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Examining COVID-19 vaccine intention and receipt through the Health Belief Model and the Theory of Planned Behavior

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Examining COVID-19 vaccine intention and receipt through the Health Belief Model and the Theory of Planned Behavior

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2019

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Epidemiology
2023

Abstract

Examining COVID-19 vaccine intention and receipt through the Health Belief Model and the Theory of Planned Behavior
By Lauren Miller

Background. Few studies have used health behavioral theories to understand both COVID-19 vaccine intention and receipt. We used data from a longitudinal population-based survey to understand how the theoretical variables from the Health Belief Model (HBM) and the Theory of Planned Behavior (TPB) are associated with vaccine intention and vaccine receipt.

Methods. Participants with responses for the 3-month survey in which health beliefs were assessed, and who reported their COVID-19 vaccination status at follow-up (6- and/or 18-months) were included in this study. Multivariable logistic regression models were used to estimate the association between HBM and TPB variables with vaccine intention and vaccine receipt. Phi coefficient, positive predictive value, and negative predictive value were used to compare vaccine intention to vaccine receipt.

Results. Among the 661 participants in the sample, 82% (543) intended to receive the COVID-19 vaccine while 90% (592) had received the vaccine at follow-up. The theoretical predictors were observed to be similar for vaccine intention and receipt in the univariable analysis, while they differed in the multivariable analysis. Perceived susceptibility, perceived benefits, and positive attitude were associated with vaccine intention. Perceived benefits, employer mandated vaccination, subjective norm, and positive attitude were associated with vaccine receipt.

Conclusions. There is relatively little overlap between theoretical variables predicting vaccine intention and vaccine receipt. Most studies have only investigated vaccine intention, which is unlikely to produce results that will adequately inform public health action. External factors are more likely to impact vaccine receipt, including workplace vaccine mandates and factors influencing subjective norms.

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Introduction

The release of COVID-19 vaccines in December 2020 in the United States (U.S.) following a period of substantial morbidity and mortality associated with COVID-19 disease provided respite from prior SARS-CoV-2 pandemic control that relied on non-pharmaceutical interventions [1-4]. Initial vaccine shortages necessitated an allocation scheme prioritizing those at increased risk of morbidity and mortality, including the elderly, frontline healthcare workers, and those with underlying health conditions [5]. The vaccinated population steadily increased from February 2021, when 9% of the U.S. population had received a first dose, to April 12, 2021, when the 7-day moving average of newly vaccinated individuals peaked at 3.4 million and 39% of the population had received a first dose [6]. Following that, the increments of daily vaccinations slowed despite expanded access and continued vaccination recommendations [7]. Currently, 92% of the U.S. population ages 18 years or older has received at least one vaccine dose [6].

Vaccine hesitancy is the decision to delay or refuse vaccine receipt, independent of vaccine accessibility. The concern over increasing vaccine hesitant attitudes preceded the COVID-19 pandemic[8], leading to its classification as one of the ten threats to global health in 2019 by the World Health Organization (WHO). The WHO identified complacency, inconvenience, and lack of confidence in vaccines as the key issues driving hesitancy [9]. Studies investigating the complex factors varying by person, place, and time that underlie the decision to receive or refuse each recommended vaccination are often organized with health behavioral theories, which facilitate improved rigor of measurement and replicable studies [8, 10]. The Health Belief Model (HBM) was created to understand the refusal or acceptance of disease preventatives and screening tests[11], and the Theory of Planned Behavior (TPB) was created to understand the variations in intention and behavioral action across a variety of settings, including for vaccination behaviors [12].

Most existing literature combining the HBM and TPB in a comprehensive model to understand COVID-19 vaccination behaviors have been limited in their abilities to understand both intention and receipt due to their cross-sectional study designs and frequent reliance on stated intentions. There is a lack

of consensus on the performance utility of the HBM versus the TPB to understand COVID-19 vaccine intention, with various findings emerging from cross-sectional studies. Perceived susceptibility, perceived severity, perceived benefits, subjective norm, and attitude have been associated most with COVID-19 vaccine intention [13-19]. But, these findings do not allow for causality to be established between vaccine intention and health beliefs, and do not allow for investigation into the drivers of the intention-behavior gap, the name for the frequent inability of intention to predict actual behavior [20].

