Article

JHP

Journal of Health Psychology
1–18

DOI: 10.1177/13591053211042062
journals.sagepub.com/home/hpq
SAGE

A more comprehensive measure of vaccine hesitancy: Creation of the Multidimensional Vaccine Hesitancy Scale (MVHS)

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Abstract

This article aimed to develop the Multidimensional Vaccine Hesitancy Scale (MVHS). In Study 1 ($n = 336$), we identified 13 possible vaccine hesitancy dimensions and developed an item list. In Study 2 ($n = 444$), we performed an exploratory factor analysis that supported an eight-dimension structure and reduced our measure to 32 items. We supported its validity by establishing relations with associated variables, even while controlling for measures of the same and similar constructs. In Study 3 ($n = 575$), we confirmed its factor structure and replicated its validity results. Support was provided for the psychometric properties and validity of the MVHS.

Keywords

adherence, health behavior, health psychology, public health psychology, scale, validation

An increasing number of authors have recognized that the benefits of vaccines can only be realized if people choose to receive them, causing the study of vaccine hesitancy to quickly grow in recent years (Bedford et al., 2018; Dubé et al., 2013; Larson et al., 2014; Marti et al., 2017; Paterson et al., 2016). While the definition of vaccine hesitancy is debated, MacDonald (2015) and the SAGE Working Group on Vaccine Hesitancy proposed likely the most popular definition, which is, "delay in acceptance or refusal of vaccination despite availability of vaccination services. Vaccination hesitancy is complex and context specific, varying across time, place, and vaccines. It is influenced by factors such as complacency, convenience, and confidence" (p. 4163). These three influencing factors include, but are not limited to, perceived risks of illness, need of vaccines (complacency), availability, affordability (convenience), and trust in vaccines and associated parties (confidence). More recent authors have argued that this definition does not sufficiently differentiate vaccine hesitancy from its determinants, wherein vaccine hesitancy should reflect decisional conflict alone and its determinants should be recognized as separate constructs (Bedford et al., 2018; Betsch et al., 2018; Quinn et al., 2019). Other more recent authors argue, though, that the interchangeability of vaccine hesitancy and its determinants is too established in our lexicon, and the construct,

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"should only refer to the specific situation of having concerns about vaccines, regardless of actual vaccine receipt" (Dudley et al., 2020: 711). Despite these disagreements, researchers have demonstrated that scales intended to assess vaccine hesitancy significantly predict vaccination intentions and behaviors (Bish et al., 2011; Dubé et al., 2013; Jarrett et al., 2015; MacDonald, 2015).

Due to the clear importance of vaccine hesitancy, several authors have created self-report scales to gauge the construct, near-synonymous constructs, and near-antonymous constructs (e.g. vaccine confidence, vaccine acceptance) (Gilkey et al., 2016; Larson et al., 2015; Shapiro et al., 2018). These scales typically gauge perceptions and include items that represent the determinants of vaccine hesitancy. For instance, the Vaccine Hesitancy Scale (Larson et al., 2015) includes items that represent complacency, convenience, and confidence (e.g. "New vaccines carry more risks than old vaccines," p. 4172). Some authors distinguish vaccine hesitancy from its determinants in developing scales for the latter, such as the 5C Psychological Antecedents of Vaccination Scale (Betsch et al., 2018), but these measures of relabeled constructs have seen less application than scales of vaccine hesitancy (Cataldi et al., 2019; Kocoglu-Tanyer et al., 2020; Oduwole et al., 2019). Therefore, measures of vaccine hesitancy and associated constructs largely gauge perceptual determinants of vaccination.

Despite their significant contributions, consistent concerns are evident with these scales of vaccine hesitancy and associated constructs. First, certain scales are based on unclear construct definitions, wherein the authors did not directly state their operational definition. This causes these measures to include items that represent determinants, decisional conflict, and even behaviors—often resulting in ambiguous factor structures (Kocoglu-Tanyer et al., 2020; Quinn et al., 2019). Second, many scales include items that prevent their broad application, such as items that assess the perceived risk of the respondent's children being vaccinated (Cataldi et al., 2019; Gilkey et al., 2016; Larson et al., 2015). While these items can provide insights into the perceptions of parents, they prevent the participation of those without children. Third, vaccine hesitancy is known to be multidimensional, but many authors have not shown efforts to identify the entire scope of representative dimensions when creating their scales (Betsch et al., 2018; Shapiro et al., 2016), such as initial qualitative investigations recommended by prior scale development guidelines (Hinkin, 1995, 1998). It is unclear whether extant scales gauge the entire criterion domain of vaccine hesitancy, and these measures may provide only a partial view of the construct. Fourth, these scales are typically created and studied in isolation, with little empirical evidence for the extent that any new measure provides benefits beyond extant scales (Sarathchandra et al., 2018; Wallace et al., 2019).

Given these considerations, it appears that a new multidimensional vaccine hesitancy scale is needed to address these concerns and accurately gauge the construct. In the current article, we created a scale by applying modern guidelines (Brown, 2015; Hinkin, 1995, 1998; Hu and Bentler, 1999; Jackson et al., 2009; Marsh et al., 2004; Presser et al., 2004). To do so, we applied the following definition, "vaccine hesitancy is . . . the specific situation of having concerns about vaccines, regardless of actual vaccine receipt" (Dudley et al., 2020, p. 711), focusing on perceptual determinants as recommended and done by many authors (Larson et al., 2015; Oduwole et al., 2019; Shapiro et al., 2018). In Study 1, we qualitatively identified a preliminary set of vaccine hesitancy dimensions as well as an initial extensive item list. In Study 2, we reduced the item list and assessed its underlying factor structure via exploratory factor analysis (EFA), which we then labeled the Multidimensional Vaccine Hesitancy Scale (MVHS). We also assessed the relation of the MVHS with measures of the same and similar constructs (convergent validity), and we tested whether the MVHS predicts outcomes beyond these existing measures (predictive validity). In Study 3, we confirmed the

factor structure of the MVHS via confirmatory factor analysis (CFA) and replicated the validity tests of Study 2. From these efforts, we provided robust support for the psychometric properties and validity of the MVHS.

