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Measuring psychosocial determinants of vaccination behavior in healthcare professionals: validation of the Pro-VC-Be short-form questionnaire

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ABSTRACT

Background: Vaccine confidence among health care professionals (HCPs) is a key determinant of vaccination behaviors. We validate a short-form version of the 31-item Pro-VC-Be (Health Professionals Vaccine Confidence and Behaviors) questionnaire that measures HCPs' confidence in and commitment to vaccination.

Research design and methods: A cross-sectional survey among 2,696 HCPs established a long-form tool to measure 10 dimensions of psychosocial determinants of vaccination behaviors. Confirmatory factor analysis (CFA) models tested the construct validity of 69,984 combinations of items in a 10-item short form tool. The criterion validity of this tool was tested with four behavioral and attitudinal outcomes using weighted modified Poisson regressions. An immunization resource score was constructed from summing the responses of the dimensions that can influence HCPs' pro-vaccination behaviors: vaccine confidence, proactive efficacy, and trust in authorities.

Results: The short-form tool showed good construct validity in CFA analyses (RMSEA = 0.035 [0.024; 0.045]; CFI = 0.956; TLI = 0.918; SRMR 0.027) and comparable criterion validity to the long-form tool. The immunization resource score showed excellent criterion validity.

Conclusions: The Pro-VC-Be short-form showed good construct validity and criterion validity similar to the long-form and can therefore be used to measure determinants of vaccination behaviors among HCPs.

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Healthcare professionals; short-form tool; vaccines; vaccine confidence; vaccine hesitancy

1. Introduction

In 2019, the World Health Organization (WHO) ranked vaccine hesitancy as one of the 10 most important health threats in the world [1]. The WHO Strategic Advisory Group of Experts on Immunization (SAGE) Working Group on Vaccine Hesitancy defines vaccine hesitancy as the 'delay in acceptance or refusal of vaccination despite availability of vaccination services' [2]. In the context of the current COVID-19 pandemic, vaccine hesitancy constitutes a significant barrier to sufficient vaccine coverage to curb preventable infections and ultimately end the pandemic [3]. Healthcare professionals (HCPs) play an integral role in the vaccination of the public, from communicating current recommendations to providing accurate information about vaccines (i.e. production, benefits/risks, side effects, etc.) [4]. However, HCPs can themselves be vaccine hesitant [5], which decreases their likelihood to self-vaccinate [6] and negatively influences their recommendation behaviors and counseling of patients [7,8]. Therefore, measuring vaccine hesitancy in HCPs using easily accessible, validated tools is of considerable importance to better understand public health concerns and develop tailored interventions to improve confidence in vaccines among professionals and improve their vaccine-related interactions with patients. In general, vaccine-confident HCPs are more often vaccinated themselves and tend to vaccinate their patients more frequently than hesitant HCPs [9].

Validated tools to measure attitudes related to vaccination and determinants of vaccine hesitancy in the general population have been developed in both long-form and short-form versions [10,11]. Only recently, a tool to measure psychosocial determinants of vaccination behaviors in HCPs, the Health **Pro**fessionals **V**accine **C**onfidence and **Be**haviors (Pro-VC-Be), was developed and validated in three French-speaking countries: France, Belgium, and Canada (Quebec) [12]. This questionnaire, in addition to measuring HCPs' vaccination behaviors and attitudes, included 10 dimensions of their psychosocial determinants. (1) Perceived risks of vaccines [7,8], (2)

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complacency (also referred to as the perception of their lack of usefulness) [7,13], (3) perceived benefit/risk balance of vaccines [14], and (4) perceived collective responsibility (willingness to contribute to community immunity) [7,8,12,15] were the dimensions found to measure the latent dimension 'vaccine confidence.' (5) Commitment to vaccination (the extent to which HCPs are devoted to and proactive in motivating their patients to accept vaccinations) [16] and (6) their self-efficacy (how well-equipped and prepared HCPs feel, in terms of knowledge and skills, to address vaccination with their patients) [17] were found to measure the same latent dimension of 'proactive efficacy.' (7) Trust in authorities refers to trust in institutions and health authorities as reliable sources of information on the benefits and safety of vaccines, and trust in them to adequately define the vaccine strategy [13,18]. (8) Perceived constraints refer to constraints that could arise from HCPs' working conditions and environment, which can limit their commitment to vaccination of their patients [10]. (9) Openness to patients measures HCPs' attitudes toward vaccine-hesitant patients: the extent to which HCPs listen to their patients, in an empathetic, nonjudgmental way, matters for the occurrence of behavior change [19]. (10) Reluctant trust is conceptualized to describe the 'leap of faith' that people make about expert systems and technologies that are not under their direct scrutiny [20]. In the Pro-VC-Be, it measures the extent to which HCPs might trust the vaccination system despite the concerns they may have about some vaccines or the system itself [12,18].

The long-form Pro-VC-Be questionnaire addressed these 10 dimensions through 31 items, taking HCPs an average of 10 minutes to complete online [12]. A short-form version of the Pro-VC-Be would make the tool more accessible to busy HCPs and more cost-effective for projects targeting these populations. A short-form tool could also serve to evaluate and reevaluate participants in intervention studies aiming to reduce vaccine hesitancy in HCPs. Therefore, the first objective of this article was to study the construct and criterion validity of a short-form tool developed from the selection of 10 items from the initial 31-item Pro-VC-Be questionnaire, each representing one of the original 10 dimensions. The second objective was to generate a global score from the short tool to measure immunization 'resourcefulness' (i.e. the psychosocial resources at the disposal of HCPs) to manage the vaccination of their patients.

