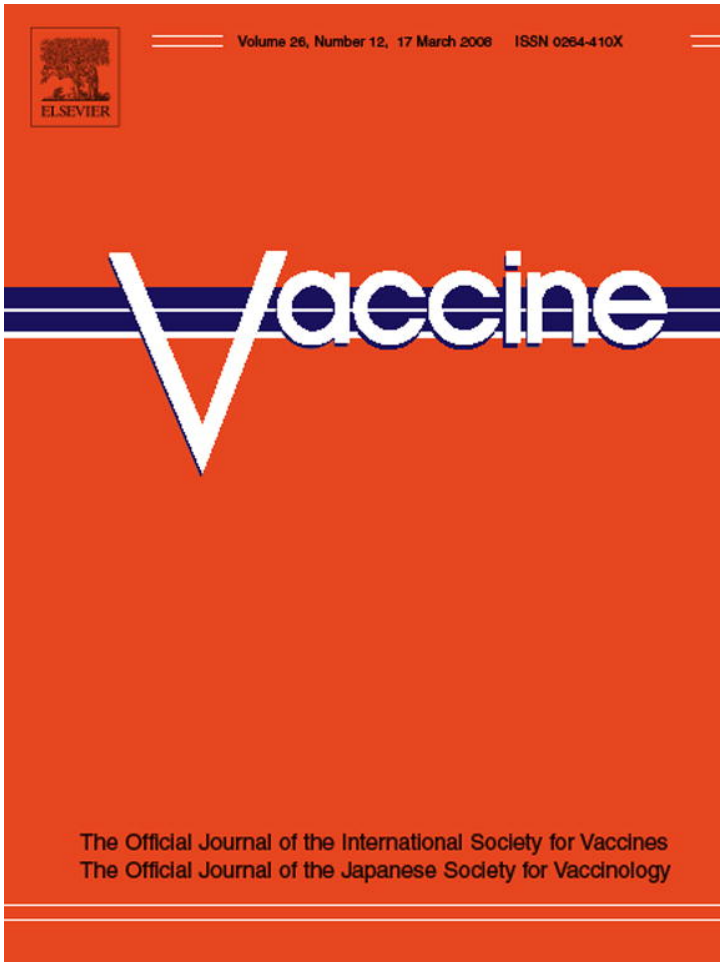

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Parents' vaccination comprehension and decisions

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Summary We report on 30 in-depth *mental models* interviews with parents discussing vaccination for their children, both in general terms and in response to communications drawn from sources supporting and opposing vaccines. We found that even parents favourable to vaccination can be confused by the ongoing debate, leading them to question their choices. Many parents lack basic knowledge of how vaccines work, and do not find the standard information provided to them to be particularly helpful in explaining it. Those with the greatest need to know about vaccination seem most vulnerable to confusing information. Opportunities for education may be missed if paediatricians do not appreciate parents' specific information needs.

Introduction

Vaccines have substantially reduced, and in some cases essentially eliminated, the risk of previously common childhood diseases [1]. Current vaccination rates in the United States are high enough to achieve herd immunity for many diseases, protecting even those children who are not vaccinated [2]. However, some parents' decision not to vaccinate their children threatens to undermine this success. Recent drops in measles-mumps-rubella (MMR) vaccination rates in the UK and Japan [3] have led to a resurgence of preventable diseases [4–7]. This pattern recalls previous periods of vaccine mistrust [8], leading to reduced vaccination rates [9] and disease outbreaks [10,11].

Why parents may not vaccinate

Some failures to vaccinate are oversights. Parents often think that their children have more current vaccinations than medical records indicate [12]. Other failures reflect socioeconomic barriers, associated with low income, multiple children, and health care divided across providers [13,14].

In other cases, though, not vaccinating reflects conscious decisions [13,15]. Some parents object on religious or personal grounds [16]. In rare instances, children are exempted due to medical contraindications [17]. The trade-off between long-term benefits and short-term costs, such as crying or pain, is acknowledged even by parents who have their child vaccinated [18]. Two beliefs that predict

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decisions not to vaccinate are that vaccines (a) are unsafe when administered [13] and (b) can have long-term negative health effects [18]. These concerns also predicted vaccination decisions in a prospective study [19].

Vaccination is also less likely among parents who see fewer benefits. Some parents believe that they will be able to protect their child from disease without immunisation [20]. Others see little disease threat, ironically, because of vaccines' success in reducing disease incidence [21], a trend seen in previous periods with anti-vaccination movements [22]. Some parents say explicitly that the shot is riskier than the disease [23]. Others seem motivated by *omission bias*, whereby they would feel worse if their child were injured from their action (getting the vaccine) than from their inaction (not getting it) [20,24,25].

Public concerns about vaccines are not new. Early vaccines, such as smallpox in England [26] and polio in the United States [27], faced strong opposition. As a result of these protests, parents in Britain won the right to decline vaccination [28]. Activists lobbied for acellular pertussis vaccine [29], which is now the standard, even though there was never strong evidence that the whole-cell version was risky [28]. Despite continued improvements in vaccine administration safety [30], the global perception that vaccines are risky is growing [31].

Some of those fears seem to be grounded in evidence that is incompletely understood, such as early, small sample studies suggesting that the MMR vaccine can cause autism [32—34]. Many subsequent studies, using more rigorous methods, failed to substantiate this claim [35—40], including a large epidemiological study with the statistical power to reveal even a small MMR-autism correlation [41]. Research into possible links between neurological conditions and thimerosal, a preservative used in some vaccines, has not shown consistent, replicable relationships [42]. Nonetheless, negative reports persist.

One form of negative publicity concerns adverse events among individual children who have received vaccines [43]. A second form is investigative journalism, like a widely read essay printed in *Rolling Stone* magazine and *Salon.com* criticizing thimerosal, citing environmental contaminants and questionable government motives [44]. Such accusations can spread widely on the Internet [45], potentially resonating with parents holding anti-vaccination beliefs [22]. Alternative medicine practitioners, such as those using holistic and homeopathic approaches, often recommend against vaccination [46,47]. The impact of homeopaths' recommendations may be amplified by their willingness to give immunisation advice by e-mail more often than physicians do [48]. School officials who advocate alternative medicine or hold common misconceptions about vaccination are also more likely to advise parents to opt out or to grant exemptions [49]. Parents who favour alternative medicine are less likely to vaccinate their children [15].