These efforts provide many benefits for research and practice. An accurate scale that captures the entire criterion space of vaccine hesitancy may show that the construct more strongly relates to outcomes than previously believed, as prior measures may have not included all important facets of the construct. If the case, then the importance of vaccine hesitancy may be even greater than already known. Identifying the scope of vaccine hesitancy dimensions also provides firmer boundaries to the construct, which informs debates regarding which dimensions may or may not be representative of vaccine hesitancy (Bedford et al., 2018; Dudley et al., 2020). Our scale development process further identifies dimensions that are too similar to adequately distinguish. Many dimensions have been proposed to be independent in discussions and reviews of vaccine hesitancy, but they may instead be differing labels for largely the same concepts. Lastly, creating a clear list of inclusive dimensions can guide future intervention creators to relevant perceptions that should be targeted to effectively promote vaccination, enabling the current results to provide immediate real-world impacts.

Study 1: Qualitative item generation study

The goals of Study 1 were to qualitatively (a) identify preliminary vaccine hesitancy dimensions and (b) obtain a set of statements for each dimension to create an initial item list. The associated dataset is provided in Supplemental Material A.

Method

Participants. Participants ($N = 336$; 88% Western English-Speaking Countries) were recruited from MTurk and provided US$0.10. MTurk provides samples with diverse backgrounds that are desirable for studying health perceptions and behaviors (Howard, 2020), and we followed recommended precautions for ensuring adequate data quality when using MTurk (Buhrmester et al., 2018; Mellis and Bickel, 2020; Robinson et al., 2019; Woo et al., 2015). We restricted participation to those who had completed at least 50 MTurk tasks with a 95% or higher lifetime approval rate. We removed those that provided nonsensical qualitative responses (26 participants), which we considered responses that clearly did not answer the qualitative questions (e.g. "Pay me money"). The sample size above reflects the sample after removing these participants. For all studies, participants must have been 18 years of age or older to participate.

Procedure. Participants enrolled via the MTurk platform and immediately completed the survey.

Measures. Participants were provided four open-ended qualitative questions. The first two read: "Vaccines are often recommended to prevent illnesses, but many people do not get vaccines. In the box below, please list as many reasons as possible that [you (Question 1)/people in general (Question 2)] do not get vaccines. Please write at least three reasons." The second two read: "The COVID-19 vaccine may prevent people from getting COVID-19, but many people may not get the COVID-19 vaccine when it is approved. In the box below, please list as many reasons as possible that [you (Question 3)/people in general (Question 4)] will not get the COVID-19 vaccine. Please write at least three reasons." Many participants provided more than three reasons to each question. By asking these four questions, we obtained participants' personal and perceived "concerns about vaccines" in general as well as about a specific vaccine (Dudley et al., 2020, p. 711), which advantages the scope and generalizability of our findings to help ensure the content validity of our created scale.

Table 1. Qualitative coding results of study 1.

Dimension	Definition—each begins with: vaccines. . .	Personal general	Others' general	Personal COVID-19	Others' COVID-19
1. Health risks	Have possible health risks.	**55%**	**65%**	**50%**	**49%**
2. Costs	Cost too much money.	**28%**	**35%**	**30%**	**37%**
3. Distrust	Are managed by untrustworthy people.	**27%**	**33%**	**60%**	**55%**
4. Not needed	Are not needed to be healthy.	**26%**	**17%**	**21%**	**27%**
5. Efficacy doubts	Are not effective.	**21%**	**17%**	**31%**	**25%**
6. Physical pain	Are painful to receive.	**18%**	**14%**	6%	6%
7. Inconvenience	Are inconvenient to get.	**18%**	**15%**	4%	3%
8. Personal reactions	Cause personal reactions (e.g. allergies).	**13%**	8%	4%	3%
9. Access	Are difficult to get.	**12%**	**14%**	**24%**	**21%**
10. Healthy	Are not needed because I am too healthy.	**11%**	1%	6%	3%
11. Forget	Are easy to forget.	8%	7%	1%	3%
12. Unnatural Ingredients	Contain unnatural ingredients.	7%	9%	4%	2%
13. Beliefs	Go against my personal beliefs.	6%	**20%**	2%	**16%**
14. Doctors office	Require visits to a doctor's office.	4%	1%	5%	1%
15. Lack of understanding	Involve complex information.	3%	**11%**	3%	5%
16. Fear	Are scary.	1%	5%	3%	5%
17. Misinformation	Are surrounded by false information.	0%	**10%**	0%	5%
18. Other	Other.	5%	8%	7%	9%

Bold indicates a frequency of 10% or more. Personal general refers to participants' reasons for not getting vaccinated in general. Others' general refers to beliefs about others' reasons for not getting vaccinated in general. Personal COVID-19 refers to participants' reasons for not getting a COVID-19 vaccine when available. Others' COVID-19 refers to beliefs about others' reasons for not getting a COVID-19 vaccine when available.

Data sharing statement. For all studies, the supplemental materials includes the complete raw dataset collected in the study including the participants' data set, syntax file, and log files for analysis.