2. Materials and methods

2.1. Study population

A cross-sectional survey collected data on vaccination behaviors and attitudes and various psychosocial determinants from 1,209 General Practitioners (GPs) in France, 432 physicians in French-speaking parts of Belgium (Brussels and Wallonia), and 1,055 nurses in French-speaking Canada (Quebec) from October to mid-November in 2020. Professionals were chosen based on their involvement in immunization of the general population. Detailed methods on the recruitment, sample size estimation, and data collection procedure are described in the previous publication for the validation of the long-form tool [12]. The ethics boards of the ANONYMIZED approved the original study protocol and questionnaire.

2.2. Selection of items in the short-form tool

The short-form version of the Pro-VC-Be was constructed and validated in several steps. First, we randomly divided the sample into two halves to obtain a test and a validation sample. The original 31 items were combined in 69,984 possible combinations (3 perceived risk items * 3 complacency items * 4 benefit/risk balance items * 2 collective responsibility items * 3 commitment items * 4 self-efficacy items * 3 perceived constraint items * 3 trust in authority items * 3 openness to patients' items * 3 reluctant trust items), selecting one item from each of the 10 established dimensions of the long-form Pro-VC-Be previously described. These items were collected on 4-point Likert scales (from 1 = *'strongly disagree'* to 4 = *'strongly agree'*) with a *'I don't know'* option. Confirmatory factor analysis (CFA) assessed the fit of the models for the 69,984 combinations of items in the test sample [21,22]; the latent structure of these models having already been established using exploratory factor analysis for the validation of the long-form tool. The hierarchical structure of the validated long-form [12] was also respected in the short-form tool by combining six observed dimensions into two latent dimensions: 1) confidence in vaccines, based on the dimensions of perceived risks of vaccines, complacency, perceived benefit/risk balance, and perceived collective responsibility and 2) proactive efficacy, based on the dimensions of commitment to vaccination and perceived self-efficacy. The four remaining dimensions, trust in authorities, openness to patients, reluctant trust, and perceived constraints, were kept as single items and handled in the model by correlating each of them with all other dimensions. Models were performed using maximum likelihood with robust standard errors (MLR) [23,24]; those with good to excellent fit (Root Mean Square Error of Approximation (RMSEA) <0.06; Standardized Root Mean Square Residual (SRMR) <0.08; Comparative Fit Index (CFI) ≥0.95; Tucker Lewis Index (TLI) ≥0.95) were retained [25].

2.3. Construct validity of the short-form: convergent and discriminant validity

The CFA model retained for the evaluation of construct validity of the short-form tool included the most frequently identified item for each of the 10 dimensions among the CFA models with good to excellent fit run on the test sample. When items had competing frequencies for the same dimension, items were then selected based on frequency within the 10 best-fit models (Supplemental Material 1), and also through expert reasoning. This approach allowed us to select for the item that best represented each validated dimension from previous CFA analyses within the long-form Pro-VC-Be [12], rather than creating a single latent concept of vaccine confidence, while taking into account the inter-relationships between these dimensions. Selecting items based on the highest loadings (i.e. effect estimate) in each dimension would not

necessarily result in a better-fit model, as inter-correlations between items vary between models.

The final CFA model was conducted on the validation sample to determine whether the short-form tool could fit a new, independent sample using the same criteria. The convergent validity of factors was assessed using CFA factor loadings (cutoff criteria: ≥0.71 (excellent), 0.63–0.70 (very good), 0.55–0.62 (good), 0.45–0.54 (fair), 0.32–0.44 (poor)) [26], and discriminant validity between dimensions was assessed using Pearson correlations (≥0.80 indicating poor discriminant validity) [22].

2.4. Criterion validity of the short-form

Four HCP behavioral and attitudinal measurements from the long-form Pro-VC-Be served as outcome criteria to assess the extent to which the short form tool was associated with them (Table 1) [21]. Behaviors were measured through 1) HCPs' frequency of general immunization activity, based on items on vaccination practice in general (3 items) and 2) HCPs' frequency of recommendations in six specific vaccine situations (6 items). Attitudes toward COVID-19 vaccines, before they were marketed, were also addressed (2 items). Items were collected on 4-point Likert scales (from 1 = *'never'* or *'strongly disagree'* to 4 = *'always'* or *'strongly agree'*) with a *'don't know'* option. An additional behavioral criterion, self-vaccination behavior, was measured only among participating French GPs (3 items). For each criterion, a score was constructed by summing HCPs' answers to the corresponding items with no missing values, andividing the sum by the number of items. Because of their non-normal distributions, scores were dichotomized for analyses. The first two behavioral scores were linearly transformed to obtain scores ranging from 0 (*no vaccination behavior*) to 100 (*systematic vaccination behavior*); the thresholds were held at 75% to represent HCPs with very frequent immunization activity and very frequent vaccine recommendation. The score of stated willingness to accept future COVID-19 vaccines was dichotomized to distinguish stronger acceptance (score >4/6) from the other attitudes (*moderate acceptance* and *reluctance/hesitancy*). The threshold of the personal vaccine uptake's score was held at 3/3 to represent French GPs up-to-date with influenza and whooping cough vaccines, or intending to be vaccinated.

Table 1. Set of items used in the Pro-VC-Be questionnaire to measure vaccination behaviors and attitudes.

