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Association between vaccination beliefs and COVID-19 vaccine uptake in a longitudinal panel survey of adults in the United States, 2021–2022

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ABSTRACT

COVID-19 vaccine hesitancy has been a major limiting factor to the widespread uptake of COVID-19 vaccination in the United States. A range of interventions, including mass media campaigns, have been implemented to encourage COVID-19 vaccine confidence and uptake. Such interventions are often guided by theories of behavior change, which posit that behavioral factors, including beliefs, influence behaviors such as vaccination. Although previous studies have examined relationships between vaccination beliefs and COVID-19 vaccination behavior, they come with limitations, such as the use of cross-sectional study designs and, for longitudinal studies, few survey waves. To account for these limitations, we examined associations between vaccination beliefs and COVID-19 vaccine uptake using data from six waves of a nationally representative, longitudinal survey of U.S. adults ($N = 3{,}524$) administered over a nearly 2-year period (January 2021–November 2022). Survey-weighted lagged logistic regression models were used to examine the association between lagged reports of vaccination belief change and COVID-19 vaccine uptake, using five belief scales: (1) importance of COVID–19 vaccines, (2) perceived benefits of COVID-19 vaccination, (3) COVID-19 vaccine concerns and risks, (4) normative beliefs about COVID-19 vaccination, and (5) perceptions of general vaccine safety and effectiveness. Analyses controlled for confounding factors and accounted for within-respondent dependence due to repeated measures. In individual models, all vaccination belief scales were significantly associated with increased COVID-19 vaccine uptake. In a combined model, all belief scales except the benefits of COVID-19 vaccination were significant predictors of vaccine uptake. Overall, belief scales indicating the importance of COVID-19 vaccines and normative beliefs about COVID-19 vaccination were the strongest predictors of COVID-19 vaccine uptake. Findings demonstrate that changes in vaccination beliefs influence subsequent COVID-19 vaccine uptake, with implications for the development of future interventions to increase COVID-19 vaccination.

Introduction

The COVID-19 pandemic has impacted many facets of society: the environment, the economy, education, health, and human psychology [1]. As of May 11, 2023, there were more than 104 million COVID-19 cases and over 1.1 million COVID-19 deaths in the United States (U.S.; Centers for Disease Control and Prevention [CDC], [2]). COVID-19 vaccines are highly effective at preventing SARS-CoV-2 (the virus that causes COVID-19) infections, COVID-19-related hospitalizations, admissions to the intensive care unit, and death [3]. From mid-December 2020 to the end of March 2022, COVID-19 vaccines averted more than 66 million COVID-19 cases and 17 million COVID-19-related hospitalizations, saving more than 2 million lives and almost $900 billion in health care costs in the U.S. [4]. Furthermore, COVID-19 vaccines have been demonstrated to be effective in preventing severe COVID-19, including variants of the COVID-19 virus, such as the Alpha, Beta, Gamma, and Delta variants [5].

Despite the benefits and availability of COVID-19 vaccines, which were free for children and adults in the U.S. until the end of the COVID-19 public health emergency on May 11, 2023, vaccination rates in the U.S. lag behind those of other high-income countries [6]. As of May 11, 2023, 69.5 % of the U.S. population has completed their primary

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vaccination series (Centers for Disease Control and Prevention (CDC), 2023a). The lag in vaccine uptake, despite accessibility and effectiveness, suggests that beliefs about vaccines and vaccine hesitancy may play a role in vaccine behavior [6]. Vaccine hesitancy, which refers to "the delay in the acceptance or refusal to vaccinate despite the availability of vaccine services" [7]), has been well documented in the scientific literature [8] and COVID-19 hesitancy has been shown to be more prevalent among Black, Indigenous, and people of color [9]. COVID-19 vaccine hesitancy in the U.S. is associated with concerns such as vaccine compatibility with current medications, vaccine safety, the speed of testing and approval of the vaccines, and conspiratorial thinking [8,10–12].

To address these concerns, public health mass media campaigns such as the U.S. Department of Health and Human Services (HHS) "We Can Do This" campaign (the Campaign) were implemented (U.S. Department of Health and Human Services, [13]). Best practices indicate that campaigns should be guided by empirically tested theories of behavior change, such as the theory of reasoned action (TRA; [14]), the theory of planned behavior (TPB; [15]), and the health belief model (HBM; [16]). These theories posit that a range of beliefs influence individuals' behavioral intentions and volitional behavior. According to the TRA and TPB, an individual's decision to engage in a behavior is primarily predicted by their intention to engage in that behavior. Intention and behavior, in turn, are influenced by behavioral beliefs (e.g., the benefits and drawbacks of engaging in the behavior) and subjective normative beliefs (e.g., perceptions of whether other people want them to perform a behavior).

Additionally, the HBM suggests that an individual's decision to engage in or abstain from a behavior is dependent on several factors, including their perceptions of the benefits of the behavior and the barriers to behavioral performance [17]. When applied to COVID-19 vaccination, these theories suggest that the decision to get a COVID-19 vaccine may be informed by beliefs such as the benefits of vaccination (e.g., protecting people from getting seriously ill, being hospitalized, or dying), whether important others (e.g., friends and family) have been or will get vaccinated, and concerns about vaccination (e.g., vaccine side effects and safety; [18–20].

