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Parental education disparities in childhood vaccination in Denmark: A test of two explanations for the role of misinformation

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ABSTRACT

How does misinformation contribute to socioeconomic disparities in childhood vaccine uptake? While prior research has extensively examined the determinants of vaccination at the population-level, less attention has been paid to the mechanisms generating disparities across socioeconomic status (SES) groups. A fundamental cause theory perspective suggests that vaccination disparities driven by misinformation are due to unequal access to resources that enable higher-SES parents to avoid the influence of such misinformation. By contrast, a neoliberal cultural frames of parenting perspective suggests that higher-SES parents, in trying to avoid risks for their child, would be more receptive to inaccurate claims that arise outside the mainstream medical and scientific community. We test hypotheses from these two perspectives using 22 birth cohorts of Danish national health registry data (1990–2011) analyzing uptake of children's first dose of the measles, mumps, and rubella vaccine (MMR1) by parental education level in the context of three major vaccine misinformation events: two promoting and one correcting misinformation. We find that educational disparities in MMR1 uptake emerged following a 1993 national radio broadcast that falsely linked the vaccine to autism and helped catalyze anti-vaccine activism in Denmark. Children of parents with the lowest education were most severely impacted, and these disparities persisted through the 1998 publication and 2010 retraction of Andrew Wakefield's widely publicized MMR vaccine and autism study. Together, these findings generally support fundamental cause theory-based explanations and demonstrate persisting and unequal harms of misinformation on child and community health.

How does health-related *misinformation* contribute to the creation and reproduction of health disparities? The history of medicine and public health is replete with examples of the harms caused by misinformation—from medical quackery and "snake oil" therapies to misleading tobacco marketing (Smith et al., 2011; Southwell et al., 2023). The COVID-19 pandemic starkly highlighted the dangers of misinformation for undermining public health *and* exacerbating long-standing socioeconomic status (SES)-related health disparities (e.g., Omer et al., 2021; Clouston et al., 2021). Because health-related knowledge and discourse are tied to scientific evidence and institutions (e.g., public health and medical fields), it is useful to conceptualize scientific misinformation as publicly accessible information that (a) "is misleading or deceptive relative to the best available scientific evidence or expertise at the time" and (b) "counters statements by actors or institutions who adhere to scientific principles without adding accurate evidence for consideration" (Southwell et al., 2022, p. 100).

Childhood vaccination offers an important case for investigating how misinformation shapes health disparities. In 2019, the World Health Organization classified vaccine hesitancy—defined as "delay in acceptance or refusal of vaccination despite availability of vaccination services" (MacDonald and The SAGE Working Group on Vaccine Hesitancy, 2015, p. 4163)—as a global health threat (WHO, 2019). While parental vaccine hesitancy is a complex phenomenon, vaccine-related misinformation—sometimes spread deliberately as *disinformation*—has been identified as a key factor undermining public confidence in vaccination (Carrieri et al., 2019; Pierri et al., 2022).

This study draws on two sociological perspectives to formulate and test hypotheses about how vaccine misinformation influences SES-based inequalities in childhood vaccine uptake in Denmark. Using national

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health registry data for 22 Danish birth cohorts (1990–2011), we evaluate the magnitude of parental education-based disparities in childhood measles, mumps, and rubella (MMR) vaccine initiation and examine changes following three key public incidents involving anti-vaccine messaging—two that *promoted* misinformation and one that *corrected* misinformation.

1. 1993: A Danish Broadcasting Corporation (DR) radio program aired a mother's concerns about a possible MMR vaccine–autism link, leading to increased public challenging of established medical science.
2. 1998: Andrew Wakefield and colleagues published a now debunked study in *The Lancet* medical journal, falsely linking the MMR vaccine to autism.
3. 2010: *The Lancet* retracted Wakefield and colleagues' 1998 study after an investigation revealed ethical improprieties and empirical falsehoods.

Denmark offers an advantageous setting to study how misinformation influences vaccination disparities. Childhood vaccinations are voluntary and not required for school or daycare attendance—unlike in countries such as France, Germany, and the United States (Vanderslott and Marks, 2021)—making Danish parents' vaccination decisions more vulnerable to misinformation. Denmark's universal healthcare system further reduces vaccine access barriers: each child is automatically assigned a local general practitioner—typically shared by the entire family—even after relocation, and parents can easily schedule free vaccination appointments, with no cost for either the visit or the vaccine. Denmark also provides robust family support across all social backgrounds, and its strong work–life balance culture facilitates parents' capacity to keep their children's vaccinations up to date (Denmark, n.d.). Finally, Statistics Denmark maintains a national health registry for all residents, including children's vaccination records, which can be linked to parent and household census records. This allows us to test hypotheses about SES disparities in MMR vaccination using population-level data for 22 birth cohorts.

1. Background

1.1. MMR vaccinations and coverage in Denmark

The MMR vaccine protects against measles, mumps, and rubella—highly contagious diseases that can cause serious complications including brain damage, deafness, encephalitis, miscarriage, and death (CDC, 2023). The two-dose series is highly effective: MMR1 provides 93 % protection against measles, 78 % against mumps, and 97 % against rubella (CDC, 2021). Measles infection can weaken the immune system's memory, leaving individuals more susceptible to other infections after recovery, highlighting the critical importance of widespread vaccination (Mina et al., 2019).

Denmark introduced the MMR vaccine into its national vaccination schedule in 1987. While national coverage currently meets the WHO-recommended 90–95 % threshold for herd immunity (WHO, 2024), uptake has fluctuated over the past three decades. During several periods—including 1990–1997, 2008–2011, and 2013—measles vaccine coverage dropped to 81–89 % (WHO, 2024).

Childhood vaccine uptake is often lower among more socially disadvantaged groups across Europe (Arat et al., 2019). A study comparing MMR vaccination rates among select birth cohorts in Denmark (in 2005–2008), Sweden (in 2009), Finland (in 2013), and Iceland (in 2013) found Denmark had the lowest overall uptake and widest socioeconomic disparities (Arat et al., 2020). Additionally, a matched cohort analysis revealed MMR vaccine uptake was lower among refugee and low-income children in Denmark compared to their Danish-born and higher income peers (Moller et al., 2016).

1.2. Vaccine misinformation and the media in Denmark

Anti-vaccine sentiment and activism are as old as vaccines themselves. In Denmark, however, major media events beginning in 1993 marked the rise of modern anti-vaccine activism and may have had enduring consequences for childhood vaccine uptake, particularly for MMR (see Fig. 1).

The first major event occurred in April 1993, when DR, Denmark's oldest and largest media enterprise, aired a national radio program featuring Annelise Matthiesen—a mother who claimed her daughter developed autism after the MMR vaccine—sparking public debate (see Berg, 2020a for details). Other parents on the program also linked their children's health conditions to vaccinations, while medical doctors present struggled to counter these claims due to limited research on the subject at the time (Berg, 2020a). Matthiesen pursued compensation for her daughter through a lawsuit that drew media attention, but the Danish Supreme Court rejected the claim in 2005.

By 1996, Matthiesen co-founded "Vaccinationsforum," an association that emerged from the community formed around the DR radio program. The group argued that vaccine consent in Denmark involved a *de facto* coercion (Berg, 2020a). That year, the association published *Vaccinations – Are They Effective and Safe?*, a book critical of vaccines with a foreword by Danish medical doctor and homeopath Gunnar Ødum, which received significant press coverage (Berg, 2020a). In 1997, Vaccinationsforum helped produce the documentary "A Shot in the Fog" which aired on Danish public television and criticized the MMR vaccine, featuring several physicians, including Andrew Wakefield, as experts. Hence, the DR radio program initiated a series of vaccine criticism efforts that attracted significant media attention.