General immunization activity	B1. With the patients you treat: a. How often do you bring up the subject of vaccination? b. How often do you recommend the vaccines that are indicated for them? c. How often do you prescribe indicated vaccines to them?
Vaccine recommendation frequency	B3. How often do you recommend the following vaccines? A. Catch-up MMR for adolescents B. Pertussis vaccine in pregnancy (Quebec)/ pertussis vaccine in mothers who have just given birth, if not vaccinated before pregnancy (France) C. Meningitis C vaccine at 12 months of age D. Human papilloma virus vaccine in young girls and boys aged 11 to 14 years old E. Catch-up hepatitis B vaccine in adolescents F. Seasonal flu vaccine in adults under 65 years old with chronic illness
Stated willingness to accept future COVID-19 vaccines	I. If a Covid-19 vaccine were available (Oct-Nov 2020): 1. Would you agree to recommend it to your patients? 2. Would you agree to vaccinate yourself?
Self-vaccination behavior	VP1. Were you vaccinated against seasonal influenza for the winter 2019–2020 season? VP11. For this coming winter (2020–2021), do you intend to be vaccinated against seasonal influenza? (France and Belgium only) VP2. Have you had a pertussis vaccination booster dose during your adult life in the past 20 years? (France only)

The explanatory variables for criterion validity of the short-form were the following latent and observed dimensions of the Pro-VC-Be: vaccine confidence, proactive efficacy, trust in authorities, openness to patients, reluctant trust, and perceived constraints. Vaccine confidence and proactive efficacy were constructed by summing the underlying dimensions' items then dividing by the number of items within them, in order to give the same range (1 to 4) to all explanatory variables. They were then dichotomized around their mean to assess the extent to which HCPs with above-average scores differed in their behaviors from those with below-average scores.

Criterion validity of the short-form was assessed by performing weighted multiple modified Poisson regressions with robust error variance estimation. Modified Poisson regression allows to estimate relative risks instead of odds ratio, which overstate the associations when the outcome is not rare [27]. We compared the results to those obtained from the original long-form explanatory variables to explore the extent to which using this smaller set of short-form items would yield similar results as the whole set of the original 31 Pro-VC-Be items. All regression models were adjusted for gender, age, and profession to estimate the relative risks between each outcome and the six factors of the Pro-VC-Be questionnaire. We first tested each factor separately and then together in a global model, as some factors were moderately inter-correlated.

2.5. Validation of an immunization resources score

The three short-form Pro-VC-Be factors of vaccine confidence, proactive efficacy, and trust in authorities reflect the constructive resources that HCPs can utilize for their daily immunization practices; whereas the remaining factors of perceived constraints, reluctant trust, and openness to patients more closely represent barriers to these practices. For this reason, an immunization score was developed from these three constructive dimensions, resulting in a Likert-scale score ranging from 1 to 4 (1 = '*No resources*' to 4 = '*Full resources*'). Its internal consistency was measured with Cronbach's alpha coefficient, with values ≥.7 being considered as satisfactory [28,29]. The same models as those run in criterion validity analyses were applied to investigate associations between the immunization resource score and behavioral and attitudinal criteria. A test for linear trend was performed using

contrasts, in order to evaluate whether a 'dose-response' association was implied between the outcomes and the immunization resource score gradients.

Data in all analyses were weighted to match the sample to the national French GP, Belgian GP, and Quebec nurse populations for age, gender, and region; weighting for French GPs also matched them to the national population for workload and GP density in their practice area [30,31]. All analyses were based on two-sided *P*-values, with $P < 0.05$ indicating statistical significance, and were performed with SAS 9.4; the CFA model with final item selection was performed using MPlus 7.2.

3. Results

3.1. Selection of items in the short-form tool

Of the 69,984 CFA models that were run on the test sample, with all possible combinations of the 31 original items, 3,169 (5%) had a good to excellent fit (RMSEA <0.06; SRMR <0.08; CFI and TLI ≥0.95) (Table 2). The great majority of them (77%) included the item '*R1. Some vaccines can cause autoimmune diseases*' from the 'perceived risks of vaccines' dimension; this item was therefore selected to represent this dimension in the short-form version. In the same manner, the dimensions of complacency, collective responsibility, trust in authorities, openness to patients, commitment to vaccination and reluctant trust were much more frequently (48.31–69.20%) represented by one particular item in the good-to-excellent fit CFA models, so this item was retained for the short-form tool. The dimensions of benefit/risk balance, perceived constraints, and self-efficacy showed items with more competing frequencies (Table 2), therefore short-form items were selected using the frequencies of items found within the 10 best-fit CFA models (Supplemental Material 1), as well as through expert reasoning. While the item 'BRB3. *The benefits of the vaccine against hepatitis B in infants (or as catch-up in adolescents) are much greater than its potential risks*,' included in 9 out of 10 best-fit models, was selected and analyzed in CFA models, a general item to represent benefit/risk balance ('The benefits of vaccines are much greater than their potential risks') would be more appropriate to several countries and contexts; thus, the final short-form tool that we proposed did not include this specific item, but a general one, based on expert reasoning. The self-efficacy item 'SE4. *I feel sufficiently trained on how to approach the question of vaccines*

Table 2. Frequency of each item from the long-form Pro-VC-Be included in CFA models with good to excellent fit conducted on the test sample (n = 1,348 participants; 3,169 models)*.