Results

Adhering to item generation and scale pretesting guidelines (Hinkin, 1995, 1998; Howard, 2018; Presser et al., 2004), the primary author qualitatively analyzed and thematically categorized the participant responses. Coding results are presented in Table 1, which includes category definitions. Eighteen categories were identified. Nine categories included qualitative responses from 10% or more participants for two or more questions, indicating that they should be included within the initial item list. Four categories included qualitative responses from 10% or more participants for one response format. Two represented potentially useful constructs to gauge via self-report, the intended format of the final measure (Personal Reactions and Healthy). Two would likely fail to be accurately represented via self-report (Lack of Understanding and Misinformation). We included the former two categories within the initial item list, but we excluded the latter two categories. Lastly, two categories approached

the cutoff across multiple response formats (Forget and Unnatural Ingredients). Because initial item lists should be overinclusive, we also included these two categories. Together, 13 categories were included within our initial item list, representing possible dimensions in our multidimensional vaccine hesitancy scale.

Brief conclusion

Study 1 identified 13 possible dimensions for our measure. While no prior study has investigated all 13 dimensions, most of these dimensions have individually appeared in prior discussions and studies of vaccine hesitancy (Bedford et al., 2018; Dubé et al., 2013; Larson et al., 2014; MacDonald, 2015; Marti et al., 2017; Paterson et al., 2016), and they represent—but are not necessarily limited to—each category of vaccine hesitancy proposed by many prior frameworks (e.g. 3C model; 5C subscales; 5A taxonomy; Betsch et al., 2018; Rosselli et al., 2016). These two features support the representativeness of our identified dimensions within the scope of vaccine hesitancy (e.g. criterion validity). One dimension should be discussed, however. The dimension of Access is similar to availability, which some authors do not consider to be representative of vaccine hesitancy. We investigate subjective perceptions of access, however, which are influenced by more than objective availability alone. Our conceptualization of Access also includes perceptions of vaccines being difficult to both obtain as well as know where to obtain, representing more than unavailability alone. Thus, we consider this dimension to be a part of vaccine hesitancy due to its distinctness from availability.

Because we intended to create a relatively concise scale, we initially created six to eight items per category (94 total) with the intent of reducing the number of items for each category to four in Study 2. Participants' qualitative answers were used to generate these items, and Supplemental Material B includes the full initial item list.

Study 2: Exploratory factor analysis and validity assessment

We performed an EFA on our initial item list in Study 2, recognizing that fewer than 13 dimensions may be retained. We reduced the number of items for each dimension to four, and we assessed the convergent and predictive validity of our scale by evaluating its relations with related variables and outcomes. The associated dataset is provided in Supplemental Material C.

Method

Participants. Participants ($N\ Time\ 1 = 1{,}027$, $N\ Time\ 2 = 534$, $N\ Time\ 3 = 444$, $M_{age} = 36.7$, $SD_{age} = 11.7$, 47% female, 86% Western English-Speaking Countries) were recruited from MTurk and provided US$1.85. By using multiple timepoints, we ensured that our analyses solely included participants that were sufficiently motivated, and we again restricted participation to those who had completed at least 50 MTurk tasks with a 95% or higher lifetime approval rate. We removed participants if they failed more than one of ten attention checks (24 participants). All statistics, including the sample size above, reflect the sample after removing these participants. Our item list was administered at Time 2, and the sample size for this timepoint (534) provides accurate EFA estimates with our number of items (94) (Costello and Osborne, 2005; Fabrigar et al., 1999; Hinkin, 1995, 1998; Howard, 2016).

Procedure. Participants enrolled via the MTurk platform and immediately completed the first survey (Time 1). One week later, they completed a second survey (Time 2). One week after the second survey, they completed a third survey (Time 3).

Measures. Unless noted otherwise, all measures utilized a 1 (Strongly Disagree) to 7 (Strongly Agree) scale.

Time 1

Demographic information. Participants were asked to provide their age, gender, location, and other unreported demographic variables.

Time 2

Vaccine hesitancy dimensions. The items developed in Study 1 were given at Time 2. Each of the 13 dimensions included 6–8 items, resulting in 94 total vaccine hesitancy items. Once reduced to four items each, the Cronbach's alpha of each dimension was 0.88 or higher.

Time 3

Vaccine hesitancy. The Vaccine Hesitancy Scale (Larson et al., 2015; Shapiro et al., 2018) was administered (Cronbach's alpha = 0.94). These items assess general vaccine perceptions as well as parents' perceptions regarding vaccines for their children (example item: "Childhood vaccines are important for my child's health" (reverse coded)). To ensure that our survey applied to all participants, we reworded these latter items to be more general (example item: "Vaccines are important for my health").

Vaccine confidence. The Vaccination Confidence Scale (Gilkey et al., 2014, 2016) was administered (Cronbach's alpha = 0.91). Some items assess general vaccine perceptions, whereas others assess parents' beliefs about vaccines for their children (example item: "If I vaccinate my teenager, he/she may have serious side effects" (reverse coded)). We reworded these latter items to be more general (example item: "If I get vaccinated, I may have serious side effects" (reverse coded)).

Vaccine acceptance. We administered Sarathchandra et al.'s (2018) 20-item vaccine acceptance scale (Cronbach's alpha = 0.94), which assesses attitudes toward vaccines (example item: "Vaccines are safe").

Flu vaccine willingness. We used two items to measure participants' willingness to receive a flu vaccine (Cronbach's alpha = 0.85), which were taken from prior studies (Perez et al., 2016; Shapiro et al., 2016). These two items read, "Please indicate how willing you would be to get a flu vaccine next year if it was [free/US$40.00]." The response options ranged from 1 (Extremely Unwilling) to 7 (Extremely Willing).

COVID-19 vaccine willingness. We used two similar items to measure participants' willingness to receive a COVID-19 vaccine (Cronbach's alpha = 0.92). These two items read, "Please indicate how willing you would be to get a COVID-19 vaccine next year if it was [free/US$40.00]." The response options ranged from 1 (Extremely Unwilling) to 7 (Extremely Willing).