A second key event occurred in February 1998, when *The Lancet* published a now-discredited case series study by Wakefield and colleagues claiming a link between MMR vaccination and autism. Although this link was later disproven by more rigorous and population-based studies, the publication had a global impact and is widely considered a pivotal event in the rise of 21st century anti-vaccine activism (A timeline of the Wakefield retraction, 2010). The study is also credited with causing significant declines in MMR vaccination in Sweden and the United Kingdom (Dowden, 2019; Bragesjö and Hallberg, 2009 as cited in Berg, 2020a).

The third event occurred in February 2010, when *The Lancet* retracted Wakefield and colleagues' 1998 article after an investigation revealed ethical improprieties and falsified data. Despite this retraction and Wakefield's subsequent loss of his U.K. medical license, the claimed vaccine–autism link continued to receive considerable public attention worldwide (A timeline of the Wakefield retraction, 2010).

Multiple studies have examined how media coverage has influenced MMR vaccine uptake in Denmark. Berg (2020b) examined the impact of the above and other media events on MMR vaccination in the 1990s and found limited or no negative effect on population compliance with either dose. Hansen et al. (2019) analyzed Danish print media coverage from 1997 to 2014, classifying it as pro-vaccine, anti-vaccine, or neutral. Between 1998 and 2004, they found a positive correlation between MMR1 uptake and both pro-vaccine and neutral media coverage—particularly during measles outbreaks—but observed no significant correlations between 2005 and 2014. Altogether, these findings suggest that media coverage was generally beneficial for MMR1 vaccination rates, and that negative media had limited influence on the general population.

However, previous research has not examined how media coverage may have shaped *SES disparities* in MMR1 uptake. Even if media coverage was broadly positive or neutral, how might parents from different socioeconomic backgrounds have differentially perceived it during or following misinformation events, potentially contributing to disparities in vaccination rates? We offer two potential explanations for how misinformation introduction and correction may have contributed to such disparities.

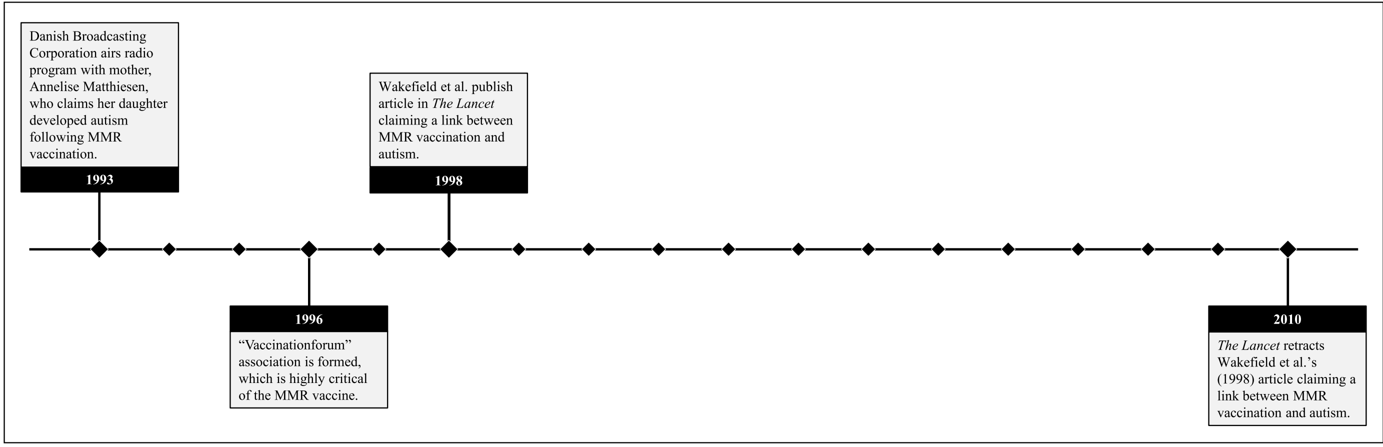


Fig. 1. Timeline of events with a possible impact on measles, mumps, and rubella (MMR) vaccine uptake in Denmark.

1.3. *Explanation 1: fundamental cause theory, misinformation, and predictions about vaccination disparities*

Fundamental cause theory (FCT) posits that socioeconomic inequalities in health emerge and endure because individuals with greater access to resources—such as knowledge, money, status, and beneficial social connections—are better positioned to utilize health-promoting tools and avoid diseases and their negative consequences (Link and Phelan, 1995). Empirical tests have found support for FCT across various health outcomes, with vaccine uptake emerging as a specific focus over the past decade (Clouston and Link, 2021). For example, Polonijo and colleagues (Polonijo and Carpiano, 2013; Polonijo et al., 2016; Polonijo, 2020) documented SES-based differences in interest in, recommendation for, and uptake of human papillomavirus (HPV) vaccines among U. S. adolescents, while Clouston et al. (2014) identified SES disparities in early childhood vaccinations in Madagascar.

A key facet of FCT is that health inequalities become apparent under *conditions of change*, as new risk or protective factors come to be known (Link and Phelan, 1995). Per FCT, access to resources allows higher-SES individuals to be among the first to hear about and act on new health information, thereby benefiting from it sooner (Wang et al., 2012). This key element of positioning amidst the diffusion of new information motivates several empirically testable hypotheses of FCT.

FCT predicts a positive relationship between SES and vaccine uptake, similar to other health-promoting technologies like antiretroviral therapy for HIV (Rubin et al., 2010) and statins for cholesterol control (Chang and Lauderdale, 2009). The inoculation theory of misinformation (Compton et al., 2021) further suggests that early exposure to accurate health-promoting information, such as MMR vaccine recommendations, may, akin to a vaccine, protect against later exposure to misinformation. If misinformation diffuses inequitably by SES, lower-SES individuals, who may have relatively lower health literacy and less educated networks, may remain more vulnerable even after it is debunked. Furthermore, once misinformation is debunked, FCT would predict little change among higher-SES individuals because they were less likely to be influenced by misinformation initially. Thus, any substantial change in disparities attributable to misinformation would likely be among lower-SES individuals learning of the correction and, consequently, reversing the course of their prior decisions to now favor vaccination for their children. Accordingly, any such previously existing SES-based disparity would likely be truncated.

1.4. *Explanation 2: neoliberal cultural frames of parenting, misinformation, and predictions about vaccination disparities*

An alternative possibility is that higher-SES individuals, with better access to resources, may be among the first to learn about and act on new health information—including vaccine-related risks—even if it lacks mainstream scientific support. Early awareness of potential risks among higher-SES parents could lead to earlier and greater declines in vaccine uptake among their children. This behavior aligns with neoliberal cultural frames of parenting (NCFP), whereby parents (typically mothers) assume the role of advocates for their children's health, "often viewing themselves as uniquely qualified to do so, even if it supersedes the authority of medical professionals" (Reich, 2014, p. 681). This approach is rooted in "intensive parenting" (especially motherhood), a parenting style that is "child-centered, expert-guided, emotionally absorbing, labor intensive and financially expensive" (Hays, 1996, p. 8). Research finds intensive parenting/motherhood is widespread in many countries (Dotti Sani and Treas, 2016), and its time-intensive parenting activities help explain why higher-educated parents devote more time to childcare (e.g., England and Srivastava, 2013).

Layered onto this parenting style is "healthism"—an ideology that frames health as a matter of individual responsibility and moral obligation, rather than collective trust in public institutions (Kirbiš, 2023). From this perspective, socially privileged parents may prioritize their own risk assessments over expert consensus, viewing standardized immunization programs with suspicion and favoring individualized, self-directed approaches they believe are uniquely suited to their child (Kirbiš, 2023). This may help explain why some higher-SES parents are more receptive to vaccine-skeptical messages, even from sources that lack scientific credibility.