Dimension		N = 3169	%
Perceived risks of vaccines	**R1. Some vaccines can cause autoimmune diseases**	**2442**	**77.06**
	R2. The measles vaccine can cause autism in children	564	17.80
	R3. Some vaccines can cause multiple sclerosis	163	5.14
Complacency	**U1. Today, some vaccines recommended by authorities are not useful, because the diseases they prevent are not serious**	**2193**	**69.20**
	U2. Children are vaccinated against too many diseases	847	26.73
	U3. Children are vaccinated at too young an age	129	4.07
Perceived benefit/risk balance	BRB1. The benefits of the vaccine against measles are much greater than its potential risks	517	16.31
	BRB2. The benefits of the vaccine against influenza in people with a chronic disease are much greater than its potential risks	533	16.82
	BRB3. The benefits of the vaccine against hepatitis B in infants (or as catch-up in adolescents) are much greater than its potential risks	**1120**	**35.34**
	BRB4. The benefits of the vaccine against human papillomaviruses are much greater than its potential risks	999	31.52
Perceived collective responsibility	**CR1. I recommend the vaccines on the vaccination schedule to my patients because it's essential to contribute to protection of the population (community immunity)**	**1873**	**59.10**
	CR2. I recommend the vaccines in the official schedule to my hesitant patients, explaining to them the importance of community immunity	1296	40.90
Trust in authorities	TA1. I trust the ministry of health to provide reliable information about the risks and benefits of vaccines	867	27.36
	TA4. I trust the ministry of health to establish the vaccination strategy	771	24.33
	TA5. I trust the ministry of health to ensure that vaccines are safe	**1531**	**48.31**
Perceived constraints	**PC1. The cost of some vaccines is a problem for some patients and can keep me from prescribing them**	**1172**	**36.98**
	PC2. The lack of availability of certain vaccines is often a problem that can keep me from prescribing them to my patients.	864	27.26
	PC3. Not having vaccines in my office is a problem in my practice	1133	35.75
Openness to patients	OP1. Patients who are hesitant about the benefits and risks of vaccines have legitimate questions	747	23.57
	OP2. I inform my patients about the benefits and risks of vaccines but I let them make their decision without trying to influence them	**1602**	**50.55**
	OP5. I am willing to let parents delay immunizing their children	820	25.88
Commitment to vaccination	**CV1. I am actively involved in ensuring that my patients are vaccinated**	**1814**	**57.24**
	CV3. I am committed to keeping my knowledge about vaccination up-to-date (CME, conferences, reading)	980	30.92
	CV4. I am committed to developing the skills needed to communicate better with my patients about vaccination	375	11.83
Self-efficacy	SE1. I feel comfortable advising my patients about the risks and benefits of vaccines	461	14.55
	SE2. I feel comfortable discussing vaccines with my patients who are highly hesitant about vaccination	928	29.28
	SE3. I feel sufficiently trained and informed to discuss vaccines with all patients	888	28.02
	SE4. I feel sufficiently trained on how to approach the question of vaccines with hesitant patients	**892**	**28.15**
Reluctant trust	RT1. I recommend the vaccines in the official schedule even though I sometimes feel that I am not sufficiently informed about some of them	627	19.79
	RT2. I recommend the vaccines in the official schedule even though I feel that the objectives of the vaccination policy are not clear enough	**2190**	**69.11**
	RT3. I recommend vaccines on the official schedule although I sometimes have doubts about their safety	352	11.11

*Items in bold are those retained in the short version of the Pro-VC-Be; those underlined are also retained in the construction of the immunization resources score.

with hesitant patients' was included in 8 out of the 10 best-fit models and was therefore selected for the short-form tool. The perceived constraint dimension, however, showed that two items were most frequently present in these 10 best-fit models: *'PC1. The cost of some vaccines is a problem for some patients and can keep me from prescribing them to my patients'* (in 5 out of 10) and *'PC3. Not having vaccines in my office is a problem in my practice* (in 4 out of 10).' Expert reasoning was subsequently used to select item PC1 to represent this dimension and is detailed later in the discussion. The final, recommended selection of 10 items for the short-form tool is found in Table 3.

3.2. Construct validity of the short-form: convergent and discriminant validity

The CFA model with the 10 selected short-form items run on the validation sample showed good fit (RMSEA = 0.035 [0.024;0.045]; CFI = 0.956; TLI = 0.918; SRMR 0.027) (Figure 1); TLI was <.95 but met the >.90 criterion cutoffs [32]. Items within the latent dimension 'confidence in vaccines' had fair or good convergent validity (absolute loadings between 0.41 and 0.65, $P < 0.001$) and items within the latent dimension 'proactive efficacy' had very good to excellent convergent validity (absolute loadings between 0.68 and 0.78, $P < 0.001$).

Confidence in vaccines was moderately correlated with trust in authorities ($\rho = 0.52$, $P < 0.001$) and proactive efficacy ($\rho = 0.66$, $P < 0.001$). All other dimensions were poorly or not at all correlated with each other (absolute value correlations between 0.00 and 0.23). These results were similar to those with the long-form [12].

Table 3. Final short-form Pro-VC-Be tool to measure determinants of vaccine confidence in HCPs*.

Dimension	Item
Perceived risks of vaccines	1. Some vaccines can cause autoimmune diseases
Complacency	2. Today, some vaccines recommended by authorities are not useful, because the diseases they prevent are not serious
Perceived benefit/risk balance	3. 'The benefits of vaccines are much greater than their potential risks'
Perceived collective responsibility	4. I recommend the vaccines on the vaccination schedule to my patients because it's essential to contribute to protection of the population (community immunity)
Trust in authorities	5. I trust the ministry of health to ensure that vaccines are safe
Perceived constraints	6. The cost of some vaccines is a problem for some patients and can keep me from prescribing them
Openness to patients	7. I inform my patients about the benefits and risks of vaccines but I let them make their decision without trying to influence them
Commitment to vaccination	8. I am actively involved in ensuring that my patients are vaccinated
Self-efficacy	9. I feel sufficiently trained on how to approach the question of vaccines with hesitant patients
Reluctant trust	10. I recommend the vaccines in the official schedule even though I feel that the objectives of the vaccination policy are not clear enough

*The following response scale applies to all items: strongly disagree, somewhat disagree, undecided, somewhat agree, strongly agree

3.3. Criterion validity of the short-form

Regarding vaccine recommendation scores (Table 4), the short-form items for vaccine confidence, proactive efficacy, and openness to patients showed the same validity (or absence of validity) as the long-form items in their associations with very frequent vaccine recommendation (>75%). Vaccine confidence and proactive efficacy were associated with higher vaccine recommendations in separate and global models, while openness to patients was not associated with this outcome. The criterion validity of the short-form differed from the long form in terms of trust in authorities in the global model, which remained positively associated with higher vaccine recommendations in the short-form; reluctant trust in the separate models, which was not statistically significant in the short-form; and perceived constraints, which was negatively associated in the short-form separate model.