Parents' trust in healthcare providers makes them potentially valuable educators [50], with opportunities that arise frequently, as when they encounter parents raising safety concerns [13,51]. However, physicians may miss these opportunities due to fear of litigation [45] or preference for referring sceptical patients elsewhere [51]. And some patients are frustrated that their practitioners seem to lack the time to talk [52].

Although there has been considerable research into factors that predict parents' perceptions of risks and benefits, relatively little attention has been paid to parents' underlying conceptual model of vaccination and its role in their interpretation of vaccine-related communications. Flawed mental models may increase susceptibility to anti-vaccination campaigns, which often rely on flawed logic [53]. Without knowing parents' mental models, it is difficult to develop effective communications, for delivery by providers or other sources. Under the time and conversational constraints of modern medical practice, doctors may not understand parents' concerns about vaccination. The research reported here presents a more comprehensive picture of these concerns, based on in-depth interviews with American parents who have faced the prospect of vaccinating their children. We examine their general understanding of vaccines and response to new information.

Overview of research

We adopted a *mental models* approach to identifying parents' patterns of beliefs regarding vaccinations. This approach [54] builds on a legacy of related approaches in cognitive psychology, tailored to the demands of understanding different phenomena [55—58]. All mental models approaches begin with a formal analysis of the domain, followed by open-ended interviews structured around that analysis. Subsequent studies may include structured surveys suited to administration to large samples for estimating the population prevalence of beliefs, as well as the creation of interventions that improve lay understanding and decision making [59,60]. The research reported here takes the first two steps, characterizing the phenomena that parents must understand (vaccine risks and benefits) and then describing parents' mental models of these processes, as revealed in open-ended interviews.

We have applied this strategy to topics as diverse as domestic radon [61], adolescent sexual behaviour [59], mammography [62], climate change [54], electromagnetic fields [63], carbon dioxide sequestration [64], paint stripper [65], nuclear energy sources in space [66], breast implants [67], and cancer [68].

In the first step, we use a standard approach to characterizing complex, open-ended systems, creating an *integrated assessment* of decision-relevant knowledge. It uses the formalism of influence diagrams [69,70], in which nodes represent variables and links represent relationships. When an arrow connects two nodes, knowing the value of the variable at its tail helps to predict the value of the variable at its head. Like other models, influence diagrams are incrementally refined. At all stages, the aspiration is a computable model, in the sense of working toward a sufficiently precise representation that would allow outcomes to be predicted if data requirements were met [71]. Whether actual computation is pursued depends on the application. Here, an intermediate level of formalism seemed best suited to ensuring that the full set of potentially relevant issues was represented, without unduly favouring those issues that are more readily quantified.

The second step uses the integrated assessment to characterize the target audience's decision-relevant beliefs.

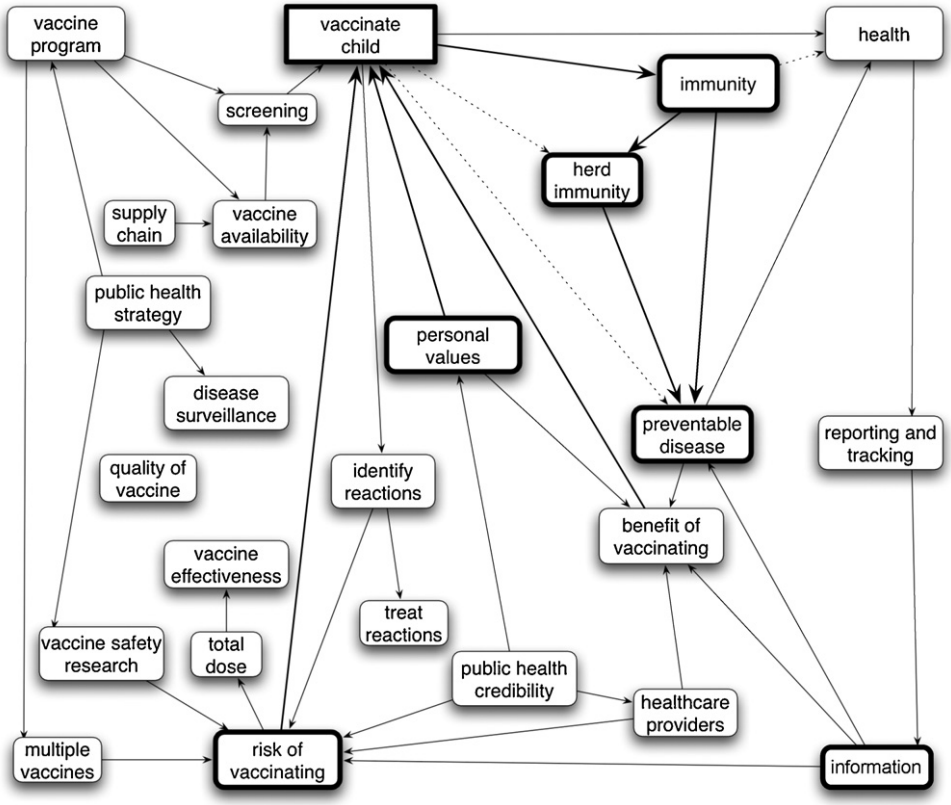

Figure 1 Integrated assessment: Solid black arrows indicate links between variables described by experts; dotted black arrows indicate unmediated links mentioned by respondents; links mentioned by experts but not interviewees are not shown.

Open-ended interviews are used so that people can address any issue on their minds, in their natural mode of expression. The interviews begin very generally, and then ask if the interviewee has anything to say about each topic in the model. Such interviews lay the foundation for the content and wording of structured surveys and interventions.

Method

Formal analysis of vaccine decisions

The integrated assessment of the variables relevant to vaccination decisions was developed in collaboration with experts at the National Immunization Program at the Centers for Disease Control and Prevention. In order to capture the range of issues on parents' minds, especially beliefs potentially dividing them from public health officials, the model takes an expansive view. As a result, it includes issues not ordinarily part of public health planning, and relationships that are unsupported (or even contradicted) by scientific evidence.

The integrated assessment is shown in Fig. 1. The nodes of greatest relevance to the analyses in this paper focus on parents' key reasons for vaccinating their children (including the risks and benefits of the inoculation, their personal values and their sources of information) and the mechanisms by which vaccines work (through bolstered immunity and broader herd immunity). The Appendix describes each node.