Received flu vaccine in past year. We asked participants, "Have you received the flu vaccine within the past year?" The response options were Yes (1) and No (0).

Received other vaccines. We asked participants, "Are you up to date on your vaccines other than the flu vaccine?" The response options were Yes (1) and No (0).

Results

We followed guidelines of prior authors in performing our EFAs (Costello and Osborne, 2005; Fabrigar et al., 1999; Hair et al., 2019; Hinkin, 1995, 1998; Howard, 2016). We used a principal axis factoring method with direct oblimin rotation. To determine the number of factors to retain, we utilized parallel analyses, visual scree plot analyses, and the Kaiser criterion. KMO and Bartlett's test supported all EFAs. Supplemental Material D reports our process of reducing each dimension to four items as well as reducing our number of dimensions from 13 to 8. The final eight-factor solution is presented in Table 2, which includes the dimensions of Health Risks, Cost, Physical Pain, Inconvenience, Personal Reactions, Access, Healthy, and Forget. Construct definitions are included in Table 1. Each item loaded strongly (>0.48) with minimal cross loadings (<0.24). Appendix A presents the

Table 2. Exploratory factor analysis results of study 2.

	1	2	3	4	5	6	7	8
HR 1	0.88							
HR 2	0.65							
HR 3	0.80							
HR 4	0.90							
Cost 1		1.00						
Cost 2		0.54						
Cost 3		0.81						
Cost 4		0.79						
Pain 1			0.97					
Pain 2			0.94					
Pain 3			0.57					
Pain 4			0.80					
Incov 1				0.92				
Incov 2				0.83				
Incov 3				0.77				
Incov 4				0.68				
PR 1					0.98			
PR 2					0.89			
PR 3					0.87			
PR 4					0.79			
Acc 1						0.90		
Acc 2						0.82		
Acc 3						0.92		
Acc 4						0.75		
Health 1							0.94	
Health 2							0.80	
Health 3							0.93	
Health 4							0.77	
Forget 1								0.93
Forget 2								0.85
Forget 3								0.48
Forget 4								0.86
Eigen	13.05	3.24	2.48	2.22	1.95	1.30	1.22	1.08
% Var	40.78	10.13	7.76	6.96	6.10	4.08	3.81	3.38

Factor loadings less than 0.25 not shown. Eigenvalues for factors after the eighth were: 0.621, 0.433, 0.403, 0.386. HR: health risks; Cost: cost; Pain: physical pain; Incov: inconvenience; PR: personal reactions; Acc: access; Health: healthy; Forget: forget; Eigen: eigenvalue; % Var: percentage of variance explained.

final Multidimensional Vaccine Hesitancy Scale (MVHS). We also include items for the five excluded dimensions in Appendix A. While we do not include these five dimensions in subsequent analyses or the MVHS, they may aid future investigations of specific vaccine hesitancy perceptions.

Supplemental Material D includes correlations for all Study 2 variables. Each MVHS dimension significantly correlated with vaccine hesitancy, vaccine confidence, and vaccine acceptance (all $p < 0.01$). These three variables were then regressed onto the MVHS dimensions (Table 3). No variance inflation factor

Table 3. Regression results of study 2.

	Vaccine hesitancy	Vaccine confidence	Vaccine acceptance	Flu vaccine willingness	COVID-19 vaccine willingness[a]	Received flu vaccine in past year[b]	Up to date on other vaccines[b]
1. HR	0.54**	−0.55**	−0.53**	−0.39**	−0.43**	−0.19**	−0.15*
2. Cost	0.01	−0.02	−0.01	−0.02	−0.03	0.01	−0.12*
3. Pain	−0.01	0.00	0.01	−0.04	0.01	−0.08	0.06
4. Incov	0.05	−0.04	−0.09*	0.08	−0.13*	0.19**	0.02
5. PR	0.00	−0.05	−0.08*	0.13*	0.13*	0.02	0.01
6. Acc	−0.09*	0.06	0.06	0.05	0.17**	−0.03	−0.12
7. Health	0.38**	−0.32**	−0.38**	−0.37**	−0.33**	−0.21**	−0.31**
8. Forget	−0.04	−0.01	0.06	−0.08	0.07	−0.21**	0.03
R^2	0.65	0.67	0.75	0.36	0.38	0.16	0.27

Numbers represent standardized beta coefficients.
HR: health risks; Cost: cost; Pain: physical pain; Incov: inconvenience; PR: personal reactions; Acc: access; Health: healthy; Forget: forget.
[a]Supplemental Material D includes a reanalysis of this variable while excluding participants that tested positive for COVID-19 or believe that they had COVID-19.
[b]Supplemental Material D includes reanalysis of these variables using binominal logistic regression.
*$p < 0.05$. **$p < 0.01$.

(VIF) value was above 3. VIF values are indicators of multicollinearity with a standard cutoff of 3 (Hair et al., 2019), indicating that multicollinearity is not an issue in the present analyses. Health Risks and Healthy significantly predicted all three variables (all $p < 0.01$). Inconvenience, Personal Reactions, and Access significantly predicted one (all $p < 0.05$), but no other dimensions were significant predictors. These results highlight a benefit of the MVHS. These relations indicate that prior measures largely access perceptions of Health Risks and Healthy alone, whereas they may not include aspects of the other six dimensions. Thus, prior measures do not gauge the entire scope of vaccine hesitancy, and prior measures may have less predictive ability than the MVHS.

Next, we assessed the correlations of MVHS dimensions with vaccination willingness and behaviors (Supplemental Material D). Each dimension was significantly correlated to these four outcomes (all $p < 0.05$) except for the relation of Physical Pain and Received Other Vaccines ($p > 0.05$), indicating that 31 of 32 relations were statistically significant. When each outcome was regressed onto the MVHS dimensions (Table 3), Health Risks and Healthy significantly predicted all four outcomes (all $p < 0.05$). Personal Reactions and Inconvenience significantly predicted two (all $p < 0.05$), whereas Cost, Access, and Forget significantly predicted one (all $p < 0.05$). While Health Risks and Healthy were the two dominant predictors, the other dimensions were influential in predicting outcomes and their explanatory power can benefit future research.