Regarding general immunization activity scores (Table 4), vaccine confidence, proactive efficacy and trust in authorities were found to be associated with a higher immunization activity in the separate models for both the long- and short-form criterion validity. In global models, the criterion validity of the long and short form disagreed in terms of vaccine confidence, which remained significantly associated with very frequent immunization activity in the short-form. Proactive efficacy and trust in authorities remained significantly associated with higher immunization activity in the global model, for both long- and short-form versions. Short-form criterion validity also differed from the long-form's regarding reluctant trust in separate analysis – not associated with immunization activity in the short-form, and of perceived constraints – associated with lower activity in the short-form separate and global models. Openness to patients was not a significant factor associated with frequent immunization activity, in the short- or long-form versions, in separate or global models.

Regarding strong acceptance of future COVID-19 vaccine scores (Table 4), the criterion validity of the long and short form were not aligned only in terms of perceived constraints, which were slightly associated with less acceptance in the long-form separate model, but not in the short-form model. Otherwise, factors of vaccine confidence, proactive efficacy, and trust in authorities were associated with strong acceptance of future COVID-19 vaccines in the short and long-form versions of the Pro-VC-Be in both separate and global models. Reluctant trust was associated with a lower acceptance in the separate models and openness to patients was not a significant factor.

Finally, regarding self-vaccination behavior scores in French GPs (Supplemental Material 2), the long- and short-form criterion validity differed in terms of openness to patients and reluctant trust, both of which were not associated with being up-to-date on vaccinations in the separate short-form models, while trust in authorities remained associated with higher self-vaccination in the global short-form model.

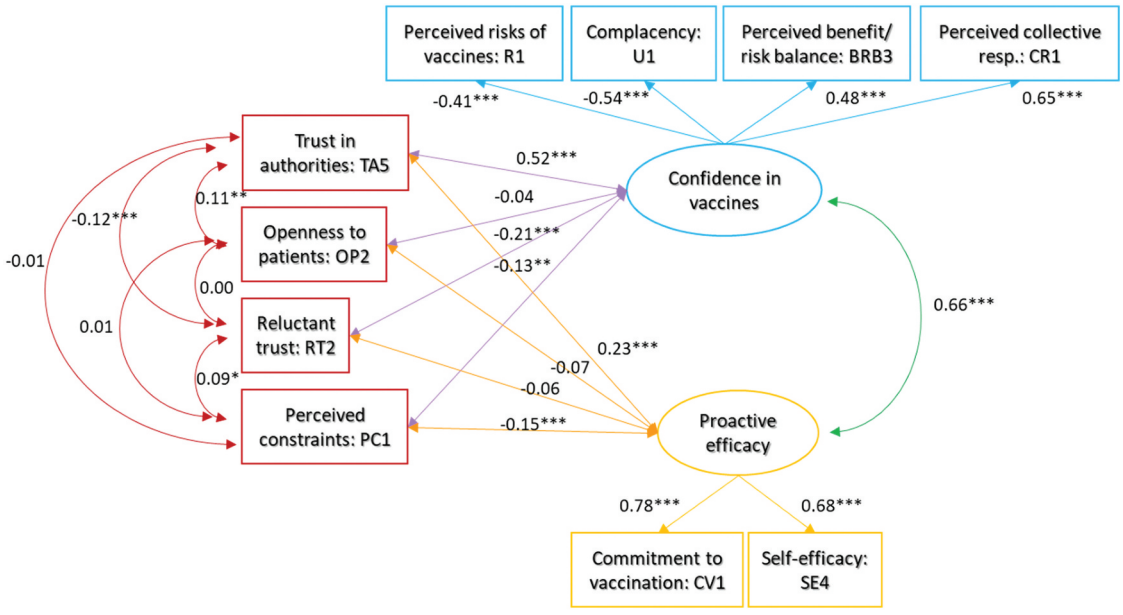

Figure 1. Confirmatory factor analysis [a] on the validation sample using the short-form version of the Pro-VC-Be (N = 2,696) [b].

RMSEA = 0.035 [0.024;0.045]; CFI = 0.956; TLI = 0.918; SRMR = 0.027 [a]Factors were allowed to correlate. All factor loadings were set to be free, and the metrics of the factors were defined by fixing their variances to 1. *p ≤ 0.05 ** p ≤ 0.01 *** p ≤ 0.001. Single-headed arrows illustrate the standardized loadings, i.e. the linear-regression coefficients of items within latent variables; double-headed arrows illustrate Pearson correlation coefficients between items and/or latent variables.
Abbreviations: resp, responsibility; RMSEA, root mean square error of approximation; CFI, comparative fit index; TLI, Tucker-Lewis index; SRMR, standardized root mean square residual.

