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Assessing vaccine hesitancy in the UK population using a generalized vaccine hesitancy survey instrument

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ABSTRACT

Background: In many regions of the world, vaccine hesitancy has become an important concern to public health. A key part of any effective solution to it is to gain an in-depth understanding of the problem: its scope, who holds hesitant views and for which reasons.
Methods: We adapt the original 10-item Vaccine Hesitancy Scale (VHS), which targets parental attitudes, to a more generic version that captures general attitudes to vaccination. We use this adapted VHS in a sample of 1402 British citizens, selected from a large online panel (N > 1,000,000) based on quota for age, gender, educational attainment and region (response rate 43%). The existence of VHS subscales is evaluated via exploratory and confirmatory factor analysis. We describe the extent of vaccine hesitancy in the sample, and use simple and multiple regression analysis to examine associations between respondent characteristics and vaccine hesitancy.
Results: Despite ambiguities in defining hesitancy, we found that a substantial part of our sample held hesitant views about vaccination, particularly for those items reflecting aversion to risks of side effects. Four percent responded in a hesitant way to all ten items and ninety to at least one of the ten items. In line with recent studies in other populations, we identified two subscales within the VHS: lack of confidence in the need for vaccines and aversion to the risk of side effects. We found significant associations between hesitancy and various respondent characteristics but the predictive power of these associations remained limited.
Conclusion: Our study suggests that whereas a substantial percentage of the British population is vaccine hesitant, these views are not clustered in typical demographic features. The small but important adaptation of the VHS to target general attitudes seems to result in highly similar psychometric characteristics as the original scale that exclusively targets parents. We provide suggestions for further validation of the VHS.

1. Introduction

Since Edward Jenner's cowpox experiments in the eighteenth century, vaccination has been a divisive subject and fractions of the public have always resisted it [1–3]. Nonetheless, from a scientific perspective, the benefits of vaccination have long been demonstrated with rigorous empirical research. To the individual being vaccinated, vaccines provide almost invaluable protection against serious infections, but high coverage levels can also create an additional benefit emerging at the population level [4]. This public good of 'herd immunity', i.e. heavily reduced transmission of a pathogen in the population because of low numbers of susceptible hosts in the population, is an important layer of protection for those individuals who cannot receive vaccination themselves, those with a dysfunctional immune system, and those whose protection has waned [5]. It is mainly for the latter reason that many ethicists believe that vaccination is not merely a matter of personal choice but that it can also be a social obligation (see e.g. [6,7]).

Despite the demonstrated effectiveness of vaccination programs, there is evidence that in many parts of the world, substantial numbers of people are questioning the need to become vaccinated, seek alternative vaccination schedules, delay or refuse vaccination. As a result, it can be difficult to sustain high levels of vaccine coverage [8]. The consequences are increasingly becoming

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visible. Recent disease outbreaks of e.g. measles, mumps and diphtheria have been linked to regional clustering of vaccine refusals [9,10]. Europe had an alarming 41,000 measles cases in the first six months of 2018 and 37 casualties, compared to 24,000 cases in 2017 and 5000 in 2016, a surge in infections largely due to insufficient vaccine uptake [11]. The World Health Organization (WHO) recently labeled people's reluctance or refusal to become vaccinated one of the top ten threats to global health in 2019, next to e.g. antimicrobial resistance or air pollution and climate change [12]. A key mission for public health is therefore to understand these harmful dynamics, to timely counter them and to highlight the necessity of continued vaccination efforts to the population [13].

Public health protection is a central responsibility of the state, but this mandate is also bounded by democratic freedoms such as people's right to individual autonomy (in taking or forgoing medical interventions such as vaccination) and freedom to express diverging opinions (on the science and politics behind vaccination) [14–16]. Perhaps the best way to counter anti-vaccination sentiments and to secure compliance is to continuously invest in effective communication between policy makers, scientists and the public on public health matters [17]. A key aspect of this is that communication should be a 'two-way process': a dialogue that, besides conveying scientific information, requires in equal measure listening to the concerns of the receptors. Evolutions in vaccine attitudes need to be monitored over time and space and more in-depth understanding is needed about who it is that doubts vaccination and why. As such, public health communication can be better tailored towards the worries of specific groups of individuals [18,19]. It can be focused on those who are hesitant, but also on those who do vaccinate, to strengthen their confidence and enhance their ability to have a supporting conversation with those who are (becoming) hesitant.