Analysis of existing communications

To illustrate the application of an integrated assessment, as well as the communication environment facing parents, we began by applying it to four existing communications, two from official sources and two from anti-vaccine activists, with one each on the general issue of MMR vaccination and the specific claim of an MMR-autism link. This analysis is designed to show how contrasting sources structure their arguments. Each communication was divided into discreet ideas, with each idea then coded into the relevant node or link in the integrated assessment. The resulting codes were used to compare and contrast the communications.

Interview participants

Mental models interviews were conducted with thirty parents, recruited by a market research company from three cities identified by the company as providing diversity in race, background, and vaccination attitudes: Kansas City (Missouri), Philadelphia (Pennsylvania), and Eugene (Oregon). Eugene residents were anticipated to be likely to endorse alternative medical beliefs relevant to vaccination. Parents were eligible if they had a child between 18 and 23 months of age.

The sample size of 30 balances the resource-intensive demands of in-depth interviews and their analysis against the marginal return of new insights from additional participants. Drawing on ethnographic norms, Morgan et al.

Table 1 Sample questions from interview protocol

Can you tell me, to the best of your knowledge, how vaccines are supposed to work in the body to prevent a disease?
Can you tell me anything about what happens once many people get vaccinated for a disease? *Prompt*: Do you think that would make any difference in preventing the disease?
Did you think there were any risks to getting [your first child] vaccinated? • (I*f not mentioned*) What do you think could happen? • From 1 to 7, how bad do you think that would be if it happened, using 1 for not bad at all and 7 for extremely bad? • How likely do you think that would be? • Can you give a guess at the percent chance that this would happen?

[54] identify a sample of 15 as sufficient to reveal (at least once) any belief held by 10% or more of the population. A sample of 30 also allows basic comparisons between subsamples. The similar reasoning on many issues in the results reported below suggests that theoretical saturation was likely achieved, even with our small sample.

Interview procedure

One-on-one interviews were conducted by telephone. The interview protocol had two segments: *mental models*, assessing beliefs about vaccination, and *communication assessment*, measuring trust in communications designed with different information properties. The mental models portion used 24 questions following the structure of Fig. 1, starting with how vaccines work, and then proceeding to decisions about vaccination. Table 1 shows sample questions, along with prompts used to stimulate thinking, without directing it. The protocol included structured questions eliciting quantitative ratings on several topics, including the risks and benefits of vaccination, trust in information sources, and the adequacy of official information, on scales anchored at 1 (*not at all*) and 7 (*completely* or *extremely* safe, trustworthy, sufficient, etc.). Interviewees were asked to explain their ratings.

The communication assessment segment presented two vaccine communications, varying on three dimensions: (a) *position* (pro-vaccine vs. anti-vaccine), (b) *evidence* (statistical vs. anecdotal), and (c) *structure* (a logical argument with ''linked'' concepts vs. repetition of key concepts). These dimensions were crossed orthogonally to create eight communications. In order to avoid presenting communications with repeated content, each interviewee received two complementary communications, with opposite values on each dimension. This design allows us to explore main effects of each of the three dimensions using within-subjects comparisons, while controlling for the other two dimensions, not considering interactions. Each communication was rated on a scale anchored at 1 (do not trust) and 3 (trust highly).

Coding of interviews

Interviews were transcribed verbatim. As mentioned, respondents were prompted to clarify their thinking, recognizing that the ensuing ambiguity or confusion could be revealing. Responses to the structured questions were used only if the interviewee initially gave an unequivocal response (e.g., giving a number rather than saying ''not a lot''), before any request to elaborate.

Each sentence in the transcript was coded by two independent judges. They were trained by the first author until they could accurately and reliably apply the coding scheme. Where possible (91% of codes), ideas were coded into one of the 40 links in Fig. 1, hence represented statements drawing connections between two model variables. Ideas not addressing relationships were coded into a single node. Initially, each coder applied as many codes as seemed relevant to each sentence. To attain similar complexity in the coding, each coder then learned how many (but not which) codes the other had assigned to each sentence (with the numbers agreeing 76.9% of the time). Each coder could then revise the initial codes to show similar complexity, if it seemed warranted. After this partial recoding, 94.7% of sentences received the same number of codes. Final codes shared at least one node 87.5% of the time, compared to the 42% agreement expected by chance. Final codes agreed perfectly 67.5% of the time, compared to the 5.8% agreement expected by chance. The analyses focus on the most reliably coded and most central concepts.

Content analyses

For each of the 24 interview questions, we collapsed each interviewee's identical codes to avoid overweighting mere repetition and then computed the percentage of codes that mentioned each model link (Fig. 1). These percentages reflect respondents' *relative* emphasis on each link overall, irrespective of the respondent's total number of comments. Category scores were created by summing these scores across all links to each of six major topics: *vaccine risk*, *preventable disease*, *individual immunity*, *herd immunity*, *information*, and *personal values*. For example, the score for *immunity* in response to any given question was the sum of the scores for that question (in percent) for impacts of (a) vaccination on immunity, (b) immunity on herd immunity, (c) immunity on preventable disease, and (d) immunity on health.

Two *k*-means cluster analyses of these scores were conducted. Due to the small sample size, each analysis considered only a limited number of variables and only a two-cluster solution. The first cluster analysis examined interviewees' understanding of vaccines, as expressed in responses to the first interview question, which asked how

vaccines work in the body and whether vaccinating more people had any additional effect. We used the category scores for the two key concepts relating to vaccine function, *individual immunity* and *herd immunity* (which were highly correlated, $r = .59$). The second cluster analysis examined interviewees' responses summed across the remaining 23 questions, using two pairs of categories potentially affecting vaccination behaviour: vaccine risk and information ($r = .37$), as well as preventable disease and personal values ($r = .32$).

Because all variables in each analysis were measured in terms of percentages summed across the same number of questions, we did not perform any weighting or autoscaling. The cluster memberships emerging from these analyses were used to predict individuals' responses to scaled questions using analyses of variance (ANOVA), and to dichotomous questions using Chi-square tests.

Self-reported trust of the communications was analyzed with three separate repeated-measures ANOVAs, with position (pro-vaccine vs. anti-vaccine), evidence (statistical vs. anecdotal), and structure (a logical argument with ''linked'' concepts vs. repetition of key concepts) as the repeated factor, and cluster memberships as between-subjects factors. Given the small samples and between-subjects design, interactions were not examined.