3.4. Validation of an immunization resources score

An immunization score was developed from the three short-form Pro-VC-Be constructive dimensions (vaccine confidence, proactive efficacy, trust in authorities), which were inter-correlated and most significantly associated with vaccination behaviors and attitudes in analyses. A CFA model run on the 7 items representing these three factors (vaccine confidence – latent variable based on 4 items; proactive efficacy – latent variable based on 2 items; trust in authorities – 1 item handled in the model by correlating it with the other dimensions) proved to have very good fit (Supplemental Material 3). The other 3 items for dimensions of openness to patients, reluctant trust, and perceived constraints were not included in this score, but their potential use is explained later in this paper. The score of immunization resources constructed from these three dimensions ranged from 1 to 4, each 1-point increase in score being equivalent to a 33% increase in supplemental resources in immunization. Its internal consistency was satisfactory, with a Cronbach's alpha of 0.71.

Modified Poisson regression models adjusted for gender, age, and profession indicated that higher immunization resource scores were significantly associated with higher general immunization activity, higher vaccine recommendations, higher acceptance of COVID-19 vaccines, and higher self-vaccination behaviors among French physicians (Table 5), with results remaining similar for both the long- and short-form versions of the Pro-VC-Be. Dose–response effects, i.e. linear trends, were highlighted between the levels of the immunization resource score and the four outcomes ($P < 0.001$), for both the long-form and short-form versions of the Pro-VC-Be.

4. Discussion

Our analyses revealed good construct and criterion validity of a short-form tool comprised 10 items from the original 31-item Pro-VC-Be questionnaire to measure vaccine confidence in HCPs. The long- and short-form tools followed the same hierarchical structure in CFA analyses: a six-dimension structure comprised two latent variables and four observed variables. Comparisons of modified Poisson regression models between the long- and short-form tools showed similar criterion validity, particularly for the three dimensions of vaccine confidence, proactive efficacy, and trust in authorities. An immunization resource score, reflecting the resources that HCPs can utilize for their daily immunization practice, was constructed from these three dimensions and showed excellent criterion validity for vaccine-related behavioral and attitudinal criteria in HCPs.

Short-form items were chosen based on frequency of inclusion in CFA models with good to excellent fit, as well as expert reasoning when needed, with the objective of maintaining the structure of the validated long-form tool and including these same previously identified constructs of vaccine confidence to validate a 10-item short-form tool. For each of the 10 established dimensions in the long-form Pro-VC-Be, the item that was most frequently involved in these models was retained to represent that dimension. Items with similar frequencies were then selected based on their frequency among the top 10 best-fit models. When running the 69,984 CFA models on the test sample, we observed that the models including items with the highest loadings were not retained among the good-to-excellent fit models based on TLI criteria, most likely due to the inter-correlations between items. This observation provided evidence that our methodology of selecting

Table 4. Associations between vaccination behavioral and attitudinal scores and Pro-VC-Be factors among HCPs (n = 2,696) using multiple modified Poisson regressions with robust standard errors.

	Long form		Short form	
Pro-VC-Be factors	Separately[a]	Global[b]	Separately[a]	Global[b]
	aRR [95% CI]			
Self-reported very frequent (>75%) vaccine recommendation score				
Vaccine confidence > mean (ref. No)	**1.5 [1.4;1.7]**	**1.3 [1.1;1.4]**	**1.4 [1.2;1.5]**	**1.2 [1.04;1.3]**
Proactive efficacy > mean (ref. No)	**2.2 [1.9;2.5]**	**2.0 [1.8;2.4]**	**2.4 [2.0;2.8]**	**2.2 [1.9;2.6]**
Trust in authorities > mean (ref. No)	**1.3 [1.2;1.5]**	1.1 [1.0;1.2]	**1.4 [1.2;1.5]**	**1.2 [1.04;1.3]**
Openness to patients > mean (ref. No)	1.1 [1.0;1.2]	1.1 [1.0;1.2]	1.0 [0.9;1.1]	1.0 [0.9;1.2]
Reluctant trust > mean (ref. No)	**0.9 [0.8;0.9]**	1.0 [0.9;1.1]	0.9 [0.8;1.0]	1.0 [0.9;1.1]
Perceived constraints > mean (ref. No)	1.0 [0.9;1.1]	1.0 [0.9;1.1]	**0.8 [0.8;0.9]**	0.9 [0.8;1.0]
Self-reported very frequent (>75%) immunization activity score				
Vaccine confidence > mean (ref. No)	**1.3 [1.2;1.5]**	1.0 [0.9;1.2]	**1.4 [1.2;1.5]**	**1.1 [1.01;1.3]**
Proactive efficacy > mean (ref. No)	**2.5 [2.1;2.9]**	**2.3 [2.0;2.8]**	**3.0 [2.4;3.7]**	**2.7 [2.2;3.4]**
Trust in authorities > mean (ref. No)	**1.4 [1.2;1.5]**	**1.1 [1.01;1.3]**	**1.4 [1.2;1.6]**	**1.2 [1.1;1.3]**
Openness to patients > mean (ref. No)	1.1 [1.0;1.2]	1.1 [1.0;1.2]	1.0 [0.9;1.1]	1.0 [0.9;1.2]
Reluctant trust > mean (ref. No)	**0.8 [0.7;0.9]**	0.9 [0.8;1.0]	1.0 [0.9;1.1]	1.0 [0.9;1.2]
Perceived constraints > mean (ref. No)	0.9 [0.8;1.0]	1.0 [0.9;1.1]	**0.8 [0.7;0.9]**	**0.9 [0.8;0.95]**
Strong acceptance of COVID-19 vaccines score				
Vaccine confidence > mean (ref. No)	**1.8 [1.6;2.1]**	**1.6 [1.4;1.8]**	**1.6 [1.4;1.8]**	**1.4 [1.2;1.5]**
Proactive efficacy > mean (ref. No)	**1.4 [1.2;1.5]**	**1.1 [1.02;1.3]**	**1.4 [1.3;1.6]**	**1.2 [1.1;1.3]**
Trust in authorities > mean (ref. No)	**1.8 [1.6;2.0]**	**1.5 [1.4;1.7]**	**1.9 [1.7;2.0]**	**1.7 [1.5;1.8]**
Openness to patients > mean (ref. No)	0.9 [0.8;1.0]	0.9 [0.9;1.0]	0.9 [0.8;1.0]	0.9 [0.8;1.0]
Reluctant trust > mean (ref. No)	**0.9 [0.8;0.9]**	1.0 [0.9;1.1]	**0.9 [0.8;0.99]**	1.0 [0.9;1.1]
Perceived constraints > mean (ref. No)	**0.9 [0.8;0.97]**	1.0 [0.9;1.1]	1.0 [0.9;1.1]	1.0 [0.9;1.1]