In many countries, initiatives have been launched to build such a deeper understanding. The WHO's Strategic Advisory Group of Experts (SAGE) on Immunization agreed that the earlier focus on refusal and skepticism was too narrow and acknowledged that vaccine attitudes need to be tackled long before actual refusal takes place, even before underlying skeptical attitudes that lead to this refusal emerge [13]. Moreover, polarizing the debate by splitting people up into either a pro or a contra-vaccination camp leads to unnecessary and unproductive polarization. The concept of 'vaccine hesitancy' was suggested and defined broader and less judgmental than skepticism or refusal [20]. Unlike these latter two, the SAGE working group defined hesitancy as "the delay in acceptance or refusal of vaccination despite availability of vaccination services" and hence as a continuum in between blindly accepting and complete refusal of all vaccines [21]. Hesitancy does not just point at lack of confidence in vaccines but it also encompasses issues of complacency (insufficiently valuing vaccines or the need to become vaccinated) and convenience (procrastination in actually becoming vaccinated or limitations in access) [21]. So, rather than a set of general anti-vaccine opinions, the concept of vaccine hesitancy is thereby defined as a vaccine and context-specific, behavioral phenomenon that needs to be understood against an expectation of reaching a specific coverage goal, and this under circumstances of sufficient access to vaccination [21].

Measuring vaccine hesitancy has become a key focus of recent studies in the field (e.g. [8,22–26]). Several measurement scales have been developed in order to tap into the core of hesitant vaccine attitudes ([25,27–33]). In 2015, the WHO-SAGE Working Group on Vaccine hesitancy developed a scale, called the 'Vaccine Hesitancy Scale' (VHS) that aimed to unify existing research on the many determinants of vaccine hesitancy in a workable framework and to standardize the measurement of vaccine attitudes [34]. The VHS allows comparing parental levels of hesitancy across regions as well as to map evolutions of hesitancy over time, and can be linked to socio-demographics in order to identify priority groups. Recent studies have validated the scale for a Canadian (N = 3779) [26] and Guatemalan (N = 720) [22] sample. The VHS significantly related to other scales' outcomes (e.g. Vaccine Conspiracy Belief Scale), attitudes towards human papillomavirus vaccination and vaccine refusals in the past. Shapiro et al. [26] concluded that the VHS is valid to identify vaccine hesitant parents, whereas Domek et al. [22] reported problems with its practical use in a low and middle-income setting. Both studies identified two subscales within the 10-item scale with one reflecting the problem of 'lack of confidence' in vaccines and the other pointing at 'risk perceptions'.

Our study aims to contribute to this emerging literature in two ways. First, we broaden the applicability of the VHS by focusing on vaccine hesitancy within the respondents themselves, rather than an exclusive focus on parental attitudes regarding childhood vaccines. As argued by Martin and Petrie [25], existing vaccine hesitancy scales focus either on particular subpopulations (e.g. parents or particular target-groups) or specific vaccines (e.g. HPV) but a single measure that taps into the more generalized attitudes to vaccination may be the most efficient way to identify individuals with vaccine-related concerns. To broaden the scope of the VHS, we made modifications in the perspective and wording adopted in the original VHS, without losing its intended conceptual meaning. Second, using this revised version of the VHS, we examine vaccine hesitancy among a representative sample of the UK population, and we study the association between vaccine hesitancy and various respondent characteristics.

2. Methods

2.1. Sample

From a consumer panel of more than 1 million UK members collected by market research company 'Vision One', 9613 random panelists were approached in November 2016 to participate in a scientific study on healthcare resource allocation (reported elsewhere [35]). Respondents did not know the specific subject of vaccination before deciding to participate. Of these contacted people, 4144 (43%) responded to the invitation. We recruited 1950 of them via stratified random selection to fulfill predetermined quotas, which provide a representative sample of the UK population in terms of socio-economic strata (indicated by the occupation of the head of the household), gender and urban vs. rural background. Because our primary interest was in responses in age groups that frequently have to make vaccination decisions, and because panel membership became more sparse and less representative for elderly age groups (due to, among others, a lower level of online activity), we defined five age groups (20–29, 30–39, 40–49, 50–59, 60+ years) and recruited evenly within these groups.

An email containing a link to the survey website was sent to participants and by clicking on the link respondents consented to participate, although they were free to stop or close the survey at any point. All respondents received a nominal incentive for study completion (£0.50 per 12-minute questionnaire). The vaccine hesitancy scale was asked before the start of the resource allocation experiment so no order effects are to be expected. The survey was executed in between 20 November and 15 December 2016.