The HBM and TPB have been utilized to understand influenza and human papillomavirus (HPV) vaccination behaviors. In a longitudinal study of influenza vaccination incorporating HBM and TPB, attitude was the strongest predictor of both vaccine intention and receipt, while another study found perceived benefits, perceived susceptibility, self-efficacy, and perceived barriers were predictive of vaccine intention, but were not predictive of actual vaccination [21, 22]. Similarly, a longitudinal study using the HBM model to understand HPV vaccination found perceived susceptibility, self-efficacy, and social norms were associated with vaccine intention, but were not associated with actual vaccination [23].

Longitudinal studies have found COVID-19 vaccine hesitancy to be an unstable characteristic, with an increase in both intention and receipt occurring over time, especially among non-Hispanic Black adults. These studies did not incorporate health behavioral theories and thus do not allow for insight into what might lead these changes to occur [24-26]. When health behavioral theories have been incorporated into longitudinal studies of COVID-19 vaccination intention and receipt, the HBM and TPB have not been used together in a comprehensive model. A longitudinal study in China using only the HBM found that none of the HBM variables were predictive of vaccine receipt [27]. There is a need to better understand the relation between COVID-19 vaccine intention and vaccine receipt, as well as to explore whether theoretical predictors of vaccine intention also predict vaccine behavior.

COVIDVu is a national serological study in the U.S. that measured community-level COVID-19 prevalence and vaccination behaviors [28]. The present study leverages the longitudinal nature of COVIDVu to describe how components of the HBM and TPB are related to vaccine intention and future vaccine receipt.

Methods

Utilizing a longitudinal population-based survey described elsewhere [28], participants ineligible for COVID vaccination at the time of survey completion, and who completed any subsequent follow-up, were included in this analysis. A flow diagram provides details regarding participant selection for this analysis (see Supplementary Figure 1). Of the 3464 survey respondents of the 3-month follow-up survey (March to April 2021) in which COVID-19 vaccination beliefs were assessed, 1798 (52%) were excluded due to previous COVID-19 vaccination receipt. While vaccines were not fully disseminated at the time of the survey, 647 participants identified as eligible for vaccination and were excluded because they had already made a choice to not receive the vaccine prior to our measurement of theoretical constructs. Among participants who were vaccine ineligible or did not know their vaccine eligibility status (n=1019), those with missing vaccine receipt data from 6- and 18-month surveys (July to September 2021 and April to May 2022) and participants with incomplete HBM, TPB, and potential confounder variables were excluded (n=358). 661 participants were included in this analysis.

The relative predictive abilities of HBM and TPB constructs are quantified through examining health beliefs and vaccine intention of the U.S.-based probability sample, measured during a period of vaccine shortage when vaccines were known and described in the media, but not all persons had access to the vaccine. We then examined vaccination receipt at future follow-up when all persons had access to vaccines. Demographic measures were adapted from the Census Bureaus' American Community Survey [28]. HBM and TPB items were adapted from previous assessments of pandemic swine flu vaccine and COVID-19 vaccine intentions [14, 29].

At 3-month follow-up, participants self-reported vaccination intention with the question "How likely are you to get a COVID-19 vaccine once it is made available to you?" with those responding "very likely" or "somewhat likely" being classified as intending to receive the COVID-19 vaccine, and those responding "I don't know," "somewhat unlikely" or "very unlikely" being classified as not intending to receive the COVID-19 vaccine. Participants self-reported vaccine receipt at 6- and/or 18-month surveys with the question "Have you received a COVID-19 vaccine?" Vaccine receipt was dichotomously

classified, with those who received any number of COVID-19 vaccine doses classified as having received a COVID-19 vaccine, and those who had received no vaccine doses through the 18-month survey as not having received a COVID-19 vaccine.

HBM variables included self-efficacy towards COVID-19 vaccination[29], perceived susceptibility towards COVID-19 infection (Cronbach α=0.65)[29], perceived benefits towards COVID-19 vaccination (Cronbach α=0.81)[14, 29], perceived barriers towards COVID-19 vaccination (Cronbach α=0.65)[29]. Cues to action was included through inquiry about whether participants expected their employer to mandate COVID-19 vaccination. A binary variable was created with those responding "no," "don't know" or "not applicable" being classified as not expecting an employer mandate[14]. TPB variables included subjective norm towards COVID-19 vaccination (Cronbach α=0.82)[29] and positive attitude towards COVID-19 vaccination (Cronbach α=0.78)[29].