aRR [95% CI] = adjusted relative risk and 95% confidence interval
[a]Pro-VC-Be factors introduced separately as explanatory variables in models, adjusted for gender, age, and profession.
[b]All Pro-VC-Be factors introduced in the same model, adjusted for gender, age, and profession.

Table 5. Associations between the resource score and vaccination outcomes, adjusted on gender, age, and profession (n = 2,696) using multiple modified Poisson regression with robust standard errors.

	All (n = 2,696)						French GPs (n = 1,209)	
	Immunization activity > 75%		Vaccine recommendations > 75%		Strong acceptance of COVID-19 vaccines		Up-to-date with personal vaccinations	
Pro-VC-Be factors	Long-form	Short form	Long-form	Short form	Long-form	Short-form	Long-form	Short form
	aRR [95% CI]							
Resources [1;4] (ref. 1–2: No to low)[a]								
3: Moderate	**2.2 [1.5;3.3]**	**1.9 [1.4;2.7]**	**2.5 [1.7;3.6]**	**2.6 [1.8;3.8]**	**4.1 [2.6;6.3]**	**4.1 [2.7;6.2]**	**2.7 [1.4;5.1]**	**2.4 [1.4;4.0]**
4: Full	**3.5 [2.4;5.1]**	**3.0 [2.1;4.2]**	**4.0 [2.7;5.8]**	**3.8 [2.7;5.4]**	**6.3 [4.0;9.7]**	**6.1 [4.1;9.2]**	**3.2 [1.7;6.0]**	**2.7 [1.6;4.7]**
Test for trend (dose-response effect)[b]	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0004**	**0.0002**

aRR [95% CI] = adjusted relative risk and 95% confidence interval
[a]Scores of 1–2 grouped together to increase sample size of reference group.
[b]Test for a linear trend determining whether increasing levels of the immunization resources score are associated with increasing levels of the outcomes.

items based on frequency in good-to-excellent fit models was more robust than choosing items based on loadings.

The selected higher-frequency items for the short-form tended to be more global, generalized items used to represent each dimension and also often corresponded to similar variables that have been used in previous studies to measure vaccine hesitancy in HCPs [9,18,33,34]. The item 'BRB3. *The benefits of the vaccine against hepatitis B in infants (or as catch-up in adolescents) are much greater than its potential risks*' was actually the only one focusing on a specific vaccine situation. This could have been due to the controversial nature of the hepatitis B vaccine, particularly in francophone countries [9,35–37], which led to HCPs' having varied opinions on the benefits and risks of this vaccine. In order to have a more global short-form tool applicable to several countries and contexts, experts involved in this study recommend using a more general item for the dimension of benefit/risk balance. Two items for perceived constraints were found to have the same frequency in the top 10 best-fit models; however, based on the heterogeneity of vaccine costs among European countries and previous literature showing that HCP's view cost to be a significant barrier to vaccination [15,38], item 'PC1. *The cost of some vaccines is a problem for some patients and can keep me from prescribing them*' was retained in the short-form tool.

The immunization resource score was constructed from the seven short-form items pertaining to the three dimensions that may lever HCP vaccination behaviors in daily practice, and which were also moderately correlated between each other (confidence in vaccines, proactive efficacy, and trust in authorities, Supplemental Material 3). These dimensions were most consistently associated with behavioral and attitudinal outcomes in both the long- and short-form versions. These results highlight the importance of HCPs' confidence in vaccines, their trust in authorities, and their commitment to promoting vaccination as fundamental factors for improving

vaccination practices of patients. These dimensions can be interpreted as necessary psychosocial resources for HCPs in the promotion of vaccination for their patients and themselves. In particular, self-efficacy and commitment (the two observed variables of proactive efficacy) have been theorized and shown to be important drivers in the promotion of prevention behaviors by HCPs to patients [39].

The three dimensions not included in the immunization resource score (openness to patients, perceived constraints and reluctant trust) could provide supplemental information to researchers examining specific aspects of psychosocial determinants of vaccination behaviors and could be added into the short-form tool where necessary. The dimension 'Openness to patients,' for example, would be beneficial to evaluate the efficacy of counseling approaches where empathy and non-judgment patient listening are important behavioral principles [19]. Contrary to the Pro-VC-Be long form, the dimension 'Perceived constraints' in the short form was negatively associated with HCPs recommendation behavior and immunization activity. The item selected in the short form corresponds to financial constraints, which have been shown to persist in western countries regarding vaccination [40]. Other constraints may exist – such as the unavailability of certain vaccines – and can be country, culture, or time dependent, and therefore not applicable in all contexts. Finally, the dimension of 'Reluctant trust' emphasizes the fact that HCPs may have uncertainties about certain vaccines and vaccination strategies, which cannot be filled by a complete knowledge of scientific data, due to lack of time, and therefore requires trusting a third party (authorities, experts …) to accomplish its vaccination work. This concept merits further research to understand its modifying role in vaccination attitudes and behaviors among HCPs in several contexts [18].