Results

Figs. 2 and 3 map the concepts mentioned in the four actual communications into the integrated assessment. The thickness of the borders and arrows reflects the attention devoted to each node and link, respectively. These examples reveal starkly different foci.

Fig. 2 depicts communications providing general information about the MMR vaccine, with 2a supporting it and 2b opposing it. The pro-vaccination communication is the Centers for Disease Control and Prevention (CDC) Vaccine Information Statement (VIS), which US physicians must give to parents before administering the vaccine. As seen in the figure, it addresses basic information, but none of the underlying mechanisms (e.g., how vaccines create immunity). Fig. 2b's anti-MMR communication comes from the UK activist group Justice Awareness and Basic Support (JABS) [72], opposing the delivery of all three antigens in a single injection. It addresses many more concepts and links between them. For example, it discusses bureaucratic forces involved in vaccine production in some depth. In the figure, this expository strategy emerges as a more ''linked'' model, telling a more comprehensive story.

Fig. 3 shows two communications regarding a possible MMR-autism link. The pro-vaccine communication (3a) is CDC's ''MMR-Autism Theory and CDC's Conclusion Based on Several Studies.'' Fig. 3a reflects its extensive citation of statistical evidence refuting the claim that MMR has a role in autism. It makes no reference to any source of concern, beyond citing Wakefield et al. [32] nor is there any reference to experts' reasons for rejecting the original study. Rather, it rests on the citations, which individuals without a scientific background may struggle to integrate with their mental models of these processes. The anti-vaccine communication (3b), ''Why I don't vaccinate,'' was written by a parent and published on the website Parents' Place [73]. It cites statistics (sometimes inaccurate or out of context) that, it argues, show that benefits and risks are both measured poorly, that vaccines' negative effects have been understated and benefits overrated, and that overall the risks outweigh the benefits. As in Fig. 2, the anti-vaccine communications tells a more comprehensive and connected story than does CDC's scientific document.

CDC's communications might complete the mental models of readers who trust its claims and understand the basic processes of vaccination. However, the spare scientific summaries might not reassure other readers. In contrast, the activist communications tell more coherent stories, supported by narrative explanations. They address every issue in CDC's messages, and raise additional ones that CDC's messages ignore.

Interview respondents

Twenty-six (87%) of the 30 participating parents were mothers. Twenty-two (73%) were white, 7 (23%) African American and one (3%) Native American. Given the small sample, no gender or race comparisons were made. Nineteen (63%) had attended college. In all but one case, the focal child had been given all prescribed MMR shots.

Knowledge and opinions about vaccination

Twenty-four parents (80%) reported first learning about MMR vaccination from their doctors, with most of the others having read about it. Twenty-four (80%) reported reading the VIS, as required by the CDC, which they rated as very helpful ($M = 6.1$, S.D. = 1.0, on the 1—7 scale). Trust in their first information source was high ($M = 6.1$, S.D. = 1.0). Parents generally felt that the vaccine was well explained when they first learned about it ($M = 5.9$), but not by the VIS ($M = 3.6$), $t(21) = 6.72$, $p < .001$. Ten parents (33%) reported having heard discussion of the MMR vaccine's safety, with considerable variance in how much they trusted those reports ($M = 3.3$, S.D. = 2.4) and in how important those concerns seemed ($M = 4.4$, S.D. = 2.5). Ten parents (33%) reported having heard of children experiencing side effects from MMR; these reports were unrelated to whether they had heard about safety issues ($r = .02$). Parents had mixed opinions about whether MMR had caused these side effects (mean = 4.4, SD = 2.5). Twenty-three (77%) thought that some children were more susceptible to reactions, 13 of whom (57%) thought a doctor could identify those children in advance.

When asked, 11 parents (37%) said that there were drawbacks to getting their child vaccinated, which they rated as only moderately serious ($M = 2.9$, S.D. = 1.7). Seventeen parents (57%) thought that vaccination had risks, estimating the probability as fairly low (median = 5%) but severity as moderate (mean = 4.3, S.D. = 2.2). These judgments of probability and severity were not significantly related ($r = —.14$, $p = .60$).

On average, parents thought that foregoing the MMR vaccination did more to hurt than to help both the unvaccinated child ($M = 2.8$, S.D. = 1.8) and other children ($M = 2.8$,

