108.270 (83)
18-35	635.300	436.490 (69)
36-50	599.820	482.760 (80)
51-66	726.450	644.130 (89)
67-79	430.150	399.600 (93)
80+	161.940	145.290 (90)
Strongly urbanised	3.600.060	2.854.700 (79)
18-35	969.800	621.040 (64)
36-50	840.940	647.600 (77)
51-66	970.810	842.780 (87)
67-79	580.300	531.760 (92)
80+	238.210	211.530 (89)
Extremely urbanised	3.510.730	2.607.110 (74)
18-35	1.333.780	868.060 (65)
36-50	801.410	575.810 (72)
51-66	778.710	640.920 (82)
67-79	423.720	373.530 (88)
80+	173.120	148.790 (86)
Unknown	990	440 (44)
18-35	500	180 (36)
36-50	240	100 (41)
51-66	180	110 (61)
67-79	60	40 (77)
80+	.	.
Medical risk groups		
Low medical risk	10.598.450	8.259.750 (78)
18-35	3.577.840	2.385.010 (67)
36-50	2.708.720	2.084.480 (77)
51-66	2.743.830	2.367.020 (86)
67-79	1.216.950	1.110.960 (91)
80+	351.120	312.290 (89)
Intermediate medical risk	3.216.720	2.749.800 (85)
18-35	399.380	273.340 (68)
36-50	488.490	389.270 (80)
51-66	976.410	860.680 (88)
67-79	891.360	819.930 (92)
80+	461.090	406.570 (88)
High medical risk	360.480	313.250 (87)
18-35	35.110	25.480 (73)
36-50	62.910	52.920 (84)
51-66	125.370	111.760 (89)
67-79	103.600	93.640 (90)
80+	33.490	29.460 (88)
Long term care recipients, residential, nursing home		
No	14.066.530	11.232.240 (80)
18-35	4.012.270	2.683.780 (67)
36-50	3.259.660	2.526.300 (78)
51-66	3.840.720	3.335.270 (87)
67-79	2.188.690	2.004.750 (92)
80+	765.200	682.160 (89)
Yes	109.110	90.550 (83)
18-35	60	50 (81)
36-50	450	370 (82)
51-66	4.890	4.190 (86)

	N	Uptake (N, %)
67-79	23.220	19.790 (85)
80+	80.490	66.160 (82)
Long term care recipients, residential, mentally impaired		
No	14.100.410	11.260.710 (80)
18-35	3.984.460	2.662.280 (67)
36-50	3.242.510	2.511.740 (77)
51-66	3.825.040	3.321.600 (87)
67-79	2.204.090	2.017.940 (92)
80+	844.310	747.140 (88)
Yes	75.230	62.090 (83)
18-35	27.870	21.540 (77)
36-50	17.600	14.930 (85)
51-66	20.560	17.860 (87)
67-79	7.820	6.590 (84)
80+	1.390	1.170 (84)
Long term care recipients, non-residential, mentally impaired		
No	14.149.170	11.303.980 (80)
18-35	3.993.510	2.670.900 (67)
36-50	3.255.850	2.523.510 (78)
51-66	3.843.000	3.337.370 (87)
67-79	2.211.190	2.023.940 (92)
80+	845.620	748.260 (88)
Yes	26.470	18.820 (71)
18-35	18.820	12.920 (69)
36-50	4.260	3.170 (74)
51-66	2.610	2.090 (80)
67-79	720	590 (83)
80+	70	50 (76)
Voting proportions political movements (%)		
Progressive liberal		
0-0.1	1.458.190	1.113.830 (76)
18-35	386.960	237.550 (61)
36-50	328.030	240.330 (73)
51-66	413.890	347.260 (84)
67-79	239.630	213.130 (89)
80+	89.690	75.550 (84)
0.1-0.2	8.902.660	7.139.080 (80)
18-35	2.301.410	1.493.560 (65)
36-50	2.031.010	1.570.240 (77)
51-66	2.530.710	2.211.210 (87)
67-79	1.481.490	1.365.810 (92)
80+	558.040	498.270 (89)
0.2-0.3	2.635.610	2.126.450 (81)
18-35	795.040	551.320 (69)
36-50	642.250	512.170 (80)
51-66	666.320	581.160 (87)
67-79	373.450	341.140 (91)
80+	158.560	140.660 (89)
0.3-0.4	1.042.600	828.770 (79)
18-35	453.500	340.020 (75)
36-50	235.450	184.540 (78)
51-66	211.780	179.520 (85)
67-79	105.840	93.840 (89)
80+	36.030	30.850 (86)
0.4-0.5	135.420	114.110 (84)
18-35	74.860	61.170 (82)

Chapter 5

	N	Uptake (N, %)
36-50	23.070	19.240 (83)
51-66	22.690	20.160 (89)
67-79	11.440	10.570 (92)
80+	3.360	2.980 (89)
Unknown	1.160	560 (48)
18-35	560	210 (38)
36-50	310	150 (48)
51-66	220	150 (66)
67-79	70	50 (78)
80+	10	.
Right-wing liberal		
0-0.1	373.280	245.010 (66)
18-35	157.910	94.170 (60)
36-50	91.290	58.280 (64)
51-66	80.420	58.910 (73)
67-79	33.880	26.410 (78)
80+	9.790	7.240 (74)
0.1-0.2	5.449.320	4.123.990 (76)
18-35	1.797.910	1.149.040 (64)
36-50	1.231.000	899.710 (73)
51-66	1.353.570	1.132.140 (84)
67-79	771.610	688.840 (89)
80+	295.230	254.260 (86)
0.2-0.3	7.101.440	5.876.040 (83)
18-35	1.764.450	1.222.390 (69)
36-50	1.638.170	1.316.970 (80)
51-66	2.042.290	1.812.370 (89)
67-79	1.197.490	1.112.150 (93)
80+	459.050	412.160 (90)
0.3-0.4	1.244.820	1.072.320 (86)
18-35	290.730	217.470 (75)
36-50	298.130	250.530 (84)
51-66	367.320	334.310 (91)
67-79	207.720	196.010 (94)
80+	80.920	74.000 (91)
0.4-0.5	5.620	4.880 (87)
18-35	780	540 (70)
36-50	1.220	1.030 (85)
51-66	1.780	1.580 (89)
67-79	1.160	1.080 (93)
80+	690	650 (93)
Unknown	1.160	560 (48)
18-35	560	210 (38)
36-50	310	150 (48)
51-66	220	150 (66)
67-79	70	50 (78)
80+	10	.
Right-wing Christian		
0-0.1	13.501.210	10.833.030 (80)
18-35	3.821.890	2.574.950 (67)
36-50	3.107.460	2.419.810 (78)
51-66	3.662.560	3.190.390 (87)
67-79	2.105.720	1.933.000 (92)
80+	803.590	714.880 (89)
0.1-0.2	359.010	278.500 (78)
18-35	95.340	59.940 (63)

	N	Uptake (N, %)
36-50	81.040	60.680 (75)
51-66	98.680	83.980 (85)
67-79	59.720	53.500 (90)
80+	24.230	20.400 (84)
0.2-0.3	169.960	120.090 (71)
18-35	49.670	27.450 (55)
36-50	38.160	26.120 (68)
51-66	45.170	36.170 (80)
67-79	26.330	22.290 (85)
80+	10.630	8.050 (76)
0.3-0.4	48.250	31.370 (65)
18-35	15.310	7.960 (52)
36-50	11.710	7.380 (63)
51-66	12.510	9.440 (75)
67-79	6.400	5.020 (78)
80+	2.330	1.570 (67)
0.4-0.5	42.880	23.380 (55)
18-35	14.350	5.820 (41)
36-50	9.720	5.120 (53)
51-66	10.860	7.110 (66)
67-79	5.730	4.020 (70)
80+	2.220	1.320 (59)
0.5-0.6	21.750	8.720 (40)
18-35	8.030	2.040 (25)
36-50	5.190	1.970 (38)
51-66	5.160	2.770 (54)
67-79	2.530	1.540 (61)
80+	830	400 (48)
0.7+	400	160 (39)
18-35	180	50 (26)
36-50	100	40 (43)
51-66	100	50 (50)
67-79	20	10 (58)
80+	10	.
Unknown	32.180	27.550 (86)
18-35	7.570	5.620 (74)
36-50	6.720	5.550 (82)
51-66	10.580	9.540 (90)
67-79	5.460	5.150 (94)
80+	1.850	1.690 (91)
Christian middle		
0-0.1	5.671.140	4.325.370 (76)
18-35	1.899.850	1.228.340 (65)
36-50	1.349.300	1.002.580 (74)
51-66	1.401.260	1.184.530 (85)
67-79	742.270	666.560 (90)
80+	278.450	243.370 (87)
0.1-0.2	6.818.410	5.633.990 (83)
18-35	1.674.670	1.157.410 (69)
36-50	1.532.780	1.228.230 (80)
51-66	1.965.300	1.738.410 (88)
67-79	1.186.740	1.099.500 (93)
80+	458.920	410.440 (89)
0.2-0.3	1.371.420	1.103.080 (80)
18-35	355.040	238.790 (67)
36-50	307.190	239.030 (78)
51-66	389.670	337.710 (87)

Determinants of COVID-19 Vaccination Uptake

	N	Uptake (N, %)
67-79	230.780	210.420 (91)
80+	88.740	77.150 (87)
0.3-0.4	276.010	229.180 (83)
18-35	71.300	51.340 (72)
36-50	61.410	49.410 (80)
51-66	79.080	69.780 (88)
67-79	46.480	42.900 (92)
80+	17.740	15.760 (89)
0.4-0.5	37.490	30.600 (82)
18-35	10.910	7.730 (71)
36-50	9.110	7.280 (80)
51-66	10.080	8.890 (88)
67-79	5.570	5.110 (92)
80+	1.830	1.600 (88)
Unknown	1.160	560 (48)
18-35	560	210 (38)
36-50	310	150 (48)
51-66	220	150 (66)
67-79	70	50 (78)
80+	10	.
Right-wing conservative		
0-0.1	1,122.670	875.120 (78)
18-35	479.340	350.980 (73)
36-50	254.890	194.940 (76)
51-66	232.860	193.770 (83)
67-79	115.110	100.800 (88)
80+	40.480	34.630 (86)
0.1-0.2	5,939.710	4,798.900 (81)
18-35	1,691.030	1,157.600 (68)
36-50	1,388.260	1,096.670 (79)
51-66	1,576.110	1,378.350 (87)
67-79	916.020	840.240 (92)
80+	368.290	326.060 (89)
0.2-0.3	6,238.150	4,973.740 (80)
18-35	1,621.070	1,043.330 (64)
36-50	1,423.280	1,093.280 (77)
51-66	1,777.640	1,547.310 (87)
67-79	1,032.020	948.690 (92)
80+	384.140	341.130 (89)
0.3-0.4	815.300	631.040 (77)
18-35	205.270	122.990 (60)
36-50	179.320	131.760 (73)
51-66	241.060	205.290 (85)
67-79	139.510	126.700 (91)
80+	50.140	44.300 (88)
0.4-0.5	32.580	23.490 (72)
18-35	8.310	4.430 (53)
36-50	7.940	5.470 (69)
51-66	10.210	8.300 (81)
67-79	4.730	4.140 (88)
80+	1.390	1.150 (83)
0.5-0.6	26.080	19.930 (76)
18-35	6.750	4.280 (63)
36-50	6.100	4.410 (72)
51-66	7.500	6.290 (84)
67-79	4.470	3.910 (87)

	N	Uptake (N, %)
80+	1.250	1.040 (83)
Unknown	1.160	560 (48)
18-35	560	210 (38)
36-50	310	150 (48)
51-66	220	150 (66)
67-79	70	50 (78)
80+	10	.
Progressive left-wing		
0-0.1	467.900	339.290 (73)
18-35	137.840	80.980 (59)
36-50	107.150	74.860 (70)
51-66	125.820	102.030 (81)
67-79	69.990	59.950 (86)
80+	27.100	21.480 (79)
0.1-0.2	5,206.530	4,340.030 (83)
18-35	1,272.160	895.490 (70)
36-50	1,218.320	988.790 (81)
51-66	1,516.920	1,350.910 (89)
67-79	870.730	810.120 (93)
80+	328.410	294.730 (90)
0.2-0.3	6,603.020	5,195.710 (79)
18-35	1,839.480	1,175.010 (64)
36-50	1,509.220	1,147.940 (76)
51-66	1,783.490	1,539.630 (86)
67-79	1,055.650	965.120 (91)
80+	415.190	368.020 (89)
0.3-0.4	1,660.520	1,278.500 (77)
18-35	674.370	476.470 (71)
36-50	367.600	274.760 (75)
51-66	359.590	299.830 (83)
67-79	189.950	168.110 (89)
80+	69.000	59.320 (86)
0.4-0.5	236.510	168.710 (71)
18-35	87.930	55.670 (63)
36-50	57.520	40.190 (70)
51-66	59.570	46.910 (79)
67-79	25.530	21.180 (83)
80+	5.980	4.770 (80)
Unknown	1.160	560 (48)
18-35	560	210 (38)
36-50	310	150 (48)
51-66	220	150 (66)
67-79	70	50 (78)
80+	10	.

S4 Vaccine uptake in the Netherlands per neighbourhood

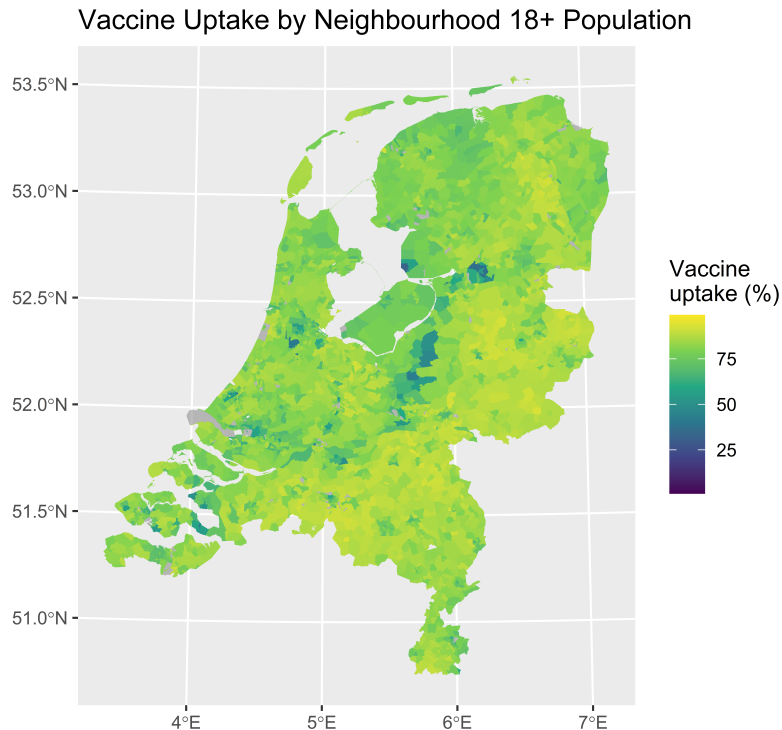


Figure S4.1 Vaccine uptake (%) in the Netherlands per neighbourhood in the population of 18 years and older

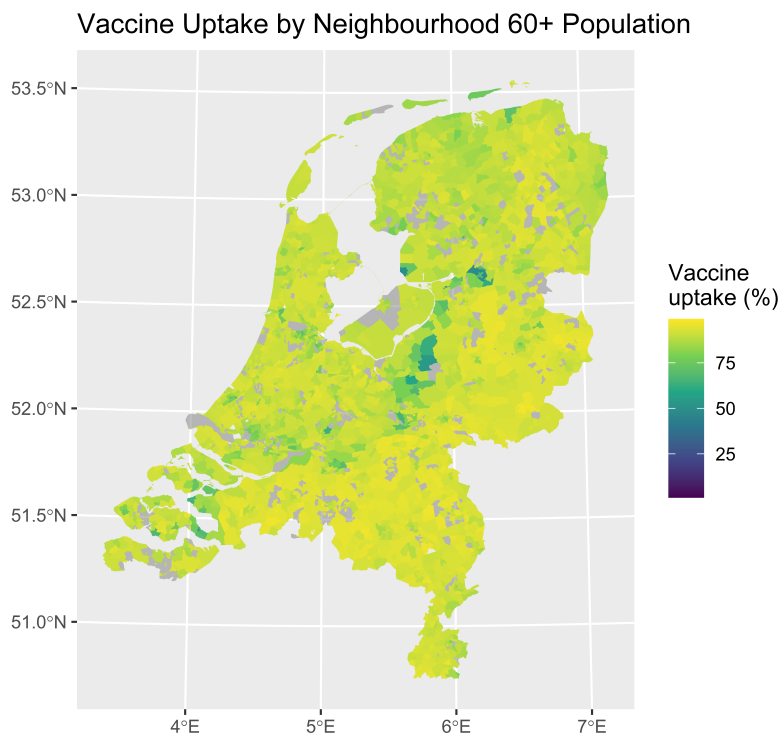


Figure S4.2 Vaccine uptake (%) in the Netherlands per neighbourhood in the population of 60 years and older

Note: the grey areas indicate neighbourhoods with frequencies <10 and were therefore excluded.



Chapter 6

Mobile vaccination units to increase COVID-19 vaccination uptake in areas with lower coverage: a within-neighbourhood analysis using national registration data, the Netherlands, September–December 2021

Mattijs Lambooij, **Joyce Pijpers**, Jan van de Kassteele, Mirjam P Fransen, Susan JM Hahné Niek Hof, Floor M Kroese, Hester de Melker, Mart van Dijk, Ellen Uiters, Marijn de Bruin

Eurosurveillance, 2024

DOI: 10.2807/1560-7917.ES.2025.30.39.2500251

ABSTRACT

BACKGROUND: Vaccine uptake differs between social groups. Mobile vaccination units (MV-units) were deployed in the Netherlands by municipal health services in neighbourhoods with low uptake of COVID-19 vaccines.

AIM: We aimed to evaluate the impact of MV-units on vaccine uptake in neighbourhoods with low vaccine uptake.

METHODS: We used the Dutch national-level registry of COVID-19 vaccinations (CIMS) and MV-unit deployment registrations containing observations in 253 neighbourhoods where MV-units were deployed and 890 contiguous neighbourhoods (total observations: 88,543 neighbourhood-days). A negative binomial regression with neighbourhood-specific temporal effects using splines was used to study the effect.

RESULTS: During deployment, the increase in daily vaccination rate in targeted neighbourhoods ranged from a factor 2.0 (95% confidence interval (CI): 1.8–2.2) in urbanised neighbourhoods to 14.5 (95% CI: 11.6–18.0) in rural neighbourhoods. The effects were larger in neighbourhoods with more voters for the Dutch conservative Reformed Christian party but smaller in neighbourhoods with a higher proportion of people with non-western migration backgrounds. The absolute increase in uptake over the complete intervention period ranged from 0.22 percentage points (95% CI: 0.18–0.26) in the most urbanised neighbourhoods to 0.33 percentage point (95% CI: 0.28–0.37) in rural neighbourhoods.

CONCLUSIONS: Deployment of MV-units increased daily vaccination rate, particularly in rural neighbourhoods, with longer travel distance to permanent vaccination locations. This public health intervention shows promise to reduce geographic and social health inequalities, but more proactive and long-term deployment is required to identify its potential to substantially contribute to overall vaccination rates at country level.

Introduction

Willingness to be vaccinated is affected by individual, social, organisational and vaccine-specific factors [1]. Both willingness to be vaccinated and actual vaccine uptake vary significantly across different social groups. Even in countries with relatively low inequality, such as Finland, socioeconomic aspects affect vaccine uptake [2]. Reducing inequality in vaccine uptake may be considered an effective means to reduce health inequalities between social groups. Vaccination against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (hereinafter called COVID-19 vaccine) has proven highly effective in mitigating severe illness and reducing mortality caused by the virus [3]. Demographic factors such as age, education level, ethnicity and geographical factors (e.g. degree of urbanisation) are associated with differences in vaccine uptake [1,4,5]. As low vaccine uptake tends to cluster socioeconomically or spatially [6,7], effective interventions to reduce inequality may teach valuable lessons to reduce overall inequity in health. During the COVID-19 pandemic, mobile vaccination units (MV-units) were deployed in the Netherlands, like in other countries [6,7], to specifically target neighbourhoods with lower vaccine uptake.

In the Netherlands, the primary COVID-19 vaccination campaign started in January 2021. The vaccines were rolled out in staggered fashion, first the oldest people and people with a high risk due to chronic conditions were offered vaccination, followed by subsequent younger age groups. Within the oldest age groups (>90 years), 89% had received at least one COVID-19 vaccine and 87% had received the complete primary vaccination set of two doses on 1 September 2021 [8]. From September to October 2021, the increase in vaccine uptake had levelled off and, only a very limited number of people came to vaccination locations to receive their first dose. Besides differences in age, the uptake differed between neighbourhoods. Recognising these disparities, the Dutch municipal health services strategically deployed mobile vaccination units (MV-units) in neighbourhoods with lower vaccine uptakes guided by regional vaccination registration and knowledge of hard-to-reach population segments. Typically, these targeted neighbourhoods exhibited a higher proportion of individuals with (i) lower educational attainment, (ii) a non-western migration background and (iii) >5% of voters for the Reformed Political Party (RPP, Dutch: *Staatkundig Gereformeerde Partij*, a conservative Reformed Christian political party) [8-10]. In addition, lower vaccine uptakes were seen in the most urbanised areas of the Netherlands [8-10].

The purpose of the MV-units (either as buses or temporal pop-up locations) was to facilitate vaccination by improving the physical accessibility of vaccination services and easy accessibility to healthcare professionals to answer vaccine-related questions. The MV-units were equipped with enough vaccines, registration facilities and a waiting room. This was supported by communication and information provision. Posters, flyers, flags and social media were used to announce the presence and oftentimes healthcare professionals (doctors, nurses) were on site to answer

Chapter 6

questions. The 25 Dutch municipal health service regions and each location were autonomous in the forms of support, resulting in different strategies per region. In practice, this meant that in neighbourhoods with a higher proportion of people with lower educational levels, with more people with non-western migration backgrounds or higher percentage of voters for the RPP, the municipal health services cooperated with local key figures, other than healthcare professionals. These key figures differed per region and could be religious leaders but also social workers or volunteers.