COVID-19 vaccination beliefs and vaccine uptake

Although various studies have examined the associations between COVID-19 vaccination beliefs and vaccination intentions/uptake and have reported significant associations, many of these studies have been limited in their ability to accurately measure and/or estimate these relationships. Several studies used cross-sectional study designs that measured individuals' beliefs and vaccination intentions and/or uptake at the same time point [21–24], which limits the ability to establish the temporal ordering of the belief–intention or belief–behavior relationships. Accordingly, it is unclear whether such relationships indicate that vaccination beliefs influenced vaccination intentions/uptake or whether they indicate that vaccination intentions/uptake influenced vaccination beliefs.

Recent longitudinal studies have attempted to address this temporal ordering concern by examining longitudinal changes in COVID-19 vaccination beliefs and COVID-19 vaccination intentions and uptake [25–27]. Although the use of longitudinal data reduces the temporal ordering concerns noted above by assessing beliefs in one wave and intentions/uptake in a subsequent wave, some of these studies have been limited in other ways. These limitations include failure to use theoretical frameworks to guide the selection of factors or beliefs that were associated with changes in COVID-19 vaccination behaviors [25], the use of a single item to measure each belief in a set of vaccination beliefs [26], and the use of only two waves of data to measure changes in vaccination beliefs and behavior [25–27]. Given the dynamic nature of the change in individuals' beliefs and vaccination behavior over time and the evolving science relevant to COVID-19 vaccination, additional time points (i.e., multiple waves of data) may be needed to strengthen the observed relationship and provide evidence of belief–behavior association over a longer period.

To enhance our understanding of the true relationships between changes in vaccination beliefs and COVID-19 vaccination, and to guide future interventions, additional research that assesses the associations between vaccination beliefs and COVID-19 vaccine uptake and addresses the limitations of existing research is warranted. In service of these goals, this study examined the association between changes in vaccination beliefs and COVID-19 vaccine uptake in U.S. adults using six waves of nationally representative longitudinal survey data, tracking belief and behavior change from 2021 to 2022.

Methods

Data

The data used for this study were obtained from the first six waves of the COVID-19 Attitudes and Beliefs Survey (CABS; HHS, [28]). The CABS is a nationally representative, longitudinal survey of U.S. adults administered every 4 months; Waves 1–6 were fielded between January 2021 and November 2022. The survey assesses topics related to adherence to COVID-19 preventive behaviors, including vaccine uptake; beliefs about COVID-19, vaccination, and COVID-19 vaccination; and sociodemographic characteristics. CABS respondents were recruited from the NORC at the University of Chicago's AmeriSpeak research panel [29]. More details about survey recruitment, sampling, weighting, and survey wave fielding dates and sample sizes are provided in the Supplement to this article and in previously published research [30]. Written informed consent was obtained from respondents electronically, and institutional review board (IRB) approval for this study was obtained from the Biomedical Research Alliance of New York (BRANY), an external IRB service accredited by the Association for the Accreditation of Human Research Protection Programs.

Measures

Dependent Variable

The dependent variable, COVID-19 vaccine uptake, was defined as the self-reported receipt of at least one dose of a COVID-19 vaccine. This variable was coded as a dichotomous variable (1 = receipt of at least one dose of a COVID-19 vaccine, 0 = not vaccinated against COVID-19) and assessed at each survey wave.

Independent Variables

The independent variables were a set of five belief scales reflecting categories of vaccination beliefs. The belief scales included a three-item "importance of COVID-19 vaccines" scale, a five-item "perceived benefits of COVID-19 vaccination" scale, a five-item "COVID-19 vaccine concerns and risks" scale, a three-item "normative beliefs about COVID-19 vaccination" scale, and a six-item "perceptions of general vaccine safety and effectiveness" scale. Hereafter, the belief scale names have been abridged to Importance, Benefits, Concerns, Norms, and General Effectiveness, respectively. The 22 belief items that comprise these five scales were assessed at each survey wave. Respondents reported the extent of their agreement or disagreement with each item on a five-point Likert scale (1 = Strongly disagree, 5 = Strongly agree). We used factor analysis to determine which belief items had sufficiently high factor loadings to warrant inclusion in each belief scale, and computed Cronbach's alpha for each belief scale to assess scale reliability. Further details regarding the individual belief items and the psychometric results are documented in the Supplement.

Covariates

Several covariates were included in the analysis to adjust for sociodemographic, geographic, and temporal variables that could confound

observed relationships between vaccination beliefs and COVID-19 vaccine uptake. The sociodemographic and geographic factors controlled for in this analysis were respondent age, sex, race/ethnicity, education, annual household income, political ideology, U.S. Census Region of residence, rurality, essential worker status, and pre-existing health condition status. These covariates adjust for pre-existing differences in access to and eligibility for the COVID-19 vaccine that could affect uptake; accordingly, the values for each covariate reflect those obtained in the Wave 1 survey. In addition, dummy codes corresponding with each survey wave were included in the analysis to control for the effects of exogenous events (e.g., the Delta variant surge) that could confound belief–vaccine uptake relationships. Details about how the covariates were measured and prepared for analysis are provided in the Supplement.

