Vaccine 41 (2023) 1390–1397

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

A longitudinal assessment of variability in COVID-19 vaccine hesitancy and psychosocial correlates in a national United States sample

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ARTICLE INFO

Article history:
Received 9 March 2021
Received in revised form 15 October 2022
Accepted 29 December 2022
Available online 2 January 2023

Keywords:
COVID-19
Vaccine hesitancy
Disgust sensitivity
Germ aversion
Longitudinal design
SARS-CoV-2

ABSTRACT

Recent evidence suggests that COVID-19 vaccine hesitancy is not static. In order to develop effective vaccine uptake interventions, we need to understand the extent to which vaccine hesitancy fluctuates and identify factors associated with both between- and within-person differences in vaccine hesitancy. The goals of the current study were to assess the extent to which COVID-19 vaccine hesitancy varied at an individual level across time and to determine whether disgust sensitivity and germ aversion were associated with between- and within-person differences in COVID-19 vaccine hesitancy. A national sample of U.S. adults (N = 1025; 516 woman; M_{age} = 46.34 years, SD_{age} = 16.56, range: 18 to 85 years; 72.6 % White) completed six weekly online surveys (March 20 – May 3, 2020). Between-person mean COVID-19 vaccine hesitancy rates were relatively stable across the six-week period (range: 38–42 %). However, there was considerable within-person variability in COVID-19 vaccine hesitancy. Approximately, 40 % of the sample changed their vaccine hesitancy at least once during the six weeks. There was a significant between-person effect for disgust sensitivity, such that greater disgust sensitivity was associated with a lower likelihood of COVID-19 vaccine hesitance. There was also a significant within-person effect for germ aversion. Participants who experienced greater germ aversion for a given week relative to their own six week average were less likely to be COVID-19 vaccine hesitant that week relative to their own six-week average. This study provides important information on rapidly changing individual variability in COVID-19 vaccine hesitancy on a weekly basis, which should be taken into consideration with any efforts to decrease vaccine hesitancy and increase vaccine uptake. Further, these findings identify-two psychological factors (disgust sensitivity and germ aversion) with malleable components that could be leveraged in developing vaccine uptake interventions.

1. Introduction

The coronavirus disease 2019 (COVID-19) pandemic is a global health crisis of unprecedented magnitude. As of April 2022, there were over 80 million confirmed COVID-19 infections and over 980,000 deaths due to COVID-19 in the United States [10]. The authorization of three highly effective COVID-19 vaccines by the U.S. Food and Drug Administration (FDA) has substantially reduced illness and death due to COVID-19 [51]. However, vaccination rates have not reached levels estimated to achieve herd immunity, prolonging the prevalence of COVID-19 and leading to the emergence of more contagious or severe variants [7,53]. Indeed, in October 2021, the Centers for Disease Control and Prevention (CDC) recommended COVID-19 booster doses for all fully vaccinated individuals due to waning effectiveness of vaccinations, particularly against new variants [9]. As of April 2022, 75.6 % of the U.S. adult population were fully vaccinated, but only 48.6 % had received a booster dose [11].

A significant limiting factor for any vaccination campaign is vaccine hesitancy (i.e., people's uncertainty about or unwillingness to receive a vaccine when it is available; [6,27]). Furthermore, COVID-19 vaccine hesitancy is not static, i.e., people may become more or less hesitant overtime [46,16]. As such, it is necessary to understand the extent to which COVID-19 vaccine hesitancy varies at an individual level (i.e., within person effects) and to identify both within- and between-person factors associated with vaccine hesitancy, in order to develop more effective interventions to increase COVID-19 vaccine uptake. Longitudinal study designs are

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https://doi.org/10.1016/j.vaccine.2022.12.065
0264-410X/

strategically positioned to accommodate the fast-changing nature of the COVID-19 pandemic while separating within- versus between-person processes.