We also assessed the extent that the MVHS dimensions predicted outcomes beyond established measures. We conducted a series of regression analyses wherein the prior vaccine hesitancy, confidence, or acceptance scales were entered into the first step and the MVHS dimensions were entered into the second step, such that we could assess the predictive abilities of the MVHS beyond the prior measures (Supplemental Material D). In each analysis, the ΔR^2 from the second step was statistically significant (all $p < 0.01$), indicating that the MVHS provides significant predictive benefits beyond these prior measures. Table 4 presents these results using the extant vaccine hesitancy scale as the Step 1 predictor. Inconvenience, Personal

Table 4. Hierarchical regression results of study 2 with vaccine hesitancy as step 1 predictor.

	Flu vaccine willingness		COVID-19 vaccine willingness[a]		Received flu vaccine in past year[b]		Up to date on other vaccines[b]	
	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
1. Vacc Hes	−0.67**	−0.59**	−0.71**	−0.63**	−0.37**	−0.30**	−0.46**	−0.25**
2. HR		−0.07		−0.09		−0.03		−0.03
3. Cost		−0.02		−0.02		0.01		−0.11*
4. Pain		−0.04		0.00		−0.08		0.06
5. Incov		0.11*		−0.10		0.21**		−0.00
6. PR		0.13**		0.13**		0.01		0.02
7. Acc		−0.01		0.10*		−0.08		−0.14*
8. Health		−0.15**		−0.09		−0.09		−0.21**
9. Forget		−0.11*		0.04		−0.23**		−0.02
ΔR^2	0.45**	0.03**	0.50**	0.03**	0.14**	0.06**	0.22**	0.07**

Numbers represent standardized beta coefficients.
Vacc Hes: vaccine hesitancy; HR: health risks; Cost: cost; Pain: physical pain; Incov: inconvenience; PR: personal reactions; Acc: access; Health: healthy; Forget: Forget.
[a]Supplemental Material D includes a reanalysis of this variable while excluding participants that tested positive for COVID-19 or believe that they had COVID-19.
[b]Supplemental Material D includes reanalysis of these variables using binominal logistic regression.
*$p < 0.05$. **$p < 0.01$.

Reactions, Health, and Forget each significantly predicted two outcomes (all $p < 0.05$), whereas Cost and Access significantly predicted one outcome (all $p < 0.05$) in the second step of these analyses. These results strongly support that the MVHS provides benefits beyond existing measures of vaccine perceptions, particularly its stronger relation with relevant outcomes.

Lastly, it was expected that the MVHS dimensions would relate to less willingness and fewer vaccine behaviors, but some MVHS dimensions produced regression results that were in the opposite direction than the other dimensions. Notably, those who report lower Access have lower vaccine hesitancy ($\beta = -0.09$, Table 3) and higher COVID-19 vaccine willingness ($\beta = 0.17$, Table 3; $\beta = 0.10$, Table 4); those who report higher Inconvenience have higher flu vaccine willingness ($\beta = 0.11$, Table 3) and rates of receiving the flu vaccine ($\beta = 0.19$, Table 3; $\beta = 0.21$, Table 4); and those who report higher Personal Reactions have higher flu vaccine willingness ($\beta = 0.13$, Table 4) and COVID-19 vaccine willingness ($\beta = 0.13$, Table 4).

Brief conclusion

Study 2 reduced our initial 13 possible dimensions to 8 using EFA, identified a reduced set of 32 total items that we labeled the MVHS, and supported its convergent and predictive validity. Each result strongly supports the continued development of the MVHS. These results also showed that some dimensions produced results in the opposite direction of the others with outcomes, indicating that certain negative perceptions regarding vaccines may not be deterrents. This important implication is discussed further in our general discussion below.

Study 3: Confirmatory factor analysis and validity

Most scale development guides recommend CFA to provide robust psychometric insights. We performed a CFA and reinvestigated the MVHS's validity information in Study 3. The associated dataset is provided in Supplemental Material E.

Participants

Participants ($N = 575$, $M_{age} = 26.5$, $SD_{age} = 8.9$, 41% female, 23% Portuguese, 20% Polish, 14% British, 43% Other) were recruited from Prolific and provided US$0.75 for completing the survey. Prolific is a data collection service similar to MTurk, and prior research has supported that it can provide data quality that often exceeds most other platforms (e.g. MTurk) (Palan and Schitter, 2018; Taneva and Yankov, 2020). We included three attention checks and removed participants if they failed any (68 participants). All statistics, including the reported sample size above, reflect the sample after removing these participants. The sample size for the current study (575) provides accurate CFA estimates with our number of included parameters (Brown, 2015; Harrington, 2009; Schreiber et al., 2006).

Procedure

Participants enrolled via the Prolific platform and immediately completed the survey.

Measures

Demographic information. Participants were asked to provide their age, gender, location, and other unreported demographic variables.

Multidimensional Vaccine Hesitancy Scale. The 32-item MVHS was administered. The Cronbach's alpha of each dimension was 0.85 or higher.

Vaccine hesitancy. The Vaccine Hesitancy Scale (Larson et al., 2015; Shapiro et al., 2018) was given with the same changes as Study 2 (Cronbach's alpha = 0.88).

Outcomes. The same outcomes as Study 2 were applied. These included flu vaccine willingness ($\alpha = 0.76$), COVID-19 vaccine willingness ($\alpha = 0.88$), received flu vaccine in past year, and received other vaccines.