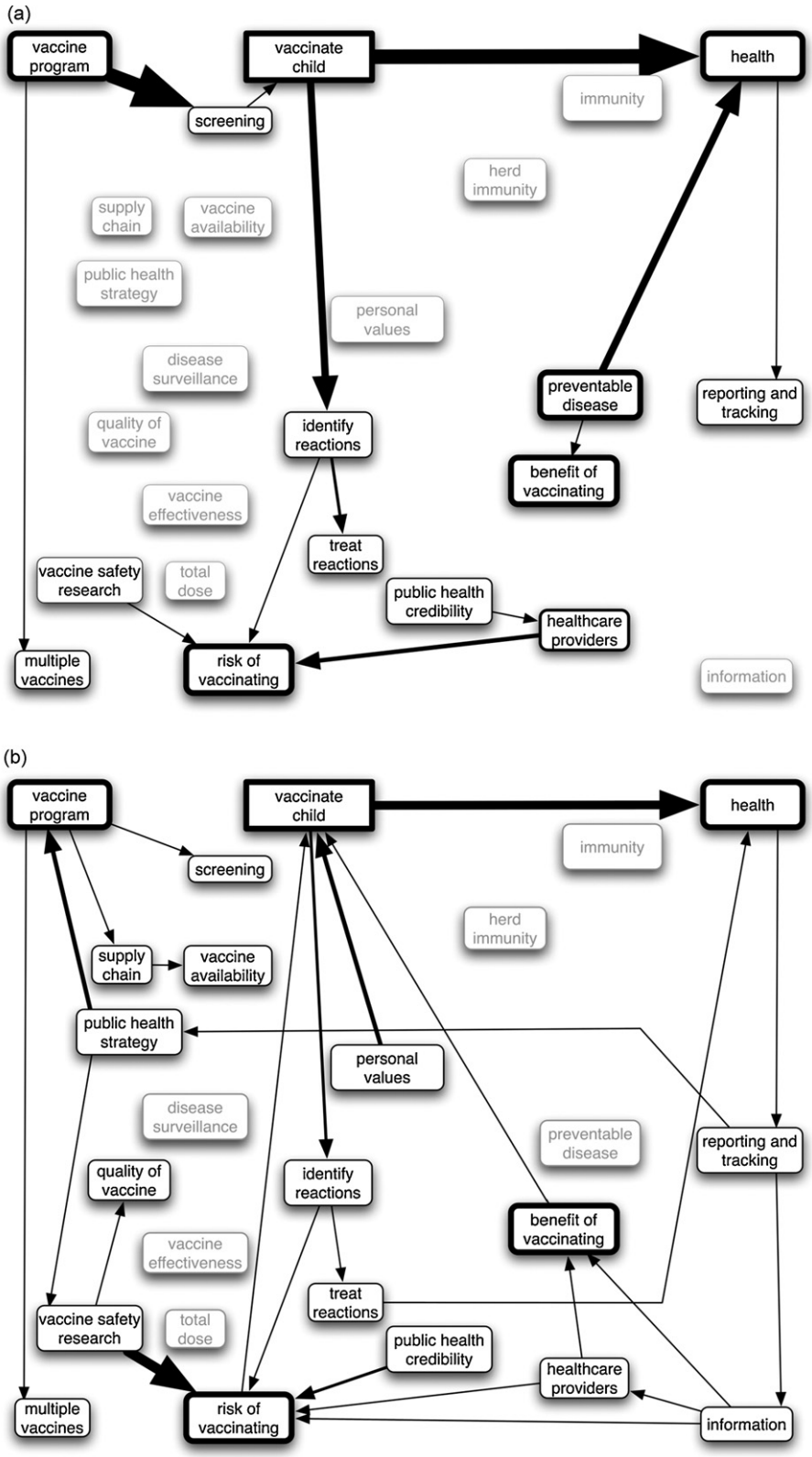

Figure 2 Models implicit in communications about MMR vaccine from (a) an official source and (b) an activist Internet source. The thickness of each arrow corresponds to how frequently that link was mentioned.

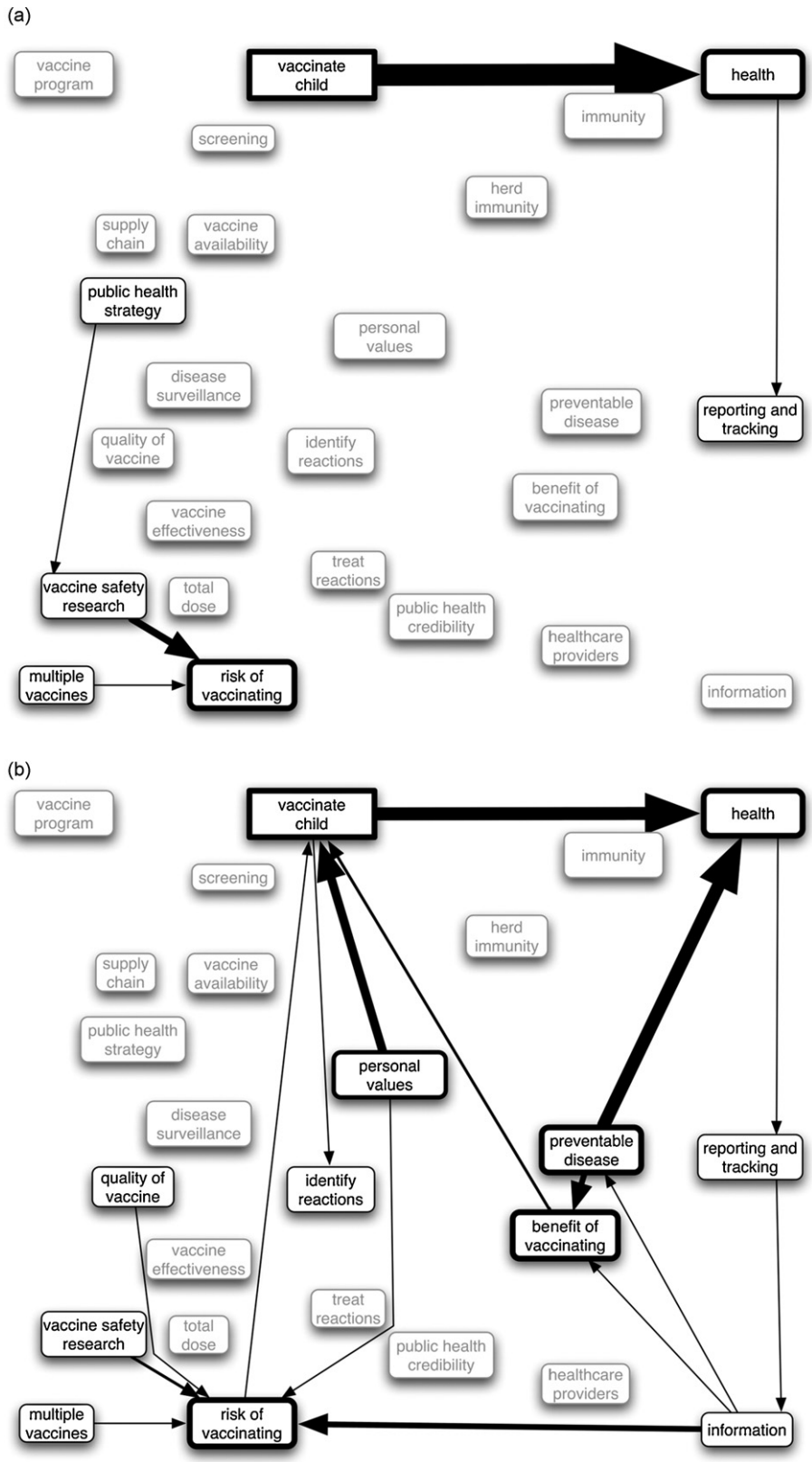

Figure 3 Models implicit in communications about the link between MMR vaccine and autism from (a) an official source and (b) an Internet source. The thickness of each arrow corresponds to how frequently that link was mentioned.