Statistical analysis

Data Preparation

The data were formatted in long form, with respondent–wave observations (rows) for each survey wave in which a respondent remained in the panel. As we aimed to assess belief–vaccination associations relevant to changes in vaccination status, observations for any respondent after the first wave in which they reported having been vaccinated were omitted. In addition, each of the five belief scales were lagged by one wave for the analysis, such that each respondent–wave observation included vaccine uptake reported in a given wave and the belief scales reflecting beliefs reported during the preceding wave (e.g., COVID-19 vaccine uptake at Wave 2 and vaccination belief scales at Wave 1). Belief scales were lagged to maintain the temporal ordering of predictor and outcome variables (i.e., Wave 1 vaccination belief scales predicting Wave 2 vaccine uptake). In so doing, we removed Wave 1 respondent–wave observations for vaccine uptake from the data set, as we did not assess vaccination beliefs prior to Wave 1 (and therefore did not have belief observations with which to predict Wave 1 vaccine uptake), while retaining covariates reported at Wave 1. Respondent–wave observations were also removed if they had missing values for any of the analysis data. The analysis included 3,524 respondents who completed at least the first two survey waves and 6,452 respondent–wave observations across Waves 2–6.

Regression Models

To assess the bivariate relationships between vaccination belief scales and COVID-19 vaccine uptake, we first estimated a series of survey-weighted lagged logistic regression models (individual models) in which each of the five lagged vaccination belief scales were separately used to predict COVID-19 vaccine uptake, controlling for the covariates described above and survey wave dummy codes. Next, to assess the differential relationships between each of the five vaccination belief scales and COVID-19 vaccine uptake, we estimated a combined survey-weighted lagged logistic regression model (combined model) in which all five lagged vaccination belief scales were used to predict COVID-19 vaccine uptake, controlling for all covariates and survey wave dummy codes. The standard errors for all model coefficients were cluster-adjusted by respondent for within-respondent dependence due to repeated measures. Standardized coefficients were fit first by unit-standardizing all belief scales (i.e., to have a mean of 0 and standard deviation of 1) and then by refitting the data with the standardized belief scales. All analyses were conducted using R statistical software (R Core Team, 2022) with the *sandwich* [31,32] and *parameters* [33]packages.

Results

Descriptive Statistics

The weighted descriptive statistics for the study sample are reported in Table 1.

In the sample, 51.2 % of respondents were female and 48.8 % were male. The majority of respondents (54.8 %) were age 45 or older. Most respondents self-identified as non-Hispanic White (63.9 %), with smaller respondent proportions identifying as Hispanic or Latino (16.2 %), non-Hispanic Black (11.8 %), and non-Hispanic, Another Race (8.2 %). Nearly half (46.1 %) of respondents reported an annual household income below $50,000, and more than one-third of the sample (34.6 %) reported having completed at least one college degree. Many respondents reported residing in suburban areas (43.8 %); fewer respondents indicated that they lived in urban (38.6 %) or rural (17.6 %) areas. Over one-third of respondents reported living in the South (37.4 %), whereas 23.7 % reported living in the West, 21.2 % in the Midwest, and 17.8 % in the Northeast. Respondents differed by political ideology, with proportionally similar groups of politically moderate (38.0 %), conservative (34.4 %), and liberal (27.6 %) respondents. Finally, nearly

Table 1
Descriptive Statistics of the Study Sample ($N = 3,524$).

Sociodemographic Variable	Subgroups	Sample Size	Unweighted %	Weighted %
Sex	Male	1,717	48.7	48.8
	Female	1,807	51.3	51.2
Age (Years)	18–24	192	5.4	10.2
	25–44	1,523	43.2	35.0
	45–64	1,093	31.0	33.8
	≥65	716	20.3	21.0
Race/Ethnicity	Non-Hispanic White	2,197	62.3	63.9
	Non-Hispanic Black	371	10.5	11.8
	Hispanic/ Latino	707	20.1	16.2
	Non-Hispanic, Another Race[a]	249	7.1	8.2
Household Income	Less than $50,000	1,595	45.3	46.1
	$50,000–$74,999	733	20.8	19.9
	$75,000–$99,999	474	13.5	13.4
	≥$100,000	722	20.5	20.6
Education	High School or Less	740	21.0	37.1
	Some College	1,589	45.1	28.3
	Bachelor's Degree or Greater	1,195	33.9	34.6
Rurality	Urban	1,494	42.4	38.6
	Suburban	1,457	41.3	43.8
	Rural	573	16.3	17.6
U.S. Census Region	Northeast	499	14.2	17.8
	Midwest	891	25.3	21.2
	South	1,197	34.0	37.4
	West	937	26.6	23.7
Political Ideology	Liberal	1,051	29.8	27.6
	Moderate	1,287	36.5	38.0
	Conservative	1,186	33.7	34.4
Pre-Existing Health Condition	Pre-Existing Health Condition	2,256	64.0	63.8
	No Pre-Existing Health Condition	1,268	36.0	36.3
Essential Worker Status	Essential Worker	1,149	32.6	30.3
	Non-Essential Worker	2,375	67.4	69.7

Note: Percentages may not sum up to 100% due to rounding.

[a] Non-Hispanic, Another Race includes the following categories: "American Indian or Alaska Native," "Asian Indian Only," "Chinese Only," "Filipino Only," "Japanese Only," "Korean Only," "Vietnamese Only," "Other Asian," "Native Hawaiian Only," "Samoan Only," "Other Pacific Islander," "Some other race," and "Multirace".

two-thirds of respondents (63.8 %) reported having a pre-existing health condition, and just over two-thirds of respondents (69.7 %) were not essential workers.