To date, no studies have been conducted investigating the effect of the deployment of MV-units in the Netherlands. In the United Kingdom (UK), the vaccine uptake in nine regions increased by 25% when deploying MV-units [11], and in the United States (US), MV-units increased vaccination rates among groups with lower uptake than average [12]. Therefore, the aim of this study was to investigate whether and, if so, to which extent, the deployment of MV-units was effective in increasing uptake of COVID-19 vaccine in neighbourhoods.

Methods

Study design

We used a natural-experimental design to assess the effect of the deployment of MV-units on daily vaccination rate and vaccine uptake. Unlike a randomised controlled trial, where participants are randomly assigned to intervention or control groups, the deployment of MV-units was determined by regional health services based on low vaccination coverage compared with other neighbourhoods in their region. As a result, the deployment of MV-units varied over time and over neighbourhood. An overview of the deployment of the MV-units is shown in Supplementary Figure S3. We used this variation to study whether and to which extent the number of daily administered vaccines significantly differed from periods when MV-units were not deployed.

Study setting and population

The study population comprised neighbourhoods within 16 of 25 municipal health regions in the Netherlands. The 16 municipal health regions comprised a total of 1,183 neighbourhoods. For administrative use by municipalities and data collection by Statistics Netherlands (CBS), all municipalities are subdivided into districts, which in turn are subdivided into neighbourhoods. Districts and neighbourhoods have no formal status. Districts and neighbourhoods are coherent areas that are based on several characteristics like age, geographical barriers such as busy roads, having similar urban and/or architectural features or having similar functional, social or political characteristics. The MV-units were present in 256 neighbourhoods for at least 1 day. Three units were placed at one location for a longer period: 28, 57 and 90 consecutive days. We considered these to be non-incidental vaccination units and

these neighbourhoods were therefore excluded for this analysis. In the remaining 253 neighbourhoods, most units were present for only 1 day and for no more than six consecutive days in all neighbourhoods.

Contiguous neighbourhoods

The MV-units served all people who wished to receive a COVID-19 vaccine, regardless of which neighbourhood people lived in. This means that inhabitants of contiguous neighbourhoods could also be reached across the borders of the neighbourhood where the unit was stationed. This is called a spill-over effect [13]. We defined a contiguous or spill-over neighbourhood as a neighbourhood that shares a border with a neighbourhood where a MV-unit was present, here called targeted neighbourhood. We included 253 targeted neighbourhoods and 890 contiguous neighbourhoods. Because of overlapping targeted and non-targeted neighbourhoods, the total number of neighbourhoods included for analyses was 973. Table 1 presents information on relevant characteristics of included and excluded neighbourhoods.

Chapter 6

Table 1. Descriptive statistics of neighbourhoods included and excluded in a study on the effect of mobile vaccination units on COVID-19 vaccine uptake, the Netherlands, September-December 2021

Characteristics	Population size	Vaccine uptake (%)	People with migration background (%)	Voters for the RPP (%)
Mobile vaccination unit deployed				
Not urbanised	135,589	61.0	3.62	10.9
Hardly urbanised	446,598	64.1	5.28	6.40
Moderately urbanised	452,112	64.5	9.56	3.72
Strongly urbanised	1,246,298	60.9	19.5	1.55
Extremely urbanised	778,406	51.9	40.6	0.61
Mobile vaccination unit not deployed				
Not urbanised	1,174,951	67.9	3.02	3.88
Hardly urbanised	1,255,181	68.3	5.01	2.80
Moderately urbanised	1,453,003	65.0	10.2	2.73
Strongly urbanised	2,448,989	63.3	15.0	1.71
Extremely urbanised	2,528,944	58.5	26.8	0.65

RPP: Reformed Political Party (in Dutch: Staatskundig Gereformeerde Partij, a conservative Reformed Christian political party). Not urbanised (< 500 addresses/km²); hardly urbanised (500–999 addresses/km²); moderately urbanised (1,000–1,499 addresses/km²); strongly urbanised (1,500–2,499 addresses/km²) and extremely urbanised (> 2,5000 addresses/km²).

Outcome measures

In this study, two outcome measures were used. Firstly, the vaccination rate, defined as the daily number of individuals that received a vaccination against COVID-19 divided by the number of eligible people in that neighbourhood. Secondly, the vaccine uptake, defined as the proportion of individuals in a neighbourhood who received at least one dose of COVID-19 vaccination. Vaccination data were retrieved from the COVID-19 Vaccination Information and Monitoring System (CIMS). The CIMS database includes data of people who gave informed consent to register their vaccination data (93%).

Covariates

The level of urbanisation, socioeconomic status (SES), the presence of people with a non-western migration background and voters for the RPP have been associated with vaccine uptake [9]. Therefore, data on the level of urbanisation, socioeconomic status score (based on income, assets, education and recent labour activity [14], percentage of people with a non-western migration background and percentage of voters for the RPP [15,16] in the neighbourhoods were included in the analysis. Historically, lower vaccination coverage regarding vaccines included in the national immunisation programme (NIP) have been seen among people practising a Reformed Protestant faith in the Netherlands [17]. As we did not have data on church membership or other individual-level data on religion, we used the percentage of votes for the RPP as a proxy variable for people practising the Reformed Protestant faith, as has been done in previous epidemiological studies of the Dutch context [18,19]. Areas with a high percentage of people practising the Reformed Protestant faith, also referred to as the Dutch Bible Belt, are defined by areas with > 5% of the votes for the RPP. Results of these studies indicate strong associations between the proxy variable and vaccination outcomes [18,19]. The level of urbanisation was divided into five categories: not urbanised (< 500 addresses/ km²); hardly urbanised (500–999 addresses/km²), moderately urbanised (1,000–1,499 addresses/km²), strongly urbanised (1,500–2,499 addresses/km²) and extremely urbanised (≥ 2,500 addresses/km²).

Descriptive analysis

We created a geographical map to present vaccine uptake per neighbourhood on 1 September 2021. Furthermore, we created another map showing the placement of MV-units in the 973 neighbourhoods included in the study between 1 September and 1 December 2021. The map is shown in Supplementary Figure S2. The total number observations was 88,543 neighbourhood-days.

Statistical analysis

Because of the quasi-experimental design, we formulated expectations about the causal relationships between the presence of MV-units and the daily vaccine uptake, before designing the regression model. Date, weekday, vaccine uptake and the neighbourhood itself were identified as confounding variables. The graph of the expected causal pathways is shown in Supplementary Figure S1, presenting the minimal sufficient adjustment set for estimating the total effect of the presence of the MV-units on the vaccination rate including the confounding variables [20]. The main advantage of this model is that neighbourhoods serve as controls of themselves. Consequently, all factors related to neighbourhoods are incorporated in the analyses.

Chapter 6

Regression analysis

Effect of mobile vaccination units on daily vaccination rate

We formulated a negative binomial generalised linear mixed model to describe the daily number of people that received a vaccination in a neighbourhood as a function of combinations of variables of the minimal adjustment set. We specified a neighbourhood specific smooth temporal effect using a spline construct and neighbourhood specific day-of-the-week effect to describe the daily baseline vaccine uptake in a neighbourhood. The effect of the presence of a MV-unit is modelled as a neighbourhood specific deviation from this baseline uptake. Similar terms were added for spill-over effects. In pseudo-equation form the model can be written as follows:

$$\begin{aligned} V_{t,n} &\sim \text{NegBin}(\mu_{t,n}, \theta) \\ \log(\mu_{t,n}) &= \log(\text{pop}_{t,n}) + \log(\lambda_{t,n}) \\ \log(\lambda_{t,n}) &= \text{constant} \\ &\quad + s(\text{date}_t) + \text{re}(\text{neigh}_n) + s(\text{day}_t) \\ &\quad + s(\text{date}_t, \text{neigh}_n) + \text{re}(\text{day}_t, \text{neigh}_n) \\ &\quad + \text{unitpresent}_{t,n} + \text{re}(\text{unitpresent}_{t,n}, \text{neigh}_n) \\ &\quad + \text{unitspillover}_{t,n} + \text{re}(\text{unitspillover}_{t,n}, \text{neigh}_n) \end{aligned}$$

Here $V_{t,n}$ represented the daily number of people that received a vaccination at date t in neighbourhood n , $\mu_{t,n}$ the expected number of daily vaccinations, and θ the overdispersion parameter of the negative binomial distribution. This parameter was treated as a nuisance parameter, $\log(\text{pop}_{t,n})$ was the offset term and represents the number of persons eligible for vaccination. $\lambda_{t,n}$ was the expected vaccination rate. Term $s(\text{date}_t)$ represented the overall smoothly varying time effect, modelled as a penalised spline (s), $\text{re}(\text{neigh}_n)$ represented a neighbourhood-specific random effect (re) and $\text{re}(\text{day}_t)$ a periodic day-of-the-week random effect. The time effect and day-of-the-week effect were allowed to vary between neighbourhoods by the $s(\text{date}_t, \text{neigh}_n)$ and $\text{re}(\text{day}_t, \text{neigh}_n)$ terms, respectively. The $\text{unit-present}_{t,n}$ term represented effect of the presence of a mobile vaccination Sunit in a hypothetical average neighbourhood. This so-called average neighbourhood embodied the average characteristics of the population studied. This effect was allowed to vary between neighbourhoods by the $\text{re}(\text{unit-present}_{t,n}, \text{neigh}_n)$ random effect term, resulting in heterogeneous treatment effects. Two similar terms were included for possible spill-over effects to contiguous neighbourhoods. To reduce complexity of the model, the effect of MV-units was held constant over time.

The model appeared to be too complex to be fitted to all neighbourhoods together.

Therefore, we stratified the analyses into quintiles of the level of urbanisation, because it could be expected that neighbourhoods in these strata had similar characteristics. We could have chosen any other variable to stratify on, since each neighbourhood serves as its own control.

The effects of the deployment of MV-unit in a neighbourhood on the daily vaccination rate are presented in the form of relative rates (RR), compared with the same neighbourhood with no MV-unit deployed (baseline).

Effect of mobile vaccination units on vaccine uptake

Assuming that people who chose to get vaccinated in a MV-unit would not have been vaccinated otherwise, the regression model can be used to estimate the increase in vaccine uptake caused by the deployment of MV-units.

The eventual vaccine uptakes in case MV-units had not been deployed, could be found by setting the effect sizes of the MV-units for each neighbourhood to zero for both the targeted and contiguous neighbourhoods. For each date and neighbourhood, expected vaccination rates $\lambda_{t,n}$ and $\lambda_{0t,n}$ were calculated with deployment and without deployment of MV-units, respectively. These rates can be considered as hazard rates. There is a direct relation between the cumulative hazard rate Λ and the proportion of individuals that have encountered an event, here, in this context, getting vaccinated. The vaccine uptake U_n in neighbourhood n at the end of the study period at $t = 91$ was calculated as follows: $U_n = 1 - \exp(-\Lambda_n)$, where $-\Lambda_n = \Lambda_{t=0,n} + \sum_{t=1..91} \lambda_{t,n}$. Here, $\Lambda_{t=0,n}$ was the cumulative hazard rate at the beginning of the study period, calculated from the given vaccine uptake at $t = 0$. The effect size for each neighbourhood was calculated as the difference $U_n^1 - U_n^0$. Because the relation between the vaccine uptake and the vaccination rates was nonlinear, 95% confidence intervals (CI) were calculated by Monte Carlo simulation of the estimated regression model parameters.

The effects of the deployment of MV-unit in a neighbourhood on the eventual vaccine uptake are presented in the form of absolute risk differences (RD, expressed a percentages), compared with the same neighbourhood with no MV-unit deployed at all.

All analyses were carried out in R [21]. The regression model was fitted using the bam function from the mgcv package [21-23]. The pooled estimates are based on random-effect meta-analyses.

Results

Descriptive analysis

Figure 1 shows a map of the presence of MV-units for at least 1 day between 1 September and 1 December 2021, in 16 of the 25 municipal health regions. The duration of the presence of a MV-unit varied considerably. In most neighbourhoods, the MV-units were deployed on multiple occasions, but only for 1 day each time. More detailed information on the presence of MV-units by date and neighbourhood can be found in Supplementary Figure 3.

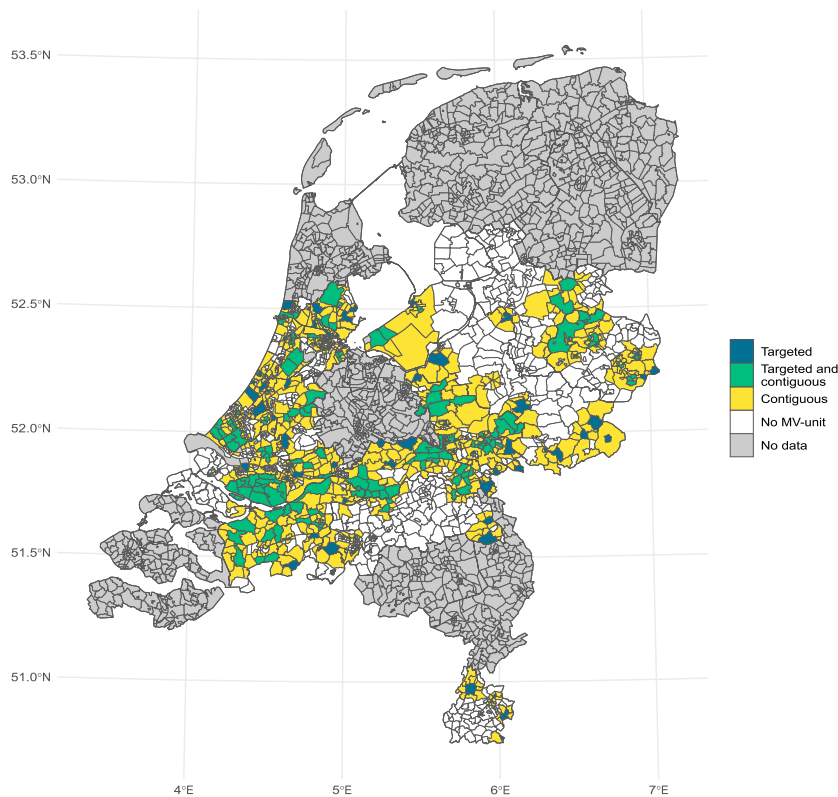


Figure 1. Map showing the placement of mobile vaccination units for COVID-19 vaccine in targeted neighbourhoods for at least 1 day, the Netherlands, September-December 2021 (n = 973)^a

MV-unit: mobile vaccination unit.

16 of the 25 municipal health regions were included

The blue-coloured and green-coloured areas are neighbourhoods where a unit was present. The green-colour regions were also indicated as contiguous neighbourhoods during this period. The yellow-coloured regions are contiguous neighbourhoods where no unit was present. The thick grey lines indicate the boundaries of the 25 municipal health regions in the Netherlands.

Regression analysis, impact of mobile vaccination units

In an average targeted neighbourhood where a MV-unit was deployed, during deployment, the daily vaccination rate in for example a moderately urbanised neighbourhood was a factor 5.7 (95% CI: 4.9–6.8) higher compared with the same neighbourhood when a unit was not deployed (Table 2). In an average neighbourhood, the spill-over effect in for example a moderately urbanised neighbourhood resulted in a factor 2.0 higher daily vaccination rate.

In the neighbourhoods where a unit was present, we found large differences in effect sizes between neighbourhoods (1.1–35.8) (Figure 2). In the contiguous neighbourhoods, the effect size varied between 0.8 and 6.8. Effect sizes decreased with an increasing level of urbanisation, as shown in Supplementary Figure S5.

Because the effects of the deployment of MV-units were very heterogeneous, we further investigated which neighbourhood characteristics were associated with these different effect sizes. Figure 3 shows the estimated effect sizes RR in relation to a selection of neighbourhood characteristics: percentage of votes for the RPP, SES and percentage of people with a non-western migration background. The association between SES and vaccine uptake was explained by the level of urbanisation in the neighbourhood (Figure 3C), in areas where more people voted for the RPP, the effect of the MV-unit was stronger, and in areas with more people with a non-western migration background, the effect was smaller (Figures 3A and B).

Chapter 6

Table 2. Pooled relative rates of daily vaccination rates against COVID-19 on a day with and without a deployed mobile vaccination unit in a neighbourhood, stratified by level of urbanisation, the Netherlands, September-December 2021.

Characteristics	Relative daily vaccination rate	95% CI
Targeted neighbourhoods ^a		
Not urbanised	14.5	11.6 - 18.0
Hardly urbanised	8.4	7.3 - 9.6
Moderately urbanised	5.7	4.9 - 6.8
Strongly urbanised	3.8	3.4 - 4.2
Extremely urbanised	2.0	1.8 - 2.2
Contiguous neighbourhoods ^b		
Not urbanised	2.7	2.6 - 2.8
Hardly urbanised	1.8	1.7 - 2.0
Moderately urbanised	2.0	1.9 - 2.2
Strongly urbanised	1.8	1.7 - 1.8
Extremely urbanised	1.4	1.3 - 1.5

CI: confidence interval.

a Neighbourhood where a mobile vaccination unit was deployed.

b Neighbourhood that shares a border with a targeted neighbourhood.

Not urbanised (< 500 addresses/km²); hardly urbanised (500–999 addresses/km²); moderately urbanised (1,000–1,499 addresses/ km²); strongly urbanised (1,500–2,499 addresses/km²) and extremely urbanised (≥ 2,500 addresses/km²).

Differences in eventual vaccine uptake

Table 3 and Figure 4 present the relative difference in eventual vaccine uptake during the intervention period; it represents the difference in overall vaccine uptake between deployment and non-deployment of MV-units. The difference in eventual vaccine uptake over the study period varied from 0.33 percentage points (CI: 0.28–0.37) in rural neighbourhoods, to 0.22 percentage points in very urbanised neighbourhoods (CI: 0.18–0.26).

Table 3. Pooled relative differences, total difference in vaccine uptake in neighbourhoods, by level of urbanisation, the Netherlands, September-December 2021.

Characteristics	Relative difference	95% CI
Not urbanised	0.33	0.28-0.37
Hardly urbanised	0.30	0.24-0.36
Moderately urbanised	0.35	0.28-0.42
Strongly urbanised	0.31	0.26-0.36
Extremely urbanised	0.22	0.18-0.26

CI: confidence interval.

Not urbanised (< 500 addresses/km²); hardly urbanised (500–999 addresses/km²); moderately urbanised (1,000–1,499 addresses/ km²); strongly urbanised (1,500–2,499 addresses/km²) and extremely urbanised (≥ 2,500 addresses/km²).

Figure 4 presents the difference in vaccine uptake per neighbourhood, calculated by comparing the model outcomes with MV-units with the model without MV-units. In the most urbanised areas, the difference in vaccine uptake ranged from 0 to ca 1.5% percentage points, with the largest CI not reaching 2. In the hardly urbanised neighbourhoods, the difference in uptake ranged from 0 to almost 2, and the largest CI exceeded 2 percentage points. In the least urbanised neighbourhoods, we saw a difference in uptake of 0 in a few neighbourhoods, increasing in a somewhat convex manner to a difference between 1 and 2 on average, indication that in some neighbourhoods, the increase in vaccine uptake was near 2 percentage points. The differences between the different levels of urbanisation were similar. In lesser urbanised neighbourhoods, the effect of the MV-units appeared to be stronger than in the more urbanised neighbourhoods. These effects were statistically different.

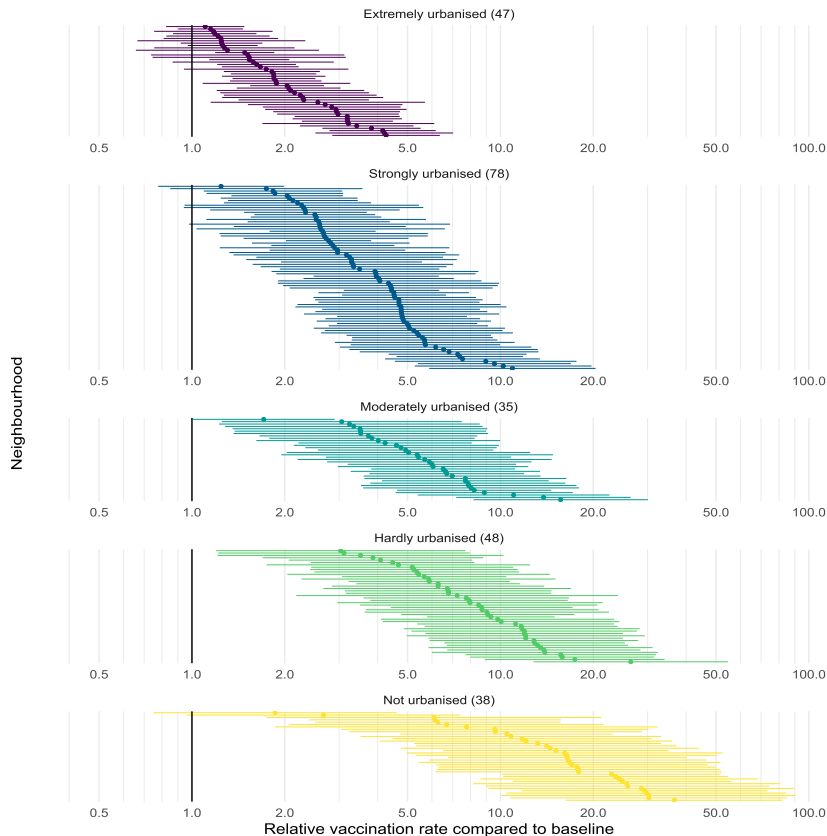


Figure 2. Relative rates of daily vaccination rates against COVID-19 on a day with and without a mobile vaccination unit in a neighbourhood, stratified by level of urbanisation, the Netherlands, September-December 2021

The figure presents the relative rates and their 95% confidence intervals by neighbourhood. Not urbanised (< 500 addresses/km²); hardly urbanised (500–999 addresses/km²); moderately urbanised (1,000–1,499 addresses/km²); strongly urbanised (1,500–2,499 addresses/km²) and extremely urbanised (≥ 2,500 addresses/km²).