S.D. = 1.6), where 1 = ''would hurt very much,'' 4 = ''neither help nor hurt,'' and 7 = ''would help very much''. These ratings were not significantly different for the unvaccinated child than for other children, $t(25) = 0.04$, $p = .97$. The better parents felt about how well vaccination had been explained when they had first heard about it, the more they thought that not vaccinating a child would hurt other children ($r = -.54$, $p < .01$).

Understanding of vaccines

The first cluster analysis sorted respondents according to their beliefs about vaccine mechanisms. The mean category score was higher for individual immuni2ty (.27) than for herd immunity (.15), $p < .01$. Fig. 4a and b pool responses of individuals in each of the two clusters, which might be described as contrasting parents with a *naïve understanding* and those with a *focused understanding* of vaccine mechanisms. The thickness of each arrow reflects how frequently that link was mentioned, with thin grey lines representing links that were never mentioned. The thickness of a node's outline reflects how frequently it was mentioned without being linked to other concepts.

The 16 respondents in the *naïve understanding* cluster typically just mentioned a link between vaccination and the disease, without explaining any underlying mechanism, beyond perhaps a vague reference to the role of immunity. None mentioned herd immunity. For example, a Philadelphia father's description was limited to:

> They get in your body to make sure that any bacteria that are supposed to hurt the child, stops it from hurting the child.

When asked to expand on their answers, parents in this group often strayed to other topics. For example, a Kansas City mother said:

> They go to doctors, and get the vaccination and should be vaccinated against whatever one it is that they don't want to get. [*Interviewer*: Can you tell me anything about what happens once many people get vaccinated for a disease? (pause) You know, several people?] They, used to, you'd get sick. [*Interviewer*: Pardon?] Usually you might get sick after you get a vaccination.

The 14 interviewees with more *focused understanding* (Fig. 4b) made more statements about the link between vaccination and disease prevention, fewer extraneous comments, and more comments about immunity and herd immunity. For example, a Philadelphia mother described vaccines' mechanism as:

> Some vaccines, what they do is they — it's a dead version of the, of the virus. And what they do, they put it into your body and your body builds up the immunity to learn how to fight it. [*Interviewer*: OK] The [other] ones that I think are a, like a weak strand of the disease. And then, again, your body builds up an immunity to fight it so that later on in life you don't have to worry about getting the disease. [*Interviewer*: Would it make any difference in preventing the disease if a lot of people were vaccinated?] I would think that if you had a lot of people getting vaccinated that you would severely reduce, uh, the incidences of that disease occurring. And that, that would reduce any chance of it spreading.

Few parents described herd immunity this clearly, in terms of the reduced chance of spreading disease. Most talked about eradication, like this Kansas City mother:

> Well, it's like smallpox, it can be eradicated. [*Interviewer*: OK. So if I were to ask you, do you think that would make any difference in preventing the disease, how would you answer that?] Yes. [*Interviewer*: OK, Would you like to elaborate on that?] Uh, well if you can get everybody vaccinated, then we don't have to worry about measles and chicken pox, etc.

The *focused* parents were slightly, but not significantly, more likely to be college educated ($\chi^2 = 2.63$, $p = .11$). Parents in both groups were equally likely to say that they would look on the Internet for vaccine information (70%, $\chi^2 = 0.92$, $p = .34$). However, parents in the *naïve* cluster were much more likely to say that they would seek information from their doctor or a government agency, 56% (9 of 16) versus 7% (1 of 14), $\chi^2 = 8.10$, $p < .01$. Those in the *focused* group were more likely to value convenience over trust (100% of the 10 who addressed the trade-off, vs. 69% of the 16 *naïve* parents who addressed it, $\chi^2 = 3.87$, $p < .05$).

Topics of concentration in vaccination decisions

The second cluster analysis examined differences in topics mentioned in response to the remaining 23 mental models questions, about vaccinating one's child. The mean category scores were higher ($p < .01$) for preventable disease (2.72) than for risk (1.81), personal values (1.35), or information (1.31). The two emergent groups overlapped one another, with members of both groups talking most about the *benefits* of vaccines, the need to *identify reactions*, the impact of vaccination on *disease prevention* and *health*, and how *screening* decisions are made and implemented. Beyond these similarities, one group ($n = 16$) concentrated on *health-oriented* aspects of vaccination, while the second ($n = 14$) added *risk-oriented* issues, such as research, dosage, and the credibility of US public health agencies. Parents in the *risk-oriented* group were more likely to report having heard reports of issues surrounding the MMR vaccine (57%, or 8 of 14, vs. 13%, or 2 of 16, $\chi^2 = 6.70$, $p = .01$) and of some parents not vaccinating their children (86%, or 12 of 14, vs. 27%, or 4 of 15, $\chi^2 = 10.21$, $p = .001$). The *risk-oriented* parents were slightly more likely to be in the *focused understanding* group of the other cluster analysis, on vaccine understanding ($\chi^2 = 3.27$, $p = .07$).

A Kansas City mother classified as *risk oriented* with a *focused understanding* said:

> From what I understand I think it's giving him, when they get that, that's kind of a mild form or it could be a mild form of the disease and then their body becomes immune to it . . . . It wasn't until he was probably six months old or so that I started reading a lot of questionable material on vaccinations. But it still would have never really been a consideration. I read some scary stories that kind of make you think twice but I, I'm still in favour of vaccination.