Results

We first assessed the MVHS via a second-order CFA using a regression imputation method to address item-level missing data. To construct our model, each set of four items loaded onto their respective first-order latent factors, and then each first-order latent factor loaded onto a single second-order latent factor. We considered cutoffs for both acceptable (CFI > 0.92, IFI > 0.92, RMSEA < 0.08, SRMR < 0.08, $\chi^2/df < 4$) and excellent (CFI > 0.95, IFI > 0.95, RMSEA < 0.05, SRMR < 0.05, $\chi^2/df < 3$) model fit based on prior guidelines (Brown, 2015; Hu and Bentler, 1999; Jackson et al., 2009; Marsh et al., 1988, 2004).

Initially, our model met recommended cutoffs for acceptable but not excellent model fit (CFI = 0.93, IFI = 0.93, RMSEA = 0.06, SRMR = 0.06, $\chi^2/df = 3.03$). Three pairs of items that loaded onto the same factors had very strong modification indices (>30) for adding a covariance between their error terms. This variance unexplained by the modeled latent factors could be justified for each of these item pairings, as each item pairing was near synonyms (e.g. "I am too busy to get a vaccine" and "I do not have the time to get a vaccine"). As recommended by prior authors (Brown, 2015; Harrington, 2009), we covaried the error terms of these item pairs, as they each loaded onto common latent factors and their associations could be justified. The new model fit indices met or very closely approached recommended cutoffs for excellent model fit (CFI = 0.96, IFI = 0.96, RMSEA = 0.05, SRMR = 0.06, $\chi^2/df = 2.29$), and each item loaded strongly onto its intended latent factor (>0.60) (Table 5). The factor structure of the MVHS was confirmed.

Correlations and Cronbach's alphas for Study 3 are provided in Supplemental Material F. The MVHS dimensions produced Cronbach's alphas between 0.85 and 0.92. Each MVHS dimension was again significantly correlated with the vaccine hesitancy scale (all $p < 0.05$), supporting the convergent validity of the measure. Table 6 provides all regression results described below,

Table 5. Confirmatory factor analysis item loadings in study 3.

Item	Factor loading
Health risks 1	0.88
Health risks 2	0.82
Health risks 3	0.74
Health risks 4	0.76
Cost 1	0.88
Cost 2	0.68
Cost 3	0.95
Cost 4	0.60
Physical pain 1	0.95
Physical pain 2	0.95
Physical pain 3	0.64
Physical pain 4	0.82
Inconvenience 1	0.61
Inconvenience 2	0.92
Inconvenience 3	0.93
Inconvenience 4	0.72
Personal reactions 1	0.77
Personal reactions 2	0.85
Personal reactions 3	0.85
Personal reactions 4	0.84
Access 1	0.71
Access 2	0.82
Access 3	0.90
Access 4	0.85
Healthy 1	0.79
Healthy 2	0.80
Healthy 3	0.90
Healthy 4	0.81
Forget 1	0.76
Forget 2	0.81
Forget 3	0.90
Forget 4	0.77

Numbers represent standardized item loadings.

and all VIF values were below three (Hair et al., 2019). When the vaccine hesitancy scale was regressed onto the MVHS dimensions, Health Risks and Healthy were again the two dominant dimensions (both $p < 0.01$). Next, we assessed the amount of variance that the MVHS explains in the four outcomes beyond the extant vaccine hesitancy scale. The additional percent of variance explained ranged from 0.05 to 0.11, and it was statistically significant in all four analyses (all $p < 0.01$). Once again, the MVHS predicted relevant outcomes beyond extant measures, supporting the measure's validity. In the second step of these regression analyses, Inconvenience and Forget was significant predictors in three; Health Risks, Access, and Healthy were significant predictors in two; and Cost, Pain, and Personal Reactions were significant predictors in one (all $p < 0.05$). These results again show that each MVHS dimension is important in understanding vaccine-related intentions and behaviors.

Lastly, only one dimension produced regression results in the opposite direction as the other dimensions. Access again had a positive relation with flu vaccine willingness ($\beta = 0.17$, Table 6) and rates of receiving the flu vaccine in the past year ($\beta = 0.16$, Table 6).

Brief conclusion

Study 3 confirmed the factor structure of the MVHS, robustly supporting the measures' psychometric properties, and we replicated its validity information. We again showed that the MVHS is associated with outcomes beyond an extant vaccine hesitancy scale, indicating that the MVHS provides notable implications regarding vaccine hesitancy. Likewise, we again showed that Access produced positive relations with vaccination outcomes, indicating that not all negative perceptions regarding vaccines result in decreased willingness and behaviors.

General discussion

The results of three studies produced an 8-dimension, 32-item measure that we labeled the Multidimensional Vaccine Hesitancy Scale (MVHS). The MVHS was shown to have excellent psychometric properties, and each retained dimension was shown to be relatively distinct. The Cronbach's alphas of the dimensions were routinely in the acceptable range (0.80−0.90; Hair et al., 2019), whereas many of the existing measures of vaccine perceptions produced Cronbach's alphas that were above this range (>0.90). This indicates that the number of items

Table 6. Regression and hierarchical regression results of study 3.