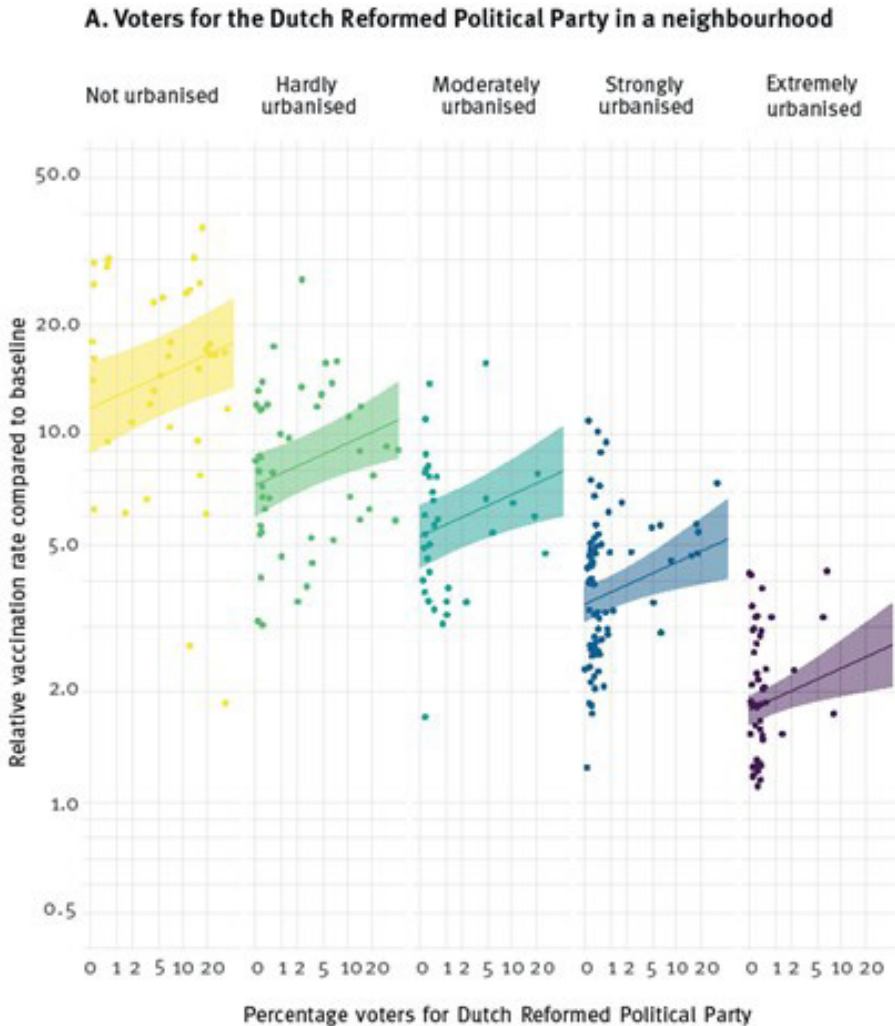


Figure 3. Effect of deployed mobile vaccination units on relative vaccination rates in neighbourhoods by percentage of voters for the Dutch Reformed Political Party (A), percentage of people with a non-western migration background (B) and socioeconomic status score (C), stratified by level of urbanisation, the Netherlands, September-December 2021 ($n = 252$ targeted neighbourhoods).

RPP: Reformed Political Party (in Dutch: Staatkundig Gereformeerde Partij, a conservative Reformed Christian political party); RR: relative rate. The panels show the estimated effect sizes RR (dots) in relation to a selection of corresponding neighbourhood characteristics. The lines represent the estimated regression lines. Note: some variables have been transformed. Not urbanised (< 500 addresses/km²); hardly urbanised ($500-999$ addresses/km²); moderately urbanised ($1,000-1,499$ addresses/km²); strongly urbanised ($1,500-2,499$ addresses/km²) and extremely urbanised ($\geq 2,500$ addresses/km²)

B. People with a non-western migration background in a neighbourhood

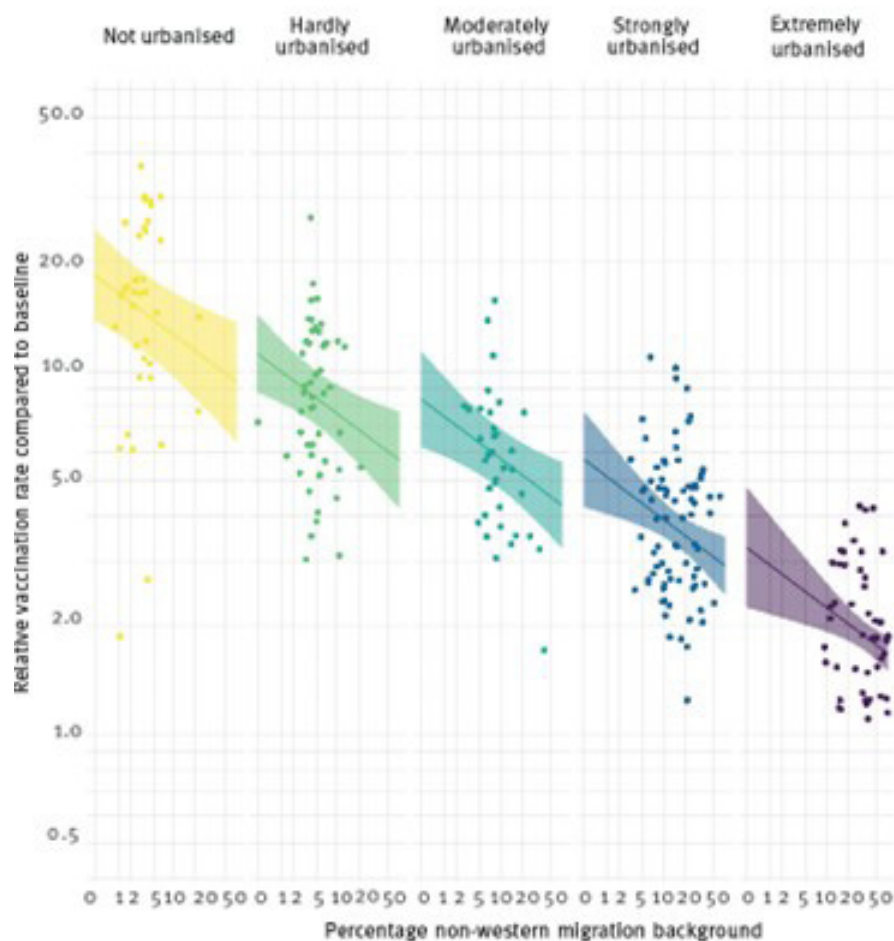


Figure 3. (continued)

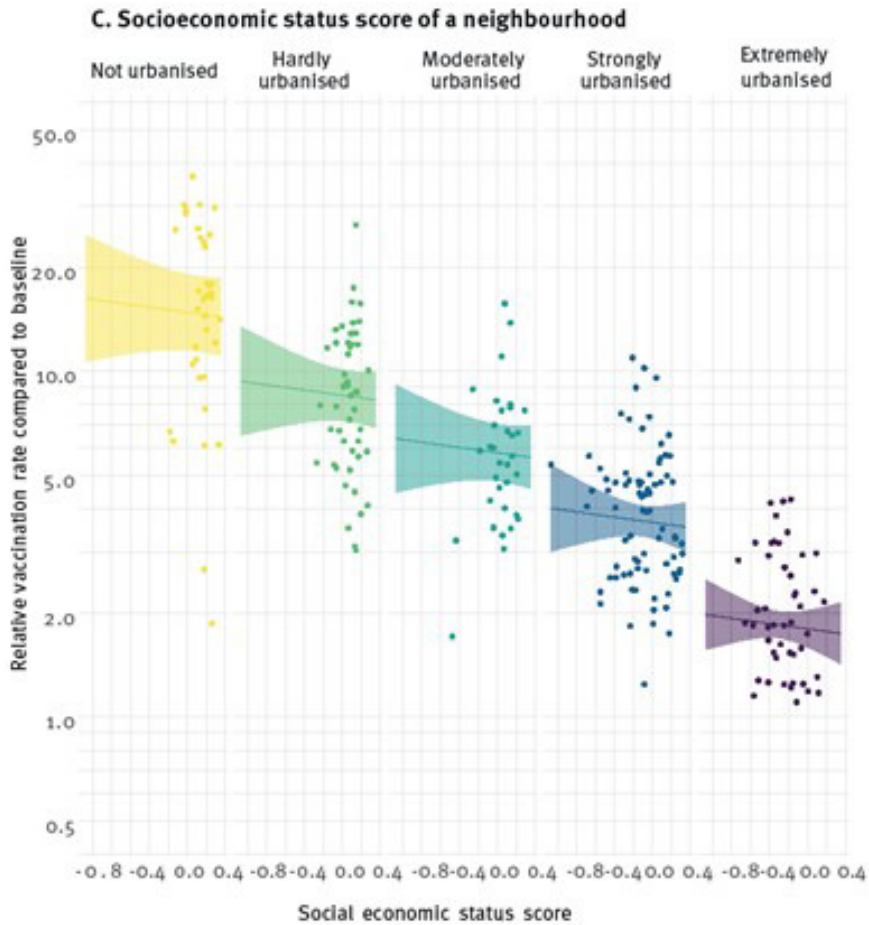


Figure 3. (continued)

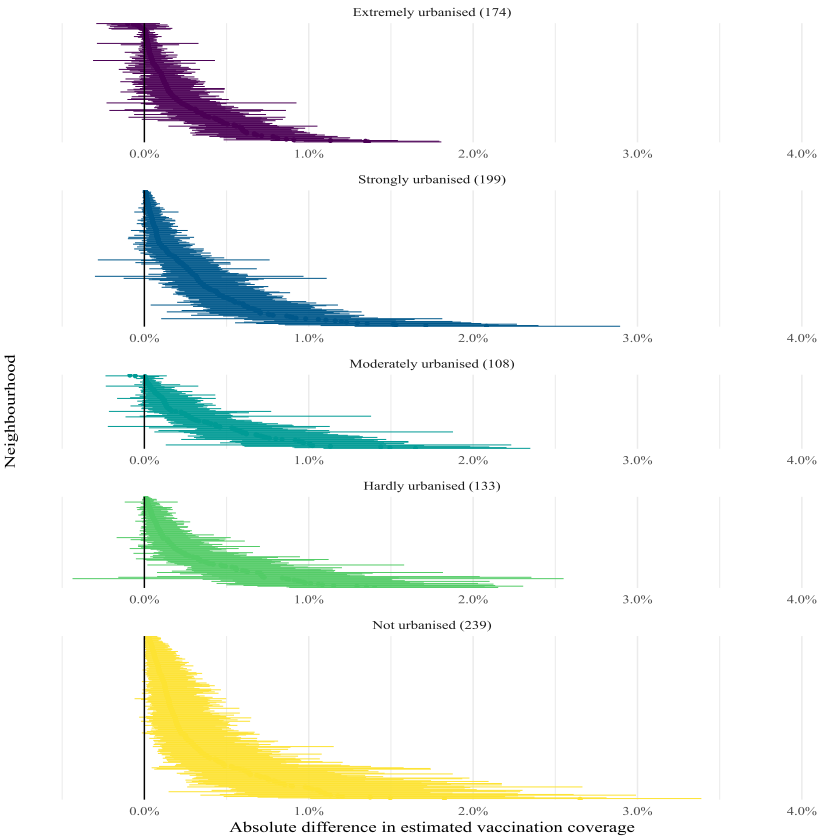


Figure 4. Difference in vaccine uptake in neighbourhoods with and without mobile vaccination units, stratified by level of urbanisation, the Netherlands, September-December 2021

Not urbanised (< 500 addresses/km²); hardly urbanised (500–999 addresses/km²); moderately urbanised (1,000–1,499 addresses/km²); strongly urbanised (1,500–2,499 addresses/km²) and extremely urbanised (≥ 2,500 addresses/km²)

Discussion

This study, where national vaccination registration data were combined with data on MV-unit deployment, showed that vaccination rate increased in most neighbourhoods where MV-units were deployed in the autumn of 2021 during the COVID-19 pandemic as well as in the contiguous neighbourhoods. In the targeted neighbourhoods, the increase in vaccination rate varied between a factor 1.1 in urbanised neighbourhoods and a factor 14.5 in rural neighbourhoods. The increase in vaccine uptake over the complete intervention period ranged from 0.22 percentage points (95% CI: 0.18–0.26) in the most urbanised neighbourhoods to 0.33 percentage points (95% CI: 0.28–0.37) in rural neighbourhoods.

The seemingly modest effect on eventual vaccine uptake may conceal the relevance on the neighbourhoods the MV-units were active. Compared with the long mass vaccination campaign, the MV-units were deployed for only a short time in few locations. The absolute effect estimate was very small despite the large relative rate due to the short and late deployment of the MV-units. In our observations, we compared 7.7% neighbourhood-days with MV-units with 92.3% neighbourhood-days without MV-units. More proactive and long-term deployment is required to identify its potential to substantially contribute to reduction of social and geographical inequalities in vaccine uptake [24, 25].

Subgroup analyses showed that in neighbourhoods with more than 5% voters for the RPP, the effect of an MV-unit was stronger, while in areas with more people with a non-western migration background, the effect was weaker. It is important to note though, that there were still positive effects of MV-unit deployment. It is relevant that MV-units were often combined with additional educational activities - although their intensity, cultural-sensitivity and mode of delivery could not be analysed in this study. In neighbourhoods with higher percentages of voters for the RPP party, the presence of a MV-unit appeared to be a reason, more often than for other subgroups, to get vaccinated. Mistrust in the vaccinating institutions and religious motives are reasons to doubt getting a vaccine [26]. Being able to interact face-to-face in the MV-units and the opportunity to get additional information may have been facilitators of increased trust and increased uptake for these persons. It may be that those activities more effectively addressed hesitancy among people with a Reformed Protestant background than among people with diverse migration backgrounds.

We were able to evaluate the impact of MV-units on national scale in real-life (rather than in a more artificial e.g. randomised controlled trial setting) over a 3-month period, combining intervention exposure data with national vaccination registries and neighbourhood characteristics. The flexible mixed-effects regression model shares information between neighbourhoods, resulting in a smaller effective number of parameters to be estimated. The amount of smoothing was automatically estimated by the amount of information in the data using RMLE. Because of the shrinkage

Chapter 6

of effect sizes (i.e. effect sizes are pulled towards the average neighbourhood), no correction for multiple testing was needed [24,25].

The most important limitation in our study is the fact we could not determine causality in the effect of MV-units on vaccine uptake since we were unable to conduct a randomised study (i.e. the deployment of MV-units was not random). To estimate the effect of the deployment of the mobile vaccination units, some assumptions were made that weaken conclusions regarding causality. Firstly, we assumed that individuals that chose to get vaccinated in a MV-unit would not have been vaccinated otherwise. In addition, neighbourhoods served as their own controls, meaning we assumed the baseline vaccination coverage would not change. Furthermore, other unobserved factors may have influenced the results and have affected the vaccine uptake in a way that is not captured in the model. While we recognise these assumptions, we believe our study provides valuable insights into the potential impact of MV-units on vaccine uptake as it addresses a critical gap in the literature and offers valuable real-world data that can inform public health strategies.

There are a number of less important limitations that are worth noticing. Firstly, the national vaccination registry CIMS only contains the 93% of vaccinated people who consented to be registered. If people with less trust in the government are also less likely to consent to registration of their vaccination, this may cause little distortion in the registered uptake. However, for people who decide to get vaccinated, but refuse to consent to registration, this may have resulted in an underestimation in the effect of MV-units. Therefore, there is an unknown chance that the reported effects are in fact underestimations. Secondly, our data contains all MV-units made available by the National organisation of municipal health services (GGD-GHOR), but in some regions, other types of temporary vaccination locations in areas where many people worked or lived were deployed. These data were not available to us, which may have had some influence on our effect estimates. A third limitation is that even though the analyses identified significant mean differences between neighbourhoods, the heterogeneity is still considerable. We were able to include several neighbourhood level confounders, but not differences in the additional education and outreach activities that were organised around MV-units [25, 27]. Lastly, although the use of proportion of votes for the RPP as a proxy for vaccine hesitancy is supported by previous studies, this approach may not capture all aspects of vaccine hesitancy, as individual motivations could also influence both vaccination and voting behaviour.

Conclusion

Mobile vaccination units are effective in increasing vaccination rates in areas where initial vaccine uptake is lagging. The effect of the deployment of MV-units greatly varied between neighbourhoods and was highest in rural neighbourhoods. Also, in urban neighbourhoods with a high proportion of people with a non-western migration background, the presence of MV-units increased the vaccination rate. Although it is unclear whether the effects of MV-units would have sustained if deployed on a larger scale and for a longer time, it appears that their brief and late deployment has limited their impact on national-level vaccine uptakes. The conditions under which MV-units are cost-effective remains to be evaluated.

References

1. Al-Jayyousi GF, Sherbash MAM, Ali LAM, El-Heneidy A, Alhussaini NWZ, Elhassan MEA, et al. Factors influencing public attitudes towards COVID-19 vaccination: a scoping review informed by the socio-ecological model. *Vaccines (Basel)*. 2021;9(6):548. <https://doi.org/10.3390/vaccines9060548> PMID: 34073757
2. Hartonen T, Jermy B, Sönaajalg H, Vartiainen P, Krebs K, Vabalas A, et al. Nationwide health, socio-economic and genetic predictors of COVID-19 vaccination status in Finland. *Nat Hum Behav*. 2023;7(7):1069-83. <https://doi.org/10.1038/s41562-023-01591-z> PMID: 37081098
3. Zheng C, Shao W, Chen X, Zhang B, Wang G, Zhang W. Real-world effectiveness of COVID-19 vaccines: a literature review and meta-analysis. *Int J Infect Dis*. 2022;114:252-60. <https://doi.org/10.1016/j.ijid.2021.11.009> PMID: 34800687
4. Massion SP, Murry VM, Grijalva CG. Racial disparities in COVID-19 outcomes: Unwarranted statistical adjustments and the perpetuation of stereotypes. *Lancet Reg Health Am*. 2022;14:100352. <https://doi.org/10.1016/j.lana.2022.100352> PMID: 36060432
5. Robinson E, Jones A, Lesser I, Daly M. International estimates of intended uptake and refusal of COVID-19 vaccines: A rapid systematic review and meta-analysis of large nationally representative samples. *Vaccine*. 2021;39(15):2024-34. <https://doi.org/10.1016/j.vaccine.2021.02.005> PMID: 33722411
6. European Centre for Disease Prevention and Control (ECDC). Facilitating vaccination acceptance and uptake in the EU/EEA. Stockholm: ECDC; 15 Oct 2021. Available from: <https://www.ecdc.europa.eu/en/publications-data/facilitating-covid-19-vaccination-acceptance-and-uptake>
7. Gupta PS, Mohareb AM, Valdes C, Price C, Jolliffe M, Regis C, et al. Mobile health services for COVID-19: counseling, testing, and vaccination for medically underserved populations. *Am J Public Health*. 2022;112(11):1556-9. <https://doi.org/10.2105/AJPH.2022.307021> PMID: 36223583
8. National Institute of Public Health and the Environment (RIVM). Vaccinatiegraad COVID-19 vaccinatie Nederland, 2021. RIVM-rapport 2022-0055. [Vaccination rate of COVID-19 vaccination, the Netherlands, 2021]. Bilthoven: RIVM; 2022. Dutch. Available from: <https://www.rivm.nl/bibliotheek/rapporten/2022-0055.pdf>
9. Labuschagne LJE, Smorenburg N, van de Kasstele J, Bom B, de Weerd AC, de Melker HE, et al. Neighbourhood sociodemographic factors and COVID-19 vaccine uptake in the Netherlands: an ecological analysis. *BMC Public Health*. 2023;23(1):1696. <https://doi.org/10.1186/s12889-023-16600-z> PMID: 37660018
10. Pijpers J, van Roon A, van Roekel C, Labuschagne L, Smagge B, Ferreira JA, et al. Determinants of COVID-19 vaccine uptake in the Netherlands: a nationwide registry-based study. *Vaccines (Basel)*. 2023;11(9):1409. <https://doi.org/10.3390/vaccines11091409> PMID: 37766087
11. Zhang X, Tulloch JSP, Knott S, Allison R, Parvulescu P, Buchan IE, et al. Evaluating the impact of using mobile vaccination units to increase COVID-19 vaccination uptake in Cheshire and Merseyside, UK: a synthetic control analysis. *BMJ Open*. 2023;13(10):e071852. <https://doi.org/10.1136/bmjopen-2023-071852> PMID: 37802621
12. Gupta PS, Mohareb AM, Valdes C, Price C, Jolliffe M, Regis C, et al. Expanding COVID-19 vaccine access to underserved populations through implementation of mobile vaccination units. *Prev Med*. 2022;163:107226. <https://doi.org/10.1016/j.ypmed.2022.107226> PMID: 36029925

13. Benjamin-Chung J, Arnold BF, Berger D, Luby SP, Miguel E, Colford JM Jr, et al. Spillover effects in epidemiology: parameters, study designs and methodological considerations. *Int J Epidemiol*. 2018;47(1):332-47. <https://doi.org/10.1093/ije/dyx201> PMID: 29106568
14. Centraal Bureau voor de Statistiek (CBS). Berekenwijze SES score per wijk/buurt. [Computation SES score per block/ neighbourhood]. The Hague: CBS; 11 Nov 2021. Dutch. Available from: <https://www.cbs.nl/nl-nl/maatwerk/2021/45/berekenwijze-ses-score-per-wijk-buurt>
15. Kiesraad. Verkiezingsuitslag Tweede Kamerverkiezingen 2021. [Result elections Second Chamber 2021]. The Hague: Kiesraad; 13 Nov 2023. Dutch. Available from: <https://data.overheid.nl/dataset/verkiezingsuitslag-tweede-kamer-2021>
16. Centraal Bureau voor de Statistiek (CBS). Kerncijfers wijken en buurten 2022. [Key numbers blocks and neighbourhoods 2022]. The Hague: CBS; 15 Mar 2024. Dutch. Available from: <https://www.cbs.nl/nl-nl/maatwerk/2024/11/kerncijfers-wijken-en-buurten-2022>
17. Ruijs WL, Hautvast JL, van Ansem WJ, Akkermans RP, van't Spijker K, Hulscher ME, et al. Measuring vaccination coverage in a hard to reach minority. *Eur J Public Health*. 2012;22(3):359-64. <https://doi.org/10.1093/eurpub/ckr081> PMID: 21715468
18. Hahné S, Macey J, van Binnendijk R, Kohl R, Dolman S, van der Veen Y, et al. Rubella outbreak in the Netherlands, 2004- 2005: high burden of congenital infection and spread to Canada. *Pediatr Infect Dis J*. 2009;28(9):795-800. <https://doi.org/10.1097/INF.0b013e-3181a3e2d5> PMID: 19710586
19. Ruijs WL, Hautvast JL, van der Velden K, de Vos S, Knippenberg H, Hulscher ME. Religious subgroups influencing vaccination coverage in the Dutch Bible belt: an ecological study. *BMC Public Health*. 2011;11(1):102. <https://doi.org/10.1186/1471-2458-11-102> PMID: 21320348
20. Textor J, van der Zander B, Gilthorpe MS, Liśkiewicz M, Ellison GT. Robust causal inference using directed acyclic graphs: the R package 'dagitty'. *Int J Epidemiol*. 2016;45(6):1887-94. PMID: 28089956
21. R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2020. Available from: <https://www.R-project.org>
22. Wood SN, Goude Y, Shaw S. Generalized additive models for large data sets. *Appl Stat*. 2015;64(1):139-55. <https://doi.org/10.1111/rssc.12068>
23. Wood SN, Pya N, Säfken B. Smoothing parameter and model selection for general smooth models. *J Am Stat Assoc*. 2016;111(516):1548-63. <https://doi.org/10.1080/01621459.2016.1180986>
24. Gelman A, Hill J, Yajima M. Why we (usually) don't have to worry about multiple comparisons. *J Res Educ Eff*. 2012;5(2):189-211. <https://doi.org/10.1080/19345747.2011.618213>
25. Sanders JG, Spruijt P, van Dijk M, Elberse J, Lambooy MS, Kroese FM, et al. Understanding a national increase in COVID-19 vaccination intention, the Netherlands, November 2020-March 2021. *Euro Surveill*. 2021;26(36):2100792. <https://doi.org/10.2807/1560-7917.ES.2021.26.36.2100792> PMID: 34505565
26. de Munter AC, Hautvast JLA, Ruijs WLM, Henri Spaan D, Hulscher MEJL, Ruiter RAC. Deciding about maternal pertussis vaccination: associations between intention, and needs and values in a vaccine-hesitant religious group. *Vaccine*. 2022;40(35):5213-22. <https://doi.org/10.1016/j.vaccine.2022.07.036> PMID: 3592713
27. De Vries M, Claassen L, Lambooy M, Leung KY, Boersma K, Timen A. COVID-19 vaccination intent and belief that vaccination will end the pandemic. *Emerg Infect Dis*. 2022;28(8):1642-9. <https://doi.org/10.3201/eid2808.212556> PMID: 35797995

Supplementary material

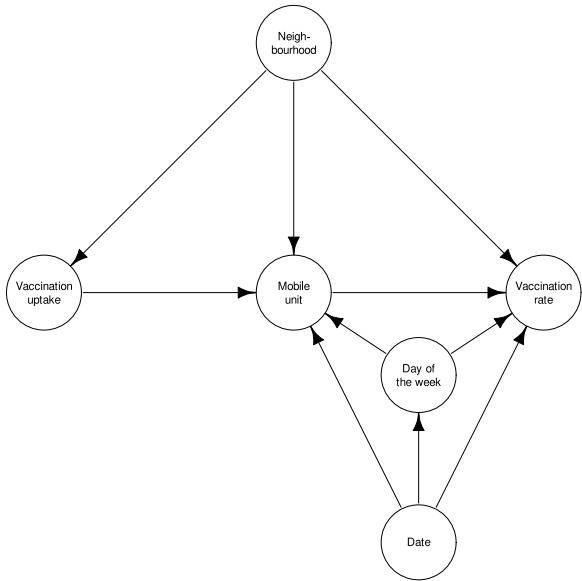


Figure S1. Expected causal diagram leading to the daily vaccination rate. Variables are denoted by the vertices (circles), causal pathways by the edges (arrows).