Regression Model results

Individual Regression Models

The results from individual logistic regression models assessing the bivariate relationships between lagged vaccination belief scales and COVID-19 uptake (Models 1–5) are reported in Table 2.

Results demonstrate that lagged scores for all five vaccination belief scales were significantly associated with COVID-19 vaccine uptake in each given wave (Table 2). The Importance, Benefits, Norms, and General Effectiveness belief scales were positively associated with vaccine uptake, such that increases in these belief scales were associated with increases in COVID-19 vaccine uptake (Importance: $B = 1.098$, $p < 0.001$, SE = 0.056; Benefits: $B = 1.137$, $p < 0.001$, SE = 0.062; Norms: $B = 1.297$, $p < 0.001$, SE = 0.067; General Effectiveness: $B = 1.560$, $p < 0.001$, SE = 0.089). Conversely, the Concerns belief scale was negatively associated with vaccine uptake, indicating that increased concerns were associated with decreases in COVID-19 vaccine uptake ($B = –1.162$, $p < 0.001$, SE = 0.069).

With few exceptions, when the vaccination belief scales were held at their means, the following covariates were significantly associated with COVID-19 vaccine uptake across all models: sex, race/ethnicity, income, education, rurality, U.S. Census Region, political ideology, and pre-existing health condition. Specifically, vaccine uptake was positively associated with being non-Hispanic Black or Hispanic/Latino, having an income of at least $50,000 (for all income groups compared to the reference group), having at least a bachelor's degree, and having a pre-existing health condition. Vaccine uptake was negatively associated with being female; living in a rural locale; living in the Midwest, South, or West regions; and being politically conservative. See Table 2 for the reference groups for each comparison and for exceptions to the associations described here.

Combined Regression Model

The results from a combined logistic regression model in which all five lagged vaccination belief scales were used to predict COVID-19 vaccine uptake (Model 6) are provided in Table 3.

Results from Table 3 show that lagged scores for four of the five vaccination belief scales were significantly associated with COVID-19 vaccine uptake in a given wave, and that the direction of these effects mirrored those demonstrated by the individual regression models (Models 1–5). Specifically, the Importance, Norms, and General Effectiveness belief scales were positively associated with vaccine uptake, such that increases in these belief scales were associated with increases in COVID-19 vaccine uptake (Importance: $B = 0.462$, $p < 0.001$, SE = 0.085; Norms: $B = 0.467$, $p < 0.001$, SE = 0.106; General Effectiveness: $B = 0.305$, $p < 0.05$, SE = 0.133). Conversely, the Concerns belief scale was negatively associated with vaccine uptake, indicating that increased concerns were associated with decreases in COVID-19 vaccine uptake ($B = –0.302$, $p < 0.01$, SE = 0.100). The Benefits belief scale was not significantly associated with vaccine uptake (Benefits: $B = 0.171$, $p > 0.05$, SE = 0.095).

To assess the relative predictive strength of each vaccination belief scale, we examined the standardized regression coefficients from Model 6 (Table 3). A comparison of these standardized coefficients indicates that the Importance and Norms beliefs scales were the strongest predictors of COVID-19 vaccine uptake. Specifically, a one–standard deviation (SD) increase in the Importance beliefs scale resulted in an 84.2 % increase (i.e., $e^{.611}$) in the odds of reporting vaccination in a given survey wave. Similarly, a one-SD increase in the Norms beliefs scale corresponded with a 63.9 % increase in the odds of reporting vaccination. The Concerns belief scale was a moderately strong predictor of vaccine uptake, with a one-SD increase in this belief scale resulting in a 35.4 % decrease in the odds of reporting vaccination. Lastly, the General Effectiveness belief scale was the weakest predictor of vaccine uptake, with a one-SD increase in this scale corresponding with a 28.9 % increase in the odds of reporting vaccination in each survey wave.

The results reported in Table 3 also indicate that when the vaccination belief scales were held at their means, the following covariates were significantly associated with COVID-19 vaccine uptake: race/ethnicity, income, education, rurality, U.S. Census Region, political ideology, and pre-existing health condition. Indeed, the significance and direction of these associations largely mirrored the findings from Models 1–5 as reported in Table 2. As shown in Table 3, the odds of reporting vaccination in a given survey wave was higher for respondents who were non-Hispanic Black or Hispanic/Latino, had an income of at least $50,000 (for all income groups compared to the reference group), had a bachelor's degree or more education, or had a pre-existing health condition. The odds of reporting vaccination in a given survey wave was lower for respondents living in a rural locale; living in the Midwest, South, or West regions; and who reported being politically conservative. See Table 3 for the reference groups for each comparison.

Sensitivity analyses and robustness checks

Given the non-significant results for the Benefits belief scale in Model 6, we estimated an alternative combined regression model (Model 7) in which the Benefits belief scale was omitted, and the four other belief scales were included as predictors of COVID-19 vaccine uptake. We then compared the fit of these two models using two model selection metrics—Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC)—to ascertain whether one model was a better fit to the data compared to the other model. More details about AIC and BIC are provided in the Supplement.