Some limitations of this paper include the use of attitudes toward future COVID-19 vaccines for criterion validation, rather than a further criterion related to vaccination behavior. However, as the original survey panel participated in the study prior to the roll-out of COVID-19 vaccines, this was not possible at the onset of the study period. The nature of the COVID-19 pandemic across different countries, including differing infection rates, vaccination strategies, public health restrictions, and perceived risks of the virus, may have certainly impacted the behaviors and attitudes of HCPs regarding vaccination. We were unable to take these factors into account in this study due to temporal restraints; since COVID-19 vaccination was not available until mid-December 2020, after the study period. However, the purpose of validating this short-form tool was to provide an easy and timely tool to be used by researchers in several health contexts; therefore, it was not necessary within our analyses to take into account the sanitary situation at the time.

We were still able to show that the importance of the Pro-VC-Be short form dimensions was not the same depending on whether the analyses focused on behaviors or attitudes. Proactive efficacy predominated in behaviors toward vaccines in routine use, whereas trust in authorities was a more important factor regarding attitudes toward COVID-19 vaccines not yet in use at the time of survey. The recommended, general item for the dimension of benefit/risk balance ('The benefits of vaccines are much greater than their potential risks') was selected *post-priori* based on expert reasoning, in order to provide a short-form item encompassing general vaccination scenarios. Due to this, we were not able to validate this item within analyses; however, other studies can use this recommended short-form version and test this item's association with vaccination behaviors and attitudes. While the short-form tool and psychosocial immunization resource score were validated based on data from several countries and healthcare professions, they were developed and validated in high-income, French-speaking countries. Therefore, their use in other cultural contexts has not yet been validated; however, current studies are underway to validate this tool in additional European countries among several additional types of HCPs.

A strength of this paper is that it provides a detailed and transparent methodology of the construction and validation of a short-form tool to measure psychosocial determinants of vaccine behaviors in HCPs, as well as a comparison of criterion validity with the preexisting long-form version. Previous scales measuring attitudes toward vaccination have been developed in the general population [10] and among parents [11], in both long- and short-form versions. Betsch et al. present the validation of the long- and short-form 5C scale, used to measure determinants of vaccine hesitancy in the general public, within the same article and compare their construct validities through correlation analyses with vaccination behavior measures, similar to our analyses [10]. However, the exact methods used to choose items for the short-form version are not made explicit in their article [10]. Similarly, Opel et al. do not specify how items were selected and validated for their short-form Parent Attitudes about Child Vaccinations (PACV) scale [11]. Their short-form scale was validated in a further study [41] through correlation analyses with vaccine acceptance and child immunization status; however, the long- and short-form results were not compared. Our paper presents the first short-form tool, to our knowledge, that is validated among HCPs and can be used to measure psychosocial resources available to HCPs and represent their vaccine confidence and preparedness to promote vaccination of their patients. Additionally, this short-form tool was validated for two different professions (nurses and doctors) in three separate countries, thus providing a tool for several professional and cultural contexts.

The short-form version of the Pro-VC-Be provides a more cost-effective and time-effective method for collecting vaccine-related information from HCPs, a population that is often costly to solicit and has strict time-constraints due to the nature of their work. This short-form tool will also be useful to measure the efficacy of various kinds of interventions to make HCPs more comfortable, confident, and proactive in vaccinating patients and themselves. Such interventions could consist in improving HCPs' level of scientific knowledge on vaccines, training them in using various approaches to address false information and myths about vaccination and motivate their hesitant patients [42].

5. Conclusions

In conclusion, our analyses provide construct and criterion validation for a ten-item tool, the Pro-VC-Be short form, to

measure psychosocial determinants of HCP vaccine behaviors for themselves and their patients. This short instrument will facilitate its integration into questionnaires documenting HCPs' vaccination behavior determinants. From this tool, we selected 7 items that allowed us to develop and validate an immunization resource score, measuring HCP confidence in vaccination and commitment to promote vaccination among their patients. Measuring the impact of this score on the behaviors and attitudes of HCPs related to vaccination is of great public health concern: HCPs role in vaccination remains essential as a trusted source of information and advice for their patients and as role models. Improving resources available to HCPs can thus improve resources available to the general public and promote vaccination of the public against vaccine-preventable diseases. Intervention research to improve HCP vaccine confidence and psychosocial resources to promote vaccination remains a priority.

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Declaration of interest

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

Ethical considerations

The ethics boards of the University-Hospital-Centre Saint-Pierre (Belgium, CE/20-10-14), the University of Aix-Marseille (France, 2020-12-03-010), and the University-Hospital Centre of Québec–Laval University (Québec, #2021-5286) approved the original study protocol and questionnaire.

The survey was conducted exclusively via the Internet in Quebec and Belgium, and via the Internet or telephone in France, therefore ethics committees approved that the completion of a questionnaire constituted participant consent by the health professionals and that written consent was not required.

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Author contributions

PV, ED, and AG were involved in the conception and design of the original, long-form Pro-VC-Be. PV and ED were involved in the organization and implementation of data collection. LF, PV, and AmG were involved in the statistical analysis, interpretation of the data, and drafting of the paper. AG, ED, AF, LK, SL, AS, and PS were involved in the interpretation of the data and revising the paper critically for intellectual content; they approved it for publication. All authors agree to be accountable for all aspects of the work.

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