S2. Vaccination uptake per neighbourhood

Supplementary figure S2 shows the vaccination uptake per neighbourhood on September 1st, 2021. The map indicates geographical variation in vaccination uptake, where the vaccine uptake is lower in the Dutch Bible Belt area, an area with a high concentration of voters for right-wing Christian parties, stretching from the southwest through the centre of the country, to parts in the northeast. In all regions, vaccinations were less likely administered on Sundays, compared to other days of the week. This is the result of limited opening hours for many of the vaccination locations on Sundays. A timeline of the daily vaccine uptake in the 973 neighbourhoods can be found in supplementary file 4.

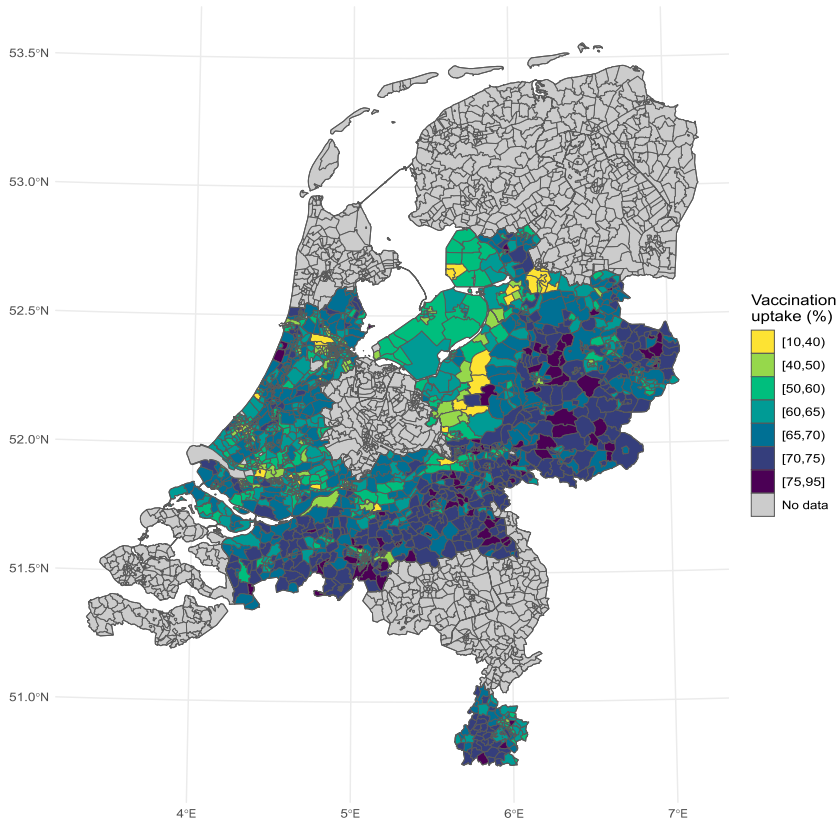


Figure S2. Map showing the percentage of individuals that received at least one COVID-19 vaccination for all neighbourhoods within the 16 included municipal health regions on September 1st, 2021. The thick grey lines indicate the boundaries of the 25 municipal health regions in the Netherlands.

S3. Presence of mobile vaccination units

Supplementary figure 3 shows a timeline of the presence of MV-Units by date and neighbourhood. The blue-coloured bars are dates when a unit was present in that neighbourhood, the yellow-coloured bar are dates when a neighbourhood was indicated as a contiguous neighbourhood. For most neighbourhoods, a unit was present for only one day.

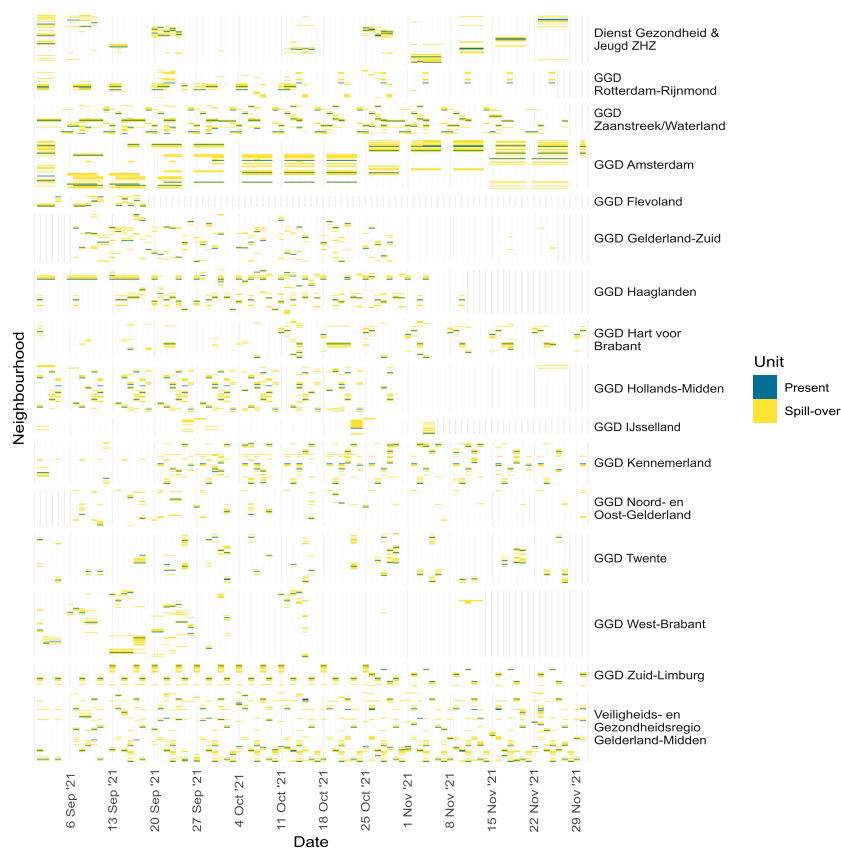


Figure S3. Timeline of the presence of MV-Units for the 973 neighbourhoods that are either targeted (present) or non-targeted (contiguous) (as in figure 3), stratified by municipal health region. Each horizontal line represents a neighbourhood, arranged by neighbourhood-code.

S4. Vaccination rates over time

Supplementary figure 4 shows that vaccination rates varied over time with relatively higher rates in September and November. Furthermore, vaccinations were less likely administered on Sundays, compared to other days of the week.

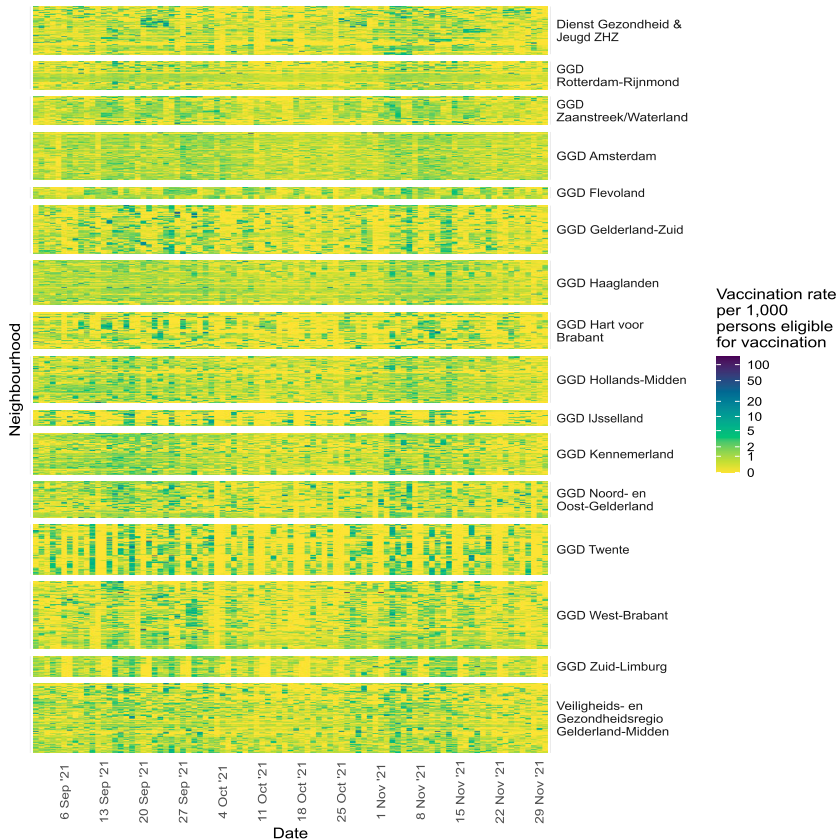


Figure S4. Daily vaccination rates for the 973 neighbourhoods (as in figures 2 and 3) per 1,000 persons eligible for vaccination, stratified by municipal health region. Each horizontal line represents a neighbourhood, arranged by neighbourhood-code.

Chapter 6

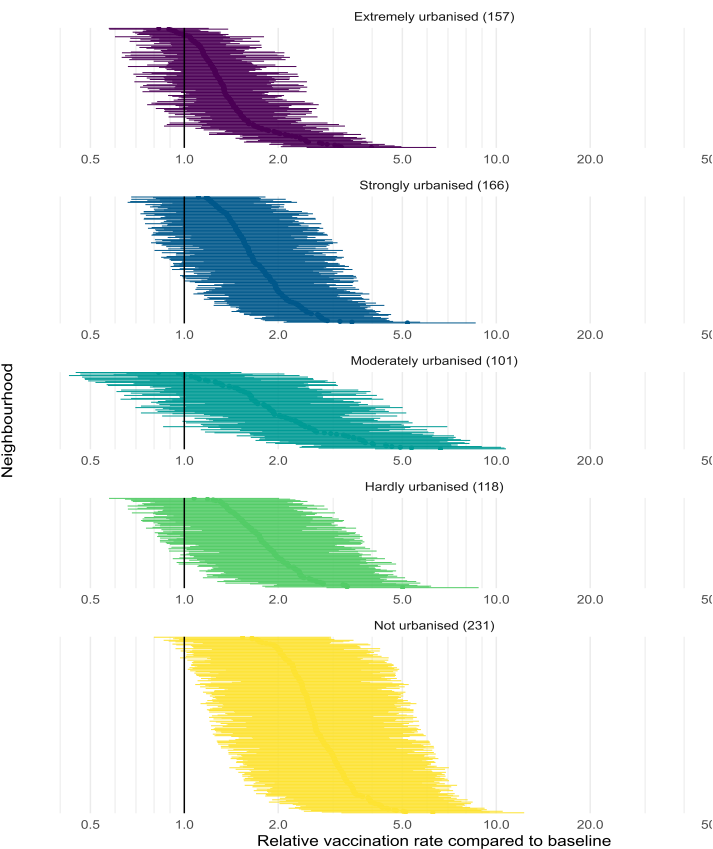


Figure S5. Relative rates and 95% confidence intervals` for contiguous neighbourhoods of daily vaccination rates on a day with a MV-unit deployed, compared to the same neighbourhood with no MV-unit deployed, stratified by level of urbanisation.

Effect of Mobile Vaccination Units

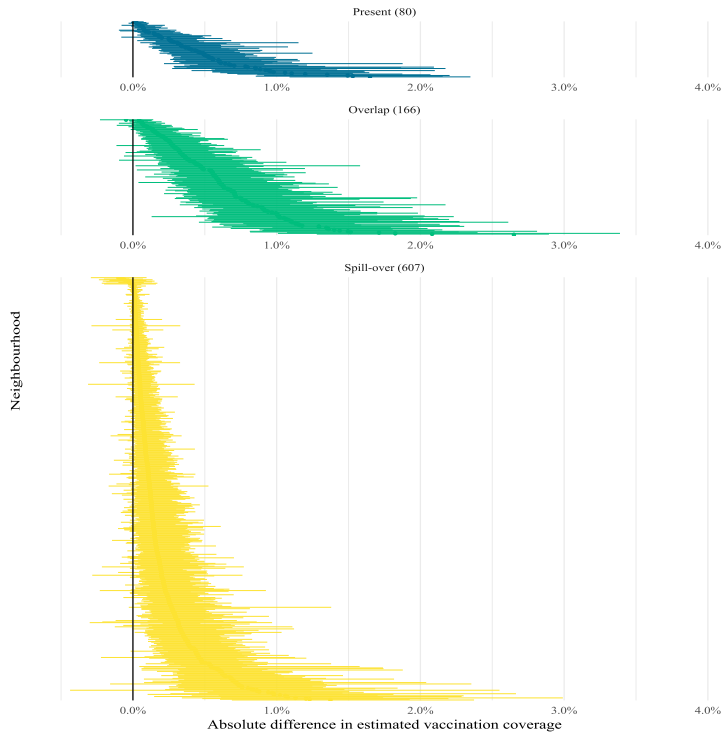


Figure S6. Difference in vaccination uptake in target neighbourhoods, contiguous neighbourhoods and neighbourhoods with overlap of present and spill-over exposure at the end of the study period.



Chapter 7

Summary and general discussion

Summary

Monitoring vaccination coverage is a central component of the National Immunisation Programme (NIP) monitoring and evaluation framework in the Netherlands. High vaccination coverage is needed to ensure individual protection against vaccine-preventable diseases, especially relevant for vulnerable individuals, such as those at increased risk for severe infection. At population level it is needed to achieve herd immunity, thereby protecting those who are not (yet) vaccinated, to prevent outbreaks and to reduce morbidity and mortality. To reach these aims in addition to reaching high overall coverage, it is important to achieve equitable vaccination uptake across all population groups. Equity in vaccination programmes is essential to ensure that all individuals, regardless of their background, have fair access to vaccines and are protected from infectious diseases. Monitoring and reporting vaccination coverage by relevant population subgroups, as well as by social contact networks such as schools, can help identify clusters of under-vaccinated individuals that may not be visible in general geographic analyses. Linking national vaccination registers with sociodemographic data enables comprehensive assessments of vaccination uptake and the identification of determinants of lower coverage.

The aim of this thesis was to investigate sociodemographic factors associated with routine childhood and COVID-19 vaccination coverage in the Netherlands, including changes and trends over time. By analysing linked national registry data, this work sought to identify subgroups at risk of under-vaccination and to provide a basis for further research into the underlying reasons for lower uptake in these groups. This is essential to gain a deeper understanding of barriers and facilitators, which can then be used to generate evidence to inform targeted interventions and promote vaccine equity. The studies in this thesis followed the first step of the World Health Organization's (WHO) Tailoring Immunisation Programmes (TIP) method, which involves a situation analysis in order to describe patterns of vaccination coverage and to explore associated sociodemographic factors in detail. Subsequent steps of the TIP method involve conducting formative research to identify the underlying determinants of under-vaccination in specific groups, followed by the development, implementation, and evaluation of tailored interventions to increase vaccine uptake and reduce inequities.

In the following sections, the key findings of this thesis are summarised, beginning with the assessment of changes in sociodemographic determinants of routine childhood vaccination coverage (Part I), followed by the findings on determinants of COVID-19 vaccination coverage in the adult population in the Netherlands (Part II).

Part I Determinants of routine childhood vaccination

In **Chapter 2**, sociodemographic differences in routine childhood vaccination coverage in the Netherlands were investigated for birth cohorts 2008 to 2020. Using individual-

level linked national registry data, coverage for both MMR and DTaP-IPV vaccinations at age 24 months was analysed in relation to a range of sociodemographic factors. Between these birth cohorts, a substantial decline in vaccination coverage was observed across all population subgroups, with overall MMR coverage decreasing from 95% in the 2008 cohort to 89% in the 2020 cohort. The decline was more pronounced and occurred more rapidly in specific groups, including children of non-Dutch origin (particularly those of Moroccan and Turkish background), children not attending daycare, those living in larger families, children of self-employed mothers, and those in the lowest income households. Multivariable analyses confirmed that these sociodemographic factors were independently associated with lower coverage, and that disparities between groups increased over time; similar trends were seen for DTaP-IPV vaccination. These findings highlight that, alongside the general decline in childhood vaccination coverage, inequities in vaccination coverage between population groups have developed and widened, increasing the risk of outbreaks of vaccine-preventable diseases, particularly where unvaccinated children may cluster. The results underscore the need for further research to understand the underlying causes of under-vaccination in affected subgroups and for the development of targeted interventions to ensure equitable protection of public health.

Lower vaccination coverage becomes a significant public health concern when unvaccinated children cluster geographically, as this increases the risk of outbreaks of vaccine-preventable diseases. Schools are important settings for the transmission of infectious diseases due to the high density of children and frequent close contact, particularly when vaccine coverage is low. In the Netherlands, school denomination may serve as a proxy for social networks, as the school system allows parents to select schools aligned with their religious or philosophical beliefs. Therefore, in **Chapter 3**, childhood vaccination coverage was assessed at the school level, stratified by denomination, for children born between 2013 and 2020. Nationwide vaccination data was linked with sociodemographic registries for children attending primary school on 01-10-2024. Individual vaccination status for first-dose MMR (at 14 months), primary DTaP-IPV (at (2)3-5-11 months), and DTaP-IPV booster (at 4 years) was retrieved from the national immunisation register. Vaccination coverage was stratified by school denomination and birth year. The results showed that vaccination coverage was high (>94%) in general, Catholic, Protestant, collaborative, and other schools, but substantially lower in Anthroposophical (approximately 78% for first-dose MMR and 77% for primary DTaP-IPV), Islamic (74% for first-dose MMR and 75% for primary DTaP-IPV), and Orthodox Protestant schools (57% for first-dose MMR and 58% for primary DTaP-IPV). DTaP-IPV booster coverage was consistently lower than the primary series, with the lowest rates observed in Orthodox Protestant schools. Over time, primary coverage remained stable in most denominations but declined notably in Islamic schools and moderately in Orthodox Protestant schools, while coverage at Anthroposophical schools fluctuated. Adjustment for sociodemographic variables did not substantially alter these patterns. These findings demonstrate

Chapter 7

that although most children, including the majority of unvaccinated children, attend schools with high overall coverage, the clustering of unvaccinated children in Orthodox Protestant, Anthroposophical, and increasingly in Islamic schools poses an increasing risk for outbreaks. This underscores the importance of monitoring vaccination coverage by social networks and further investigating the barriers and drivers of vaccination within these communities.