2.2. Vaccine hesitancy scale

Participants were asked to answer ten questions related to their confidence in vaccines on a five point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 agree,

5 = strongly agree). Three questions (questions five, nine and ten) were phrased negatively. In the original VHS, these ten items were targeted at parents to measure attitude towards childhood vaccination. We adapted these ten items so that they could be asked to anyone, without reference to children. For instance, the first item was changed from "Childhood vaccines are important for my child's health" to "Vaccines are important for my health". Two of the authors (JL and AV) rephrased the items independently and in case of difference, it was jointly discussed which version was closest to the original meaning.

2.3. Other measures

Respondents were asked various socio-demographic questions, whether they have or had children (and their age) and they self-rated their health status. In addition, their optimistic or pessimistic expectations about the future were measured via the Revised Life Orientation Test (LOT-R) [36], This is a standard instrument to measure 'dispositional optimism', the relatively stable personality trait of anticipating a good or a bad future (for a review, see [37]). Other studies have documented relationships between future expectations and attitudes to prevention [38], pro-active problem solving [37] and time discounting [39] and we hypothesized that this inter-individual difference may also explain variation in attitudes to vaccination.

2.4. Statistical methods

To study the latent dimensions of the VHS, the dataset was randomly and evenly split into a construction and a validation set [26]. Exploratory factor analysis was conducted on the construction set. Factors were extracted using varimax rotation. Subsequently, a confirmatory factor analysis was used on the validation set to confirm the latent structure that resulted from the exploratory factor analysis. Simple and multiple regression analyses were used to identify significant associations between the identified VHS subscales and hypothesized explanatory variables. The analyses for this paper were generated using SAS software, Version 9.4 of the SAS System for Windows.

2.5. Ethical approval

We obtained informed consent from all respondents and ethical approval of the study from the Ethics Committee of the London School of Hygiene & Tropical Medicine (Ref 10335). We conducted the research in accordance with the Code of Conduct of the Market Research Society, which ensured that information is collected for research purposes only, is kept confidential, and respondent anonymity is guaranteed.

3. Results

3.1. Descriptive statistics

Forty-three percent of the contacted panel members were willing to participate in this study and of these, 1950 were selected based on a number of predetermined quota. As shown in Table 1, 1546 participants completed the questionnaire. When asked how difficult the survey was and whether their answers were sufficiently valid to be used for public policy purposes, 47 (2%) indicated that the survey (which included a discrete choice experiment) "was very difficult and I am not sure that I made a valid contribution". In addition, there were 97 (6.5%) 'straightliners' in our sample, i.e. participants who selected the same response category for each of the 10 items. Sixty-four of them consistently answered the middle category 'neither agree nor disagree'. These 97 respondents were excluded from the analysis, leaving us 1402 respondents for analysis. Note that this does not automatically imply that respondents showing hesitancy with all ten items were excluded, since three questions were phrased negatively and required a shift in response pattern. Compared to demographic data of the UK from the Office for National Statistics our final sample was considered sufficiently representative across most dimensions (see Table 1). Old people and those with lower educational attainment were underrepresented.

Table 1
Respondent characteristics.

	Sample	UK population
Total recruited	1546	50.5 million*
Excluded for analysis	144	
Included in the analysis	1402 (100%)	
Gender		
Male	654 (47%)	49%*
Female	748 (53%)	51%*
Age (years)		
20–29	277 (20%)	17%*
30–39	258 (18%)	17%*
40–49	262 (19%)	17%*
50–59	286 (20%)	18%*
60 and over	319 (23%)	31%*
Living in a city with more than 10,000 inhabitants	956 (68%)	83%**
Social grades based on the profession of the highest paid household member		
A (upper middle class)	81 (6%)	4%**
B (middle class)	279 (20%)	23%**
C1 (lower middle class)	359 (26%)	27%**
C2 (skilled working class)	310 (22%)	21%**
D (working class)	62 (4%)	16%**
E (non-working)	311 (22%)	9%**
Education level		
No qualifications	48 (3%)	23%***
Secondary education	297 (21%)	13%***
Post-secondary education	270 (19%)	26%***
Vocational qualification	233 (17%)	10%***
Undergraduate degree, Post-graduate degree & Doctorate	554 (39%)	29%***
Not sure	2 (0.1%)	NA
Having children		
No children	544 (39%)	42%**
Children aged 0–4 years	153 (11%)	42%** §
Children aged 5–20 years	329 (23%)	NA
Children aged over 20 years	376 (27%)	15%**
Exposure to poor health		
Participant affected by poor health	377 (27%)	NA
Close friends or family of the participant affected by poor health	454 (32%)	NA
Neither participant nor close friends nor family affected by poor health	571 (41%)	NA

NA = Not Applicable.
Source: Office for National Statistics https://www.gov.uk/government/publications).
* UK population data 2016 for UK population >19 years.
** UK population data 2016 for entire UK population.
*** UK population Census data 2011 for population >19 years.
§ Percentage of UK families living with dependent children (<18 years old).