A number of studies during the first year of the pandemic assessed COVID-19 vaccine hesitancy rates and identified between-person (i.e., differences across individuals) factors that distinguished vaccine hesitant and non-hesitant individuals (e.g., [15,16,28,31,36,39]. Prior to the development and authorization of COVID-19 vaccines, roughly-one third to one half of Americans would not accept or were unsure about accepting a COVID-19 vaccine when one became available (e.g., [15,16,28,31,36,39]. Several demographic factors (e.g., younger age, being female, conservative political ideology, lower educational attainment) and perceptions of COVID-19 (e.g., lower perceived severity or likelihood of infection) were associated with COVID-19 vaccine hesitancy in the U. S. (e.g., [15,28,31,36,39]. Since COVID-19 vaccine authorization, approximately 44 % to 20 % of U.S. adults report COVID-19 vaccine hesitancy [14,20,41], with conservative political ideology and lower income being associated with greater vaccine hesitancy and personal or family experience with COVID-19 being associated with lower vaccine hesitancy (e.g., [14]. These findings highlight between person differences in COVID-19 vaccine hesitancy, which is important in identifying populations that should be targeted to a greater extent with vaccination messaging campaigns or interventions. However, COVID-19 vaccine hesitancy may also vary within person.

Some evidence indicates that COVID-19 vaccine hesitancy levels have changed over time during the pandemic with increases and decreases (e.g., [16,20,35,46], indicating that vaccine hesitancy is not fixed. Public response to COVID-19 has changed drastically as new information, scientific discovery, and political reactions to the virus have evolved [16,22,24]. Similarly, the perceived and actual threat of the disease has changed as infections have spread and new variants have emerged [5,30,47]. Given the rapidly changing landscape of the pandemic, COVID-19 vaccination intentions may similarly shift in a relatively short period of time. It is therefore crucial to capture fluctuations in vaccine hesitancy at an individual level to understand how vaccination intentions are changing across time.

The relatively large and potentially growing proportion of U.S. adults who are hesitant about receiving a COVID-19 vaccine or booster is problematic, as it leaves these individuals at risk for contracting COVID-19, prolongs the prevalence of COVID-19, and potentially prevents herd immunity [29,54]. Identifying malleable psychological factors associated with both between- and within person differences in vaccine acceptance/hesitancy that can be leveraged in interventions and messaging campaigns may be essential to increase COVID-19 vaccine uptake.

As perceptions of COVID-19 are associated with between-person differences in vaccine hesitancy [36,39], messages to increase the perceived severity of COVID-19 may increase vaccination acceptance. However, given the politicization of COVID-19, such attempts may be unsuccessful in the U.S. [48]. Moreover, although educational messages may increase knowledge, this often does not translate into behavior change [1,12]. Indeed, educational interventions intended to decrease vaccine hesitancy often do not result in increased vaccine uptake (e.g., [32,33].

A particularly relevant set of factors for vaccine hesitancy may be psychological processes that are proposed to serve an infectious disease-avoidance function (e.g., disgust sensitivity, germ aversion; see [43], for a review). Disgust sensitivity is an individual's tendency to become disgusted and the intensity with which one feels disgust [18,50], and germ aversion is the extent to which individuals are uncomfortable with situations that may involve pathogen transmission [13]. Both constructs represent affective and cognitive processes that are proposed to facilitate detection of potential sources of pathogens and encourage prophylactic behavior, decreasing likelihood of infection [40]. Individuals reliably vary in disgust sensitivity (e.g., [18,50] and germ aversion [13]. Those higher in these psychological traits should be more sensitive to pathogen threats and more avoidant of potential contamination.

Indeed, greater disgust sensitivity was correlated with preventive health behaviors (e.g., handwashing) during the 2014 Ebola outbreak [3]. Furthermore, germ aversion and disgust sensitivity were the most consistent and strongest predictors of concern about COVID-19 and preventive health behaviors (e.g., social distancing, handwashing) in a U.S. national sample, more so than demographic, social, and personality factors [44]. Greater disgust sensitivity has also been associated with greater influenza vaccine uptake and lower influenza vaccine hesitancy [26,42]. Theoretical models of disease avoidance are inherently a within-person process—a person may be more inclined to receive the vaccine when they experience greater disgust or germ aversion—yet studies examining disease avoidance often use methods that only allow the test of between-person differences [49]. Importantly, these individual difference variables have malleable psychological components (e.g., the emotion of disgust) that could be targeted in interventions to decrease vaccine hesitancy. However, it is currently unknown whether disgust sensitivity or germ aversion are associated with COVID-19 vaccine acceptance/hesitancy.