Therefore, higher-SES parents' vaccine refusal or delay may stem from concerns about managing vaccine risks raised by perceived experts like Wakefield and Danish anti-vaccine physicians, who often seek media attention and frame themselves as being on the vanguard of new discovery or contrarian to mainstream medical thinking. (Recall, at the time of the initial MMR–autism claims by medical professionals and parents like Matthiesen, the mainstream medical community lacked systematic evidence to refute them.) Likewise, such parents may delay vaccination(s) to avoid perceived new risks they have learned about and hope to avoid disease by relying on herd immunity created by other parents vaccinating their children—essentially engaging in "free riding" behavior (Browne, 2016). For instance, Gørtz et al. (2020) found negative media coverage about adolescent HPV vaccination in Denmark led to the sharpest decline in the second dose of the MMR vaccine

(MMR2; typically administered at the same age) among girls with highly educated mothers.

If vaccine-related risk information is later proven to be false—or misinformation—an NCFP perspective would predict higher-SES individuals will be among the first to learn of the correction and reverse earlier decisions, now choosing to vaccinate their children. While this resembles FCT in leveraging SES-based resources to act on new health information, there is an important distinction. FCT suggests higher-SES parents will be *less likely* to be influenced by misinformation in making vaccination decisions in the first place, as they will be more likely to follow medical advice and trust established scientific expertise. By contrast, NCFP suggests higher-SES parents are more likely to base vaccination decisions on their own risk assessments and interpretations of emerging information, often distrusting medical expertise and giving more weight to contrarian claims (e.g., vaccine harm or autism links). As such, highly educated parents who prioritized "doing their own research" over trusting their doctor and initially avoided vaccination may be among the first to learn when false risk claims are retracted, ultimately reversing course to vaccinate their children. In this case, any existing SES vaccination patterns would shift to a more typical gradient pattern, as higher-SES parents respond to the corrected information and vaccinate their children.

1.5. Hypotheses

These considerations motivate four hypotheses—two concerning *exposure to misinformation* and two regarding exposure to its *correction*.

First, following *misinformation events* (i.e., the DR radio program featuring Matthiesen and Wakefield's *The Lancet* publication) we conjecture two opposing hypotheses:

H1a. Per FCT, there will be a positive association between parental SES and MMR1 uptake, such that children from higher (vs. lower) SES families will be more likely to be vaccinated. However, during misinformation periods, MMR1 uptake will decline among lower-SES children, widening any SES disparity.

H1b. Per NCFP, MMR1 uptake will decline more substantially among higher (vs. lower) SES children, thus constraining any pre-existing or potential SES disparities in vaccination.

Second, following the *misinformation correction* (i.e., the Wakefield article retraction and associated media coverage) we propose two competing hypotheses regarding the SES gradient in MMR1 uptake either (re-)emerging or widening:

H2a. Per FCT, higher (vs. lower) SES children will be more likely to receive MMR1 amidst a context of rising overall uptake attributable to increases across most or all SES groups (even if unequally). But any substantial change in an existing disparity attributable to misinformation will be among children of lower-SES parents who, prior to the correction, were more vulnerable to misinformation, and whose extent of post-correction uptake will reduce the magnitude of any previously existing SES-based disparity.

H2b. Per NCFP, higher-SES children will now be more likely to receive MMR1 than their lower-SES counterparts, but any increases in vaccination uptake will be mostly or completely limited to higher-SES groups.

1.6. Empirical rationale for focusing on education as one element of SES

While our hypotheses center on SES as a package of flexible resources, we focus on educational attainment for empirical testing. As discussed earlier, Denmark is an ideal empirical case in part because universal health coverage and automatic assignment to primary care physicians minimize income-based barriers to vaccination. Hence, child vaccination is far less income-dependent than in countries like the United States, where insurance, healthcare access, and continuity of care are closely tied to income. In contrast, education is a meaningful differentiator: it reflects varying degrees of general and technical knowledge and human capital, is linked to health literacy in Denmark (Friis et al., 2016), and tends to shape social ties through educational homophily (McPherson et al., 2001).

2. Methods

2.1. Data

Our study uses data from Denmark's national registers, which hold extensive demographic and socioeconomic information (e.g., gender, age, residence, health, labor market participation, income, education, household composition) and are updated annually by Statistics Denmark. Each resident has a unique personal identification number (CPR-number) through the Danish Civil Registration System, allowing linkage of individual information across all Danish national registers both within and across years, as well as between parents, children, and spouses. Vaccination data are from the Danish National Health Service Register, which records all services provided in general medical practice.

Our dataset contained >1,200,000 children, with birth cohort sizes ranging from approximately 57,000–71,000. We focused on vaccines administered between six months and four years of age to capture variability in MMR1 timing, as MMR1 is recommended at 15 months but not before six months, and MMR2 has been recommended at age four since 2008. Additionally, we only included children who had lived in Denmark for the entire first four years of their lives, as we lacked information on whether children who moved to Denmark during this period had been vaccinated in other countries.

2.2. Measures

Table 1 presents the coding for all study variables.

Dependent variable: MMR1. Our dependent variable was receipt of MMR1 between six months and four years of age, allowing for early or delayed vaccination beyond the recommended 15 months. We focused on MMR1 because the recommended age for the second dose changed from 12 years to 4 years in 2008. Hence, MMR1 allowed us to study a longer span of uninterrupted data, covering vaccines administered from 1991 to 2012 for birth cohorts from 1990 to 2011.

Until 1996, children's vaccinations were recorded in the Danish National Health Service Register under their parents' CPR-number, with an indicator showing whether the vaccine was given to a child. In these cases, we assigned the vaccine to the child in the family that was closest to the recommended vaccination age (if the child was between six months and four years old). We included such parent-linked records until 2005, although they were rare in later years. After 1996, children's vaccinations were registered under their own CPR-number.

Independent variable: education. We categorized parental education based on the highest level achieved by a child's parents: elementary/primary (9–10 years), upper secondary (general, business, or technical oriented, 2–3 additional years), vocational (e.g., carpenter, electrician), short-cycle higher (e.g., laboratory technician, dental hygienist), medium-cycle higher (e.g., teacher, nurse, bachelor's degree), and long-cycle higher/PhD (e.g., master's or doctoral degree). We relied on the mother's education level unless the child lived only with the father.

Control variables. We included several child and parent-level control variables. Number of siblings and mother's age were measured continuously. Binary variables indicated the child's sex, birth order (oldest or not), Apgar score <7 (indicating need for immediate medical attention after birth), low birth weight (<2500 g), full-term birth (39–42 weeks), single parent status, and ethnicity (ethnic Dane or immigrant/Danish-born descendent of immigrant parents). Parental employment status was measured using nine categories. Lastly, we measured household income using equivalized disposable income, adjusted for

Table 1
Descriptive statistics for study sample, Danish birth cohorts 1990–2011, Danish national health registries.

	Received MMR1		Did Not Receive MMR1		Total		
	Mean	SD	Mean	SD	Mean	SD	N
Received MMR1	–	–	–	–	.88	.33	1,283,712
Child characteristics							
Female	.49	.50	.48	.50	.49	.50	1,283,712
Oldest child	.49	.50	.41	.49	.48	.50	1,283,712
Number of siblings	.80	.84	.98	.96	.82	.86	1,283,712
Parents non-Danish	.02	.14	.02	.15	.02	.15	1,283,712
Low birthweight (<2500 g)	.05	.22	.05	.23	.05	.22	1,263,272
Full term (week 39–42)	.79	.40	.79	.41	.79	.40	1,257,612
Apgar score (<7)	9.85	.73	9.84	.80	9.85	.74	1,259,944
Parental characteristics							
Mother's age	30.95	4.75	30.82	5.11	30.94	4.80	1,282,696
Single parent	.09	.28	.15	.35	.09	.29	1,283,712
Educational level[a]							1,281,412
Elementary/primary	.20	.40	.27	.46	.21	.41	
Upper secondary	.09	.28	.10	.30	.09	.28	
Vocational	.35	.48	.31	.46	.34	.47	
Short-cycle higher	.04	.20	.03	.18	.04	.20	
Medium-cycle higher	.24	.42	.20	.40	.23	.42	
Long-cycle higher/PhD	.08	.28	.07	.25	.08	.28	
Employment[a]							1,268,320
Self-employed	.02	.15	.03	.17	.02	.15	
Employee with upper/mid skill level	.33	.47	.26	.44	.32	.47	
Employee with lower skill level	.35	.48	.32	.47	.34	.48	
Unemployed, cash benefits	.13	.33	.20	.40	.13	.34	
Sick pay, on leave	.08	.27	.09	.28	.08	.27	
Studying	.05	.21	.04	.20	.05	.21	
Incapacity benefits	.01	.07	.01	.08	.01	.07	
Early retirement, pension	.00	.05	.00	.06	.00	.05	
Other	.04	.20	.05	.22	.04	.20	
Equivalized family income/1000	256.31	155.72	238.38	204.60	254.25	162.20	1,283,712
Equivalized family income categories							1,283,712
<150,000 DKK	.08	.27	.13	.33	.09	.28	
150,000–200,000 DKK	.16	.37	.21	.44	.17	.37	
200,000–250,000 DKK	.27	.44	.27	.44	.27	.44	
250,000–300,000 DKK	.25	.43	.22	.41	.25	.43	
300,000–350,000 DKK	.13	.34	.10	.30	.13	.33	
>350,000 DKK	.11	.31	.08	.27	.10	.30	