3.2. Hesitancy score

One in five respondents disagreed or were undecided whether "vaccines are effective" (question 2), and two in three respondents did not fully reject the claim that "New vaccines carry more risks than older vaccines" (question 5). Also for the items "I am

concerned about serious adverse effects of vaccines" (question 9) and "Vaccines are not needed for diseases that are not common anymore" (question 10) a majority of respondents answered in a hesitant way. The fraction of respondents that clearly opposed was however much smaller, ranging from 4.4% disagreeing that "vaccines are important for the health of others in my community" to 32.7% stating concerns for side effects. Items 5, 9 and 10 were answered differently compared to the other seven items. These three items show an even distribution around "neither agree nor disagree" compared to a strongly skewed distribution towards "strongly agree" for the others (see Fig. 1).

Fig. 2 provides a summary of the aggregate levels of hesitancy over the ten items in the sample, depending on the definition of what counts as being 'hesitant'. If we count the middle category 'neither agree nor disagree' as an expression of hesitancy, then 90.2% of the sample responded in a hesitant way to at least one item. About four percent responded hesitant to all ten items. If we do not include the middle category in our definition of hesitancy, then much lower percentages become labelled as hesitant. Fifty-four percent of the sample responded in a hesitant way to at least one of the items and 0.6% was hesitant to all items.

3.3. Internal structure of the modified VHS

In a 10-item exploratory factor analysis, item 10 ("I do not need vaccines for diseases that are not common anymore") did not load clearly on any factor and was dropped. For the remaining 9 items, we identified a two-factor structure with eigenvalues (i.e. the amount of variance in all the VHS survey items that is accounted for by that factor) of 5.30 for the 'lack of confidence' factor and 1.16 for the 'risks' factor, see Table 2. Together, these factors explained 71.8% of the total variance in the nine survey items.

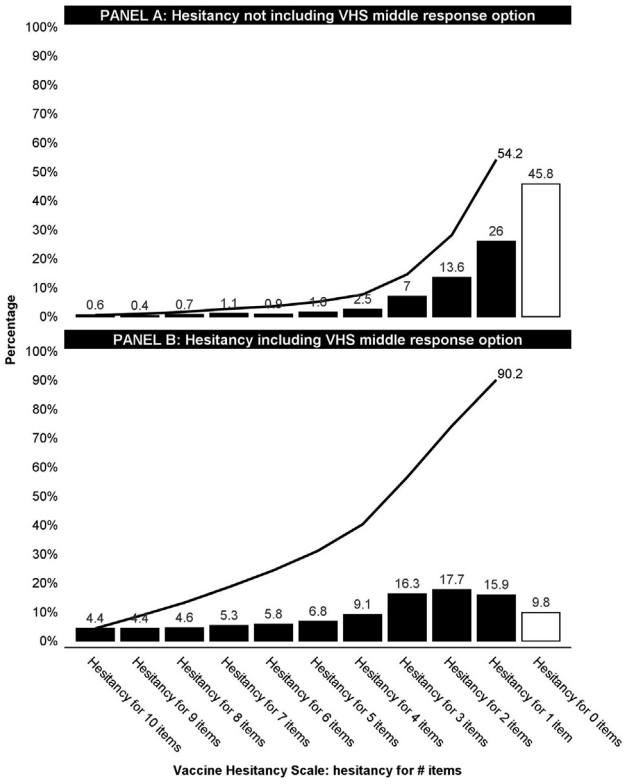

Fig. 2. Percentage hesitant responses per VHS item, with and without labelling the middle response category as 'hesitant'.