The aim of the present research was twofold. First, we assessed the extent to which COVID-19 vaccine hesitancy varied at an individual level across time. Second, we sought to determine the extent to which disgust sensitivity and germ aversion were associated with between-person and within-person differences in COVID-19 vaccine hesitancy. The current study used a weekly survey design to examine associations between disgust sensitivity, germ aversion, and vaccine hesitancy over the course of six weeks early in the pandemic (March 20 – May 3, 2020). Given the novelty of COVID-19 and the high degree of misinformation about COVID-19, we anticipated that vaccine hesitancy would vary even over a short period of time. As demographic factors have previously been associated with vaccination intentions, we controlled for these variables, as well as personality traits and other psychosocial factors that have been associated with COVID-19 preventive health behaviors [44]. We hypothesized that 1) greater disgust sensitivity and germ aversion would be associated with a lower likelihood of COVID-19 vaccine hesitancy (between-person difference) and 2) experiencing higher disgust sensitivity or germ aversion in a given week would be associated with a lower likelihood of being COVID-19 vaccine hesitant that week (within-person difference).

2. Method

2.1. Participants and procedures

A national sample of 1025 adults residing in the U.S. (516 woman; M_{age} = 46.34 years, SD_{age} = 16.56, range: 18 to 85 years; 72.6 % White; $Mdn_{Education}$ = College graduate; Mdn_{Income} = $70,000 - $79,999) were recruited through the panel provider Qualtrics for a larger, year-long longitudinal study regarding the effects of COVID-19. The only inclusion criteria were that participants had to be 18 years or older and reside in the United States. Sample size was determined based on Monte Carlo simulations (N = 10,000) of the most conservative models for the data analysis plan associated with the larger longitudinal project. A minimum sample of 500 was estimated to provide sufficient power (>95 %) to detect anticipated effects (β = 0.15 to 0.20) based on pilot data assuming α = 0.05. To account for attrition or unusable data, a panel of at least 1000 U.S. individuals was desired.

Participants completed weekly online surveys. This study utilizes six waves of data. These waves were used as they each contained the same COVID-19 vaccine hesitancy question and the interval between waves was consistent. Later waves did not necessarily assess vaccine hesitancy and the time interval between waves varied. Wave 1 (N = 1025) was collected March 20 – March 24, 2020; Wave 2 (N = 803) was collected March 30 – April 5, 2020; Wave 3 (N = 804) was collected April 6 – April 12, 2020; Wave 4 (N = 764) was collected April 13 – 19, 2020; Wave 5 (N = 753) was collected April 20 – April 26, 2020; and Wave 6 (N = 722) was collected April 27 – May 3, 2020. At Wave 6, 70.44 % of the sample were still participating (i.e., 29.56 % attrition). Participants were invited to complete all waves at each time point regardless of attrition. On average, participants completed 4.72 surveys, and 52.2 % completed all six surveys.

Before starting the Wave 1 survey, participants provided electronic consent. After agreeing to be part of the study, participants completed the primary study measures and other questionnaires in a random order, except for perceived health, health history, and demographics, which appeared last. Demographic information was only collected in Wave 1. Upon completion, participants were given monetary compensation in an amount established by the panel provider. This project was approved by the University of Connecticut IRB (Protocol #L20-0018).

2.2. Measures

COVID-19 Vaccine Intention. A single item was used to assess participants' intention to get a possible COVID-19 vaccine. Participants answered "yes", "maybe", or "no" to the question "If a vaccine is developed for COVID-19, would you get vaccinated?" A response of "yes" was coded as 1. Responses of "maybe" and "no" were coded as 2 to represent vaccine hesitancy [6,27]). Participants who responded "no" were asked to answer the open-ended question "If no, why not?".[1]

Disgust Sensitivity. The 7-item pathogen disgust subscale from the Three Domains of Disgust Scale [50] was used to assess individual differences in disgust sensitivity specifically related to pathogens. Participants indicated how disgusting they found each item (e.g., "stepping on dog poop") on a 7-point scale from 0 ("not disgusting at all") to 6 ("extremely disgusting"). A composite score was created by taking the average of the items (αs = 0.85 to 0.91). Higher scores reflected greater disgust sensitivity.