[a] Educational level and employment are based on information for the mother. If the child did not live with the mother, then information for the father was used. DKK = Danish Krone; MMR1 = the first dose of the measles, mumps, and rubella vaccine series; SD = standard deviation.

inflation with the Consumer Price Index. This measure, provided by Statistics Denmark, accounts for household composition to reflect the resources available to each member and adjusts for changes in the cost of living. Income was categorized into six groups (see Table 1), centered around the mean of 253,630 Danish Krone (DKK; approximately $37,000 USD), in increments of 50,000 DKK.

2.3. Analyses

We pooled all birth cohorts for our analyses and used multivariable binary logistic regression models to estimate the probability of a child receiving MMR1 across educational categories, before and after each misinformation-related event, net of the abovementioned confounders. To evaluate education differences in MMR1 uptake over time, these models included categorical interaction terms for parental education and the child's year of MMR1 eligibility. Both education and year were coded as a series of dummy variables representing main effects and interaction terms. Standard errors accounted for clustering at the municipal geographic level.

From this model, we tested our hypotheses regarding dynamics in educational disparities in MMR1 uptake. First, we computed the predicted probabilities of MMR1 uptake for each education category in each study year. Then, to evaluate *within-year* educational disparities in MMR1 uptake, we estimated the average marginal effect (AME) of uptake for each of the four highest educational categories (i.e., upper secondary, vocational, short-cycle higher, medium-cycle higher, and long-cycle higher/PhD) relative to the lowest category (elementary/primary) in the same year. Each AME represents the absolute (percentage point) difference between the predicted probabilities of MMR1 uptake for any education category and elementary/primary education.

To evaluate between-year educational disparities in MMR1 uptake within the period encompassing each empirical case, we estimated the difference between each of the within-year education category AMEs relative to its analogous education category AME in three reference years: 1992, 1997, and 2009. These years corresponded with key events: the 1993 DR radio program, the 1998 Wakefield article publication, and the 2010 Wakefield article retraction. We computed the statistical significance of the differences in AMEs using the lincom command in Stata 17.

To further evaluate education-specific disparities in MMR1 receipt before and after an event, we tested whether educational differences in uptake significantly differed between the entire pre- and post-event periods. We estimated this difference in pre-/post-event trend using another logistic regression model that combined the pre- (coded "0") and post-event (coded "1") years into a binary variable (excluding the event year), interacted with each education category (relative to the referent category), including all abovementioned controls. If the coefficient for the education category × pre-/post-event interaction term was statistically significant, it provided further evidence of the potential influence of the misinformation event on education-specific disparities.

For the latter two between-year sets of analyses, we accounted for potential Type I error from multiple statistical testing across years by using the Benjamini-Hochberg (Benjamini and Hochberg, 1995) procedure, which controls the False Discovery Rate (FDR) and lowers the

probability of Type II error from such multiple test corrections. These FDR corrections did not change the substantive conclusions from our findings. For reader transparency, we report all our findings using original, uncorrected *p*-values obtained from our models, with statistical significance based on an alpha of .05. Although Danish national registry data are restricted, our code for dataset creation and analyses is available upon request.

3. Results

Fig. 2 depicts overall trends in MMR1 vaccination across birth cohorts during the study period. MMR1 uptake generally increased in the early through mid-1990s, briefly leveling-off between 1992 and 1993, coinciding with the initial DR radio program. By the early 2000s, the probability of receiving MMR1 reached .90 and remained relatively stable thereafter. Nevertheless, SES disparities in MMR1 uptake emerged and persisted over this period. We present these disparities in the context of specific anti-vaccine events below.

Figs. 3–5 report results from our three empirical test periods. Each figure includes two panels: Panel A shows predicted probabilities of MMR1 receipt for each education category across the timespan of the empirical test, Panel B shows AMEs for each education category relative to elementary/primary education within each year. Bars with bold outlines indicate that the AME for a specific education category within a particular year is significantly different ($p < .05$) *from its analogous, education category-specific AME in the referent year*. The regression results that produced these estimates are in Appendix A of the online supplement.

3.1. Empirical test 1: 1993 DR radio program and subsequent activism

Fig. 3, Panels 1a (predicted probabilities) and 1b (AMEs) present results for our empirical test of the impact of the 1993 DR anti-vaccine radio program and subsequent Vaccinationsforum events (1996 book, 1997 documentary, associated media coverage) on educational disparities in MMR1 uptake. In 1991 and 1992—respectively, four and five years after the MMR vaccine was added to Denmark's vaccination schedule—there was a slight *inverse* disparity in vaccination. For 1992, one year prior to the event, the probability (per Panel 1a) of MMR1 uptake was significantly higher among children of parents from the lowest education level (elementary/primary; .836 = 83.6 %) versus the two highest educational categories: medium-cycle higher (.814 = 81.4 %) and long-cycle higher/PhD (.812 = 81.2 %). Per Panel 1b, these respective percentage point (pp) differences in uptake of 2.2pp (i.e., 83.6 %–81.4 %) and 2.4pp (83.6 %–81.2 %) were statistically significant.

However, over this seven-year period, MMR1 uptake rose overall, and children of higher-educated parents quickly caught up. By 1993—the year of the DR radio broadcast—no statistically nor substantively significant disparity existed between any of the three highest education groups relative to the elementary/primary education group. Yet, by 1997, the year before Wakefield's *The Lancet* publication, every higher education category had significantly higher uptake than the elementary/primary education group. Likewise, the AMEs for every education group in 1997 were significantly different from their respective AMEs in 1992, the year prior to the misinformation event.

Our interaction tests for differences in trends in disparities before and after 1993 (not shown) corroborate these findings. The magnitude of disparities in MMR uptake observed for each education level relative to the elementary/primary referent group was significantly higher in the 1994–1997 versus 1991–1992 period.

Altogether, findings for this 1991–1997 period suggest that the DR broadcast and the subsequent Vaccinationsforum events contributed to disparities in MMR1 uptake, particularly affecting children of parents with only elementary/primary education, whose MMR1 uptake increased minimally between the start (82.9 %) and end (84.6 %) of this period. Meanwhile, there was a relative plateauing of year-specific vaccination prevalence for children with higher-educated parents after the misinformation event.

3.2. Empirical test 2: 1998 Wakefield article published in The Lancet

Fig. 4, Panels 2a and 2b, present results for our test of the impact of Wakefield's 1998 *The Lancet* publication on educational disparities in MMR1 uptake. For every year between 1998 and 2009, each education category's AME was tested against the predicted probability for its analogous education category in 1997 (the year before *The Lancet* article publication). MMR1 uptake generally increased across all education levels post-publication (1999–2009), except for children of parents with elementary/primary education, who consistently had the lowest predicted uptake. Other education categories did not show a consistent gradient pattern.