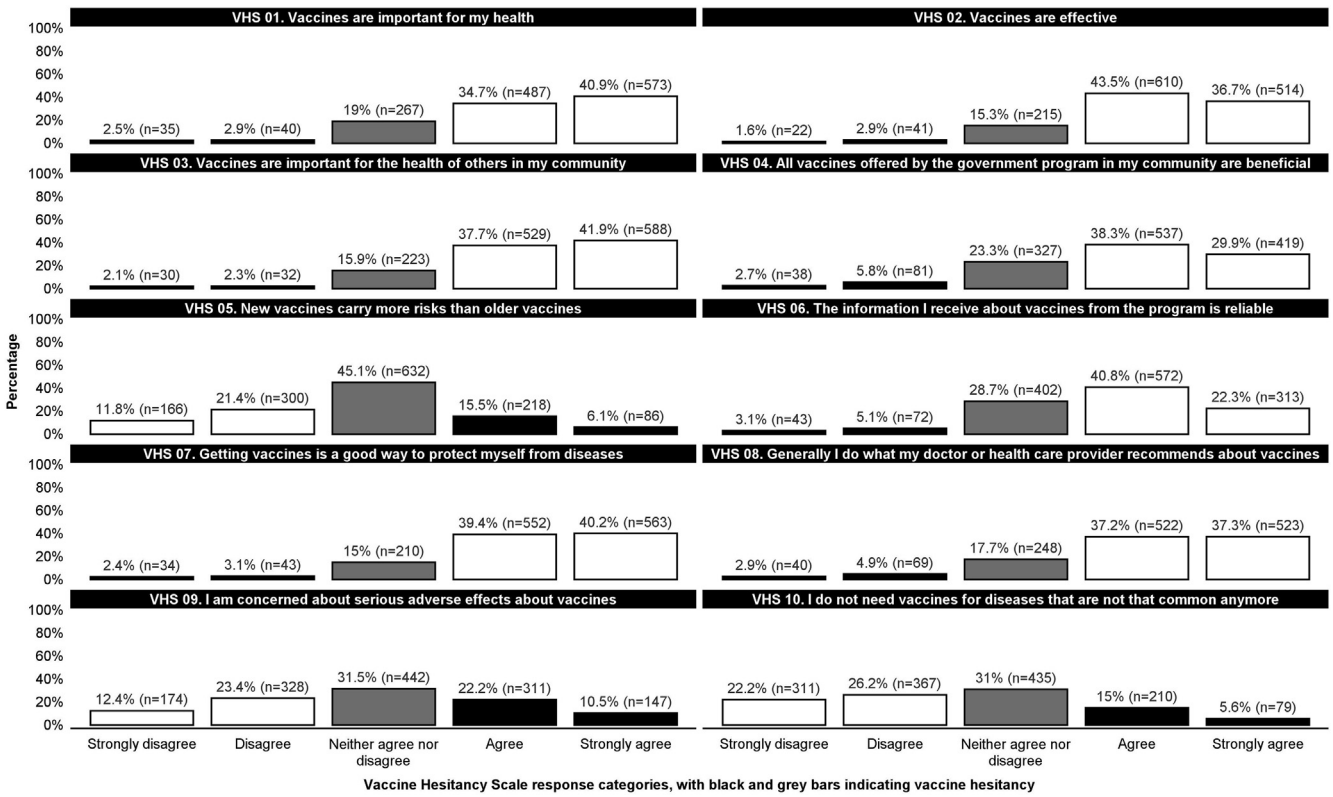

Fig. 1. Distribution of answers to the 10 items of the Vaccine Hesitancy Scale. White bars show answers that were reflecting a positive attitude to vaccination, black as negative and grey as doubtful ("neither agree nor disagree").

Confirmatory factor analysis was performed for both 9 and 10-item versions of the scale, and for both one and two-dimensional solutions, and clearly showed best goodness-of-fit for the 9-item version with two factors (RMSEA = 0.0750, CFI = 0.9, TLI = 09666). Thus, a two-factor structure, consisting of a 'lack of confidence' part with 7 items, and a 'risks perception' part with two items, showed best psychometric characteristics of the VHS. On a scale from 1 to 5 (with 5 maximal hesitancy), the average respondent scored 1.99 (SD = 0.80) for the lack of confidence factor and 2.89 (SD = 0.93) for risks, highlighting that the hesitancy of the average person in our sample was driven more by risk perceptions than by lack of confidence in vaccines.

3.4. Variables associated with vaccine hesitancy

Using regression analysis for the two VHS subscales, we found several variables that were statistically linked to respondents' answers to the clustered 'lack of confidence' and 'risks perception' items (see Table 3). For the first construct, those aged 50–59 year old showed lower lack of confidence than those aged 20–29 year old. People in rural areas showed higher lack of confidence compared to those from urban areas. Women were more confident than men and, as compared to those without children, parents with children aged >20 years were also less confident. There was no significant association between lack of confidence and employment, education, socio-economic status, health state or optimistic or pessimistic expectations for the future. Regarding the second construct, aversion to the risks of side effects, as compared to those without children, people with young children showed greater aversion to risks. The same can be said for those who were optimistic about their future versus more pessimistic individuals. However, the explanatory power of these variables remained low. Only 4% of the observed variance in the two hesitancy subscales was explained by the selected covariates. The explanatory power of the life orientation score was as high as that of all socio-demographics combined.