	Vaccine hesitancy	Flu vaccine willingness		COVID-19 vaccine willingness[a]		Received flu vaccine in past year[b]		Up to date on other vaccines[b]	
	Step 1	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
1. Vacc Hes	–	−0.46**	−0.17**	−0.60**	−0.44**	−0.07	0.11	−0.31**	−0.21**
2. HR	0.41**		−0.19**		−0.21**		−0.11		0.11
3. Cost	0.03		−0.03		−0.05		−0.09*		0.02
4. Pain	0.03		−0.12**		−0.03		−0.04		0.07
5. Incov	0.12**		−0.19**		−0.10*		−0.09		−0.17**
6. PR	0.12**		0.00		0.07		0.00		−0.11*
7. Acc	0.16*		0.17**		0.07		0.16**		−0.03
8. Health	0.28**		−0.20**		−0.10*		−0.11		−0.01
9. Forget	0.01		0.03		0.11**		−0.11*		−0.11*
ΔR^2	0.59**	0.21**	0.11**	0.36**	0.05**	0.01	0.06**	0.10**	0.07**

Numbers represent standardized beta coefficients.
Vacc Hes: vaccine hesitancy; HR: health risks; Cost: cost; Pain: physical pain; Incov: inconvenience; PR: personal reactions; Acc: access; Health: healthy; Forget: forget.
[a]Supplemental Material G includes a reanalysis of this variable while excluding participants that tested positive for COVID-19 or believe that they had COVID-19.
[b]Supplemental Material G includes reanalysis of these variables using binominal logistic regression.
*$p < 0.05$. **$p < 0.01$.

in our dimensions were appropriate, whereas prior scales may include too many repetitive items. Our studies also demonstrated that the MVHS relates to theoretically associated variables, and it explains significant variance in relevant outcomes beyond prior measures of vaccine hesitancy and similar constructs. While most of the MVHS dimensions negatively related to vaccination outcomes of willingness and behaviors, the dimension of Access consistently demonstrated positive relations with these outcomes. These results strongly support the continued use of the MVHS, and they also provide several implications for both theory and practice.

The most basic future direction is the reinvestigation of prior studies on vaccine hesitancy to integrate our newfound perspective (Bish et al., 2011; Dubé et al., 2013; Jarrett et al., 2015; MacDonald, 2015). Researchers may identify that effects are even stronger than previously believed due to the greater predicative ability of the MVHS, but also that only certain dimensions may be important in explaining previously observed relations of vaccine hesitancy.

The MVHS also resolves certain ongoing debates regarding the dimensions and criterion space of vaccine hesitancy. Researchers have proposed a multitude of possible vaccine hesitancy dimensions, but no single proposal identified all dimensions included in the MVHS (Bedford et al., 2018; Dubé et al., 2013; Larson et al., 2014; MacDonald, 2015; Marti et al., 2017; Paterson et al., 2016). This finding suggests that each prior proposal was partially correct but not fully inclusive, and certain elements of the authors' broader claims can inform future research on vaccine hesitancy. Also, Study 2 showed that many such dimensions are empirically repetitive. For instance, Health Risks and Efficacy Doubts loaded onto the same factor, resulting in the removal of the latter. Future discussions should recognize that these possible dimensions occupy the same criterion space, and they likely produce identical effects if studied independently. Likewise, the current article identified the first-order dimensions of the

unitary construct of vaccine hesitancy. Many prior authors have proposed more detailed factor structures, including intermediary dimensions between the first-order dimensions and the unitary construct (e.g. 3C model; 5C subscales; 5A taxonomy). Our dimensions represent categories in each of these proposals, and future researchers should assess whether the intermediary dimensions provide appropriate model fit when assessed using the MVHS.

It should be recognized that not all vaccine hesitancy dimensions may be detrimental. In Studies 2 and 3, the dimension of Access positively related to vaccine willingness and behaviors. Although a person may feel that vaccines are difficult to obtain, they may still be willing to receive a vaccine and fight through these difficulties to become vaccinated. Such an observation adds nuance to the study of vaccine hesitancy that was previously undetected. Prior studies treat all negative perceptions regarding vaccines as detrimental to associated outcomes, but certain aspects of vaccine hesitancy may not need to be addressed to increase vaccination rates.

Also, several models of preventive behaviors include vaccination as an outcome (Bish and Michie, 2010; Champion and Skinner, 2008; Griffin et al., 1999; Rosenstock et al., 1988). These models should be revised to reflect the newfound complexity of vaccine hesitancy. Doing so may not only enhance the theoretical accuracy and predictive abilities of these models, but it could also lead to the identification of novel relations. Notably, Bish and Michie (2010) identified five immediate antecedents of vaccination: perceived susceptibility, perceived efficacy, perceived severity, education, and ethnicity. The first three of these directly relate to dimensions of the MVHS (e.g. Health Risks and Healthy), indicating that our identified dimensions can be integrated with their model. Some other dimensions of the MVHS are also included in the model of Bish and Michie (2010), such as perceived costs (i.e. Costs), but they are not specified as antecedents to vaccination. Now that we have identified a link, the model should be revised to include this relation. Adding our dimensions could also identify mediating effects between other antecedents, such as education and ethnicity, and vaccination to enhance the conceptual accuracy of the model. We chose this model as an example due to its widespread use and comprehensiveness, but similar integrations could—and should—be conducted with additional models of preventive behaviors.

We created the MVHS to gauge perceptions regarding vaccines in general. In Study 1, however, we demonstrated that the negative perceptions regarding vaccines in general were similar to those regarding a specific vaccine, COVID-19. We designed the MVHS items to be easily modified to refer to specific vaccines by changing the referent. For example, the item, "Vaccines can cause long-term health issues," can be changed to, "The COVID-19 vaccine can cause long-term health issues." While modifying measures in this manner is common (Cortina et al., 2020), it does not ensure that the modified scale will demonstrate similar psychometric properties and validity as the original. Future researchers should assess whether modifications to the MVHS to measure perceptions regarding specific vaccines produces appropriate scales.