In 1997, MMR1 uptake was significantly lower among children of parents with elementary/primary education versus all higher education levels, with a 3.1pp gap between the elementary/primary group (84.6 %) and both the medium- and long-cycle higher groups (87.7 %). In

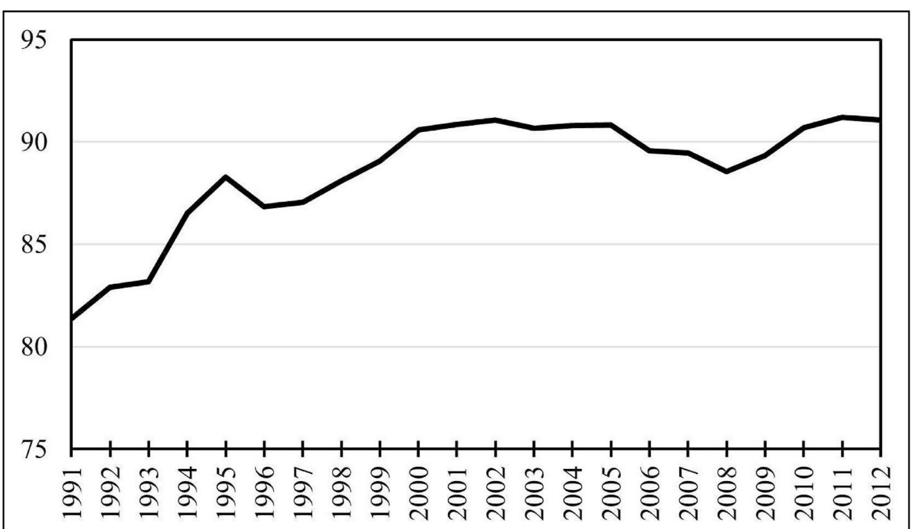
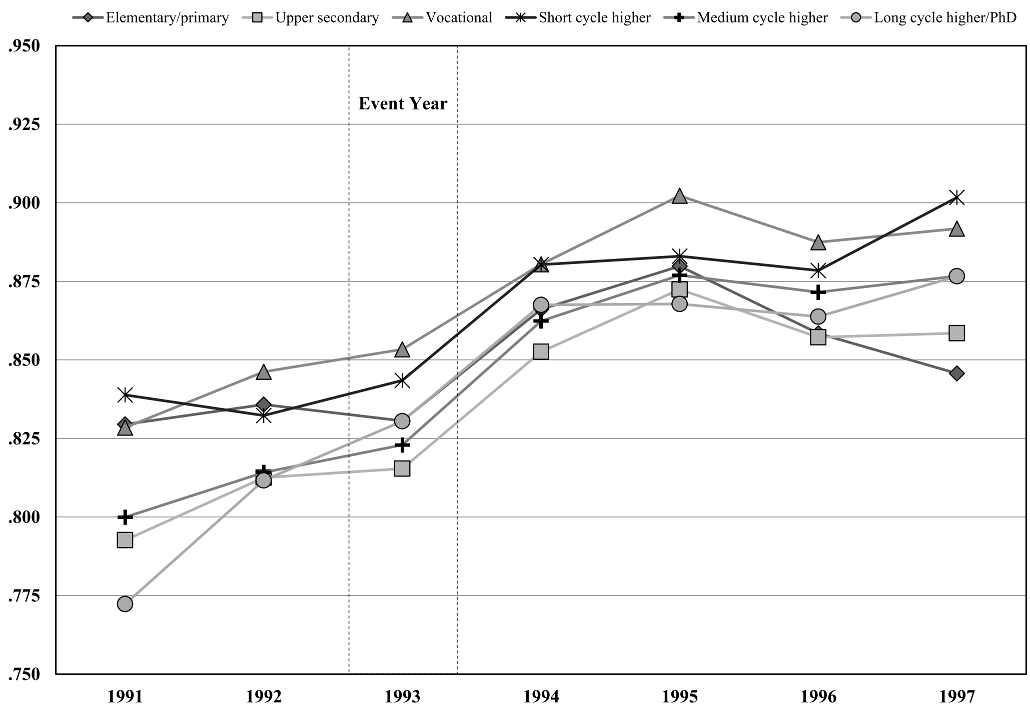


Fig. 2. Percentage of children who received the first dose of the measles, mumps, and rubella vaccine series by year of recommended age for receipt.



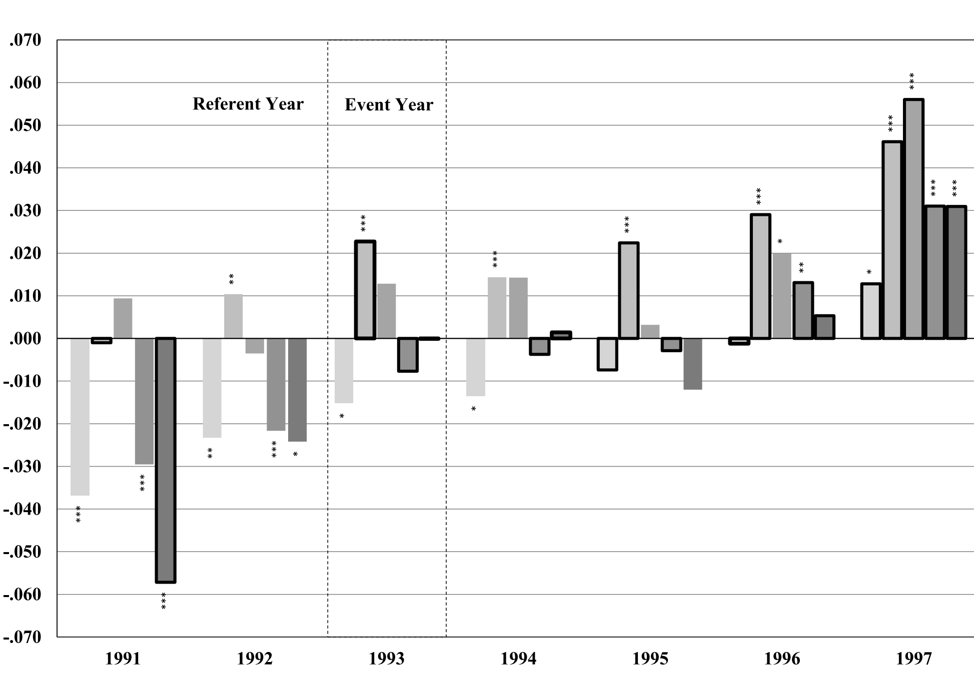
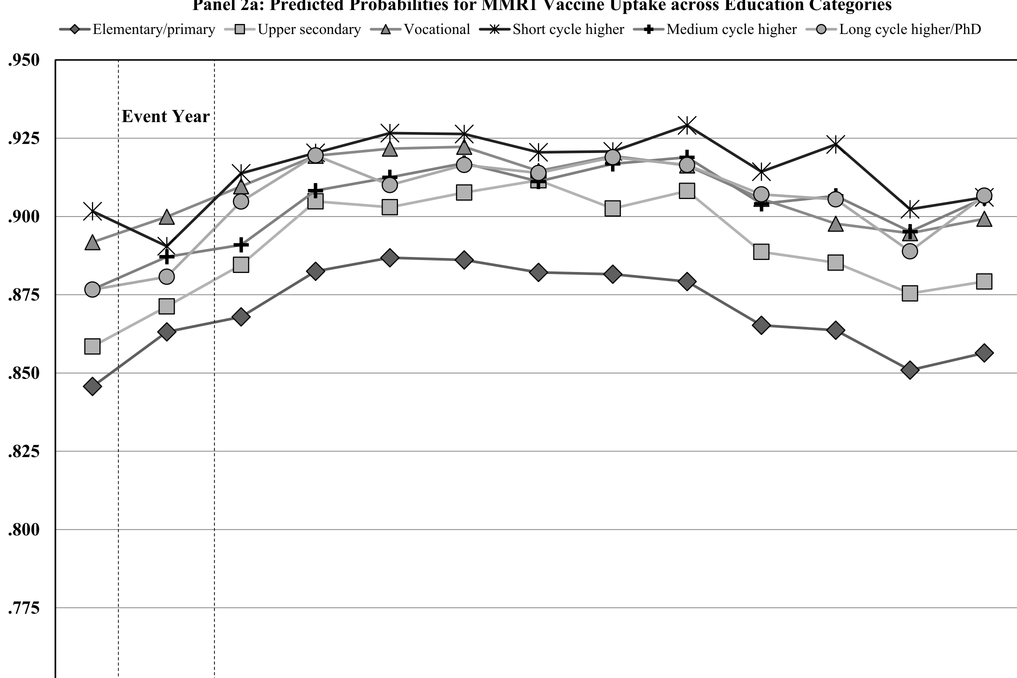