As mentioned, there were 97 (6.5%) 'straightliners' in our sample, i.e. participants who selected the same response category for each of the 10 items. Sixty-four of them consistently answered the middle category 'neither agree nor disagree'. We decided to exclude these responses from our main analysis. Results of a sensitivity analysis that included these 97 straightliners did not significantly alter the factor analytic or regression analyses, led only to minor changes in the distribution of respondents' answers per item and, in general, did not change any of our conclusions.

4. Discussion

Whereas a large majority of our sample showed favorable views towards vaccination and a trust in its benefits, there was also a substantial fraction being hesitant about vaccination. More than half of responses indicated a hesitant attitude to at least one out of ten VHS items, and more than 90% did so if the middle category "neither agree nor disagree" was considered an expression of hesitancy. About 0.6–4% showed hesitancy in all items. We especially highlight answers to item 10 "Vaccines are not needed for diseases that are not common anymore": 55% of the respondents were either undecided or agreed with this statement. This calls attention to a possible important misunderstanding in the UK population regarding the need to maintain a high coverage to keep these diseases at bay. It suggests complacency and a knowledge gap in the general population about the risks of re-emerging infectious disease threats. Whereas our analysis does point at some demographic groups, further research is needed to identify the particular population groups in which vaccine hesitancy is most typical.

A standardized, validated and well-understood survey is an important instrument to counter vaccine hesitancy, but more research is needed for the VHS to be able to fulfill this purpose. Shapiro et al. [26] previously identified two factors within the VHS, with a 'lack of confidence' underlying seven statements and two statements pointing at aversion for risks of vaccine-induced side effects. Both factors explained 67% of the variance observed in the ten items. As in our study, item 10 "My child does not need vaccines for diseases that are not common anymore" was dropped because it did not load well with the two factors. Domek et al. used a similar methodology and also identified two similar underlying constructs related to vaccine confidence and risks, explaining 76% of variation. However, the best fit was found for a two-factor structure consisting of five and two items respectively (three VHS items were dropped). Shapiro et al reported summary scores (on a scale from 1 to 5, with 5 maximal hesitancy) for the two factors of 3.07 for risks and 1.98 for lack of confidence; we found similar results (2.92 for risks, 2.03 for lack of confidence). The similarity in findings suggests that our modified version of the VHS is useable as a substitute for the original scale for parents.

However, there are several aspects of the VHS that require attention. The two constructs that we (and others) identified point at different aspects of vaccine hesitancy (risks and confidence) but the underlying items are also differently phrased (items 5, 9 and 10 are negatively phrased and require a switch in response pattern), which could also explain the emergence of these items as distinct

Table 2
Rotated EFA factor loading pattern and CFA standardized regression weights for 9-item scale.

	EFA loadings (n = 701)		CFA Standardized regression weights (n = 701)	
	VHS factor 1: lack of confidence	VHS factor 2: risks	VHS factor 1: lack of confidence	VHS factor 2: risks
Vaccines are important for my health	0.84689	0.10850	0.87215	–
Vaccines are effective	0.82918	0.11501	0.84550	–
Being vaccinated is important for the health of others in my community	0.85763	0.12646	0.82428	–
All vaccines offered by the government programme in my community are beneficial	0.85214	0.18539	0.80425	–
New vaccines carry more risks than older vaccines	0.08657	0.86229	–	0.45682
The information I receive about vaccines from the vaccine program is reliable and trustworthy	0.74456	0.27990	0.72388	–
Getting vaccines is a good way to protect myself from disease	0.85941	0.19721	0.87278	–
Generally I do what my doctor or health care provider recommends about vaccines	0.78250	0.23843	0.74457	–
I am concerned about serious adverse effects of vaccines	0.26133	0.78870	–	0.85612

EFA = Exploratory Factor Analysis, CFA = Confirmatory Factor Analysis, VHS = Vaccine Hesitancy Scale.

Table 3
Demographic characteristics and their relation to lack of confidence in the need for vaccines and aversion to the risk of side effects.