The COVID-19 pandemic and associated public health measures led to barriers in accessing preventive healthcare, including childhood vaccinations. Early national data indicated a temporary decline in vaccination coverage during periods of strict COVID-19 measures in 2020, although some catch-up occurred, vaccination coverage remained 1-2 percentage points lower compared to the year before. These disruptions occurred against a backdrop of declining vaccination coverage which predated the pandemic, although in the most recent years before the pandemic, after a slight decline from birth cohort 2012 to 2016, coverage stabilised and even showed a slight increase. In addition to logistical barriers, the pandemic coincided with increased dis- and misinformation and growing scepticism towards vaccines, potentially contributing to decreased parental confidence in childhood immunisation. In **Chapter 4**, the longer term impact of the pandemic was assessed using two complementary approaches: an interrupted time series analysis to evaluate changes in national vaccination trends, and a matched-sibling (within-family) analysis to independently assess the pandemic effect by controlling for family-level confounders. The interrupted time series analysis showed, adjusted for key sociodemographic variables, that the slightly increasing trend in first-dose DTaP-IPV vaccination uptake pre-pandemic (before March 2020) changed to a decreasing trend after the start of the pandemic in March 2020 (OR 0.984, 95% CI 0.982-0.985), which accelerated after the end of the pandemic from January 2022 onwards (OR 0.995, 95% CI 0.994-0.997). In line with this, the matched-sibling analysis among households with both vaccinated and unvaccinated children showed that children eligible for vaccination during the pandemic had lower odds of receiving the first dose compared to their pre-pandemic siblings (OR 0.66, 95% CI 0.55-0.80), and those eligible after the pandemic had even lower odds (OR 0.20, 95% CI 0.17-0.25). Also, later birth order was associated with lower odds compared to first-born siblings (second-born: OR 0.42, 95% CI 0.37-0.48). Importantly, the decline in vaccination uptake for second-born children was even more pronounced during and after the pandemic (OR for interaction 0.53, 95% CI 0.42-0.68 during the pandemic; OR for interaction 0.66, 95% CI 0.55-0.79 after the pandemic), while for third- and fourth-born children, the pandemic period was not associated with further declines in their already lower vaccination rates. Both analyses indicate a negative impact of the COVID-19 pandemic on parental vaccination decisions, which may reflect lingering pandemic effects or new post-pandemic factors. These findings highlight the importance of further research to understand the factors driving changes in barriers to vaccination, alongside continued efforts to address vaccine hesitancy in the post-pandemic era.

Part II COVID-19 vaccination coverage

While routine childhood vaccination programmes are well-established in the Netherlands, the COVID-19 vaccination campaign was introduced rapidly in response to the global pandemic. Unlike routine childhood vaccination, which targets children using a routine schedule based on age, COVID-19 vaccination required large-scale mobilisation, prioritisation of vulnerable groups, and ongoing adaptation to changing epidemiological circumstances. These differences in context, urgency, and public perception may have influenced patterns of COVID-19 vaccine uptake and the sociodemographic factors associated with vaccination coverage.

In **Chapter 5**, determinants of COVID-19 vaccine uptake in the adult population of the Netherlands were investigated using nationwide, individual-level linked registry data. By September 2022, 84% of the adult population had received at least one dose of COVID-19 vaccine. Analysis of vaccination records linked to sociodemographic data for all adults aged 18 years and older identified key determinants of primary vaccine uptake. Age was found to be the most important factor, with uptake increasing with age and peaking in the 67–79 year age group. Lower vaccine uptake was observed among individuals with lower personal income, those receiving social benefits, and individuals with a migration background, particularly those with two parents born abroad. These results indicate that, while the vaccination programme successfully reached a large proportion of the adult population, notable disparities in uptake remain. Addressing these inequities requires further research to understand underlying barriers and to inform future vaccination strategies.

Unlike previous chapters, which focused on identifying patterns and determinants of vaccination coverage, **Chapter 6** refers to the subsequent steps of the TIP framework concerning the design, implementation, and evaluation of targeted interventions. In this chapter, a targeted public health intervention aimed at increasing vaccine uptake was evaluated. Specifically, the effectiveness of mobile vaccination units (MV-units) in increasing COVID-19 vaccine uptake was assessed in neighbourhoods with relatively low coverage in the Netherlands. Using national registry data, the impact of MV-unit deployment was analysed in 253 targeted neighbourhoods and compared to 890 contiguous neighbourhoods over the period September to December 2021. The results showed that the deployment of MV-units led to a significant increase in daily vaccination rates, ranging from a twofold increase in urbanised neighbourhoods to over a fourteenfold increase in rural neighbourhoods. The effect was most pronounced in areas with longer travel distances to permanent vaccination locations and in neighbourhoods with a higher proportion of voters for the conservative Reformed Political Party, and was less pronounced in areas with a higher proportion of residents with a migration background. Although the absolute increase in uptake over the intervention period was modest, these findings indicate that targeted public health interventions facilitating easy access, such as MV-units, can help reduce geographic and social health inequalities in vaccine uptake.

General discussion

Vaccination coverage and inequity

Achieving and maintaining high vaccination coverage is essential to protect individuals and the population from vaccine preventable diseases, as highlighted throughout this thesis. However, the results from this thesis demonstrate that achieving this goal is increasingly challenged by both a general decline in coverage and widening inequities between population groups in the Netherlands. In the section below I will discuss the current trends in vaccination coverage in the Netherlands and abroad and relate these to vaccine preventable disease outbreaks. Subsequently, I will discuss widening inequities in relation to vaccine hesitancy and the role of misinformation and politization of vaccination.

Declining vaccination coverage and outbreaks

The analyses in **Part I** revealed a significant decline in routine childhood vaccination coverage across birth cohorts 2008-2020 (**Chapter 2 and Chapter 3**). This downward trend was further exacerbated by the COVID-19 pandemic (**Chapter 4**). For birth cohort 2020, the vaccination coverage by age 2 years was 89% and 91% for first-dose MMR and ≥ 3 -dose DTaP-IPV vaccination, respectively. The most recent Dutch surveillance data confirm that these declines have persisted: for example, the national vaccination coverage report 2025 shows that first-dose MMR coverage for the 2022 birth cohort has dropped further to 87.6%, and primary series DTaP-IPV coverage to 84.9% [1].

WHO estimates of first-dose measles-containing vaccine (MCV1) coverage (Figure 1) show that the decline observed in the Netherlands over the past decade is also evident in several other European countries where MMR vaccination is not mandatory, such as the UK. In contrast, coverage has gradually increased in Switzerland, while in Belgium coverage has remained consistently above 95%. In Sweden, a clear decrease was seen during the pandemic, but coverage appears to have slightly recovered in the years after the pandemic. At WHO European Region level, MCV1 coverage declined from 93% in 2021 to 90.5% in 2023 [2]. Notably, only 9% of countries in the region achieved the WHO-recommended threshold of $\geq 95\%$ MCV1 coverage, while only 30% reached $\geq 90\%$ coverage [2]. These gaps in immunization coverage threaten progress in achieving the Immunization Agenda 2030 (IA2030) goal of eliminating measles in at least five out of six WHO regions by 2030, which requires at least 95% coverage with two doses of MCV in all countries [3]. These figures suggest that the issue of declining vaccine uptake is ongoing, particularly in the aftermath of the COVID-19 pandemic. This is in line with the findings presented in **Chapter 4** of this thesis, which indicate that the decline in vaccination uptake began or intensified during the pandemic and has worsened in the years that followed.

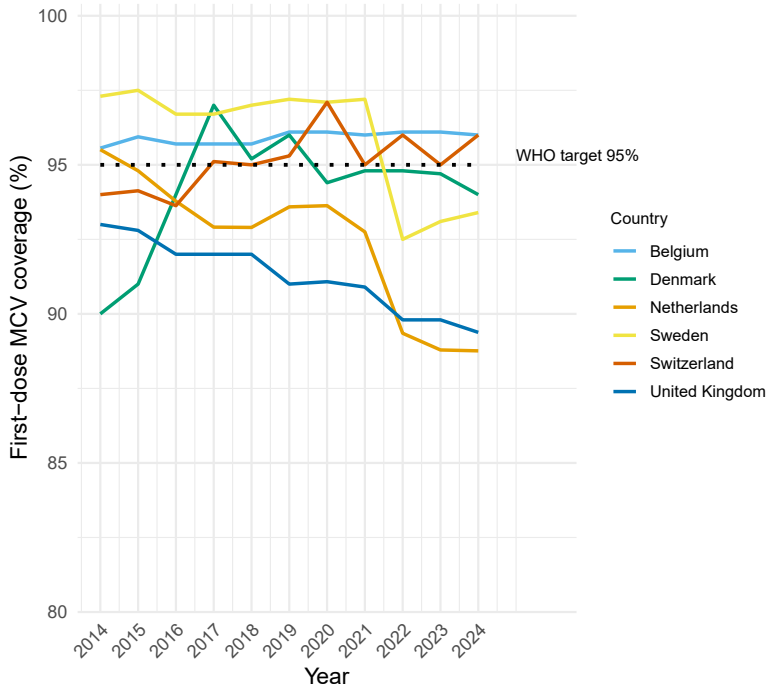


Figure 1. First-dose measles-containing-vaccine coverage (%) in European countries with non-mandatory vaccination, 2014-2024. Data source: WHO Immunization dashboard [4].

The consequences of reduced coverage are already evident, with a resurgence of outbreaks of vaccine-preventable diseases worldwide. Globally, 10.3 million measles cases were reported in 2023, with 57 countries experiencing large outbreaks [5]. According to the ECDC, measles cases have surged across the EU/EEA with over 32,000 cases and 19 deaths reported between February 2024 and January 2025, highlighting persistent gaps in vaccination coverage [6]. Even more recently in 2025, both the United States and Canada have experienced their largest measles outbreaks in decades [7]. Several European countries have also reported substantial increases in measles and pertussis cases, often concentrated in communities or regions with lower vaccination rates [8-12]. Reflecting the severity of the current situation, a number of countries, including the United Kingdom, Canada, Spain, and Austria, have recently lost their 'measles-free' status, underscoring the ongoing challenges in maintaining high enough vaccination coverage to prevent sustained transmission [13].

In the Netherlands, measles cases increased from 7 cases in 2023 to 205 cases in 2024, and 388 more cases reported in the first four months of 2025, most of them

Chapter 7

in unvaccinated children under 13 years [14]. A fatal case was recorded mid-2025 in a once-vaccinated adult with underlying medical conditions [14]. By the end of 2025, the outbreak appears to be over, with fewer than 10 cases per month reported since August and no new cases detected in December 2025 [14, 15]. However, modelling studies predict a large outbreak is likely to occur as soon as a sufficient number of susceptible children from the Orthodox Protestant community attend secondary schools [16]. This is because, when children enter secondary school, they mix with peers from a wider geographic area, which increases the likelihood of disease transmission. In addition, these age groups have limited natural immunity, as they have not previously been exposed to a large outbreak. Mumps notifications also rose sharply to 597 in 2024 (up from 93 in 2023), with the majority of cases among unvaccinated children and concentrated in the Bible Belt region and large cities [14]. Pertussis saw its highest annual numbers since 1976, with over 18,000 cases reported in 2024, primarily affecting infants and teenagers [14]. For pertussis specifically, reduced vaccination coverage and waning immunity, combined with the very low circulation of *Bordetella pertussis* during the pandemic, likely resulted in decreased population immunity and contributed to a larger post-pandemic outbreak. As long as there are groups of unvaccinated individuals within the population, such outbreaks can be expected to recur every few years, particularly in areas or communities with persistently low coverage [17]. The current resurgence of vaccine-preventable diseases is therefore the result of multiple factors, including declining vaccination coverage and changes in population immunity. Nevertheless, addressing low vaccination coverage remains a priority to prevent further outbreaks, both in the Netherlands and in other countries.

Widening inequity

While equality in the NIP ensures that vaccines are offered free of charge and under the same conditions to all, the findings of this thesis highlight persistent and widening inequities in vaccine uptake, both in routine childhood immunisation (**Part I**) and in the adult population during the COVID-19 pandemic (**Part II**). Children from families with lower income, migration backgrounds (specifically from Moroccan, Turkish, Surnames, and Dutch Caribbean origin), from larger families (≥ 4 children), and those attending Orthodox Protestant, Anthroposophical, or Islamic schools, consistently exhibit lower vaccination coverage (**Chapter 2 and Chapter 3**). Similarly, among adults, COVID-19 vaccination uptake is lower in those with lower incomes, individuals receiving social benefits, and persons with a migration background, especially when both parents were born abroad (**Chapter 5**). In research investigating determinants of uptake in follow-up (booster) COVID-19 vaccination rounds recommended to medical risk groups and individuals above 60 years of age, similar sociodemographic patterns are seen [18, 19].

Importantly, these disparities do not stem solely from practical or structural barriers, such as limited access to healthcare, language difficulties, or socioeconomic

disadvantage [20-22]. Informational and cultural environments can also play a role; for instance, communities that are disproportionately exposed to disinformation and misinformation or lack of sufficient exposure to reliable sources of information may experience eroded vaccine confidence and consequently lower uptake [23]. In this context, vaccination coverage inequity reflects an unfair disadvantage: some groups have fewer opportunities to make informed health decisions or to access preventive care [21]. This is particularly concerning because those who are most vulnerable, such as individuals with lower incomes, migration backgrounds, life-style related health risks or elderly, often have the greatest need for vaccination, yet may also be more likely to be sceptical and receptive to misinformation [24]. The findings presented in this thesis demonstrate that equal provision of vaccination services alone is insufficient; instead, achieving true equity requires targeted strategies that address the diverse practical, informational, cultural, and structural challenges faced by different population groups.

Understanding the relationship between equity, vaccine acceptance and vaccine hesitancy requires a nuanced approach. Vaccine acceptance refers to a person's willingness to receive vaccination, while vaccine uptake is the proportion actually vaccinated [17]. Vaccine hesitancy, as defined by the WHO, describes a delay in acceptance or refusal despite availability, and is often influenced by individual and contextual factors [25, 26]. It is important to recognise that inequity may exist when certain groups face additional barriers in accessing accurate information or healthcare services, such as migrants or those with low health literacy, limiting their ability to make informed choices. In such cases, lower vaccine uptake is not solely a matter of personal choice but also a consequence of unequal circumstances. However, the concept of inequity becomes more complex when considering communities where refusal is a deliberate, informed decision, for example based on religious or philosophical convictions, as seen among some Orthodox Protestant groups (as discussed in **Chapter 3**). Here, low vaccine uptake may not stem from disadvantage or lack of opportunity, but from the collective, values-driven choice of the community [27, 28]. While this may not be a classic case of inequity, since the decision is made knowingly, with, assumingly, full access to information and services, it presents major public health challenges due to clustering and increased outbreak risk. The risk of outbreaks can increase over time among specific birth cohorts within the Orthodox Protestant community due to the build-up of susceptibility, even as routine vaccination reduces disease circulation in the rest of the population. From an ethical or legal perspective, informed refusal may therefore be seen not as an inequity, but as a legitimate expression of personal or collective autonomy, exercised within a system that guarantees equal access for all. This underscores the importance of balancing public health objectives, such as preventing outbreaks and protecting vulnerable groups, with respect for individual freedom and societal values. In the Dutch context, where vaccination remains voluntary, public health policies must navigate this tension, ensuring equitable opportunities for immunisation while

Chapter 7

upholding the principle of informed choice.

Equity in vaccination is particularly complex in the context of childhood immunisation, as children depend entirely on their parents or caregivers to make health decisions on their behalf. This lack of agency means that any disadvantage experienced by the caregiver, such as limited health literacy, lack of vaccine confidence, language barriers, or practical difficulties with work schedules and transportation, can directly affect a child's opportunity to be protected against vaccine preventable diseases. In other words, when children are born into families who are vaccine hesitant, whether due to disadvantages or informed decisions based on religious or philosophical beliefs, they may be denied the benefits of immunisation without any say in the matter. From an ethical perspective, this places a special responsibility on public health systems to proactively identify and minimise barriers, address sources of hesitancy, and ensure that all children, regardless of background or parental beliefs, have a fair opportunity to benefit from vaccination. In contrast, adult vaccination involves additional complexities related to personal autonomy, individual risk perception, and - particularly evident during the COVID-19 pandemic - the impact of frequently changing public health recommendations, the role of social media in shaping perceptions, and the effects of ongoing political discussions [29].

Ultimately, addressing inequity in vaccination requires careful differentiation between barriers that limit choice and contexts where choice is exercised freely. Public health efforts must balance the promotion of equity, by removing barriers and ensuring all groups have the opportunity to be protected, with respect for informed individual and community decisions, while also managing the consequences for population health.

Disinformation, misinformation and social media

A growing body of literature identifies disinformation and misinformation as significant contributors to declining vaccine uptake and widening health inequities. Disinformation refers to the intentional dissemination of false information with the purpose of deceiving or manipulating the public, whereas misinformation involves the inadvertent sharing of inaccurate or misleading information, often by individuals unaware of its inaccuracy [30]. The widespread propagation of true and both forms of false information, referred to collectively as an "infodemic", has been greatly amplified by social media and digital communication platforms, which enable rapid and broad dissemination of anti-vaccination narratives [31, 32]. Recent research highlights the prominent role of established platforms such as TikTok and X in shaping public perceptions of vaccine-preventable diseases [33]. Social media can amplify misinformation and anti-vaccine narratives, increasing their visibility and impact on public attitudes and vaccine confidence [23]. The algorithm-driven nature of social media platforms further exacerbates these challenges by promoting content that is personally, emotionally charged or sensational, which can reinforce

users' pre-existing beliefs and contribute to the formation of echo chambers [33, 34]. Persistent myths, such as false associations between vaccines and autism or long-term health risks, continue to circulate widely despite scientific evidence to the contrary [35]. Exposure to conflicting and unreliable information during the COVID-19 pandemic, has been shown to reduce trust in vaccination programmes and vaccination intent, particularly in communities already experiencing structural barriers to healthcare and information access [36]. Another challenge in this context is that it is increasingly difficult for individuals to distinguish accurate information from false or misleading content, especially given the volume and speed at which information circulates online [37]. Given the scale and complexity of the infodemic, there is a clear need for further research into the mechanisms by which dis- and misinformation spreads, the populations most affected, and the development and evaluation of effective interventions to counteract misinformation and rebuild trust in vaccination programmes. This emerging field of research, known as infodemiology, focuses on the study of the distribution and determinants of information (and misinformation) in populations, with the aim of informing public health responses to health-related misinformation [38].

Politicisation of vaccination

The politicization of vaccination further exacerbates the challenges posed by disinformation and misinformation. In recent years, public debate and media coverage have increasingly featured high-profile figures who actively promote anti-vaccination rhetoric and propagate claims that contradict the established scientific consensus. Notably, Robert F. Kennedy Jr., currently serving as the US Secretary of Health and Human Services, has been a prominent voice in the anti-vaccination movement [39]. His influence has recently manifested in changes to the Centers for Disease Control and Prevention (CDC) vaccine safety communications, which have begun to question the scientific consensus on the relationship between vaccines and autism [40]. These alterations have been widely criticized by public health experts and autism specialists, who emphasize that extensive research consistently finds no causal link between vaccines and autism [39]. Beyond individual actors, coordinated disinformation campaigns have played a significant role in the politicization and polarization of vaccine discourse. Research has demonstrated that state actors, including Russia, have utilized social media bots and trolls to disseminate misleading and polarizing content about vaccines [41, 42]. These campaigns are thought to be designed to sow confusion, erode trust in public health authorities, and exacerbate societal divisions. Such tactics have been documented across multiple countries, further complicating the global challenge of maintaining vaccine confidence and undermining efforts to promote evidence-based public health interventions [41-43].

In the European context, similar dynamics have been observed. Political debates around vaccination mandates, personal freedoms, and public health measures have

Chapter 7

become increasingly prominent in several countries, including the Netherlands [44]. During the COVID-19 pandemic, vaccine policies and communication strategies were frequently drawn into broader political and ideological controversies, sometimes fuelling polarization and distrust [45]. The intertwining of vaccination with political and ideological debates not only obscures scientific evidence but also hinders effective communication and public engagement. As recent literature has argued, public health agencies must be prepared to anticipate and respond to politicized narratives in order to protect vaccine confidence and promote informed decision-making [39]. Addressing the politicization of vaccination will require coordinated efforts across public health, policy, and media sectors to counteract misinformation, uphold scientific integrity, and foster public trust.

Methodological and ethical considerations

This section discusses the methodological strengths and limitations of using national registration data in this thesis, as well as the ethical aspects of reporting vaccination coverage by sociodemographic characteristics and subgroups.

Strengths and limitations of registration data

The use of national registration data represents a major strength of this thesis, providing a comprehensive and objective foundation for monitoring vaccination coverage and identifying sociodemographic disparities. Electronic immunisation registers such as Praeventis (for routine childhood vaccinations) and CIMS (for COVID-19 vaccinations) offer highly up-to-date, individual-level data linked to the population register, with precise vaccination information including dates, enabling robust analyses of trends and subgroup differences. A particular advantage in the Dutch context is the ability to link vaccination data to sociodemographic and socioeconomic variables from Statistics Netherlands (CBS) using a pseudonymised citizen service number. This infrastructure allows for almost complete and accurate individual-level linkage, achieving virtually 100% matching via the secure CBS Remote Access environment, and ensures that both vaccination and background data are sufficiently current for epidemiological analyses. These features minimize recall bias and misclassification, and allow for granular, timely surveillance at both national and local levels. However, registration data are inherently limited to recorded data and do not capture the underlying attitudes, beliefs, or reasons for non-vaccination, which are essential for understanding the mechanisms behind observed disparities. Additionally, certain groups, such as recent migrants who are not yet registered in the municipal population database, may be underrepresented in the data, which could result in slight bias in subgroup analyses. Lastly, complex data not collected for research purposes, such as the data from CBS, also poses challenges; since these registration systems are primarily designed for administrative and operational needs rather than scientific inquiry, researchers may encounter issues such as missing values, varying definitions or coding practices over time, and the need for extensive

data cleaning and management before meaningful analyses can be performed. However, close collaboration between CBS and RIVM for this thesis, as well as access to expert knowledge available at CBS regarding the specific databases greatly facilitated accurate data interpretation.

Informed consent and monitoring challenges

The issue of informed consent for the registration of childhood vaccinations will continue to pose challenges for future research and surveillance of vaccination coverage in the Netherlands. If consent is not given, vaccinations are recorded anonymously and lack key identifying information, making it impossible to distinguish vaccinated from unvaccinated children. As a result, these anonymous records are excluded from standard vaccination coverage calculations, causing the reported rates to underestimate actual vaccination levels in the Netherlands [1]. While the results from **Chapter 2** and **Chapter 3** were largely unaffected by the recent consent policy change, since most children studied received their scheduled vaccinations prior to its implementation, in more recent cohorts (**Chapter 4**), the impact became more evident. Specifically, a portion of the observed reduction in vaccination coverage can be attributed to misclassification in the outcome resulting from non-consent; in the study population of **Chapter 4**, the average proportion of non-consented was relatively small: 1.7% for first-dose DTaP-IPV vaccination. A sensitivity analysis was performed in which 16% of unvaccinated children eligible after the policy change were reclassified as vaccinated, reflecting the estimated proportion of vaccination records missing due to lack of parental consent. However, this adjustment does not fully eliminate potential bias, as non-consent is likely not random and may be linked to similar factors that influence vaccination uptake. For the primary series of COVID-19 vaccination (**Chapter 5** and **Chapter 6**), the proportion of non-consent was higher, at 7%. This greater degree of misclassification introduces additional uncertainty into coverage estimates for COVID-19 vaccination. For COVID-19 booster vaccinations, the percentage of non-consent was around 2% [14]. Aside vaccination coverage estimates, a study has shown that the informed consent procedure can introduce information bias when estimating COVID-19 vaccine effectiveness, particularly among groups with high vaccination coverage or high consent rates, such as in this case older adults with high vaccination coverage [46]. Recognizing these challenges, there are ongoing discussions and indications that the Dutch government may revert to an opt-out consent model, whereby vaccination data are included in national registers unless individuals (or parents) explicitly refuse. Despite incomplete consent, nationwide data continues to provide a reliable basis for monitoring vaccination patterns. Importantly, the main objective of these analyses is to identify sociodemographic patterns and disparities in vaccine uptake rather than to produce exact coverage estimates. This ensures that, as long as non-consent is modest, meaningful differences between subgroups can still be detected and used to guide public health interventions.