Germ Aversion. The 15-item Perceived Vulnerability to Disease Questionnaire [13] is an individual difference measure consisting of two subscales: Germ Aversion and Perceived Infectability. The Germ Aversion subscale consists of eight items and assesses an individual's discomfort level in situations with high likelihood of pathogen transmission (e.g., "It really bothers me when people sneeze without covering their mouths"; αs = 0.69 to 0.78). The Perceived Infectability subscale includes seven items and assesses an individual's perception of their susceptibility to infectious disease (e.g., "I am more likely than the people around me to catch an infectious disease"; α = 0.79). Participants indicated their agreement to items on a scale ranging from 1 ("Strongly Disagree") to 7 ("Strongly Agree"). For each subscale, a composite score was created by taking the average of the items. Higher scores reflect greater germ aversion or perceived infectability. The perceived infectability subscale assesses biological susceptibility to infection [17,19]. As previous likelihood of contracting infectious diseases may influence COVID-19 vaccination intentions, the perceived infectability subscale was included as a covariate in the primary analyses.

Covariates. All covariates were assessed in the Wave 1 survey. To assess personality, the 10-item short version of the Big Five Inventory (BFI-10; [38] was used. Each trait was assessed with two items: openness to experience (e.g., "has an active imagination"; r = 0.07), conscientiousness (e.g., "does a thorough job"; r = 0.36), neuroticism (e.g., "gets nervous easily"; r = 0.39), agreeableness (e.g., "is generally trusting"; r = 0.17), and extraversion (e.g., "is outgoing, sociable"; r = 0.28). Participants indicated the extent to which they agreed that each statement was true of themselves on a scale from 1 ("Disagree Strongly") to 5 ("Agree Strongly"). A composite score for each personality trait was created by averaging the items. Higher values indicate greater identification with that personality trait.

To assess COVID-19 risk factors, 46 medical conditions were presented to participants and they were asked to indicate whether they and/or a family member ("e.g., your mother, father, sister, brother, aunt, uncle, etc.") had each condition. Participants also indicated if they were taking any immunosuppressive medication, and females indicated if they were pregnant. Twenty-two of the medical conditions presented in the health history questionnaire, pregnancy, and immunosuppressive medication were identified as placing individuals at risk for severe complications from COVID-19 [8]. Using this information, a dichotomous variable was created indicating risk of COVID-19 complications. If participants indicated they had at least one of the medical conditions identified by the CDC, were taking immunosuppressive medication, or were pregnant, they were coded 1 (high risk of complication from COVID-19). Participants who did not meet any of these criteria were coded 0 (low risk of complications from COVID-19). Based on health history information, a family variable was also created to indicate whether participants had a family member at risk for complications from COVID-19. If participants indicated that a family member had at least one of the conditions identified by the CDC, they were coded 1 as a participant with a family member at high risk for complications from COVID-19. Participants who had no family members with any of the conditions were coded as 0.

Demographic information was gathered from participants. Specifically, they reported their age, sex, race, education level, and annual family income. Participants also indicated their political orientation on a scale from 1 ("Very conservative") to 5 ("Very liberal") and their degree of religiosity on a scale from 0 ("Not at all religious") to 10 ("Extremely religious").

2.3. Analytic technique

Hypotheses were tested using generalized linear mixed-effects modeling and estimated using the lme4 package in R [2]. All models included a random effect for subject and fixed effects for other predictors. The primary independent variables were germ aversion and pathogen disgust sensitivity, which were measured at Level-1 with between-person and within-person effects calculated separately. Within-person effects for germ aversion and disgust sensitivity were estimated by calculating the deviation of each person's observed scores for a given week from that person's average across the six-week period. Between-person effects were estimated by calculating the deviation of each person's average score across the six-week period from the grand mean. Level-2 covariates included demographic characteristics, COVID-19 risk factor variables, perceived infectability, and personality, all of which were assessed at Wave 1 and grand-mean centered. The primary Level-1 dependent variable was COVID-19 vaccination hesitancy, which was recoded as clear intention to receive the vaccine (indicated by 'yes' and coded as 1) and vaccine hesitant (indicated by

[1] Reasons for responding "no" were coded (see Supplemental Material). As participants who responded "maybe" were not asked to provide reasons, qualitative analysis is not included in the main text.

'maybe' or 'no' and coded as 2). Intra-class correlation coefficients (ICCs) were estimated to quantify the within and between-person variances in the dependent variable.