	VHS Factor 1: Lack of Confidence					VHS Factor 2: Risks				
		Simple regression		Multiple Regression			Simple regression		Multiple Regression	
	Mean (SD)	Est.	P	Est	P	Mean (SD)	Est.	P	Est.	P
Gender	1.95					2.91				
Female	(0.83)	−0.0837	0.0508	−0.0948	0.0396	(0.83)	0.0530	0.2863	–	–
Male	2.03 (0.76)	–	–	–	–	2.86 (0.94)	–	–	–	–
Age	2.11					2.87				
20–29 years	(0.85)	–	–	–	–	(0.95)	–	–	–	–
30–39 years	2.05 (0.81)	−0.0602	0.3826	−0.0459	0.5211	2.95 (0.97)	0.0852	0.2863	–	–
40–49 years	2.01 (0.83)	−0.1074	0.1181	−0.0926	0.2139	3.01 (0.98)	0.1394	0.0802	–	–
50–59 years	1.92 (0.72)	−0.1924	0.0042	−0.1539	0.0438	2.85 (0.80)	−0.0168	0.8289	–	–
60 years or older	1.87 (0.78)	−0.2470	0.0002	−0.1534	0.1047	2.79 (0.92)	−0.0798	0.2929	–	–
Area	2.03					2.92				
Rural (town or village with less than 10,000 inhabitants)	(0.81)	0.0647	0.1587	0.1131	0.0112	(0.92)	0.0502	0.3439	–	–
Urban (town or city with more than 10,000 inhabitants)	1.97 (0.80)	–	–	–	–	2.87 (0.93)	–	–	–	–
Employment	1.98					2.86				
Intermediate managerial, administrative or professional	(0.79)	0.0879	0.2250	–	–	(0.96)	−0.0675	0.4201	–	–
Manual worker	2.01 (0.84)	0.1153	0.0918	–	–	2.95 (0.94)	0.1617	0.0411	–	–
Unemployed	2.11 (0.89)	0.2194	0.0266	–	–	2.89 (0.88)	0.0956	0.4028	–	–
Retired	1.89 (0.78)	–	–	–	–	2.79 (0.91)	–	–	–	–
Senior managerial or professional	2.11 (0.88)	0.2193	0.0355	–	–	2.93 (1.07)	0.1395	0.2475	–	–
Supervisor; clerical; junior managerial, administrative or professional	1.98 (0.74)	0.0872	0.2050	–	–	2.89 (0.87)	0.0973	0.2217	–	–
Socio-economic status	2.11					2.93				
A	(0.88)	0.1530	0.1263	–	–	(1.07)	0.1106	0.3386	–	–
B	1.98 (0.79)	0.0216	0.7437	–	–	2.86 (0.96)	0.0386	0.6126	–	–
C1	1.98 (0.74)	0.0209	0.7358	–	–	2.89 (0.87)	0.0684	0.3402	–	–
C2	2.01 (0.83)	0.0514	0.4238	–	–	2.97 (0.92)	0.1527	0.0401	–	–
D	1.99 (0.88)	0.0367	0.7419	–	–	2.85 (1.00)	0.0333	0.7960	–	–
E	1.96 (0.81)	–	–	–	–	2.82 (0.90)	–	–	–	–
Children	2.09					2.83				
No – I don't have any children	(0.78)	–	–	–	–	(0.89)	–	–	–	–
Yes – my youngest child is below 5 years of age	1.99 (0.94)	−0.1057	0.1459	−0.0939	0.1977	3.02 (1.01)	0.1910	0.0237	0.1374	0.1039
Yes – my youngest child is between 5 and 20 years of age	2.00 (0.79)	−0.0910	0.1009	−0.0608	0.2872	3.02 (0.96)	0.1959	0.0024	0.1528	0.0175
Yes – my youngest child is older than 20 years of age	1.82 (0.75)	−0.2750	<0.0001	−0.2111	0.0015	2.81 (0.89)	−0.0142	0.8184	−0.0098	0.8722
Education	1.93					2.90				
No qualifications	(1.00)	−0.0229	0.8632	–	–	(0.99)	−0.0147	0.9233	–	–
Post-secondary education (College, A-levels, NVQ3 or below, or similar)	2.00 (0.78)	0.0425	0.6016	–	–	2.97 (0.87)	0.0579	0.5380	–	–
Post-graduate Degree (MA, MSc etc.)	1.96 (0.80)	–	–	–	–	2.91 (1.05)	–	–	–	–
Secondary Education (GCSE/O-Levels)	1.97 (0.76)	0.0127	0.8737	–	–	2.88 (0.86)	−0.0334	0.7173	–	–
Undergraduate Degree (BA, BSc etc.)	2.00 (0.81)	0.0429	0.5750	–	–	2.81 (0.94)	−0.1054	0.2329	–	–
Vocational Qualification (Diploma, Certificate, BTEC, NVQ 4 and above, or similar)	2.01 (0.81)	0.0480	0.5662	–	–	2.94 (0.93)	0.0271	0.7787	–	–
Health	2.02					2.85				
I am not affected, but close friends or family are affected by poor health	(0.80)	0.0547	0.2774	–	–	(0.93)	−0.0388	0.4889	–	–
I consider myself affected by poor health	1.98 (0.79)	0.0071	0.8931	–	–	2.97 (0.97)	0.1160	0.0478	–	–