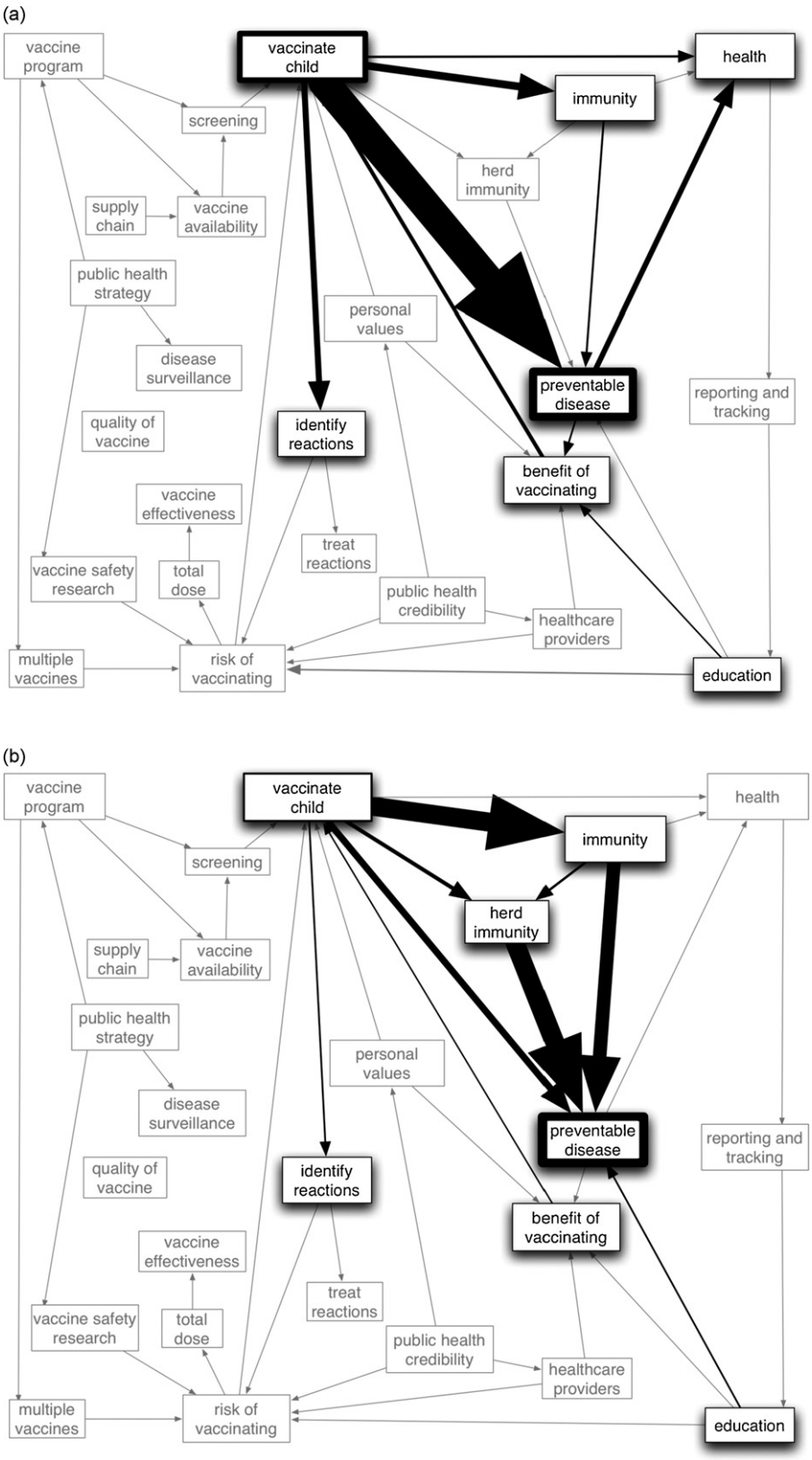

Figure 4 Parents' beliefs about how vaccines work, for parents with (a) naive understanding and (b) focused understanding. The thickness of each arrow corresponds to how frequently that link was mentioned; grey arrows indicate links that were not mentioned in response to the question about how vaccines work.

For other parents, risks seemed obvious, but confusing. For example, a *risk-oriented* Kansas City mother with a *naïve understanding* of vaccine mechanism said that she would like to know:

> Why should the child have to get three shots, why does the child have to get like three shots at one time, and I mean it may just be a convenience for the parents as well, but I just think it's a lot to stick a child two and three times when they go to the doctor for a shot. Is there, I don't know if there's ways to combine drugs and do things that way, I think it's really hard on a little person. They get shot two and three times for a doctor's appointment. And a little more clear information as to why I need it in laymen's terms, and what are some of the potential side effects I should be looking for. Not to scare myself, but just so that I can be informed.

Communication assessment

Overall, parents trusted the pro-vaccination communications more ($M = 2.53$, on the 1—3 scale) than the anti-vaccination ones ($M = 1.80$), $F(1,29) = 14.68$, $p < .001$. This difference did not interact with the order in which they heard the two communications ($p = .87$). *Risk-oriented* parents trusted the communication with statistical arguments more than the one with an anecdotal argument (2.57 vs. 2.07), whereas *health-oriented* parents trusted the anecdotal communication more (2.31 vs. 1.75), producing a significant interaction, $F(1,28) = 4.22$, $p < .05$. There were no significant main effects or interactions for naïve versus focused parents on any communication variable.

Internet searches

When asked what source(s) they would consult for more information, 10 parents (33%) said that they would ask their doctor or look for a government source and 21 (70%) said that they would look on the Internet. When asked to explain their choice, 21 (70%) cited convenience and 5 (17%) cited trustworthiness. When asked explicitly whether they would use the Internet to find information, 27 (93%) said yes. The others explained that they lacked easy Internet access, but could look on the Internet if they wanted to. Of these 27, only five (19%) said that they would look at a medical web site (such as webMD.com); 25 (93%) said that they would use a general search engine. All respondents easily generated search engine terms (e.g., ''vaccination,'' ''MMR vaccine,'' or ''measles''), typically providing 1—3 separate search terms. To determine what parents would find, we conducted web searches using the 44 distinct sets of search terms that they provided. We entered the terms into six commonly used search engines, finding similar results: Google, Yahoo, Lycos, Metacrawler, MSN and AOL. These searches revealed that 93% of respondents would find anti-vaccine websites in the top 10 hits. Anti-vaccine websites were most likely to rank higher than pro-vaccine sites with searches using simple terms like ''vaccine,'' meaning that they might be most accessible to individuals with the least knowledge. Searches with more precise terms, like ''MMR vaccine'' or ''vaccination'' routinely found official public health web sites in the first 10 hits.

Conclusions

Summary

These parents were generally favourable toward vaccination. Yet many had limited understanding of how it works, making them potentially vulnerable to misinformation (or disinformation). No one used the term ''herd immunity,'' although some discussed how a community's welfare depends on individuals' decisions. Some parents talked about eradicating diseases, usually without mentioning the steps needed to reduce exposure.

Most parents had first learned about the MMR vaccine from their doctor or another health care professional. Although they rated CDC's vaccine information statement (VIS) as helpful, most thought that it explained the vaccine poorly. As noted, it did not address the mechanisms that many parents did not understand (Fig. 2a).

Consistent with this perception of incompleteness, many parents reported seeking additional information, often saying that they would use the Internet rather than ask their doctor. Most said that they would use a general search engine, rather than consult a medical or official website. Searches using the terms that interviewees offered led to both public health and anti-vaccination sites. Those offering the simplest search terms, who might be most easily influenced, were most likely to reach anti-vaccine sites.