Fig. 3. Empirical test 1: 1993 DR radio program and subsequent activism. *Note:* For bars outlined in black, the estimate for that specific education category is statistically different ($p < .05$) from its corresponding estimate in the referent year. MMR1 = the first dose of the measles, mumps, and rubella vaccine series. *$p < .05$, **$p < .01$, ***$p < .001$.



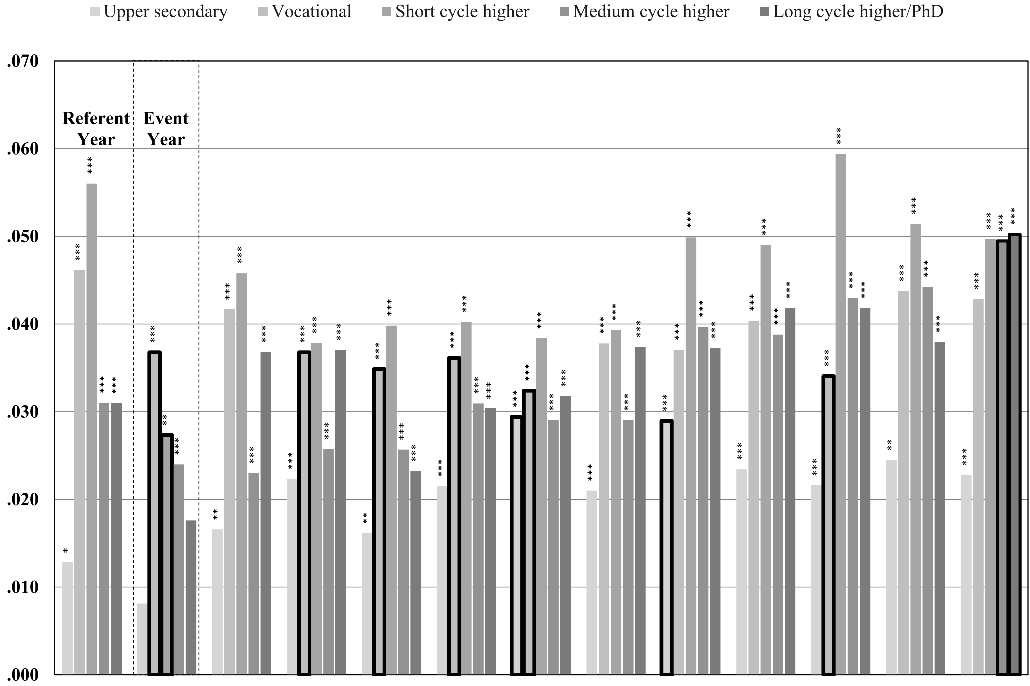
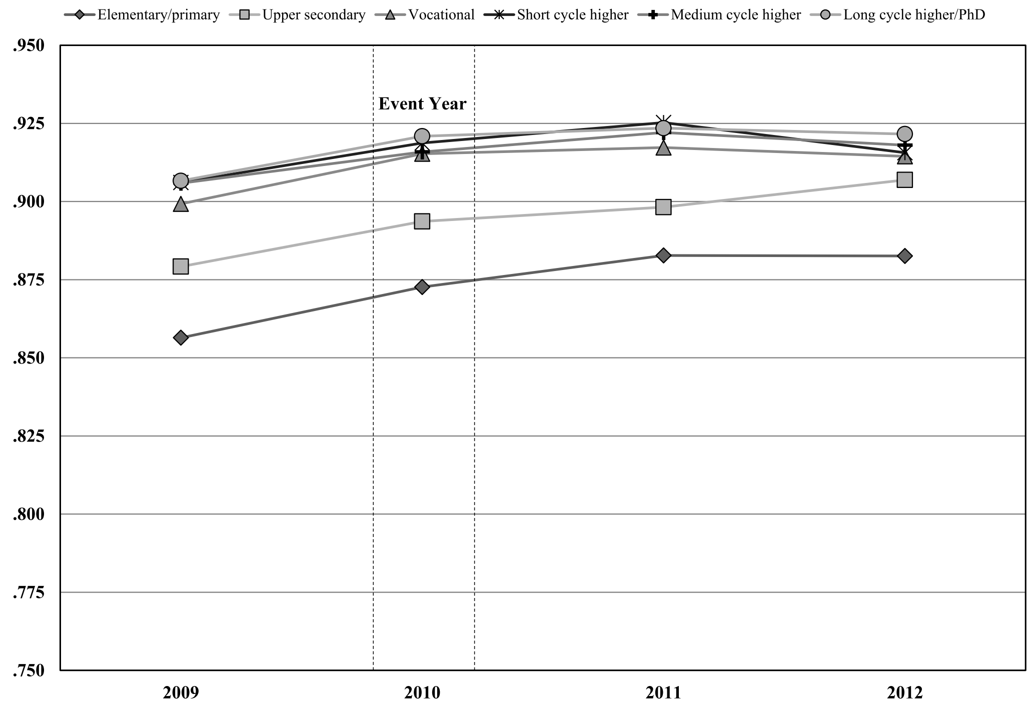


Fig. 4. Empirical test 2: 1998 Wakefield article published in *The Lancet. Note:* For bars outlined in black, the estimate for that specific education category is statistically different ($p < .05$) from its corresponding estimate in the referent year. MMR1 = the first dose of the measles, mumps, and rubella vaccine series. *$p < .05$, **$p < .01$, ***$p < .001$.



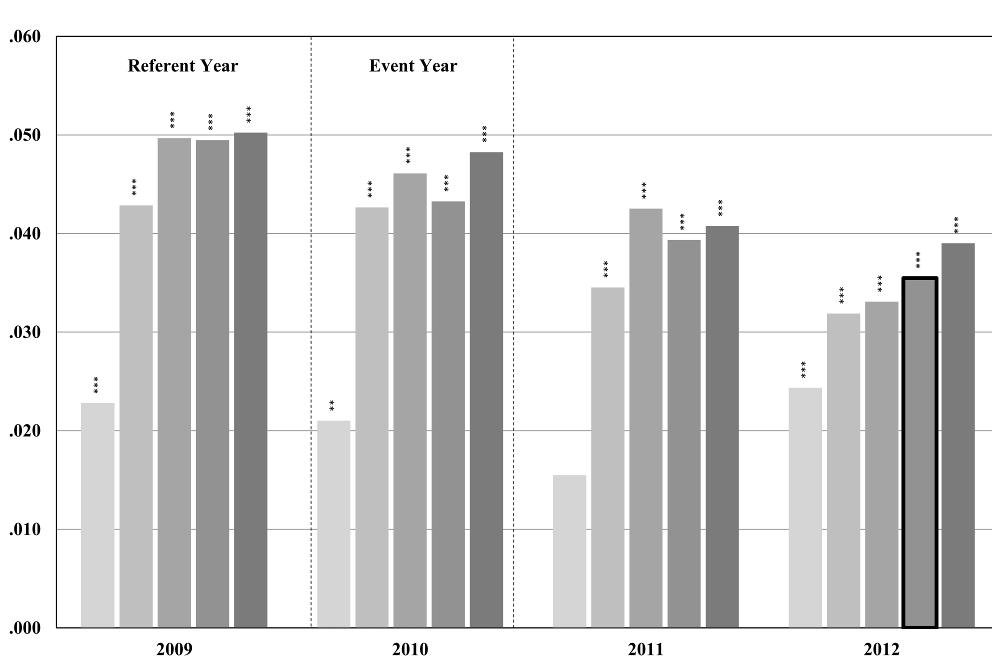


Fig. 5. Empirical test 3: 2010 retraction of Wakefield article in *The Lancet. Note:* For bars outlined in black, the estimate for that specific education category is statistically different ($p < .05$) from its corresponding estimate in the referent year. MMR1 = the first dose of the measles, mumps, and rubella vaccine series. *$p < .05$, **$p < .01$, ***$p < .001$.