The results for Model 7 were substantively similar to the results for Model 6 in that all four belief scales included in the model (Importance, Concerns, Norms, and General Effectiveness) were significant predictors of vaccine uptake, with similar estimates to those produced by Model 6 (see Table S6 in the Supplement). The AIC results suggested that Model 6, which included the Benefits belief scale, was a better fit than Model 7, which excluded the Benefits belief scale. Conversely, the BIC results suggested that Model 7 was a better fit than Model 6 (see Table S7 in the Supplement). The indeterminate results from these fit metrics did not clearly indicate that either model was a better fit to the data. One potential reason for the lack of significance for the Benefits belief scale is that overlap in the belief scales could have increased their standard errors due to variance inflation. We evaluated the generalized variance inflation factors for the belief scales in Models 6 and 7 and determined that none of the scales showed excessive multicollinearity for either model (see Tables S8 and S9 in the Supplement). Taken together with the results from Models 1–5, which demonstrate significant bivariate associations between belief scales and vaccine uptake for all belief scales (including the Benefits belief scale), the evidence suggested that the full combined Model 6 was the preferred model despite the non-significant coefficient for the Benefits belief scale.

Discussion

In this longitudinal study, we examined the association between changes in vaccination beliefs and COVID-19 vaccine uptake using six waves of data assessed from 2021 to 2022 in a nationally representative sample of U.S. adults. Findings from individual models show that belief scales relevant to the importance of COVID-19 vaccines, perceived benefits of COVID-19 vaccination, COVID-19 vaccine concerns and risks, normative beliefs about COVID-19 vaccination, and perceptions of general vaccine safety and effectiveness each predicted increased vaccine uptake. Furthermore, findings from a combined model show that all belief scales (except for the perceived benefits of COVID-19 vaccination scale) were significant predictors of vaccine uptake. These findings

Table 2
Results from Individual Survey-Weighted Lagged Logistic Regression Models in which Vaccination Belief Scales Predicted COVID-19 Vaccine Uptake.

	Model 1: Importance *B* (SE)	Model 2: Benefits *B* (SE)	Model 3: Concerns *B* (SE)	Model 4: Norms *B* (SE)	Model 5: General Effectiveness *B* (SE)
Vaccination Belief Scale	**1.098*** **	**1.137*** **	**−1.162*** **	**1.297*** **	**1.560*** **
	(0.056)	**(0.062)**	**(0.069)**	**(0.067)**	**(0.089)**
Sex (*Ref.* = Male)					
Female	**−0.248***	**−0.288****	−0.190	**−0.313****	**−0.370*** **
	(0.107)	**(0.102)**	(0.101)	**(0.104)**	**(0.103)**
Age (*Ref.* = 18–24 years)					
25–44 years	−0.332	−0.290	−0.319	−0.365	−0.204
	(0.212)	(0.201)	(0.195)	(0.198)	(0.198)
45–64 years	−0.328	−0.171	−0.267	−0.330	0.007
	(0.216)	(0.205)	(0.199)	(0.201)	(0.202)
65 + years	0.420	0.542*	0.385	0.454	0.704**
	(0.250)	(0.231)	(0.223)	(0.232)	(0.225)
Race/Ethnicity (*Ref.* = Non-Hispanic White)					
Non-Hispanic Black	**0.492****	**0.388***	**0.519*** **	**0.529*** **	**0.587*** **
	(0.177)	**(0.165)**	**(0.153)**	**(0.159)**	**(0.162)**
Hispanic/Latino	**0.278***	**0.279***	**0.667*** **	**0.420****	**0.576*** **
	(0.140)	**(0.134)**	**(0.143)**	**(0.140)**	**(0.138)**
Non-Hispanic, Another Race[a]	0.362	0.330	**0.626****	0.403	**0.514***
	(0.220)	(0.216)	**(0.205)**	(0.217)	**(0.233)**
Income (*Ref.* = Less than $50,000)					
$50,000–$74,999	**0.428****	**0.366****	0.251	**0.329***	**0.292***
	(0.151)	**(0.140)**	(0.136)	**(0.141)**	**(0.143)**
$75,000–$99,999	**0.529*** **	**0.370***	**0.310***	**0.434****	0.239
	(0.155)	**(0.146)**	**(0.141)**	**(0.146)**	(0.146)
$100,000 or Greater	**1.028*** **	**0.884*** **	**0.828*** **	**0.980*** **	**0.823*** **
	(0.156)	**(0.150)**	**(0.154)**	**(0.148)**	**(0.161)**
Education (*Ref.* = High School or Less)					
Some College	0.167	0.184	0.132	0.137	0.096
	(0.118)	(0.111)	(0.111)	(0.113)	(0.116)
Bachelor's Degree or Greater	**0.441****	**0.407****	**0.356****	**0.425****	**0.415****
	(0.139)	**(0.138)**	**(0.133)**	**(0.134)**	**(0.140)**
Rurality (*Ref.* = Urban)					
Suburban	−0.023	−0.015	−0.053	−0.015	−0.027
	(0.116)	(0.110)	(0.114)	(0.112)	(0.113)
Rural	**−0.339***	**−0.345***	**−0.446****	**−0.372***	**−0.399***
	(0.157)	**(0.150)**	**(0.151)**	**(0.152)**	**(0.156)**
U.S. Census Region (*Ref.* = Northeast)					
Midwest	**−0.639*** **	**−0.583*** **	**−0.626*** **	**−0.569*** **	**−0.630*** **
	(0.189)	**(0.174)**	**(0.171)**	**(0.172)**	**(0.169)**
South	**−0.729*** **	**−0.641*** **	**−0.699*** **	**−0.684*** **	**−0.698*** **
	(0.173)	**(0.159)**	**(0.161)**	**(0.157)**	**(0.154)**
West	**−0.464***	**−0.371***	**−0.529****	**−0.450****	**−0.484****
	(0.180)	**(0.165)**	**(0.173)**	**(0.167)**	**(0.166)**
Political Ideology (*Ref.* = Liberal)					
Moderate	−0.184(0.143)	**−0.392****	**−0.356***	**−0.333***	**−0.283***
		(0.131)	**(0.140)**	**(0.139)**	**(0.138)**
Conservative	**−0.578*** **	**−0.868*** **	**−0.821*** **	**−0.770*** **	**−0.704*** **
	(0.152)	**(0.143)**	**(0.145)**	**(0.146)**	**(0.143)**
Pre-Existing Health Condition (*Ref.* = No Pre-Existing Health Condition)					
Pre-Existing Health Condition	**0.272***	**0.354*** **	**0.429*** **	**0.296****	**0.293****
	(0.111)	**(0.106)**	**(0.106)**	**(0.107)**	**(0.107)**
Essential Worker Status (*Ref.* = Not an Essential Worker)					