Chapter 7

Ethical considerations: reporting by population subgroups

Reporting vaccination coverage by population subgroups is an important and scientifically justified practice in epidemiology and public health. Disaggregated data are essential for accurately identifying health inequalities, monitoring trends, and informing targeted interventions that address the needs of underserved or at-risk populations [26]. Without such detailed reporting, important disparities may remain concealed within overall averages, resulting in missed opportunities for prevention and the perpetuation of health inequities [22, 26]. For example, **Chapter 2** showed a steep decline in vaccination coverage among Dutch children from Moroccan origin from birth cohort 2014 onwards, particularly among children of second generation migrants, which was unknown before. Despite equality in vaccination programmes, sociodemographic determinants such as income and education significantly influence immunisation uptake even in high-income countries. Accordingly, the World Health Organization strongly recommends that countries routinely monitor and report immunisation coverage by relevant sociodemographic characteristics [26, 47]. This approach is fundamental to promoting equity and ensuring that all population groups are adequately reached by vaccination programmes [26].

However, publicly drawing attention to communities with lower vaccination coverage raises important ethical concerns. If not approached with care, such practices risk fuelling stigma, reinforcing stereotypes, or even inciting discrimination, particularly when the broader structural and systemic barriers to vaccination are overlooked [48-50]. In addition to the risk of stigma, researchers and public health professionals have an ethical responsibility to avoid causing harm to individuals or groups as a result of how data are reported or communicated. According to Dijkstra and colleagues, much of health promotion operates within a narrow paradigm that often fails to recognize its own potential for contributing to stigma and the persistence of health inequalities [49]. The narrow focus tends to prioritise individual behaviour change, while failing to address the significant influence of (and distrust in) sociopolitical actors (such as social media, pharmaceutical companies, political parties with agendas that may promote vaccine hesitancy), resulting in persistence of socioeconomic health inequalities [48, 49].

These concerns highlight the importance of framing subgroup data within a broader context and explicitly taking into account the structural inequities underlying observed differences in coverage [48, 49]. It is recommended that public health reporting avoid attributing disparities to individual or cultural shortcomings, and instead emphasize the influence of access, trust, and systemic barriers. Furthermore, there is a growing call for participatory approaches, involving affected communities in the interpretation and communication of data, to ensure that reporting is respectful, contextualized, and empowering rather than stigmatizing [50] [51]. To mitigate risks of misinterpretation and stigma, it is important to present quantitative data as objectively as possible, avoid unfounded assumptions about the role of culture,

and, where possible, report absolute numbers alongside proportions. Furthermore, careful communication is essential, including the use of non-stigmatizing and inclusive language that emphasizes respect and equality. Finally, it should be recognized that sociodemographic characteristics, such as migration background, are proxies rather than causal determinants of vaccine uptake. In reality, vaccination behaviour is influenced by a mix of factors such as fear of side effects, exposure to dis- and misinformation, religious beliefs, and practical barriers. Therefore, caution is warranted when interpreting associations, and efforts should be made to seek more precise indicators of underlying mechanisms.

In recognition of these ethical complexities, for publishing and communicating the results of **Chapter 2** and **Chapter 3** a structured moral deliberation method (moreel beraad) was used to guide decision-making around the publication of subgroup-specific vaccination coverages and determinants, specifically regarding the results of lower coverage among Dutch children of Moroccan origin. This seven-step approach provided a systematic framework for balancing the potential benefits of transparency and targeted action against the risks of stigmatization or harm [52]. Moral deliberation enabled the research team and other involved disciplines to critically consider potential actions, seek input from diverse perspectives, and reflect on uncertainties, assumptions and the responsibilities toward both the population at large and vulnerable communities. Based on this experience, I recommend that such deliberative methods are more widely adopted in epidemiological research and public health practice, particularly when working with sensitive data or vulnerable groups. Applying structured ethical frameworks can help ensure that research and reporting are not only scientifically sound but also socially responsible, thereby promoting trust, fairness, and equity in public health initiatives.

Policy implications

The ongoing decline in vaccination coverage and the widening of sociodemographic disparities highlight the need for renewed attention to effective interventions. In line with the TIP framework, it is essential to first investigate the barriers and facilitators of vaccination among subgroups with lower coverage. However, as a variety of interventions to increase vaccine uptake have already been widely implemented across countries, this section will briefly discuss common approaches and effects and reflect on the challenges of evaluating their impact. Additionally, the relevance and ongoing debate surrounding mandatory vaccination policies in public health will be considered.

Chapter 7

Current interventions

Many countries have responded to stagnating or declining childhood vaccination rates by implementing a variety of interventions aimed at increasing vaccine uptake. As shown in the international comparison by Kroneman and colleagues [53], these interventions generally fall into four categories: restrictive measures for the unvaccinated (such as expanding mandatory vaccination policies or limiting access to certain services), financial incentives for healthcare providers or parents, logistical support to make vaccination more accessible (for example, by providing alternative vaccination sites like schools), and targeted communication campaigns to enhance vaccine knowledge and acceptance among both the public and healthcare professionals. The majority of initiatives focused on improving communication and education, though restrictive measures and logistical solutions were also widely adopted across countries [53].

Despite the widespread implementation of these strategies, evidence on their effectiveness remains limited, in part because multiple interventions are often implemented simultaneously, making it difficult to attribute changes in vaccination coverage to a single measure [53]. However, certain intervention, such as sending personal invitations and reminders for vaccination appointments, have consistently been shown to increase vaccine uptake. For example, studies from Denmark and other countries demonstrate that proactive reminder systems, including personal letters and scheduled appointments, can significantly improve childhood vaccination coverage [54]. Such approaches, including reminders and planned vaccination dates, are already standard practice in the Netherlands in the NIP. For other interventions, particularly those introduced as part of broader, multifaceted strategies, evidence remains limited due to the complexity of real-world public health environments and the relative scarcity of randomized controlled trials. This complexity was also apparent in the evaluation of the deployment of mobile vaccination units in the Netherlands to increase COVID-19 vaccine uptake, as described in **Chapter 6** of this thesis. The MV-units were introduced alongside other interventions, which complicates the attribution of observed changes in vaccination coverage to one specific approach. These observations highlight the importance of ongoing evaluation and the use of robust, quasi-experimental study designs to better understand what works in practice [55]. Moreover, as emphasized in the WHO TIP framework, it is essential that interventions are not only evidence-informed but also tailored to the specific barriers and needs identified within target groups. This means moving beyond one-size-fits-all solutions and designing strategies that are responsive to local context and the challenges faced by under-vaccinated subpopulations. Such an approach increases the likelihood that interventions will be both effective and equitable.

In line with the need for context-specific strategies, in the Netherlands, there is increasing emphasis on implementing neighbourhood-level (“wijkgerichte”) interventions to address areas with lower vaccination uptake. The national

government has allocated dedicated funding to support locally tailored strategies, particularly in neighbourhoods where coverage lags behind. Key elements of these interventions include building confidence and trust regarding vaccination by collaborating with community stakeholders and ensuring easy, low-threshold access to vaccination services. In the Amsterdam municipality, for example, MMR and HPV vaccination coverage among children has increased for the second year in a row, and disparities between neighbourhoods have become smaller [56]. These observations underline the potential of context-specific, community-based approaches for reducing inequalities and improving overall vaccination coverage.

Mandatory vaccination

Mandatory vaccination policies have been introduced or expanded in several European countries in response to declining vaccination coverage, increased vaccine hesitancy, and outbreaks of vaccine-preventable diseases [57]. Mandatory vaccination means that individuals are legally required to be vaccinated, or to have their children vaccinated. The specific requirements, enforcement mechanisms, and consequences for non-compliance vary widely between countries and often include financial penalties and denial of access to education and childcare, and sometimes involves prosecution or imprisonment of the non-complier [57]. Some policies allow exemptions for medical, religious, or philosophical reasons, while others are more restrictive. Evidence shows that such policies can lead to increased vaccine uptake and help control outbreaks, as reported in countries such as France, Germany, and Italy [57-60]. For example, France expanded its list of mandatory childhood vaccines from three to eleven in 2018, which contributed to improved reported coverage for vaccines with previously low uptake, particularly among infants [58, 59, 61]. Similarly, Germany's introduction of mandatory measles vaccination for schoolchildren and certain professionals in 2020 was associated with higher reported immunisation rates and a narrowing of regional coverage gaps [59]. Italy also reported notable improvements in childhood vaccine coverage following the extension of mandates [62].

However, mandatory vaccination policies are not without drawbacks. One study investigating the effect of partial compulsory vaccination has shown they may provoke resistance, increase distrust in health authorities, and be perceived as infringing on personal autonomy, especially in societies that value individual freedom and voluntary health decisions [63]. Another study found that the effectiveness of mandatory vaccination policies depends on public trust in the government, particularly in its commitment to vaccine quality and safety. Excessive sanctions or a lack of transparency can undermine credibility and discourage future compliance [64]. Furthermore, resistance to mandatory vaccination is particularly strong in countries where cultural norms place a high value on personal choice and voluntary health decisions [59, 63]. During the COVID-19 pandemic, for example, measures

Chapter 7

such as restricting access to public spaces for unvaccinated individuals without a recent negative SARS-CoV-2 test result led some to feel coerced, further eroding trust in public health authorities [65]. Moreover, while mandates can boost uptake, their impact on fostering informed, long-term adherence to preventive behaviours remains limited, and their sustainability is questioned [57, 61]. In the Netherlands, vaccination remains voluntary, with a strong emphasis on informed decision making, public trust, and individual autonomy. Policymakers and experts generally agree that any move toward mandatory vaccination should be carefully balanced with ethical considerations, proportionality, and broad public support [65]. In recent years, there has been public and political debate about introducing mandatory vaccination for children attending daycare centres. However, such a measure would have limited impact on measles prevention, as many unvaccinated children in daycare are still too young to have received the first dose of the measles vaccine. The Dutch approach continues to rely on recommendations and prioritize education, engagement, and supportive public health measures over compulsion, reflecting the belief that sustainable high coverage is best achieved through trust and dialogue [57]. This aligns with nudge theory, a concept from behavioural economics that promotes healthier behaviours by subtly guiding individuals, for example through reminders, while still allowing them to make their own decisions [66]. The use of nudges fits the Dutch context, as it encourages vaccine uptake while respecting individual autonomy and supporting informed decision-making.

Future perspectives for research

This thesis, grounded in the WHO TIP framework, has provided comprehensive situation and trend analyses of vaccination coverage and its sociodemographic determinants in the Netherlands. Building on these findings, future research should advance through the subsequent TIP steps by deepening our understanding of why disparities persist and identifying which tailored strategies are most effective for promoting equitable vaccine uptake. To achieve this, both epidemiological and social-behavioural research should be further developed and increasingly integrated.

Epidemiological research

A significant achievement of this thesis is the establishment of an infrastructure linking national vaccination registers to rich sociodemographic data within the secure CBS Remote Access environment. This infrastructure provides a foundation for continued, detailed monitoring of vaccination coverage, enabling rapid detection of emerging trends and disparities across a variety of vaccines and population groups.

Looking ahead, aside from monitoring, this infrastructure can be leveraged to address new and pressing questions in vaccination research. First, it enables the assessment of determinants and coverage for vaccines and immunisations beyond those studied in this thesis, such as human papillomavirus (HPV), rotavirus, respiratory syncytial virus

(RSV) and maternal vaccines (pertussis, influenza). Ongoing and planned research at RIVM already utilises this infrastructure to monitor uptake and identify gaps for these and other vaccines introduced in the NIP. Second, as the vaccine landscape evolves, it will be important to study the impact of new vaccine introductions on established vaccine coverage, exploring, for example, whether the introduction of maternal vaccines affects childhood vaccine acceptance, or whether shifts in parental attitudes due to COVID-19 vaccination campaigns have spill-over effects on routine childhood immunisation. In addition, as more years pass since the onset of the COVID-19 pandemic, future studies, including those with cohorts born after 2024, will provide deeper insight into the potential lasting effects of the pandemic on vaccination behaviour, coverage trends, and sociodemographic disparities. This will build on the analyses presented in **Chapter 4**, which included children born up to 2024, and allow for the assessment of whether observed declines and changes in uptake persist, recover, or evolve over time. Importantly, the analysis on trends in MMR and DTaP-IPV vaccination coverage conducted in **Chapter 2** and **Chapter 3** of this thesis can be repeated in the future, allowing for direct comparison over time to assess whether changes in vaccination coverage, determinants, or inequities have occurred.

A key area for future research is the role of social networks in shaping vaccination behaviour. The availability of detailed CBS data makes it possible to investigate clustering of under-vaccinated individuals not only by geography, but also within social structures such as extended families, schools, households, neighbourhoods, and working environments. Understanding how social connections influence vaccine decision-making and identifying patterns of clustering can provide crucial insights for targeted interventions. Further methodological development and interdisciplinary collaboration is needed to refine network analysis and ensure that research into social networks is both informative and sensitive to avoid the risk of stigmatisation.

Social and behavioural research

While epidemiological monitoring is essential for identifying which groups are under-vaccinated, it does not elucidate the underlying reasons for suboptimal coverage. This knowledge is essential to develop equitable interventions. To address this gap, social and behavioural research is crucial. The subsequent steps in the WHO TIP framework focus on understanding the attitudes, beliefs, and contextual factors that drive vaccination decisions, particularly among groups identified as at-risk in this thesis. This approach goes beyond quantifying disparities to explore the mechanisms and motivations that shape vaccine acceptance or hesitancy.

Building on the sociodemographic patterns revealed by this thesis, future research should prioritise in-depth qualitative and quantitative studies within communities where under-vaccination is most pronounced, such as Dutch families with a Moroccan or Turkish migration background and households with lower socioeconomic status.

Chapter 7

Therefore, the Dutch National Public Health Institute (RIVM) established the SocioVax programme [67] which aims to understand and address the behavioural and social factors influencing vaccination uptake across diverse population groups. SocioVax focuses on three main goals: (1) understanding why people choose to vaccinate or not, by examining socio-demographic, psychological, and environmental factors and how these change over time; (2) identifying effective ways to inform, support, and facilitate vaccination decisions, particularly for groups with lower uptake; and (3) sharing insights with professionals and policymakers to improve communication and the organisation of vaccination programmes. The programme combines targeted qualitative research with systematic, population-level monitoring, such as annual SocioVax surveys that track parental attitudes, vaccine confidence, and trust in health authorities. Drawing on the WHO's model of behavioural and social drivers of vaccination, SocioVax provides essential evidence to inform tailored interventions and promote equitable vaccine coverage in the Netherlands.

A key area for future social-behavioural research involves examining the dynamic and rapidly evolving landscape of (dis- and mis)information, especially in the context of social media. Studies should investigate how information about vaccination is accessed, interpreted, and disseminated within different communities, and how these processes influence collective attitudes and individual choices. Moreover, research should focus on strategies to counteract misinformation, foster resilience against disinformation, and strengthen trust in health authorities and the vaccination programme.

Participatory research and public involvement

A further direction for future research is the integration of participatory approaches and patient and public involvement (PPI) in both the design and evaluation of vaccination interventions and research. Participatory research involves engaging community members, stakeholders, and affected populations as active partners throughout the research process, from defining research questions to interpreting results and co-developing interventions [68, 69].

In the context of vaccination, participatory research can help identify barriers and facilitators that may not be visible to external researchers and can build the social capital and ownership necessary for successful implementation. Recent evidence from a scoping review highlights that community-based participatory research (CBPR) approaches in vaccination promotion are effective in both identifying context-specific challenges and empowering communities to co-create and implement tailored interventions [68]. Furthermore, CBPR has been identified as a promising practice for addressing vaccine hesitancy, rebuilding trust, and reducing health disparities among racial and ethnic minority communities [51]. Involving members from target populations in the interpretation and dissemination of research findings can also help navigate sensitive results, ensuring that they are communicated in a

respectful and contextually appropriate manner. This collaborative approach can prevent stigmatisation, facilitate open dialogue about challenging or unexpected outcomes, and support the co-development of constructive solutions that resonate with target groups.

Concluding remarks

Maintaining and restoring high, equitable vaccine coverage, both for routine childhood immunisations and in the context of pandemics, is fundamental for public health. Achieving this not only protects individuals against vaccine-preventable diseases, but also helps to strengthen society by reducing health disparities. The COVID-19 pandemic showed the crucial role of vaccines in mitigating the burden of mortality and morbidity associated with the pandemic in the population and more particular protecting vulnerable groups, some of whom are also more likely to be vaccine hesitant. At the same time, sustaining high coverage for routine vaccinations remains essential to prevent the resurgence of vaccine-preventable diseases and to protect those who cannot be vaccinated. Recent trends in declining coverage and widening disparities, as demonstrated in this thesis, highlight the urgent need to move beyond universal approaches and implement ongoing surveillance and tailored interventions for groups with persistently lower uptake. Equitable access to vaccines depends not only on logistical and structural factors, but also on the availability of reliable information, public confidence in vaccination, and the ability to address dis- and misinformation and the politicization of vaccine discourse. Future research should combine epidemiological, social, and behavioural perspectives to better understand determinants of vaccine uptake and support the development of effective interventions. Collaboration between public health services, researchers, Statistics Netherlands, NGOs, and policymakers is essential to restore and maintain high coverage, reduce inequities, and strengthen resilience against future public health threats. Achieving and maintaining equitable high vaccination coverage is a shared responsibility and is central to the protection and health of all members of society and society as a whole.

Chapter 7

References

1. Van Lier A, Hament J, Holwerda M, Westra M, Giebers H, Maas Nvd, et al. Vaccinatiegraad Rijksvaccinatieprogramma Nederland. Verslagjaar 2025.: RIVM; 2025.
2. Plans-Rubio P. Measles Vaccination Coverage and Anti-Measles Herd Immunity Levels in the World and WHO Regions Worsened from 2019 to 2023. *Vaccines (Basel)*. 2025;13(2) doi:10.3390/vaccines13020157.
3. World Health Organization. Immunization Agenda 2030: A global strategy to leave no one behind. Geneva, Switzerland; 2020.
4. World Health Organization. Immunization dashboard 2026 [26 Jan 2026]. Available from: <https://immunizationdata.who.int/>
5. Minta AA, Ferrar M, Antoni S, Lambert B, Sayi TS, Hsu CH, et al. Progress Toward Measles Elimination - Worldwide, 2000-2023. *MMWR Morb Mortal Wkly Rep*. 2024;73(45):1036–42 doi:10.15585/mmwr.mm7345a4
6. European Centers for Disease Control and Prevention (ECDC). Measles on the rise again in Europe: time to check your vaccination status 2025 [Available from: <https://www.ecdc.europa.eu/en/news-events/measles-rise-again-europe-time-check-your-vaccination-status>].
7. Gould KA. Progress Toward Measles Elimination-Absence of Measles as an Endemic Disease in the United States. *Dimens Crit Care Nurs*. 2025;44(4):227 doi:10.1097/DCC.0000000000000708.
8. European Centers for Disease Control and Prevention (ECDC). Increase of pertussis cases in the EU/EEA, 8 May 2024. Stockholm: ECDC; 2024.
9. World Health Organization. Measles and rubella monthly update - WHO European Region - September 2024. WHO; 2024.
10. Unicef. Media brief. European region reports highest number of measles cases in more than 25 years.; 2025
11. Jones R, Youlden H, McDermott C, Perry M, Norwood J. Understanding measles infection and how to improve uptake of the MMR vaccine. *Nursing children and young people*. 2025;37(6):34–42 doi:10.7748/ncyp.2025.e1562.
12. Perry M, Cottrell S, Gravenor MB, Griffiths L. Determinants of Equity in Coverage of Measles-Containing Vaccines in Wales, UK, during the Elimination Era. *Vaccines [Internet]*. 2023; 11(3).
13. GAVI. The Vaccine Alliance. What does it mean to lose ‘measles-free’ status and can countries get it back? 2026 [Available from: <https://www.gavi.org/vaccineswork/what-does-it-mean-lose-measles-free-status-and-can-countries-get-it-back>].
14. Roon AM, Lanooij SJ, de Melker HE. The National Immunisation Programme in the Netherlands. Surveillance and developments in 2023-2024. 2025.
15. Rijksinstituut voor Volksgezondheid en Milieu (RIVM). Actualiteiten over mazelen. [Current events regarding measles]. 2025 [Available from: <https://www.rivm.nl/mazelen/actueel>].
16. Munday JD. Projected increase in risk of large measles outbreaks in the Netherlands as susceptible children enter secondary school in 2025/26. *Int J Infect Dis*. 2025:108240 doi:10.1016/j.ijid.2025.108240.
17. Hahné SB, K., Farrington P. Vaccination Programmes. Epidemiology, Monitoring, Evaluation.: Routledge; 2022.