1998, the year Wakefield's article was published, uptake increased to a greater degree among children of parents with elementary/primary education than those with medium- and long-cycle higher/PhD education, narrowing disparities to approximately 2.4pp (medium-cycle higher) and 1.8pp (long-cycle higher), the latter being reduced to non-significance. We observed a similar trend for all education levels, with disparities between each higher education category versus primary/elementary education decreasing, including vocational and short-cycle higher, whose respective estimates were significantly lower in 1998 versus 1997.

From 1999 onward, disparities between each educational category and the elementary/primary group typically exceeded 2.0pp, were statistically significant, and widened over time. Specifically, disparities between medium- and long-cycle higher education versus elementary/primary education grew from approximately 2.3pp and 3.7pp in 1999 (i.e., 89.1 % and 90.5 % vs. 86.8 %) to 5.0pp and 5.1pp in 2009 (i.e., 90.6 % and 90.7 % vs. 85.6 %). These 2009 estimates are significantly higher than their respective estimates in 1997, prior to the publication.

Furthermore, our test for differences during the pre-event (1996–1997) and post-event (1999–2009) periods indicated that the MMR1 disparities for each education group versus the elementary/primary referent group were significantly higher in the post-event period.

3.3. Empirical test 3: 2010 retraction of Wakefield article in The Lancet

Fig. 5, Panels 3a and 3b, present results for our test of the impact of the 2010 retraction of the Wakefield article in *The Lancet* on educational disparities in MMR1 uptake. For each year between 2010 and 2012, predicted probabilities of MMR1 receipt for each education category were tested against corresponding 2009 values (the year before *The Lancet* retraction). Across this period, the two lowest education categories—elementary/primary (87.3–88.3 %) and upper secondary (89.4–90.7 %)—consistently had the lowest predicted probabilities of MMR1 uptake. By 2012, upper secondary education (90.7 %) showed convergence with every higher education category, which ranged from 91.4 % (vocational) to 92.2 % (long-cycle higher) and remained relatively stable from 2010 (the event year) to 2012.

Disparities in MMR1 uptake between children of the lowest education level (elementary/primary) and higher education levels (vocational through long-cycle higher) were statistically significant across all years. While the gap narrowed over time, the changes were generally not statistically significant, except for medium-cycle higher versus elementary/primary in 2012 versus 2009. The disparity between long-cycle higher education and elementary/primary education decreased from 5.1pp (90.7 % vs. 85.6 %) in 2009 to 3.9pp in 2012 (92.2 % vs. 88.3 %). This 1.2pp change was not statistically significant but is attributable to a greater increase in uptake among the lowest (vs. highest) education group. In terms of national population vaccination rates, this remains a substantively significant disparity.

Further corroborating these findings, the interaction tests for differences between pre- (2008–2009) and post-retraction year (2011–2012) trends in education-based disparities found no significant differences for any educational category relative to the elementary/primary referent group.

4. Discussion

Our study aimed to evaluate how misinformation might contribute to SES-based disparities in MMR receipt. The concern that the MMR vaccine could cause autism is considered a pivotal driver of the modern anti-vaccine movement and a major contributor to declines in childhood vaccination rates across several countries (Motta and Stecula, 2021; Allan and Harden, 2015; Fitzpatrick, 2004). Despite numerous international, systematic studies refuting the claim (e.g., Hviid et al., 2019) and *The Lancet's* retraction of the infamous Wakefield article, the MMR vaccine–autism link myth still lingers among the public, fueled in part by anti-vaccine activists (Gorski, 2023). More broadly, this claim exemplifies how health misinformation, science denialism, and related social movements can undermine public health, especially for vaccine-preventable diseases.

Our three empirical tests—two regarding dissemination of vaccine risk claims and one correcting misinformation (all during a period of anti-vaccine activism that began with our first empirical test)—suggest that while such events can influence SES disparities in health innovation uptake, not all significantly impacted MMR1 disparities among Danish children. Our first empirical test, centered on the 1993 DR radio broadcast featuring Matthiessen and subsequent anti-vaccine activities (Vaccinationsforum formation, 1996 book, 1997 documentary), reveals that the negative impact of this misinformation event on MMR1 uptake was mostly restricted to children of parents with the *lowest education level*. This supports our first misinformation exposure hypothesis: consistent with FCT, higher-SES parents may be less vulnerable to misinformation than lower-SES peers due to greater access to resources for obtaining accurate information, including higher health and scientific literacy, more beneficial network ties, and more time to consult medical professionals. Notably, this misinformation event occurred amid a general increase in MMR1 receipt, likely driven by its recent addition to the vaccination schedule and promotion by family physicians. Evidence of greater susceptibility to MMR-related misinformation among lower-SES parents is further supported by MMR1 uptake prior to this event (1991–1992) being *significantly higher* among children of parents with elementary/primary-level education versus upper secondary, medium-cycle higher, and long-cycle higher education, but then reversing after this event to become *significantly lower* than every higher education group, thereby indicating greater susceptibility. Hence, the resulting disparity was due to high growth in MMR1 uptake among higher-SES children and lower growth among lower-SES children.

Our second empirical test revealed comparatively less substantial change in MMR1 disparities following Wakefield's 1998 publication in *The Lancet* and its related publicity. While the publication played a documented role in fueling vaccine hesitancy and the modern anti-vaccine movement, its impact in Denmark was relatively limited. After its publication (i.e., between 1999 and 2009), within-year disparities in MMR1 for each education level versus elementary/primary education persisted. However, while the gaps for the two highest education levels versus elementary/primary were significantly larger in 2009 versus 1997, generally, no education group showed a consistent or significant disparity change from pre-publication levels. This supports Berg's (2020a) claim that Danish public concern had already been shaped by the 1993 DR radio broadcast. Even Wakefield acknowledged his study built on an existing MMR vaccine–autism hypothesis. Although his publication amplified concerns of this hypothesis among international lay and scientific communities (Berg, 2020a), its limited impact in Denmark underscores the importance of local context in understanding misinformation's public health effects. In Denmark, the DR broadcast—not Wakefield's article—sparked significant anti-vaccine activism, followed by the 1996 formation of Vaccinationsforum, contrasting with vaccination declines elsewhere linked to Wakefield's study (e.g., Dowden, 2019; Bragesjö and Hallberg, 2009 as cited in Berg, 2020a).

Our third empirical test assessed the 2010 retraction of Wakefield's *The Lancet* article and found this misinformation correction had minimal impact on the SES disparities that had emerged years earlier. Children of parents with elementary/primary education showed evidence of catching-up in MMR1 uptake with children of higher-educated parents, but disparities persisted and showed little evidence of any statistically significant changes from 2009 (the pre-event referent year). These findings are only partially supportive of our FCT-based hypothesis of disparities after misinformation is corrected: higher (vs. lower) educated parents were still more likely to receive MMR1 amidst overall increases in uptake across SES groups, but the largest uptake increase was among children of the lowest-educated parents (i.e., those who, in our prior tests, were least likely to vaccinate after misinformation events). This

subgroup increase in uptake reduced the magnitude of enduring SES disparities, but the change was modest and not statistically significant.