The current article poses many implications for interventions to promote vaccination. Future interventions should focus on the dimensions of Health Risks and Healthy due to their consistent strong relations, and other dimensions could be targeted when appropriate. For instance, Forget was significantly related to flu vaccine behaviors, and it could be important to target this perception in messaging for flu vaccines, specifically. The multiphase optimization strategy (MOST) should be used to create these multicomponent interventions, as MOST can efficiently identify efficacious components to develop optimized interventions (Collins et al., 2007, 2011; Howard and Jacobs, 2016). Similarly, many interventions to promote vaccination deliver a single message with a one-size-fits-all approach. People may have very different perceptions regarding vaccines, and the same messaging may be effective for some

people but not others. The MVHS may be particularly useful for the development of adaptive interventions. For example, a person could provide their responses to the MVHS and receive personalized information regarding vaccines based on their dimensions' scores. It would be beneficial to apply sequential multiple assignment randomized trials (SMART) to develop these interventions, as SMART determines the sequencing of intervention components that produces the most desirable outcomes (Almirall et al., 2012; Collins et al., 2007; Howard and Jacobs, 2016).

Future studies should address our limitations. Online data collection services, MTurk and Prolific, were used for all three studies. Authors have shown that results derived from MTurk and Prolific are comparable to those derived with other sampling approaches (Buhrmester et al., 2018; Mellis and Bickel, 2020; Palan and Schitter, 2018; Robinson et al., 2019), and a benefit of these services is the ability to obtain diverse samples. Due to the diversity of our samples, the current article provides considerable support for the applicability of the MVHS. Future researchers, however, should further investigate the MVHS using samples gathered from varied populations and sampling approaches. Also, we chose scales to study alongside the MVHS based on prior support for their validity (Gilkey et al., 2016; Sarathchandra et al., 2018; Shapiro et al., 2018), but many other scales could have been chosen. It is often stated that the scale development process is never complete, and future authors should continue exploring the nomological net of the MVHS to further support its validity. Lastly, the time-separation between our measurement occasions in Study 2 was intended to reduce common method bias, as much longer time spans would be necessary to assess causal effects between the MVHS dimensions and our outcomes of interest. For instance, a year timespan would be required to assess the causal relation between vaccine hesitancy and receiving a flu vaccine in the past year. Despite these difficulties, it is essential for future research to investigate these causal effects to determine the precise effects of vaccine hesitancy on relevant behaviors. Therefore, future research should replicate the current result using longer temporal separations in their longitudinal designs.

Data availability statement

All data associated with the current submission is uploaded as supporting information (Supplemental Material B, Supplemental Material E, and Supplemental Material F).

Declaration of conflicting interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

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Supplemental material

Supplemental material for this article is available online.

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Appendix A – Multidimensional Vaccine Hesitancy Scale (MVHS)

Note: Do not include the dimension labels when administering the Multidimensional Vaccine Hesitancy Scale (MVHS) or Expanded Multidimensional Vaccine Hesitancy Scale (E-MVHS). Only include additional dimensions when administering the E-MVHS.

Instructions: Please indicate the extent that you disagree to agree with the following statements regarding vaccines using the scale provided below.

1 – Strongly Disagree
2 – Disagree
3 – Slightly Disagree
4 – Neither Disagree or Agree
5 – Slightly Agree
6 – Agree
7 – Strongly Agree

Primary Dimensions

Health Risks

1.) Vaccines can cause long-term health issues.
2.) Vaccines are unsafe.
3.) Vaccines can cause illness.
4.) Vaccines can cause certain disorders.

Cost

1.) Vaccines cost too much.
2.) I am unable to get vaccines because they cost too much.
3.) Vaccines are too expensive.
4.) Without health insurance, vaccines cost too much.

Physical Pain

1.) Needles bother me when receiving a vaccine.
2.) I worry about needles when getting a vaccine.
3.) Getting a vaccine hurts.
4.) I have a phobia of needles when receiving a vaccine.

Inconvenience

1.) I am too busy to get a vaccine.
2.) Getting a vaccine is too much of a hassle.
3.) Getting a vaccine is too much trouble.
4.) I do not have the time to get a vaccine.

Personal Reactions

1.) I have allergic reactions to most vaccines.
2.) I am a high-risk person for having a negative reaction to vaccines.
3.) I am allergic to certain ingredients in vaccines.
4.) I have a medical condition that prevents me from getting vaccines.

Access

1.) Vaccines are unavailable where I live.
2.) There is nowhere to get a vaccine.
3.) It is difficult to get a vaccine where I live.
4.) It is difficult to know where to get a vaccine.

Healthy

1.) I do not need vaccines because I rarely get sick.
2.) My strong immune system eliminates any need for vaccines.
3.) I do not need vaccines because I am a low-risk person.
4.) People in my physical condition do not need vaccines.

Forget

1.) Getting vaccines often slips my memory.
2.) I just forget about getting vaccines.
3.) I just never get around to getting vaccines.
4.) I accidentally skip getting vaccines.

Additional Dimensions (Only for E-MVHS)

Distrust

1.) There is not enough testing on vaccines.
2.) People are unknowing test subjects for vaccines.
3.) I do not trust the creators of vaccines.
4.) Vaccines are used for corrupt purposes.

Not Needed

1.) People simply do not need vaccines.
2.) The risk of infection for most illnesses is too low to need vaccines.
3.) Any illness that can be prevented by vaccines is not serious enough to need a vaccine.
4.) Natural exposure to disease is better than vaccines.

Efficacy Doubts

1.) Vaccines have a low success rate.
2.) Vaccines do not work well.
3.) Vaccines are ineffective.
4.) Vaccines do not prevent illness.

Unnatural Ingredients

1.) Vaccines contain harmful additives.
2.) Vaccines contain harmful chemicals.
3.) Vaccines include chemicals that do not belong in the body.
4.) Vaccines include viruses that should not go into your body.

Beliefs

1.) Vaccines go against my moral beliefs.
2.) Vaccines go against my beliefs.
3.) Vaccines go against my personal beliefs.
4.) Vaccines go against my religious beliefs.