- 18.van Roekel C, Labuschagne L, Pijpers J, van Roon A, Smagge B, Ferreira JA, et al. Factors associated with COVID-19 autumn 2022 booster uptake in the Netherlands among older adults aged ≥ 60 years and younger adults with chronic conditions. *Vaccine*. 2024;42(2):146–55 doi:10.1016/j.vaccine.2023.12.027.
- 19.Osmenaj T, van Roon A, Labuschagne L, Pijpers J, Smagge B, de Melker H, et al. Determinants for not keeping up to date with COVID-19 vaccination in the 2023 vaccination round among medical risk groups, the Netherlands. *Vaccine*. 2025;62:127561 doi:10.1016/j.vaccine.2025.127561.
- 20.de Figueiredo A, Karafillakis E, Larson HJ. State of vaccine confidence in the EU + UK. The vaccine Confidence Project. 2020.
- 21.MacDonald NE, Hesitancy SWGoV. Vaccine hesitancy: Definition, scope and determinants. *Vaccine*. 2015;33(34):4161–4 doi:10.1016/j.vaccine.2015.04.036.
- 22.Boyce T, Gudorf A, de Kat C, Muscat M, Butler R, Habersaat KB. Towards equity in immunisation. *Euro Surveill*. 2019;24(2) doi:10.2807/1560-7917.ES.2019.24.2.1800204.
- 23.Wilson SL, Wiysonge C. Social media and vaccine hesitancy. *BMJ Glob Health*. 2020;5(10) doi:10.1136/bmjgh-2020-004206.
- 24.Senteio C, Fields SD, Pritam Singh RK, Namata Kamoga RM, Andrews E, Gandsman D, et al. Overcoming health misinformation in marginalized groups: a systematic review. *Int J Equity Health*. 2025;24(1):323 doi:10.1186/s12939-025-02657-2.
- 25.World Health Organization. Ten threats to global health in 2019: World Health Organization WHO; 2019 [Available from: <https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019>].
- 26.World Health Organization. European Region. A practical guide to indentifying, adresssing and tracking inequities in immunization. . Copenhagen: WHO Regional Office for Europe 2024.
- 27.Ruijs WL, Hautvast JL, van der Velden K, de Vos S, Knippenberg H, Hulscher ME. Religious subgroups influencing vaccination coverage in the Dutch Bible belt: an ecological study. *BMC Public Health*. 2011;11:102 doi:10.1186/1471-2458-11-102.
- 28.Ruijs WLM, Hautvast JLA, van Ijzendoorn G, van Ansem WJC, van der Velden K, Hulscher MEJL. How orthodox protestant parents decide on the vaccination of their children: a qualitative study. *BMC Public Health*. 2012;12(1):408 doi:10.1186/1471-2458-12-408.
- 29.Pennisi F, Genovese C, Gianfredi V. Lessons from the COVID-19 Pandemic: Promoting Vaccination and Public Health Resilience, a Narrative Review. *Vaccines (Basel)*. 2024;12(8) doi:10.3390/vaccines12080891.
- 30.Pérez-Escolar M, Lilleker D, Tapia-Frade A. A systematic literature review of the phenomenon of disinformation and misinformation. . *Media and communication*. 2023;11(2):76–87 doi:<https://doi.org/10.17645/mac.v11i2.6453>.
- 31.Larson HJ, Gakidou E, Murray CJL. The Vaccine-Hesitant Moment. *N Engl J Med*. 2022;387(1):58–65 doi:10.1056/NEJMr2106441.
- 32.Sharma LD, Joshi KJ, Acharya TA, Dwivedi MG, Sethy GB. Infodemics during era of COVID-19 pandemic: A review of literature. *J Family Med Prim Care*. 2022;11(8):4236–9 doi:10.4103/jfmpc.jfmpc_2446_21.
- 33.Basch CH, Denholtz C, Castillo RG, Jaime C. Public health in the age of TikTok: A content analysis of measles narratives. *Int J Infect Dis*. 2025;160:108055 doi:10.1016/j.ijid.2025.108055.

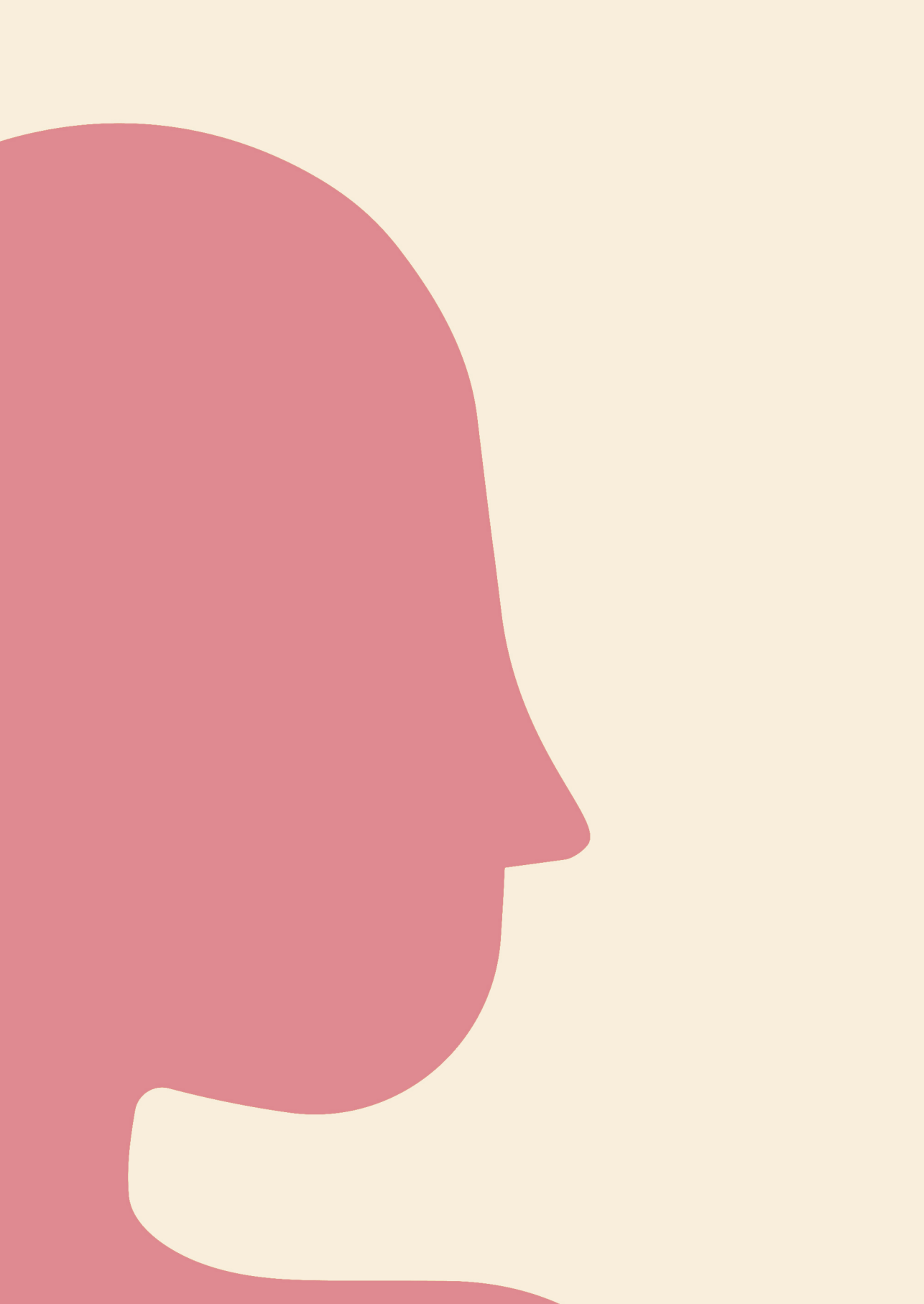
Chapter 7

34. Lutkenhaus RO, Jansz J, Bouman MPA. Mapping the Dutch vaccination debate on Twitter: Identifying communities, narratives, and interactions. *Vaccine X*. 2019;1:100019 doi:10.1016/j.jvax.2019.100019.
35. Gulati S, Sharawat IK, Panda PK, Kothare SV. The vaccine-autism connection: No link, still debate, and we are failing to learn the lessons. *Autism*. 2025;29(7):1639–45 doi:10.1177/13623613251345281.
36. Loomba S, de Figueiredo A, Piatek SJ, de Graaf K, Larson HJ. Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. *Nat Hum Behav*. 2021;5(3):337–48 doi:10.1038/s41562-021-01056-1.
37. Chou WS, Oh A, Klein WMP. Addressing Health-Related Misinformation on Social Media. *JAMA*. 2018;320(23):2417–8 doi:10.1001/jama.2018.16865.
38. Mavragani A. Infodemiology and Infoveillance: Scoping Review. *J Med Internet Res*. 2020;22(4):e16206 doi:10.2196/16206.
39. Kasstan-Dabush B, Bedford H, Chantler T. Public health agencies need to be ‘Kennedy ready’: take action now to protect vaccine confidence. *Epidemiol Infect*. 2025;153:e91 doi:10.1017/S0950268825100368.
40. Taylor L. CDC website altered to suggest possible link between vaccines and autism. *BMJ*. 2025;391:r2470 doi:10.1136/bmj.r2470.
41. Broniatowski DA, Jamison AM, Qi S, AlKulaib L, Chen T, Benton A, et al. Weaponized Health Communication: Twitter Bots and Russian Trolls Amplify the Vaccine Debate. *Am J Public Health*. 2018;108(10):1378–84 doi:10.2105/AJPH.2018.304567.
42. Warner EL, Barbat J, Duncan KL, Yan K, Rains SA. Vaccine misinformation types and properties in Russian troll tweets. *Vaccine*. 2022;40(6):953–60 doi:10.1016/j.vaccine.2021.12.040.
43. Broniatowski DA, Quinn SC, Dredze M, Jamison AM. Vaccine Communication as Weaponized Identity Politics. *Am J Public Health*. 2020;110(5):617–8 doi:10.2105/AJPH.2020.305616.
44. Kennedy J. Populist politics and vaccine hesitancy in Western Europe: an analysis of national-level data. *Eur J Public Health*. 2019;29(3):512–6 doi:10.1093/eurpub/ckz004.
45. Backhaus I, Hoven H, Kawachi I. Far-right political ideology and COVID-19 vaccine hesitancy: Multilevel analysis of 21 European countries. *Soc Sci Med*. 2023;335:116227 doi:10.1016/j.socscimed.2023.116227.
46. van Werkhoven CH, de Gier B, McDonald SA, de Melker HE, Hahne SJM, van den Hof S, et al. Informed consent for national registration of COVID-19 vaccination caused information bias of vaccine effectiveness estimates mostly in older adults: a bias correction study. *J Clin Epidemiol*. 2024;174:111471 doi:10.1016/j.jclinepi.2024.111471.
47. World Health Organization. European Region. How to equity proof your policies and interventions: a resource guide for planners and policy makers to leave no-one behind. Copenhagen: WHO Regional Office for Europe; 2023.
48. Dijkstra I, Horstman K. ‘Known to be unhealthy’: Exploring how social epidemiological research constructs the category of low socioeconomic status. *Soc Sci Med*. 2021;285:114263 doi:10.1016/j.socscimed.2021.114263.
49. Dijkstra I, Penders B, Horstman K. How health promotion prevents itself from tackling health inequalities. A critical analysis of Dutch health promotion’s paradigm through its handbooks (1995–2022). *SSM - Qualitative Research in Health*. 2025;7 doi:10.1016/j.ssmqr.2025.100533.

50. Burgess RA, Osborne RH, Yongabi KA, Greenhalgh T, Gurdasani D, Kang G, et al. The COVID-19 vaccines rush: participatory community engagement matters more than ever. *Lancet*. 2021;397(10268):8–10 doi:10.1016/S0140-6736(20)32642-8.
51. O'Bryan SE, Muñoz F, Smith D, Bearse A, Melendrez B, Kamdar B, et al. Community based participatory research as a promising practice for addressing vaccine hesitancy, rebuilding trust and addressing health disparities among racial and ethnic minority communities. *Human Vaccines and Immunotherapeutics*. 2024;20(1) doi:10.1080/21645515.2024.2326781.
52. De Jong L, Geraerds F, Meij R. Over het Morele Oordeel. H de Koningh & F van de Wouw (Red), *Handboek integriteit: Ervaringen uit de praktijk en achtergronden* 2006. p. 133–46.
53. Kroneman M, Fermin A, Rechel B, Allin S, Anell A, Behmane D, et al. Initiatives to increase childhood vaccination coverage: an international comparison. *Health Policy*. 2025;158 doi:10.1016/j.healthpol.2025.105351.
54. Funk T, Norgaard SK, Hallundbaek L, Grau J, Ethelberg S, Valentiner-Branth P, et al. Effect of a proactive childhood vaccination reminder system on vaccination coverage and uptake in Denmark: A register-based cohort study. *Vaccine*. 2025;54:126934 doi:10.1016/j.vaccine.2025.126934.
55. de Vocht F, Katikireddi SV, McQuire C, Tilling K, Hickman M, Craig P. Conceptualising natural and quasi experiments in public health. *BMC Med Res Methodol*. 2021;21(1):32 doi:10.1186/s12874-021-01224-x.
56. Gemeente Amsterdam. Meer Amsterdamse kinderen gevaccineerd in 2025 2026 [More Amsterdam children vaccinated in 2025 2026]. [Available from: <https://www.amsterdam.nl/nieuws/nieuwsoverzicht/amsterdamse-kinderen-gevaccineerd-2025/>].
57. Odone A, Dallagiocoma G, Frascella B, Signorelli C, Leask J. Current understandings of the impact of mandatory vaccination laws in Europe. *Expert Rev Vaccines*. 2021;20(5):559–75 doi:10.1080/14760584.2021.1912603.
58. Bechini A, Boccalini S, Ninci A, Zanobini P, Sartor G, Bonaccorsi G, et al. Childhood vaccination coverage in Europe: impact of different public health policies. *Expert Review of Vaccines*. 2019;18(7):693–701 doi:10.1080/14760584.2019.1639502.
59. Farina S, Maio A, Gualano MR, Ricciardi W, Villani L. Childhood Mandatory Vaccinations: Current Situation in European Countries and Changes Occurred from 2014 to 2024. *Vaccines (Basel)*. 2024;12(11) doi:10.3390/vaccines12111296.
60. Ward JK, Colgrove J, Verger P. Why France is making eight new vaccines mandatory. *Vaccine*. 2018;36(14):1801–3 doi:10.1016/j.vaccine.2018.02.095.
61. Partouche H, Gilberg S, Renard V, Saint-Lary O. Mandatory vaccination of infants in France: Is that the way forward? *Eur J Gen Pract*. 2019;25(1):49–54 doi:10.1080/13814788.2018.1561849.
62. Signorelli C, Odone A, Cella P, Iannazzo S. Childhood vaccine coverage in Italy after the new law on mandatory immunization. *Ann Ig*. 2018;30(4 Supple 1):1–10 doi:10.7416/ai.2018.2227.
63. Betsch C, Böhm R. Detrimental effects of introducing partial compulsory vaccination: experimental evidence. *Eur J Public Health*. 2016;26(3):378–81 doi:10.1093/eurpub/ckv154.
64. Jel'nov A. Mandatory vaccination. *Theory and Decision*. 2025:1–15.
65. Simons RC, Bak MAR, Legemaate J, Ploem C. Towards a less voluntary vaccina-

Chapter 7

- tion policy in the Netherlands? Findings from an expert interview study. *Health Policy*. 2023;133:104841 doi:10.1016/j.healthpol.2023.104841.
66. Navin MC. The Ethics of Vaccination Nudges in Pediatric Practice. *HEC Forum*. 2017;29(1):43–57 doi:10.1007/s10730-016-9311-2.
67. Rijksinstituut voor Volksgezondheid en Milieu (RIVM). SocioVax: social science research on vaccination 2025 [Available from: <https://www.rivm.nl/en/behavioural-science/socio-vax>].
68. Zhang Y, Xie YJ, Yang L, Cheung K, Zhang Q, Li Y, et al. Community-based participatory research (CBPR) approaches in vaccination promotion: a scoping review. *Int J Equity Health*. 2024;23(1):227 doi:10.1186/s12939-024-02278-1.
69. Haldane V, Chuah FLH, Srivastava A, Singh SR, Koh GCH, Seng CK, et al. Community participation in health services development, implementation, and evaluation: A systematic review of empowerment, health, community, and process outcomes. *PLoS One*. 2019;14(5):e0216112 doi:10.1371/journal.pone.0216112.



Appendices

Nederlandse samenvatting

List of publications

PhD Portfolio

Dankwoord

Curriculum Vitae

Nederlandse samenvatting

Het monitoren van de vaccinatiegraad is een fundamenteel onderdeel van het monitorings- en evaluatiekader van het Rijksvaccinatieprogramma (RVP) in Nederland. Een hoge vaccinatiegraad is nodig om individuele bescherming te bieden tegen door vaccinatie te voorkomen ziekten. Op populatieniveau is een hoge vaccinatiegraad belangrijk om groepsimmunitet te bereiken, waardoor ook mensen die (nog) niet gevaccineerd zijn worden beschermd en uitbraken, ziekte en sterfte worden voorkomen. Gelijkwaardig bereik in vaccinatieprogramma's is essentieel om ervoor te zorgen dat iedereen, ongeacht achtergrond, zo goed mogelijk beschermd is tegen door vaccinatie te voorkomen infectieziekten. Het monitoren en rapporteren van vaccinatiegraad naar relevante sociaaldemografische subgroepen in de bevolking, evenals naar sociale netwerken zoals scholen, kan helpen bij het identificeren van clusters van ondergevacceerde personen. In algemene geografische analyses kunnen clusters gemaskeerd zijn.

In dit proefschrift is onderzocht welke sociaaldemografische factoren samenhangen met de vaccinatiegraad van het Rijksvaccinatieprogramma (RVP) en de COVID-19-vaccinatie in Nederland, en hoe dit zich ontwikkelde over de tijd. Analyse van gekoppelde landelijke registratiedata maakte het mogelijk subgroepen te identificeren waarbij de vaccinatiegraad lager ligt dan het landelijk gemiddelde. Dit vormt de basis voor onderzoek naar de achterliggende oorzaken. De studies in dit proefschrift zijn de eerste stap van de Tailoring Immunisation Programmes (TIP)-methode van de Wereldgezondheidsorganisatie (WHO). Deze stap bestaat uit een situatieanalyse, waarin patronen in de vaccinatiegraad en de samenhangende sociaaldemografische factoren in detail worden beschreven. In de volgende fasen van de TIP-methode wordt verdiepend onderzoek naar de oorzaken van ondervaccinatie in specifieke groepen uitgevoerd, waarna interventies kunnen worden ontwikkeld, geïmplementeerd en geëvalueerd om de vaccinatiegraad te verhogen en ongelijkheid te verminderen.

In de volgende paragrafen worden de belangrijkste bevindingen van dit proefschrift samengevat, te beginnen met de analyse van veranderingen in sociaaldemografische determinanten van de vaccinatiegraad bij kinderen (Deel I), gevolgd door de bevindingen over determinanten van COVID-19 vaccinatie bij volwassenen in Nederland (Deel II).

Deel I Determinanten van reguliere kindervaccinaties in Nederland

In **Hoofdstuk 2** onderzochten we de sociaaldemografische verschillen in de vaccinatiegraad bij kinderen in Nederland voor geboortecohorten 2008 tot en met 2020. Met behulp van individueel gekoppelde landelijke registratiedata analyseerden we de vaccinatiegraad voor zowel bof-mazelen-rodehond (BMR) vaccinatie als difterie-kinkhoest-tetanus-polio (DKTP) vaccinatie op de leeftijd van 24 maanden, in relatie tot sociaaldemografische factoren. In alle bevolkingsgroepen nam de vaccinatiegraad af:

de BMR-graad daalde van 95% in cohort 2008 naar 89% in cohort 2020. De daling was sterker en sneller in bepaalde groepen. Dit betrof kinderen met een niet-Nederlandse achtergrond (met name bij Nederlandse kinderen met een Marokkaanse en Turkse afkomst), kinderen die niet naar het kinderdagverblijf gaan, kinderen uit grotere gezinnen, kinderen van moeders die zelfstandig ondernemer zijn, en bij kinderen uit de laagste inkomenshuishoudens. Deze factoren hingen onafhankelijk van elkaar samen met een lagere vaccinatiegraad en verschillen tussen bevolkingsgroepen in de tijd zijn toegenomen. De DKTP vaccinatiegraad liet vergelijkbare trends zien. Deze bevindingen tonen aan dat de verschillen tussen bevolkingsgroepen zijn toegenomen. Hierdoor is het risico op uitbraken van door vaccinatie te voorkomen ziekten groter geworden, vooral wanneer ongevaccineerde kinderen clusteren. Dit benadrukt de noodzaak voor verder onderzoek naar de achterliggende oorzaken van een lage vaccinatiegraad in het algemeen en in specifieke populatiegroepen waar de vaccinatiegraad achterblijft.

Een lage vaccinatiegraad vormt een belangrijk volksgezondheidsrisico wanneer ongevaccineerde kinderen geografisch en/of sociaal clusteren omdat dit de kans op uitbraken vergroot. Scholen zijn belangrijke locaties voor verspreiding van infectieziekten vanwege de hoge dichtheid van kinderen en veelvuldig nauw contact. In Nederland is grondwettelijk vastgelegd dat ouders scholen kunnen kiezen op basis van religieuze of levensbeschouwelijke overtuiging (vrijheid van onderwijs). De zogeheten schooldenominatie kan dienen als een indicator voor sociale netwerken. Daarom onderzochten we in **hoofdstuk 3** de vaccinatiegraad op schoolniveau, uitgesplitst naar schooldenominatie en geboortjaar, voor kinderen geboren tussen 2013 en 2020. We koppelden vaccinatiegegevens aan sociaaldemografische gegevens van alle kinderen die op 01-10-2024 stonden ingeschreven in het basisonderwijs. De individuele vaccinatiestatus voor de eerste dosis BMR (op leeftijd van 14 maanden), de primaire serie DKTP (op leeftijd van (2)3-5-11 maanden), en de DKTP-booster (op leeftijd van 4 jaar) werd verkregen uit het nationale vaccinatieregister. De resultaten laten zien dat de vaccinatiegraad hoog was (>94%) op algemeen-openbare, katholieke, protestantse, samenwerkende en overige scholen, maar aanzienlijk lager op antroposofische (78% voor de eerste dosis BMR en 77% voor de primaire serie DKTP), islamitische (74% voor de eerste dosis BMR en 75% voor de primaire serie DKTP) en orthodox-protestantse scholen (57% voor de eerste dosis BMR en 58% voor de primaire serie DKTP). De vaccinatiegraad voor de DKTP-booster was consequent lager dan voor de primaire serie, met de laagste percentages op orthodox-protestantse scholen. Door de tijd heen bleef de primaire vaccinatiegraad stabiel binnen de meeste denominaties, maar daalde opvallend sterk op islamitische scholen en enigszins op orthodox-protestantse scholen. Op antroposofische scholen fluctueerde de vaccinatiegraad. Multivariabele analyse waarbij werd gecorrigeerd voor sociaaldemografische factoren veranderde deze patronen nauwelijks. Deze bevindingen tonen aan dat de meeste kinderen, inclusief het merendeel van de niet-gevaccineerde kinderen, naar scholen gaan met

een hoge algehele vaccinatiegraad. De clustering van niet-gevaccineerde kinderen op orthodox-protestantse, antroposofische en in toenemende mate islamitische scholen vormt echter een groeiend risico op uitbraken. Het monitoren van vaccinatiegraad via sociale netwerken en het verder onderzoeken van barrières en motieven voor vaccinatie binnen deze gemeenschappen is belangrijk.