(*continued on next page*)

Table 2 (*continued*)

	Model 1: Importance *B* (SE)	Model 2: Benefits *B* (SE)	Model 3: Concerns *B* (SE)	Model 4: Norms *B* (SE)	Model 5: General Effectiveness *B* (SE)
Essential Worker	−0.112	−0.169	−0.088	−0.138	−0.140
	(0.118)	(0.113)	(0.111)	(0.111)	(0.112)
CABS Wave 3	0.258	0.199	0.142	0.176	0.234
	(0.139)	(0.135)	(0.132)	(0.133)	(0.132)
CABS Wave 4	**−0.603****	**−0.780*****	**−0.926*****	**−0.908*****	**−0.870*****
	(0.195)	**(0.184)**	**(0.188)**	**(0.194)**	**(0.193)**
CABS Wave 5	**−1.860*****	**−1.938*****	**−2.344*****	**−2.233*****	**−2.197*****
	(0.350)	**(0.334)**	**(0.335)**	**(0.349)**	**(0.339)**
CABS Wave 6	**−1.853*****	**−1.952*****	**−2.400*****	**−2.394*****	**−2.246*****
	(0.379)	**(0.364)**	**(0.367)**	**(0.378)**	**(0.355)**
Intercept	**−3.073*****	**−3.088*****	**4.249*****	**−3.686*****	**−4.620*****
	(0.367)	**(0.366)**	**(0.321)**	**(0.357)**	**(0.411)**

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; two-tailed tests. For each variable, the values of *B* represent the unstandardized coefficient and SE represents the standard error in parenthesis. The number of respondent-wave observations for each model is 6,452. Model 1 is the Importance of COVID-19 Vaccination belief scale, Model 2 is the Perceived Benefits of COVID-19 Vaccination belief scale, Model 3 is the COVID-19 Vaccine Concerns and Perceived Risks, Model 4 is the Normative Beliefs about COVID-19 Vaccination belief scale, and Model 5 is the Perceptions of General Vaccine Safety and Effectiveness belief scale. Variables that are statistically significant in the models are in **bold**.

[a] Non-Hispanic, Another Race includes the following categories: "American Indian or Alaska Native," "Asian Indian Only," "Chinese Only," "Filipino Only," "Japanese Only," "Korean Only," "Vietnamese Only," "Other Asian," "Native Hawaiian Only," "Samoan Only," "Other Pacific Islander," "Some other race," and "Multirace".

corroborate those from previous cross-sectional and longitudinal studies in the U.S. that reported increases in COVID-19 vaccine uptake that were attributed to, or corresponded with, changes in vaccination beliefs [21–24,26,27]. Furthermore, study findings are in keeping with empirically-tested theories of behavior change on which the study was grounded, which suggest that behaviors such as vaccination are influenced by behavioral beliefs (e.g., the benefits and drawbacks of engaging in a behavior) and subjective normative beliefs (e.g., perception of whether other people want an individual to perform a behavior), among other factors [14–16].

Additionally, findings from this study show that normative beliefs about COVID-19 vaccination and beliefs about the importance of COVID-19 vaccines were the strongest predictors of COVID-19 vaccine uptake. Normative beliefs about COVID-19 vaccination have been documented in other research as one of the categories of beliefs that most influence vaccine uptake [34,35]. For example, results from a large-scale randomized experiment embedded in an international survey that included respondents from the U.S. found that accurate information about descriptive norms relevant to COVID-19 vaccination (i.e., what other people do, believe, or say) increased COVID-19 vaccination intentions among vaccine-hesitant individuals [34]. These results suggest that when people are presented with accurate information about the increasing acceptance of COVID-19 vaccines, they are more likely to intend to get vaccinated, and intentions to get vaccinated predict subsequent vaccination [36]. Beliefs relevant to the importance of COVID-19 vaccination have not been explored in detail in existing literature, suggesting that our findings of a strong and significant association between this category of beliefs and vaccine uptake are novel in this context and provide a unique contribution to the existing literature. Moreover, these findings suggest that when people understand the importance of receiving a COVID-19 vaccine and its significance in helping to reduce the spread of COVID-19, they are more likely to get vaccinated.