This third test also highlights the challenges of correcting health misinformation: decades later, the vaccine–autism myth persists, fueled by anti-vaccine activists. Despite *The Lancet's* retraction of Wakefield's 1998 study and the revocation of his U.K. medical license after findings of fraud and financial conflicts of interest, Wakefield remains a leading figure in the movement. Supporters still view him as a martyr punished for challenging the medical establishment and pharmaceutical industry, dismissing extensive evidence debunking his claims (Bertrand, 2015). His study's publication and retraction coincided with the rise of the modern anti-vaccine movement and the internet, which amplified misinformation. This contrasts other public health cases, such as tobacco, where legal judgments led to successful corrective campaigns (Smith et al., 2011).

While the educational disparities in MMR1 uptake identified in our analyses were modest in absolute terms (typically 2–5 percentage points), they are nonetheless epidemiologically and socially significant. Measles is highly contagious, and 90 % is considered a critical minimum threshold for vaccine coverage, below which the risk of outbreaks rises substantially (CORI, 2024). Our findings suggest that children of parents with lower educational attainment are disproportionately represented in coverage gaps that fall beneath this threshold, thereby contributing to socially clustered vulnerability (Plans et al., 2014). Addressing these vaccination disparities is essential not only for promoting equity but also for maintaining effective population-level disease control.

4.1. Strengths and limitations

This study used high-quality Danish national registry data linking child health records to parental and household demographics. Nevertheless, several limitations exist. Our analyses exclude a small number of children who may have received MMR1 abroad before immigrating and/or were missing parental education data. For the latter, sensitivity analyses revealed most of these parents were immigrants, likely educated outside Denmark, resulting in missing registry data. Although child medical records are ideal for accurately estimating vaccine uptake, studies demonstrate a slight under-reporting of MMR vaccinations (accounting for a few percentage points) by physicians contributes to suboptimal coverage estimates (Holt et al., 2017; Wójcik et al., 2013). It is unclear whether this under-reporting varies by SES or affects the observed disparity trends.

While we have detailed data on MMR1 receipt and demographics, the Danish registry contains no information on parent vaccine attitudes, beliefs, and information sources (e.g., child's physician, other parents, media sources). Thus, we can only infer misinformation's impact through SES trends in MMR1 uptake, rather than directly analyzing SES differences in these factors that might influence parents' vaccination decisions. This limits claims about how specific education (and perhaps broader SES) mechanisms operated. Also, some parents may have delayed MMR1 vaccination beyond our observation period (ages six months to four years) and caught up later (e.g., when MMR2 became due). Nevertheless, even if this occurred and attenuated some MMR1 disparities, such a lag remains consistent with the FCT hypotheses that our findings support.

Other co-occurring events may have also influenced the observed patterns. While we focused on disparities before and after three notable events, these were merely *starting points* for broader shifts in discourse and organized anti-vaccine activism. The study period also coincided with the rise of the internet, which expanded access to information of varying accuracy—leading to the mainstreaming of doubt about a generally accepted vaccine and fomenting enduring confusion and fear that advanced the modern anti-vaccine movement. Although our data end in 2012, the subsequent emergence of algorithmic content curation, social media platforms, and cross-border digital flows has likely amplified and entrenched such misinformation (Swinford and Zadeh, 2025), potentially intensifying the SES-based vulnerability patterns we observe.

Additional factors may have also shaped the observed education dynamics, including public education efforts by the media, medical, and public health communities, plus providers increasing their efforts to educate parents during child medical visits in response to vaccine misinformation and measles outbreaks. Nevertheless, research indicates Danish media coverage generally supported MMR1 uptake, with negative media having minimal impacts (Hansen et al., 2019). Still, pro-vaccination messaging issued in reaction to vaccination misinformation may have been differentially received across SES groups—possibly providing corrective reassurance (or debunking) or inoculation against misinformation (Compton et al., 2021) to some, while triggering reactance among parents already persuaded by the DR radio program and subsequent activism promoting a vaccine–autism link. Hence, assessment of vaccine misinformation impact during this period is likely conservative, given the evolving and conflicting information landscape Danish parents faced.

Finally, while Denmark is an ideal country to test our ideas, generalizability to other countries is unclear. Unlike other European or North American countries, Denmark has no vaccination mandates and maintains a high degree of institutional trust—ranking second in trust in physicians among 29 nations (Blendon et al., 2014) and eighth in trust in government among Organization for Economic Cooperation and Development countries in 2012 (OECD, 2024). Such trust may buffer against health misinformation, in contrast to countries like the United States, where lower trust (24th in physicians, 23rd in government; OECD, 2024) could foster a culture of parental skepticism and self-directed health research, increasing susceptibility to health misinformation (e.g., Reich, 2014). Finding disparity dynamics in Denmark suggests vaccine misinformation could have even greater impacts in countries with different media environments, healthcare, and vaccination systems—though the effects may not follow the same pattern observed here and could instead align more closely with NCFP mechanisms.

5. Conclusion

Our study advances understanding of how misinformation may contribute to vaccination disparities and, more broadly, the creation, reproduction, and mitigation of health disparities. We conclude with two broader insights for future research on the role of misinformation for health disparities.

First, while our focus was on the impact of specific misinformation on SES-related vaccination disparities, fundamentally, misinformation involves *knowledge claims* (by lay public and experts) that often coincide with the introduction or availability of potentially beneficial health resources. When classifying misinformation events, it is important to recognize that not all false information originates as deliberate misinformation or disinformation. Some originate as preliminary or speculative ideas (plausible or not) by lay people or experts that are later disproven. Indeed, plentiful instances exist in the history of science and medicine. Concerns about a vaccine–autism link emerged amid rising autism diagnoses and coincided with the recommended vaccination age. Despite subsequent scientific evaluations revealing no evidence supporting this link (e.g., Hviid et al., 2019), it is understandable that early claims attracted parental attention—even before Wakefield and colleagues' now-retracted 1998 study—and that some people continued to embrace them afterward. Therefore, given that misinformation and disinformation are, fundamentally, inaccurate knowledge claims, to improve conceptual and empirical precision, future research should classify misinformation cases based on the nature of the knowledge claim, distinguishing whether it was:

a. immediately recognized as inaccurate misinformation or even disinformation (e.g., COVID-19 vaccines containing microchips; Hamel et al., 2021)

b. initially speculative with unknown plausibility, but later proven false after the accumulation of better evidence (e.g., the claim that vaccines cause autism); or
c. initially accepted by experts but later proven false upon the accumulation of better evidence (e.g., early beliefs about the safety of hormone replacement therapy that later showed risk for adverse health outcomes).

Second, in the 21st century, when disparities in health-beneficial innovations emerge, we need to consider how lags in adoption that contribute to disparities in the health outcomes that the innovation aims to avert (e.g., disease onset, progression, death) are often partly driven by misinformation—not just cost, access, or awareness. While health-related misinformation is not new, modern media platforms can rapidly amplify and globalize false or misleading claims and enable coordinated disinformation campaigns targeting innovation safety, necessity, and effectiveness. Furthermore, anti-vaccine activists often target historically marginalized groups, exacerbating their health vulnerabilities (e.g., Carpiano et al., 2023; Southwell et al., 2023). Hence, future research should consider how certain subpopulations (including those with high levels of education) may be more vulnerable to misinformation's pernicious effects and how this susceptibility can extend beyond a single issue to other health matters—affecting trust in the medical profession and public health systems more broadly.

CRediT authorship contribution statement

Vibeke Tornhøj Christensen: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Andrea N. Polonijo:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Richard M. Carpiano:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization.

Ethics approval statement

This project was reviewed and determined to be exempt by the University of California, Riverside Institutional Review Board.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2025.118914.

Data availability

The authors do not have permission to share data.

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