Missing Data. Missing data patterns for primary variables are displayed in the Supplemental Material. T-test and chi-squared analyses examined whether those who were missing data on vaccine hesitancy at Wave 6 differed on any covariates at Wave 1 or germ aversion and pathogen disgust sensitivity at each wave. At Wave 6, those who had missing data on vaccine hesitancy were younger, had less education, had lower income, were more religious, were less conscientious, were more neurotic, perceived that they had a greater vulnerability to disease, and had lower pathogen disgust sensitivity at Waves 2, 3, and 6. These differences are consistent with expectations regarding demographic differences in attrition. Thus, data was assumed to be missing at random. Multiple imputation (k = 5, N = 50) was used to estimate missing data for Level-2 covariates and FIML was used to accommodate missing data in the Level-1 variables and outcome.

3. Results

Over the six waves, the percentage of participants who reported COVID-19 vaccine hesitancy was relatively stable (W1 = 42 %; W2 = 38 %; W3 = 40 %; W4 = 40 %; W5 = 39 %; and W6 = 41 %). However, ICCs indicated individual variability in COVID-19 vaccine hesitancy overtime, with 67 % of the variance explained by between-person effects and 33 % of the variance explained by within-person effects.[2] To provide further context for within-person variability in vaccine hesitancy, we quantified differences in vaccine hesitancy between Wave 1 and Wave 6. A total of 215 (30.1 %) participants indicated that they were vaccine hesitant at Wave 1 and remained vaccine hesitant at Wave 6. Similarly, 353 (49.4 %) participants consistently indicated that they were *not* vaccine hesitant at Wave 1 and Wave 6. However, 75 (10.6 %) participants indicated that they were *not* vaccine hesitant at Wave 1 but became vaccine hesitant at Wave 6, and 71 (10.0 %) participants indicated that they were vaccine hesitant at Wave 1 but no longer vaccine hesitant at Wave 6. A total of 40 % of the sample changed their vaccine hesitance at least once during the six-week period.

We next sought to identify factors associated with between-person and within-person differences in COVID-19 vaccine hesitancy. Table 1 displays frequencies, means, and standard deviations, and Table 2 presents Pearson bivariate correlations for all variables. Those who were older, more educated, had higher income, had an at-risk health history or a family member with an at-risk health history, were White, were male, and were less religious had lower vaccine hesitancy. Additionally, higher agreeableness and consciousness were correlated with lower vaccine hesitancy, and neuroticism was correlated with more vaccine hesitancy. Greater germ aversion and disgust sensitivity were correlated with lower vaccine hesitancy.

As many of the factors associated with COVID-19 vaccine hesitancy covaried (see Table 2), we utilized a multivariate approach to test the extent to which each factor was uniquely associated with COVID-19 vaccine hesitancy controlling for other predictors. A generalized linear mixed-effects model was used to estimate between and within-person effects for germ aversion and disgust sensitivity on COVID-19 vaccine hesitancy, controlling for psychosocial and demographic factors at Wave 1. Table 3 displays the model estimates. Older age was associated with lower vaccine hesitancy, and women were more likely to be COVID-19 vaccine hesitant than men. Greater education and higher income were associated with a lower vaccine hesitancy. Additionally, those with family members at risk for COVID-19, were less religious, more strongly identified as liberal, and who had higher perceived infectability were less likely to be COVID-19 vaccine hesitant. Greater agreeableness, consciousness, and openness to experience were associated with a lower likelihood of being COVID-19 vaccine hesitant. There was a significant between-person effect for disgust sensitivity, such that those higher in disgust sensitivity were less likely to be COVID-19 vaccine hesitant relative to those lower in disgust sensitivity. There was also a significant within-person effect for germ aversion. Participants who experienced greater germ aversion for a given week relative to their own six-week average were less likely to be COVID-19 vaccine hesitant that week relative to their own six-week average.

4. Discussion

The goals of the present study were to assess the extent to which COVID-19 vaccine hesitancy varied at an individual level across six weeks and to determine whether disgust sensitivity and germ aversion, two psychological disease avoidance processes, were associated with COVID-19 vaccine hesitancy. Although mean levels of COVID-19 vaccine hesitancy did not vary much from week-to-week (range: 38–42 %), there was substantial within-person variability. Approximately 40 % of the sample changed their COVID-19 vaccine hesitancy at least once during this six-week period. Overall, we found that both disgust sensitivity and germ aversion were associated with COVID-19 vaccine hesitancy, independent of multiple demographic, health, personality, and social factors. Specifically, individuals higher in disgust sensitivity were less likely to be COVID-19 vaccine hesitant than those lower in disgust sensitivity (between-person effect). Also, during the weeks that individuals experienced higher germ aversion than their own personal average, they were less likely to be COVID-19 vaccine hesitant relative to their own personal average. These findings are novel as they are the first to link disgust sensitivity and germ aversion to COVID-19 vaccine hesitancy, and they suggest psychological processes that could be targeted in vaccine hesitancy interventions.