(*continued on next page*)

Table 3 (*continued*)

	VHS Factor 1: Lack of Confidence					VHS Factor 2: Risks				
		Simple regression		Multiple Regression			Simple regression		Multiple Regression	
	Mean (SD)	Est.	P	Est	P	Mean (SD)	Est.	P	Est.	P
Neither I nor my close friends or family are affected by poor health	1.97 (0.81)	–	–	–	–	2.87 (0.89)	–	–	–	–
Revised Life Orientation Test	–	0.0027	0.7132	–	–	–	0.0560	<0.001	0.0499	<0.001

VHS = Vaccine Hesitancy Scale, SD = Standard Deviation, Est = Estimate, GCSE = General Certificate of Secondary Education, BTEC = Business and Technology Education Council, NVQ = National Vocational Qualifications.

factors. Moreover, some items are ambiguous in meaning. As for question 5 "New vaccines carry more risks than older vaccines" we were not sure whether this question should be answered positively or negatively. And question 9, "I am concerned about serious adverse effects of vaccines" is open for interpretation as it is normal to be concerned about serious side effects. This is not necessarily an indication of vaccine hesitancy. Also, whereas the scale taps into core aspects underlying vaccine hesitancy, as acknowledged by the developers [34], its 10 items also exclude other, less salient motivations to oppose vaccination. Besides lacking confidence in vaccines and fearing side-effects, hesitancy can also be explained by various barriers to vaccination, religious or philosophical objections against vaccination, different time preferences (as side effects in the present need to be balanced against future benefits), fears of needles, etc. [14,24]. We also want to highlight the influential role that the middle response category on the Likert scale 'neither agree nor disagree' played in our results. Including or excluding it in our definition of hesitancy made a large difference. Other authors have suggested to use a neutral category but to locate it apart from the other answering categories. The mere position of this ballot can play an important role. Willits and Janota (1996) conducted experiments examining the effects of placing an undecided choice (neither) in the middle of the response options (i.e., as a midpoint) or in the last position (no opinion) [40]. The percentage of respondents choosing the undecided option doubled when it was positioned in the middle of the scale. On average, when an undecided (neither, no opinion, don't know, etc.) option is included as a response option, more than a fifth of the sample will shift from a definite position to the undecided option [40]. Also in the context of the VHS the influence of these aspects should be further tested. International uptake of the VHS to examine vaccine hesitancy also warrants examination of measurement invariance of the survey items across cultures. There are important recent advancements in examining and explaining measurement invariance of survey scales across populations that make these techniques accessible to a broader group of researchers. In addition, pre-data collection techniques such as Online Probing [41] and Anchoring vignettes [42] could also provide new insights into whether differences in vaccine hesitancy across cultures reflect true differences or are related to response style.

Main strengths of this study are that we used a nationwide, quasi-representative sample of the UK population. The sample's responses point at the aspects of vaccination about which people are most hesitant (risks) and which pieces of information are most likely to be effective in countering anti-vaccine sentiments. Moreover, we explore a more generalized version of the VHS and find highly similar results as a comparable study in Canada using the more focused parental VHS scale. Main weaknesses are that we used an online panel, which may have hidden sources of non-representativeness due to non-response bias, e.g. via different use of technology, willingness to participate in research, etc. Also, our sample is relatively large compared to other studies but is still limited in order to identify the defining characteristics of vaccine skeptics as well as their regional clustering. Some characteristics such as e.g. ethnic background or religion were not asked, although they might be of interest to identify vaccine hesitancy. Moreover, whereas scales such as the VHS, which use standardized questions and Likert scales are easier to analyze, they also mask respondent heterogeneity. Future studies should complement scales with other methods such as interviews that can probe deeper into underlying motivations. It is also recommended to add other scales (e.g. the Vaccination Confidence Scale) or questions measuring attitudes to vaccination or actual vaccination behavior to enable more in-depth validity testing.

Conflict of interest

No conflicts of interest to declare.

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