Conversely, although we did not find a significant association between changes in the benefits of COVID-19 vaccination belief and COVID-19 vaccine uptake in our combined model, findings from the individual model for this belief scale showed a strong and statistically significant association between the benefits of COVID-19 vaccination belief scale and COVID-19 vaccine uptake, even after controlling for a range of covariates. This finding is consistent with previous studies that reported significant associations between perceived benefits of COVID-19 vaccines and vaccination intention and uptake [37,38]. Given that individuals' beliefs in the benefits of COVID-19 vaccination may have led them to also perceive COVID-19 vaccines as important, it is possible that relationships between the beliefs about the importance of COVID-19 vaccines and the benefits of COVID-19 vaccination may influence the significance of their respective relationships with vaccine uptake, resulting in the non-significant effect of the benefits of COVID-19 vaccination belief scale that we observed in the combined model.

Lastly, an important observation from this study is that across all models, when vaccination beliefs were held at their means, COVID-19 vaccine uptake differed by sociodemographic subgroups. Notably, when accounting for vaccination beliefs, results demonstrated that non-Hispanic Black and Hispanic/Latino adults were more likely to report having been vaccinated relative to non-Hispanic White adults. This finding contrasts with other research that highlights racial and ethnic disparities in COVID-19 vaccine uptake [39]), as well as with evidence that shows that non-Hispanic Black and Hispanic participants, and those reporting more than one or another race, had greater COVID-19 vaccine hesitancy and lower COVID-19 vaccine uptake compared to non-Hispanic White participants [40]. Our finding may be explained, in part, by research which found that although a higher proportion of non-Hispanic Black individuals reported COVID-19 vaccine hesitancy at baseline, vaccine hesitancy decreased, and vaccine uptake increased, more rapidly among non-Hispanic Black individuals than among non-Hispanic White individuals [41] [42]. Such initial differences in COVID-19 vaccine hesitancy may be attributed to medical and institutional mistrust in the context of experienced discrimination in health care settings [43,44] and historical antecedents such as the Tuskegee syphilis study [45]. Other evidence indicates that although non-Hispanic Black adults were far less likely than non-Hispanic White adults to be vaccinated in the first months after the vaccine rollout [46], comparable majorities of non-Hispanic Black (89.2 %), Hispanic/Latino (89.1 %), and non-Hispanic White (87 %) adults received at least one dose of a COVID-19 vaccine by March 25, 2023 (Centers for Disease Control and Prevention (CDC), [47]).

Strengths and limitations

This study has several strengths. First, this study is the first to use six waves of longitudinal data to measure changes in vaccination beliefs and COVID-19 vaccination behavior. This robust data set provided multiple time points needed to strengthen the validity of the findings and address the temporal ordering limitation of previous cross-sectional studies. Second, robust statistical methods that used lagged vaccination beliefs to predict vaccine uptake helped to establish the temporal ordering of

Table 3
Results from a Combined Survey-Weighted Lagged Logistic Regression Model in which All Vaccination Belief Scales Predicted COVID-19 Vaccine Uptake.

	B	β	SE	95 % CI
Vaccination Belief Scales				
Importance	**0.462*** **	**0.611**	**0.085**	**0.295, 0.628**
Benefits	0.171	0.194	0.095	−0.015, 0.356
Concerns	**−0.302** **	**−0.303**	**0.100**	**−0.498, −0.106**
Norms	**0.467*** **	**0.494**	**0.106**	**0.260, 0.675**
General Effectiveness	**0.305***	**0.254**	**0.133**	**0.045, 0.566**
Sex (*Ref.* = Male)				
Female	−0.206	−0.206	0.110	−0.421, 0.009
Age (*Ref.* = 18–24 years)				
25–44 years	−0.299	−0.299	0.212	−0.716, 0.117
45–64 years	−0.287	−0.287	0.217	−0.713, 0.139
65 + years	0.387	0.387	0.246	−0.096, 0.869
Race/Ethnicity (*Ref.* = Non-Hispanic White)				
Non-Hispanic Black	**0.570*** **	**0.570**	**0.170**	**0.237, 0.903**
Hispanic/Latino	**0.438** **	**0.438**	**0.147**	**0.149, 0.727**
Non-Hispanic, Another Race[a]	0.438	0.438	0.229	−0.010, 0.887
Income (*Ref.* = Less than $50,000)				
$50,000–$74,999	**0.384***	**0.384**	**0.155**	**0.081, 0.688**
$75,000–$99,999	**0.480** **	**0.480**	**0.156**	**0.175, 0.785**
$100,000 or Greater	**0.977*** **	**0.977**	**0.167**	**0.650, 1.305**
Education (*Ref.* = High School or Less)				
Some College	0.142	0.142	0.121	−0.096, 0.379
Bachelor's Degree or Greater	**0.332***	**0.332**	**0.144**	**0.050, 0.613**
Rurality (*Ref.* = Urban)				
Suburban	0.029	0.029	0.119	−0.205, 0.263
Rural	**−0.347***	**−0.347**	**0.165**	**−0.671, −0.023**
U.S. Census Region (*Ref.* = Northeast)				
Midwest	**−0.665*** **	**−0.665**	**0.190**	**−1.038, −0.292**
South	**−0.737*** **	**−0.737**	**0.174**	**−1.077, −0.397**
West	**−0.479** **	**−0.479**	**0.184**	**−0.839, −0.119**
Political Ideology (*Ref.* = Liberal)				
Moderate	−0.100	−0.100	0.148	−0.391, 0.191
Conservative	**−0.438** **	**−0.438**	**0.159**	**−0.749, −0.127**
Pre-Existing Health Condition (*Ref.* = No Pre-Existing Health Condition)				
Pre-Existing Health Condition	**0.274***	**0.274**	**0.115**	**0.049, 0.499**
Essential Worker Status (*Ref.* = Not an Essential Worker)				
Essential Worker	−0.086	−0.086	0.120	−0.321, 0.150
Wave 3	**0.437** **	**0.437**	**0.140**	**0.162, 0.711**
Wave 4	**−0.461***	**−0.461**	**0.206**	**−0.864, −0.058**
Wave 5	**−1.722*** **	**−1.722**	**0.360**	**−2.427, −1.016**
Wave 6	**−1.708*** **	**−1.708**	**0.380**	**−2.452, −0.963**
Intercept	**−3.388*** **	**0.193**	**0.706**	**−4.773, −2.004**