Our results demonstrated considerable within-person variability in COVID-19 vaccine hesitancy over six weeks during the first two months of the pandemic. This is the first study to date to examine individual level fluctuations in vaccine hesitancy over multiple time points. Interestingly, similar levels of changes in vaccine hesitancy appeared in each direction with roughly 10 % of the sample becoming more hesitant and 10 % of the sample becoming less hesitant. These findings highlight potential challenges and opportunities in seeking to decrease vaccine hesitancy, as efforts will need to simultaneously maintain vaccine acceptance while decreasing hesitancy overtime. Both approaches will provide important value to public health efforts regarding the COVID-19 vaccine administration. Further research is necessary to elucidate factors that contribute to shifts from vaccine acceptance to vaccine hesitance.

Identifying individual differences in who becomes less vaccine hesitant overtime may aid in developing strategies to improve vaccine uptake. Consistent with hypotheses, those who were higher in disgust sensitivity were less likely to be vaccine hesitant relative to those who were lower in disgust sensitivity. Further, for a given person, experiencing greater germ aversion in a given week than usual was associated with less vaccine hesitancy that week than usual. These findings are generally consistent with disease avoidance theory and suggest that individual differences in germ aversion and disgust sensitivity may have important implications for intentions to receive the COVID-19 vaccine. A relatively large body

[2] See Figure 1 in Supplemental Material for a visual depiction of within-person variability in COVID-19 vaccine hesitancy.

Table 1
Descriptive statistics for all study variables.

Measure	*M* (*n*)	*SD* (%)	Min.	Max.
Demographics				
Age	46.34	16.56	18	85
Gender				
Female	516	50.8 %	–	–
Male	497	49.1 %	–	–
Other	1	0.1 %	–	–
Not reported	7	0.7 %	–	–
Ethnicity/Race				
White	788	77.3 %	–	–
Latinx/Hispanic	38	3.7 %	–	–
Black	64	6.3 %	–	–
Asian	73	7.2 %	–	–
Native American	4	0.4 %	–	–
Other	6	0.6 %		
Multi	35	3.4 %	–	–
Not reported	11	1.1 %		
Income				
Less than $10,000	36	3.5 %	–	–
$10,000 - $19,999	32	3.1 %	–	–
$20,000 - $29,999	58	5.7 %	–	–
$30,000 - $39,999	81	7.9 %	–	–
$40,000 - $49,999	86	8.4 %	–	–
$50,000 - $59,999	88	8.6 %	–	–
$60,000 - $69,999	85	8.3 %	–	–
$70,000 - $79,999	94	9.2 %	–	–
$80,000 - $89,999	59	5.8 %	–	–
$90,000 - $99,999	59	5.8 %	–	–
$100,000 - $149,999	201	19.7 %	–	–
More than $150,000	131	12.9 %	–	–
Not reported	9	0.9 %	–	–
Education				
Less than/some high school	11	1.1 %	–	–
GED/high school equivalency	19	1.9 %	–	–
High school graduate	107	10.5 %	–	–
Vocation/trade school	27	2.6 %	–	–
Some college	151	14.8 %	–	–
Associate's 2-year degree	86	8.4 %	–	–
College graduate	343	33.7 %	–	–
Graduate studies/professional degree	266	26.1 %	–	–
Not reported	9	0.9 %	–	–
Self COVID-19 risk status (high)	417	40.9 %	–	–
Family COVID-19 risk status (high)	560	55.0 %	–	–
Religiosity	5.73	3.60	1	11
Political Orientation	2.96	1.15	1	5
Germ Aversion	4.68	0.96	1	7
Pathogen Disgust	4.29	1.11	0	6
Extraversion	2.97	0.95	1	5
Agreeableness	3.47	0.86	1	5
Conscientiousness	3.84	0.89	1	5
Neuroticism	2.70	1.00	1	5
Openness	3.25	0.85	1	5

Note. ^Items were standardized before creating composite variables.

of research demonstrates that inducing disgust alters social attitudes, judgments, and decisions (see [43], for a review), as well as general behavioral tendencies [45]. More importantly, disgust has been used in messaging campaigns to increase health behaviors. For example, messages that induced feelings of disgust increased handwashing behavior to a greater extent than educational messages about hand hygiene [37]. Potentially, messages that induce disgust could be used to increase acceptance of a COVID-19 vaccine.