De COVID-19-pandemie en de daaraan gerelateerde maatregelen om verspreiding van infecties te voorkomen hebben geleid tot barrières in de toegang tot preventieve zorg, waaronder de kindervaccinaties. Vroege studies tijdens de COVID-19 pandemie lieten zien dat er tijdens periodes van strikte maatregelen in 2020 sprake was van een tijdelijke daling in de vaccinatiegraad. Hoewel er inhaalsessies werden georganiseerd, bleef de vaccinatiegraad 1-2 procentpunt lager vergeleken met het jaar ervoor. Voorafgaand aan de pandemie was er al een dalende trend in vaccinatiegraad te zien (geboortecohort 2012 tot 2016) met daarna stabilisatie en zelfs een lichte stijging in de meest recente jaren voor de pandemie (geboortecohort 2017 tot 2019). Naast logistieke barrières viel de pandemie samen met een toename van des- en misinformatie en groeiend scepticisme ten opzichte van vaccins, wat mogelijk heeft bijgedragen aan een afgenomen vertrouwen in reguliere kindervaccinaties. In **hoofdstuk 4** onderzochten we de langere termijn impact van de pandemie met behulp van twee complementaire analyses: een interrupted time series-analyse om veranderingen in de nationale vaccinatiegraad-trend te evalueren, en een matched-sibling (binnen-gezinnen) analyse om het onafhankelijke effect van de pandemie te schatten door te controleren voor counfounders op gezinsniveau. De interrupted time series-analyse liet zien dat de licht stijgende trend in de eerste dosis DKTP vaccinatie vóór de pandemie (voor maart 2020) veranderde in een dalende trend na het begin van de pandemie in maart 2020 (OR 0,984, 95% CI 0,982-0,985), welke versneld doorzette na het einde van de pandemie vanaf januari 2022 (OR 0,995, 95% CI 0,994-0,997), gecorrigeerd voor sociaaldemografische variabelen. In overeenstemming hiermee liet de matched-sibling analyse binnen gezinnen met zowel gevaccineerde als niet-gevaccineerde kinderen zien dat kinderen die tijdens de pandemie in aanmerking kwamen voor vaccinatie een lagere kans hadden om de eerste dosis DKTP te ontvangen vergeleken met hun pre-pandemische broers/zussen (OR 0,66, 95% CI 0,55–0,80), en dat kinderen die ná de pandemie in aanmerking kwamen, zelfs een nog lagere kans hadden (OR 0,20, 95% CI 0,17–0,25). Ook bleek geboortevolgorde geassocieerd te zijn met vaccinatieopkomst, waarbij later geboren kinderen minder vaak gevaccineerd zijn dan eerstgeborenen (tweede kind: OR 0,42, 95% CI 0,37–0,48). Het effect van tweede geboren kind zijn (ten opzichte van eerst geboren kind) was nog sterker tijdens en na de pandemie (OR voor interactie 0,53, 95% CI 0,42–0,68 tijdens de pandemie; OR voor interactie 0,66, 95% CI 0,55–0,79 na de pandemie). Voor derde en vierde en later geboren kinderen hing de pandemieperiode niet samen met verdere daling van hun toch al lagere vaccinatiegraad. Beide analyses wijzen op een negatief effect van de COVID-19-pandemie op de vaccinatiebeslissingen van ouders. Dit duidt op aanhoudende pandemie-effecten of nieuwe factoren in het

post-pandemische tijdperk.

Deel II COVID-19 vaccinatiegraad

Het COVID-19-vaccinatieprogramma werd in rap tempo opgezet als reactie op de snelle verspreiding van het virus en de urgente noodzaak om ernstige ziekte en sterfte te voorkomen. In tegenstelling tot de kindervaccinaties, die kinderen op vaste leeftijden bereiken via een standaard schema, vereiste de COVID-19-campagne grootschalige mobilisatie, prioritering van kwetsbare groepen en voortdurende aanpassing aan veranderende epidemiologische omstandigheden. Deze verschillen in context, urgentie en publieke perceptie hebben mogelijk invloed gehad op het patroon van COVID-19-vaccinatie en de sociaaldemografische factoren die samenhangen met de vaccinatiegraad.

In **hoofdstuk 5** onderzochten we de determinanten van COVID-19-vaccinatie bij volwassenen met behulp van landelijke registratiedata. In september 2022 had 84% van de volwassen bevolking minimaal één dosis ontvangen. Analyse van de vaccinatiegegevens gekoppeld aan sociaaldemografische kenmerken liet zien dat leeftijd de belangrijkste determinant was: de vaccinatiegraad nam toe met de leeftijd en bereikte het hoogste niveau bij volwassenen van 67-79 jaar. Lagere vaccinatiegraad werd gevonden bij mensen met een lager persoonlijk inkomen, bij mensen die een uitkering ontvingen en bij personen met een migratieachtergrond, vooral als beide ouders in het buitenland geboren waren. Dit laat zien dat, hoewel het programma een groot deel van de bevolking bereikte, er nog steeds aanzienlijke verschillen bestaan. Om deze ongelijkheid te verkleinen is aanvullend onderzoek nodig naar de onderliggende oorzaken, zodat toekomstige vaccinatiestrategieën hier beter op kunnen inspelen.

In tegenstelling tot de eerdere hoofdstukken, die zich richtten op het in kaart brengen van (trends in) determinanten van vaccinatiegraad, richten we ons in **hoofdstuk 6** op de volgende stappen van de TIP-methode: het ontwerpen, uitvoeren en evalueren van gerichte interventies. In dit hoofdstuk evalueerden we een doelgerichte interventie, namelijk het inzetten van mobiele vaccinatie eenheden (zogenoemde prikbusen) om de COVID-19-vaccinatiegraad te verhogen in wijken waar de vaccinatiegraad achterbleef. Met behulp van landelijke registratiedata vergeleken we het effect van prikbusen in 253 geselecteerde interventie wijken met 890 aangrenzende wijken in de periode september tot december 2021. De resultaten laten zien dat de inzet van prikbusen heeft geleid tot een significante stijging van het aantal dagelijkse vaccinaties: een verdubbeling in stedelijke buurten en zelfs een veertienvoudige toename in landelijke buurten. Het effect was het grootst in wijken met een langere reisafstand tot vaste priklocaties en in wijken met een groter aandeel kiezers op de Staatkundig Gereformeerde Partij (SGP) tijdens de Tweede Kamer verkiezingen in 2021, en het minst in wijken met veel inwoners met een migratieachtergrond. Hoewel de absolute toename in vaccinatiegraad beperkt was, laten deze resultaten zien dat

gerichte interventies die de toegankelijkheid vergroten, zoals prikbusen, kunnen bijdragen aan het verkleinen van geografische en sociale gezondheidsverschillen in vaccinatiegraad.

Conclusies en toekomstperspectief

In **hoofdstuk 7** werden de bevindingen uit de voorgaande hoofdstukken besproken, met een reflectie op de implicaties voor de volksgezondheid en een vooruitblik op toekomstige ontwikkelingen. Het behouden en herstellen van een hoge vaccinatiegraad in alle bevolkingsgroepen is van fundamenteel belang voor de volksgezondheid. Dit beschermt niet alleen individuen tegen door vaccinatie te voorkomen ziekten, maar draagt ook bij aan het verkleinen van gezondheidsverschillen binnen de samenleving. De COVID-19-pandemie heeft het cruciale belang van vaccins aangetoond in het verminderen van sterfte en ziektelast, vooral voor kwetsbare groepen waarin vaccinatietwijfel relatief vaker voorkomt. Tegelijkertijd blijft het essentieel om een hoge vaccinatiegraad voor reguliere (kinder)vaccinaties te behouden om heropleving van ziekten en risico's voor mensen die niet gevaccineerd kunnen worden te voorkomen. De recente daling van de vaccinatiegraad en toenemende ongelijkheid in vaccinatiegraad binnen Nederland, zoals in dit proefschrift beschreven, onderstrepen de noodzaak om verder te kijken dan universele benaderingen. Juist het inzetten van blijvende monitoring en gerichte interventies voor groepen met een structureel lagere vaccinatiegraad is nodig. Gelijkaardig bereik van vaccinaties hangt niet alleen af van logistieke en structurele factoren, maar ook van betrouwbare informatie, vertrouwen in vaccinatie en het effectief kunnen tegengaan van desinformatie en de politisering van het vaccinatiedebat. Toekomstig onderzoek zou epidemiologische, sociale- en gedragswetenschappelijke perspectieven moeten combineren om de determinanten van vaccinatiegedrag nog beter te begrijpen en effectieve interventies te ontwikkelen. Samenwerking tussen de publieke gezondheidszorgorganisaties, onderzoekers, het CBS, NGO's en beleidsmakers is essentieel om verschillen in vaccinatiegraad te verkleinen en de weerbaarheid tegen toekomstige bedreigingen te vergroten. Het herstellen en behouden van een hoge en gelijke vaccinatiegraad is een gedeelde verantwoordelijkheid en staat centraal in de bescherming en gezondheid van de burger, en van de samenleving als geheel.

List of publications

In this Thesis

Pijpers J, van Roon A, van Roekel C, Labuschagne L, Smagge B, Ferreira JA, de Melker H, Hahné S. Determinants of COVID-19 vaccine uptake in the Netherlands: a nationwide registry-based study. *Vaccines*. 2023 Aug 24;11(9):1409.

Lambooi MS, **Pijpers J**, van de Kasstelee J, Fransen MP, Hahné SJ, Hof N, Kroese FM, de Melker H, van Dijk M, Uiters E, de Bruin M. Mobile vaccination units to increase COVID-19 vaccination uptake in areas with lower coverage: a within-neighbourhood analysis using national registration data, the Netherlands, September–December 2021. *Eurosurveillance*. 2024 Aug 22;29(34):2300503.

Pijpers J, Van Roon A, Schipper M, Stok M, van den Hof S, van Gaalen R, Hahné S, de Melker H. The decrease in childhood vaccination coverage and its sociodemographic determinants, the Netherlands, birth cohorts 2008 to 2020. *Eurosurveillance*. 2025 Oct 2;30(39):2500251.

Pijpers J, van Roon A, van den Hof S, van Gaalen R, de Melker H, Hahné S. Large differences in MMR and DTaP-IPV vaccination coverage among primary schools by denomination, the Netherlands, 2024. *Vaccine*. 2026 Feb 6;72:128137.

Pijpers J, Haverkate, M, van Gaalen R, Hahné S, de Melker H, van den Hof S. Assessing the impact of the COVID-19 pandemic on routine childhood vaccination uptake. 2026. Submitted. Preprint available.

Not in this Thesis

Pijpers J, den Boer ML, Essink DR, Ritmeijer K. The safety and efficacy of miltefosine in the long-term treatment of post-kala-azar dermal leishmaniasis in South Asia–A review and meta-analysis. *PLoS neglected tropical diseases*. 2019 Feb 11;13(2):e0007173.

de Gier B, van Asten L, Boere TM, van Roon A, van Roekel C, **Pijpers J**, van Werkhoven CH, van den Ende C, Hahné SJ, de Melker HE, Knol MJ. Effect of COVID-19 vaccination on mortality by COVID-19 and on mortality by other causes, the Netherlands, January 2021–January 2022. *Vaccine*. 2023 Jul 12;41(31):4488-96.

van Roekel C, Labuschagne L, **Pijpers J**, van Roon A, Smagge B, Ferreira JA, Hahné S, de Melker H. Factors associated with COVID-19 autumn 2022 booster uptake in the Netherlands among older adults aged ≥ 60 years and younger adults with chronic conditions. *Vaccine*. 2024 Jan 12;42(2):146-55.

Smagge B, Labuschagne L, **Pijpers J**, van Roon A, van den Hof S, Hahné S, de Melker H. Factors associated with lower COVID-19 vaccine uptake among populations with a migration background in the Netherlands. *Epidemiology & Infection*. 2025 Jan;153:e87.

Osménaj T, van Roon A, Labuschagne L, **Pijpers J**, Smagge B, de Melker H, van den Hof S, Hahné S. Determinants for not keeping up to date with COVID-19 vaccination in the 2023 vaccination round among medical risk groups, the Netherlands. *Vaccine*. 2025 Aug 30;62:127561.

Hofsink Q, Lissenberg-Witte BI, Haggenburg S, Goorhuis A, Hazenberg MD, Rutten CE, den Tex P, de Vries EG, van der Veldt AA, Kemmeren JM, de Keizer NF, Huigens PC, Dinmohamed, AG, van Roon A, **Pijpers J**, van Roekel C, van den Hof S, Hahné SJM, de Gier B, Heijmans J, Nijhof IS. COVID-19 Vaccine Effectiveness in Patients With Hematologic Malignancies: A Nationwide Cohort Study. *The Journal of Infectious Diseases*. 2025 Oct 14;jiaf523.

PhD Portfolio

	Year	ECTC
Mandatory courses		
Leiden University Onboarding Inform & Connect		
Responsible research – two activities	2025	0.5
Workshop scientific conduct	2025	0.2
Basic methods and reasoning in biostatistics (exemption)	-	-
Scientific courses and training activities		
Introduction to data linkage (University of Southampton, online)	2022	0.5
Methods to evaluate public health interventions (NIHES)	2023	1.5
Statistical prediction (RIVM)	2023	0.5
Regression analysis	2024	1.5
Causal inference	2024	3
Analysis of repeated measurements	2024	1.5
Survival analysis	2024	1.5
Advanced epidemiological methods	2024	2
Prediction modelling and intervention research	2024	3
Meta-analysis	2025	1
Social & behavioural sciences: Principles and applications for public health (ECDC, online)	2025	0.5
Transferable skills courses and training activities		
Begin-R	2021	0.3
Tidy-R	2021	0.3
Vis-R	2021	0.3
Stat-R	2021	0.3
Writing of a data management plan	2023	0.1
Workshop creativity	2023	0.1
GIT course	2023	0.1
Conferences		
ESCAIDE 2021 (online attendance)	2021	0.8
SIG Symposium: Let's sail through the numbers	2022	0.2
ESCAIDE 2022 Stockholm (attendance)	2022	0.8

	Year	ECTC
European Public Health Conference (EUHPHA) Dublin (attendance + poster presentation)	2023	1.3
ESCAIDE 2024 Stockholm (attendance + poster presentation)	2024	1.3
ESPID 2025 Bucharest (attendance + poster viewing)	2025	1.3
Other activities		
Intervision (Proneri, RIVM)	2022-2023	1
Journal club: monthly article discussions for PhD students at the epidemiology and surveillance department of the RIVM	2023-2025	2
Attendance at weekly scientific seminars organised by the epidemiology and surveillance department of the RIVM, including two presentations	2021-2025	2
Weekly 'Tuesday morning discussions' organised by the epidemiology and surveillance department of the RIVM, including three presentations	2021-2025	2
Contribution to annual reports:		
The National Immunisation Programme in the Netherlands. Surveillance and developments.	2024-2025	-
Vaccination coverage of the National Immunisation Programme in the Netherlands.		
Guest Lecture 'Vaccination coverage National Immunisation Programme' at VU Amsterdam for Health Science students	2024	-
Presentation SES/SAL Seminar at CBS	2025	-
Presentation at Vaccinology Masterclass	2025	-

Dankwoord

Het boek is af! Na ruim vier uitdagende, leerzame en vooral leuke jaren ligt het resultaat er dan eindelijk, en daar ben ik ontzettend trots op. Dit proefschrift was er niet gekomen zonder de steun, begeleiding en hulp van velen, die ik hier graag wil bedanken.

Om te beginnen mijn promotie team. Wat een geluk heb ik met jullie gehad. Jullie feedback was vaak al binnen als ik nog lag bij te komen na versturen van een nieuwe versie van een manuscript. Susan, wat een aanwinst voor EPI en het LUMC dat jij sinds afgelopen jaar de leerstoel epidemiologie van infectieziekten bekleedt. Dankzij jouw scherpe vragen en inzichten ben ik steeds een stap verder gekomen in mijn onderzoek. Ruben, hoewel onze samenwerking op afstand plaats vond, was deze voor mij niet minder waardevol. Jouw kennis van de CBS-data in combinatie met je enthousiasme voor het onderwerp hebben mijn werk echt beter gemaakt. Leuk dat we elkaar nu regelmatig 'in het wild' tegenkomen op het CBS kantoor in Den Haag! Hester, als copromotor en leidinggevende ben je van onschatbare waarde geweest dankzij je enorme ervaring en betrokkenheid, zowel op professioneel als persoonlijk vlak. Heel veel dank voor je fijne begeleiding, het altijd even inchecken als het tegenzat én de gezellige momenten zoals mijn afscheid bij jou thuis - dat heeft echt het verschil gemaakt. Susan, hoewel je formeel geen lid bent van mijn promotieteam was jij onmisbaar in de totstandkoming van dit proefschrift. Jouw passie voor het vak en eindeloze stroom aan ideeën werken aanstekelijk.

Mijn dank gaat ook uit naar verschillende RIVM collega's. In het bijzonder aan Jan, Maarten en José voor jullie ondersteuning en advies rondom statistiek. Ook veel dank aan collega's van de LCI voor het meelesen en de waardevolle discussies over de ethische aspecten van mijn onderzoek. Mattijs, dank voor onze samenwerkingen aan het 'prikbussen paper', dat een waardevolle toevoeging is aan dit proefschrift.

Heel veel dank aan iedereen bij EPI en in het bijzonder RVP, de leukste afdeling van het RIVM. Anne, Maarten en Marit, het was fijn om vanaf het begin met jullie in het zelfde PhD-schuitje te zitten. Anne, jij hebt volgens mij het dikste proefschrift ooit geschreven. Ik weet zeker dat ze bij RES ook heel blij met jou zijn. Marit, veel dank voor al je gezelligheid de afgelopen jaren. Leuk dat we zo ongeveer tegelijk promoveren, ik kijk uit naar jouw dag! Bente, Cheyenne en Tea, alle lange cursusdagen in Leiden waren (nog) leuker omdat jullie er ook waren. Geniet van jullie laatste PhD jaren, voor je het weet is het voorbij! Alies, de echte vaccinatiegraad expert. Dank voor het beantwoorden van al mijn vragen over Praeventis data en informed consent. Jeanet, zonder jouw onvermoeibare inzet rondom de DPIA was ik nu nog aan het wachten op de data. Fijn dat ik altijd bij je binnen kon lopen. En natuurlijk, Eric, buurman, het is echt heel fijn om iemand in de buurt te hebben waar je zo mee kan lachen. Heel veel

dank voor je vriendschap, de B&B analyses onze gedeelde interesse in bladblazers.

Lieve (CO-)Detervax collega's, Annika, Bente, Caren, Lisanne, Manon en Tea. Wat een geluk dat ik met jullie mocht samenwerken aan de COVID-19 analyses. Lieve Annika, zonder jou was dit proefschrift er écht niet geweest. Eindeloos hebben we ons hoofd gebroken over R-scirpts (dplyr...), random forest analyses, DBC codes, zwarte schermen en outputcontroles. Ik vind het nog elke dag jammer dat we niet meer samen in U3.52 zitten, maar gelukkig spreken we elkaar nog zeer regelmatig. Tea, good luck with the last (usually most productive!) year of your PhD. Manon, erg leuk dat we op de valreep nog samen een paper hebben kunnen schrijven!

Gelukkig was ik niet alleen maar bezig met werk maar was er ook veel afleiding met familie en vrienden. Anne, ik mis soms nog steeds de tijd aan de Hogelanden! Ik ben dankbaar dat we al zo lang vrienden zijn. Neline, wat een geluk dat jij zes jaar geleden naast ons kwam wonen! Dank voor je hulp bij het ontwerpen van de cover van dit boek. Lieve 'hondjes' Jasmijn, Marit, Martje, Myrte, Paulien en Rosaly, jullie zijn mijn basis en het is moeilijk in woorden te omschrijven wat dat mij waard is. Paulien en Myrte, wie anders dan jullie als paranimfen aan mijn zijde. Ik ben dankbaar voor en trots op jullie allebei!

Lieve (schoon)familie, jullie hebben je vaak afgevraagd waar ik nu precies mee bezig was en ik ben blij dat ik het nu eindelijk kan laten zien! Pap en mam, vati en muti, het is fijn te weten dat jullie altijd trots op mij zijn.

Lieve Chris, akpe ka kaka for always supporting me even while you're busy 'inburgeren'. I am proud of what we have built together and excited for what's to come. Because of you and Bowie there is no place I rather be than home.

Curriculum Vitae

Joyce Pijpers was born on October 5, 1992, in Zwolle, the Netherlands. After completing her secondary education (HAVO 2005-2010) at Christelijk College Nassau Veluwe in Harderwijk, she earned a bachelor's degree in Nursing from Hogeschool Utrecht in 2015. Joyce subsequently completed a pre-master's program in Health Sciences at Vrije Universiteit Amsterdam (2015–2016) and continued her



studies with a Master's degree in Management, Policy Analysis, and Entrepreneurship in Health and Life Sciences (2016–2018), specializing in international public health. During her Master's program, Joyce collaborated with Doctors Without Borders on a literature thesis investigating the use of miltefosine in the treatment of post-kala-azar dermal leishmaniasis, which resulted in her first peer-reviewed publication. For her second thesis, Joyce spent five months in Kpando, Ghana conducting a mixed-methods study on the effectiveness of a health education program in primary schools. Through these experiences, she developed a strong interest in infectious diseases and public health.

From 2018 to 2021, Joyce worked as a research coordinator at Amsterdam UMC. In 2021, she began her PhD at the Center for Infectious Disease Control at the RIVM under supervision of prof. dr. Susan van den Hof, prof. dr. Ruben van Gaalen and dr. Hester de Melker. Her doctoral research focused on sociodemographic determinants of COVID-19 and routine childhood vaccination coverage. In this work, she analysed linked national registry data to examine the factors associated with vaccination uptake, including changes and trends over time. The overall aim was to identify population subgroups at risk of under-vaccination and to provide evidence to support the development of tailored interventions to improve vaccine equity.

Since 2025, Joyce has been working as a statistical researcher at Statistics Netherlands (CBS), where she focuses on societal and health-related data.