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; two-tailed tests. For each variable, the unstandardized coefficient (*B),* standardized coefficient (β), standard errors (SE), and 95 % confidence intervals (95 % CI) are reported. The number of respondent-wave observations is 6,452. The Vaccination Belief Scales are comprised of Importance (Importance of COVID-19 Vaccination), Benefits (Perceived Benefits of COVID-19), Concerns (COVID-19 Vaccine Concerns and Perceived Risks), Norms (Normative Beliefs about COVID-19 Vaccination), and General Effectiveness (Perceptions of General Vaccine Safety and Effectiveness). Variables that are statistically significant in the model are in **bold**.

[a] Non-Hispanic, Another Race includes the following categories: "American Indian or Alaska Native," "Asian Indian Only," "Chinese Only," "Filipino Only," "Japanese Only," "Korean Only," "Vietnamese Only," "Other Asian," "Native Hawaiian Only," "Samoan Only," "Other Pacific Islander," "Some other race," and "Multirace".

vaccination beliefs and COVID-19 vaccination. Third, this study was grounded in well-studied and empirically tested behavioral theories. Lastly, the study sample is nationally representative of U.S. adults and analyses employed survey weights, suggesting that study findings can be generalized to the U.S. adult population.

This study is not without limitations. COVID-19 vaccination was self-reported and may have been influenced by social desirability bias. Due to constraints on the length of the CABS questionnaire, we were not able to examine some beliefs or factors that may have also influenced vaccination (e.g., the perceived severity of COVID-19). Given the limited number of respondents who received only one dose of a two-dose COVID-19 vaccine series, we were unable to assess the differential impact of changes in vaccination beliefs on COVID-19 vaccine uptake among those who received a single dose compared to those who completed a two-dose COVID-19 vaccine series. There were no significant differences in wave-to-wave retention rates by vaccination status (vaccinated versus unvaccinated), except for between waves 1 and 2 (see Table S10 in the Supplement for more details). These differences may have biased study results; however, given that at the time of Wave 1 fielding (January—February 2021), COVID-19 vaccines were prioritized for higher risk groups, it is also plausible that the observed difference in retention is attributed to respondent characteristics associated with COVID-19 vaccine access (e.g., older age and/or pre-existing conditions) and not to vaccination beliefs. Additionally, since the study sample was limited to U.S. adults (18 years and older), study findings cannot be generalized to younger populations in the U.S. or to populations in other countries. Lastly, although the results reflect a nearly 2-year period (from January 2021–November 2022), findings may not apply to other periods in time.

Conclusions

Changes in behavioral beliefs have been established as precursors to changes in behaviors such as COVID-19 vaccination. Using six waves of nationally representative longitudinal data collected over a nearly 2-year period, this study found evidence that changes in vaccination beliefs significantly predicted increases in COVID-19 vaccine uptake among U.S. adults. In particular, normative beliefs about COVID-19 vaccination, beliefs about the importance of COVID-19 vaccines, perceptions of general vaccine safety and effectiveness, and COVID-19 vaccine concerns and risks each predicted increased vaccine uptake in U.S. adults. Normative beliefs about COVID-19 vaccination and beliefs about the importance of COVID-19 vaccines were shown to be the strongest predictors of vaccine uptake, suggesting that these categories of beliefs may hold the most promise for moving vaccine hesitant

individuals toward vaccination. Future interventions that aim to combat COVID-19 vaccine hesitancy and promote increased vaccine uptake may consider a focus on changing individuals' vaccination beliefs, with attention to a range of beliefs and consideration of which beliefs may be more promising than others.

CRediT authorship contribution statement

Elissa C. Kranzler: Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Methodology, Investigation, Conceptualization. **Joseph N. Luchman:** Writing – review & editing, Visualization, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Katherine A. Margolis:** Writing – review & editing, Writing – original draft, Supervision, Project administration. **Timothy O. Ihongbe:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Jae-Eun C. Kim:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Benjamin Denison:** Validation, Methodology, Data curation. **Victor Vuong:** Resources, Investigation. **Blake Hoffman:** Visualization. **Heather Dahlen:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Kathleen Yu:** Writing – review & editing, Writing – original draft, Supervision, Project administration. **Daphney Dupervil:** Writing – review & editing, Writing – original draft, Supervision, Project administration. **Leah Hoffman:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvacx.2024.100458.

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