While not the central aim of this study, results also indicate a variety of other between-person demographic and personality differences that may inform vaccine hesitancy. Consistent with previous studies (e.g., [14,15,28,31,36,39], older age, being a man, higher education, higher income, and liberal political orientation were associated with lower COVID-19 vaccine hesitancy. Having a family member at higher risk of COVID-19 complications and greater perceived infectability were related to lower vaccine hesitancy. Potentially, concerns about other's health, particularly loved ones, may be a strong motivator underlying vaccination intentions. Some work has demonstrated the prosocial motivations are a primary factor underlying COVID-19 preventive health behaviors (e.g., social distancing), particularly in youth (e.g., [34]. As younger adults are higher in COVID-19 vaccine hesitancy and are more likely to be asymptomatic which increases the likelihood of unintended transmission, prosocial messages may be effective in decreasing vaccine hesitancy and increasing vaccine uptake in this age group. Finally, greater agreeableness, conscientiousness, and openness to new experiences were associated with less COVID-19 vaccine hesitancy. Each of these personality traits is generally linked to promotive health behaviors [4,23], and existing health interventions tailored for different personalities may help inform vaccine hesitancy reduction strategies.

Table 2
Pearson bivariate correlations for study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Age																	
2. Education	0.10**																
3. Income	0.16**	0.45**															
4. Health Hist.	0.27**	0.01	0.03														
5. Fam. Health Hist.	0.17**	0.01	-0.00	0.27**													
6. Race: White	-0.29**	-0.09**	-0.15**	-0.13**	-0.10**												
7. Gender	-0.04	-0.07*	-0.13**	-0.06	0.04	0.01											
8. Political Or.	-0.11**	0.05	-0.05	-0.09**	-0.03	0.01	0.09**										
9. Religiosity	-0.06	-0.04	0.01	0.11**	-0.01	0.06	-0.03	-0.35**									
10. Extraversion	0.09**	0.01	0.12**	0.04	-0.05	-0.05	0.01	0.07*	0.07*								
11. Agreeableness	0.17**	-0.07*	-0.04	0.01	0.07*	-0.02	0.06*	0.02	0.09**	0.12**							
12. Consciousness	0.30**	0.09**	0.14**	-0.03	0.04	-0.08**	0.08**	-0.04	-0.04	0.14**	0.23**						
13. Neuroticism	-0.20**	-0.07*	-0.12**	0.03	0.01	0.00	0.15**	0.06*	-0.04	-0.21**	-0.30**	-0.33**					
14. Openness	-0.01	-0.01	-0.08**	-0.04	0.05	-0.04	0.05	0.17**	-0.06	0.10**	0.05	0.11**	0.08**				
15. Perceived Inf.	-0.15**	-0.03	-0.06	0.16**	-0.04	0.09**	-0.05	0.09**	0.12**	-0.06*	-0.09**	-0.31**	0.24**	0.02			
16. Germ Aversion	0.01	-0.03	-0.02	-0.00	-0.00	0.08	0.17**	-0.06	0.10*	-0.05	0.02	0.27**	-0.01	0.04	0.14**		
17. Disgust Sens.	0.04	-0.08	-0.05	0.02	-0.05	0.13**	0.09*	-0.05	0.14**	0.01	0.04	0.16**	0.09*	0.09*	0.10*	0.51**	
18. Vaccine Hesitancy.	-0.31**	-0.13**	-0.13**	-0.18**	-0.12**	0.12**	0.13**	-0.05	0.09*	-0.06	-0.14**	-0.21**	0.09*	-0.08	-0.08	-0.15**	-0.18**

Note. Variables 1–15 were assessed at Wave 1. Germ aversion, pathogen disgust, and vaccine hesitancy values represent averages across the six waves of data collection. Health history coded such that (0 = no risk of COVID-19 complications, 1 = high risk for COVID-19 complications), family health history coded such that (0 = no family risk of COVID-19 complications, 1 = high family risk for COVID-19 complications), race coded such that (0 = non-White, 1 = White), gender coded such that (1 = Male, 2 = Female), vaccine hesitancy coded such that (0 = not hesitant, 1 = hesitant). * p <.05, ** p <.01.