Cluster analyses revealed two groupings. The first divided parents according to whether they had a naïve understanding of vaccination mechanisms or one focused on immunity. The second divided parents according to whether their vaccination decisions concentrated on health or risk. Membership in these groups correlated with other measures, including their communications preferences. Parents with some knowledge about vaccine mechanisms wanted information that would complete their mental models of health and risk processes. Parents focused on health-oriented topics wanted case studies more than statistics.

Broader relevance

Although generally favourable to vaccines, these parents held beliefs that seemed relatively simple and unchallenged, meaning that they might be unduly influenced by reports of problems [76]. The superficiality of their understanding suggests that today's high vaccination rates might be vulnerable to erosion, if negative information were more effectively disseminated to parents who are ill prepared to deal with it.

The most vulnerable parents might be those with the most naïve understanding, especially if they rely on the Internet search strategies that they described. Such searches are likely to lead them to sites with communications like those depicted in Figs. 2b and 3b, with broad connected narratives about how vaccines have hurt children. If these parents go to official websites, they might find mostly statistical evidence, which they may find unconvincing. Such parents are in particular need of information that completes their mental models of how vaccines work, so that they can appropriately interpret new information.

The power of different communication strategies is ultimately an empirical question [74]. Studies like the one reported here can reveal the thought processes underlying behaviour (e.g., vaccination) that might be robust or fragile (Fig. 4). They also point to the specific content that might complement or correct existing mental models (Fig. 1), as well as the strengths and limits to existing communications (Figs. 2 and 3). Thus, the details of these interviews provide the scientific foundation for answering calls like those of Ball's [43] for presenting parents with more than just cost-benefit arguments, and Stoto's [75] for directly addressing the uncertainty inherent in vaccination. The interviews provide the conceptual bridges to parents' existing mental models that are missing from official communications like those in Figs. 2a and 3a. Unless those bridges are created, parents may be deemed incompetent to handle vaccination choices, when all they really need is better help. Research on other topics has found that people often have mental models that are complete enough to allow them to absorb material from scientifically developed and evaluated communications [59—67]. The next step in the process would be to create a structured survey, suited for efficiently assessing the prevalence of beliefs before and after interventions, followed by the development and testing of such interventions [76,77], possibly tailored to audiences varying in sophistication or orientation (Fig. 4).

Limitations

The small sample size, dictated by the labour-intensive interview coding, can identify beliefs that occur with any practically significant frequency, but only with very rough estimates of those beliefs' prevalence. In addition, the parents were interviewed some time after their children had, in all but one case, completed the MMR vaccine schedule, meaning that they were relying on inevitably imperfect memory. A third limitation is that, despite its diversity, the sample had few fathers or non-white parents. Thus, these results should be viewed as points of departure for future research.

Next steps

The logical next step in this process is creating a structured survey instrument for estimating belief prevalence and identifying parents in need of information, drawing on the interviews for content and wording. Those results should guide the creation of interventions and the evaluation of their effect on parents' understanding of vaccines. Such communications should concentrate on those parents who need information most, as suggested by the cluster analyses. In our small sample, locale and education provided no guide to identifying those parents. A structured survey might provide better diagnostics. It may also be possible to develop communications targeted to specific populations, perhaps with an interactive interface directing parents to the messages most relevant to their needs. Materials could be made available in doctors' offices or online, with attention to ensuring that they are reached through parents' intuitive search strategies. If legal considerations require a message that fails to connect with parents' mental models (e.g., Fig. 2a), an added FAQ might still provide information creating a bridge to parents' existing mental models. Like all communications, these should be evaluated empirically before they are disseminated.

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Appendix A. Detailed explanation of integrated assessment model

This appendix describes the rationale behind each node in Fig. 1. The core of the model includes the variables most central to the vaccination process: namely, the specific *public health strategy* chosen to affect the prevalence of the *preventable disease* directly, by processes shown below, and indirectly, by encouraging parents to *vaccinate their child*. Vaccination will confer some degree of *immunity* on the child, contributing to community *herd immunity*, both of which will decrease the prevalence of the *preventable disease*. That, in turn, will influence overall population *health*. Below that section of the model are other factors relevant to parents' risk-benefit calculus in deciding whether to vaccinate their child. The *risk of vaccinating* depends on the probability of *identifying reactions* following vaccination and *treating reactions* well enough to prevent (or reduce) *health* consequences. The *benefit of vaccinating* depends on the vaccine's effects on *preventable disease*.

These processes are driven by the *vaccine programme* created to implement the *public health strategy*. These affect *vaccine availability*, the associated *supply chain*, and the *screening* procedures for receiving the vaccine, whose application depends on *vaccine availability*. The programme's management might be guided by *reports and tracking* of health outcomes, whose content will depend on the *disease surveillance* procedures following from the *public health strategy*. The lower left corner of the model comprises features of the vaccines affecting these processes, including whether the *vaccine programme* advises *multiple vaccines* administered simultaneously and what the *public health strategy* entails in terms of *vaccine safety research*. That research will affect the *quality of vaccine*, which will affect *vaccine effectiveness*, as will the *total dose* being administered (e.g., whether boosters are given).

Other, non-medical factors that may affect the inputs to parents' decisions include their *personal values* (e.g., a belief in alternative medicine that reduces perceived benefits, or libertarian values that see vaccination laws as coercion). *Information* about vaccines (from any source, however accurate) may affect perceptions of the *risks* or *benefits of vaccinating*, of the *preventable disease* itself, or of *healthcare providers* who can, in turn, influence parents' assessments of *risk* and *benefit*. Finally, *public health credibility* can affect parents' perceptions of *risk* and the

effectiveness of *healthcare providers*. It might also shape parents' *personal values*, by changing the public discourse.

The integrated assessment shown in Fig. 1 eliminates links found in the research literature but never mentioned by parents in our interviews, while adding several variables that parents did mention, without evaluating their accuracy. Based on the interviews, we added links (represented by dashed lines) that some parents described as unmediated paths, representing either shorthand descriptions or ignorance of the mediating factors. For example, vaccination can only affect *preventable disease* through *immunity*; a parent who does not mention that connection might not understand it or might think that it goes without saying.

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