Table 3
Model Estimates from Linear-Mixed Model Estimates for COVID-19 Vaccine Hesitancy.

	Vaccine Hesitancy		
	Odds Ratios	*95 % CI*	*p*
Covariates			
Age	0.95	0.93 – 0.97	<0.001
Gender: Female	5.63	2.91 – 10.90	<0.001
Race: White	1.40	0.64 – 3.05	0.399
Education	0.77	0.63 – 0.93	0.008
Income	0.83	0.74 – 0.92	<0.001
At Risk Personal Health History	0.58	0.29 – 1.15	0.121
At Risk Family Health History	0.47	0.25 – 0.92	0.027
Political Orientation	0.62	0.46 – 0.84	0.002
Religiosity	1.13	1.03 – 1.24	0.013
Extraversion	1.17	0.83 – 1.64	0.374
Agreeableness	0.59	0.40 – 0.87	0.008
Consciousness	0.56	0.37 – 0.85	0.006
Neuroticism	0.96	0.67 – 1.38	0.824
Openness	0.63	0.43 – 0.92	0.016
Perceived Infectability	0.54	0.39 – 0.74	<0.001
Disease Avoidance			
Germ aversion (Between)	0.93	0.62 – 1.40	0.732
Germ aversion (Within)	0.80	0.65 – 1.00	0.049
Pathogen Disgust (Between)	0.42	0.29 – 0.59	<0.001
Pathogen Disgust (Within)	1.04	0.89 – 1.22	0.617
Random Effects			
σ^2	3.29		
$\tau_{00\ PID}$	15.89		
Observations	4798		
Marginal R^2 / Conditional R^2	0.241 / 0.870		

Notes: All Level-2 variables were grand mean centered.

4.1. Limitations

Findings should be interpreted in the context of certain limitations. Although longitudinal study design allowed us to isolate within and between-person variance, this study did not examine the temporal sequence between psychological disease avoidance processes and COVID-19 vaccine hesitancy, and causal inferences cannot be made. Experimental methods are needed to demonstrate causality and longitudinal designs seeking to establish temporal sequencing should be sensitive to the scaling of change. The national sample used in this study was primarily White, so future research is needed to more closely examine correlates of vaccine hesitancy in populations that are at a great risk of contracting and dying from COVID-19 (e.g., People of Color; [8]).

The observed changes in COVID-19 vaccine hesitancy may have been due to true changes in vaccination intentions or they may have stemmed from measurement error or weak attitudes. The current dataset cannot eliminate these alternative explanations. For example, vaccine hesitancy was measured with a single item. Although this item demonstrated face validity, future research should capture vaccine hesitancy with a wider-range of potential measures. The current data were collected in the first two months of the pandemic, before COVID-19 vaccines had even been developed. As such, our data represent vaccine hesitancy to a hypothetical COVID-19 vaccine at the time of data collection. Potentially, within-person variability in COVID-19 vaccine hesitancy may have changed as the pandemic and vaccine development progressed and people's attitude coalesced. Further, given the politization of and misinformation regarding COVID-19 vaccines [21,25,52], other factors not assessed in the current study may be particularly influential in shaping COVID-19 vaccine hesitancy.

5. Conclusions

In order to maximize the effectiveness of COVID-19 vaccination campaigns, it is critical to overcome vaccine hesitancy. The present

study adds to our understanding of COVID-19 vaccine hesitancy, demonstrating considerable variation in vaccination intentions over a relatively short period of time (i.e., six weeks). In addition to identifying demographic and psychosocial factors that characterize COVID-19 vaccine hesitant individuals in the United States, we also identified two malleable psychological processes (disgust sensitivity and germ aversion) that could be targeted in vaccine hesitancy interventions and may facilitate vaccine uptake.

Funding Source

This work was supported by a RAPID grant from the National Science Foundation under Award ID BCS-2027027. The funding organization was not involved in designing the study, collecting and analyzing the data, or preparing the manuscript.

Data availability

Data will be made available on request.

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.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2022.12.065.

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