We included several variables that were relevant to COVID-19 vaccine decision making that were not in either theoretical model. Perceived access to vaccination and knowledge of COVID-19 and mitigation (scored from 0 to 4) questions were developed for the COVIDVu survey [28]. Variables based off multiple questions were averaged, with missing assigned to any multiple question variable where only one question was answered. Higher values for each variable indicate a higher degree of the construct, e.g., higher perceived access score means the person perceives better access to vaccination. The Cronbach alpha internal reliability coefficient was calculated for multiple question variables. Questions forming the main study variables are displayed in Supplementary Table 1.

All analyses were conducted in R version 4.2.2. The association between theoretical variables and 1) vaccine intention at 3-month follow-up and 2) vaccine receipt at 6- and/or 18-month follow-up was determined with adjusted odds ratios (aORs), using logistic regression. Comparisons were two-sided with a significance set at alpha=0.05. Independent variables measuring theoretical variables at 3-month follow-up were used for both analyses. Sex was included as a potential confounder in this analysis. Race/ethnicity, education, and COVID-19 vulnerability status were considered for inclusion as potential confounders, but were dropped from the multivariable model to minimize the potential for imprecise

estimates of the theoretical constructs to arise from a large number of variables in the model [30]. Multicollinearity was assessed before conducting logistic regression analysis. Although perceived barriers had some degree of collinearity with the intercept in both models, it was retained due to the overall theoretical applicability and the similar nature of models for when the variable was removed in a sensitivity analysis.

We performed Pearson's Chi-squared tests to assess differences in demographic variables by vaccine intention and by vaccine receipt. We performed Pearson's Chi-square tests and Welch Two Sample t-tests to assess differences in theoretical variables by vaccine intention and by vaccine receipt. Phi coefficient, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were used to compare vaccine intention at 3-months to vaccine receipt at 6- and/or 18-months. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline was followed for this report [31]. All study procedures were approved by the Emory University institutional review board.

Results

345 participants (52%) identified as female; 406 (61%) identified as non-Hispanic White, 67 (10%) as non-Hispanic Black, 121 (18%) as Hispanic; mean age was 42 years (range, 18 to 80 years). 171 participants (26%) identified as having at least one COVID-19 vulnerability. 37% (247) had a bachelor's degree, and 30% (196) had some college or an associate degree. Of the 661 participants in the sample, 82% (543) intended to receive the COVID-19 vaccine. 90% (592) had received at least one dose of the COVID-19 vaccine at follow-up.

Table 1 shows an analysis of the associations between demographic variables and vaccine intention and vaccine receipt. For both vaccine intention and vaccine receipt, there were similar associations, in direction and strength. Modestly higher levels were observed among males, persons with higher education, and persons with higher income.

We found a number of univariable associations between theoretical variables and vaccine intention and vaccine receipt. Higher scores for self-efficacy, perceived benefits, subjective norm, and

positive attitude were observed among both participants intending to receive and among participants that received the vaccine relative to their counterparts. In addition, lower scores for perceived barriers were observed among participants intending to receive and who received the vaccine (see Supplementary Table 2). In the univariable analysis, most variables were associated with either vaccine intention or vaccine receipt, with the exceptions of employer mandated vaccination, perceived access to vaccination, and knowledge of mitigation strategies as variables not associated with either intention or receipt (Table 2).

While the theoretical predictors of the univariable analysis were observed to be similar for vaccine intention and vaccine receipt, the multivariate analysis found different theoretical variables to be associated with vaccine intention compared to vaccine receipt. Theoretical domains regarding internal beliefs and values were often associated with vaccine intention. These included higher perceived susceptibility to infection (aOR 1.6, 95% CI 1.2-2.3), higher perceived benefits toward vaccination (aOR 2.2, 95% CI 1.4-3.4), and positive attitude towards vaccination (aOR 1.9, 95% CI 1.3-2.7).

For vaccine receipt, the associated theoretical domains were frequently constructs external to the individual. For instance, higher subjective norm (perceived views of vaccination by friends and family) was associated with vaccine receipt (aOR 1.3, 95% CI 1.0-1.7). Employer mandated COVID-19 vaccination, a cue to action, was strongly associated with vaccine receipt (aOR 5.2, 95% CI 1.0-26.2). Finally, while higher perceived benefits were associated with both vaccine intention and vaccine receipt, the strength of the association was reduced at vaccine receipt (aOR 1.7, 95% CI 1.1-2.8).

We assessed whether baseline vaccine intention predicts future vaccine receipt (Figure). The correlation between vaccine intention and vaccine receipt was 0.34. The overwhelming majority of participants that intended to receive the vaccine did in fact get vaccinated (513/543, 95% positive predictive value). Intention, however, did not match behavior for persons stating they would not get the vaccine. Few of those who intended to not get the vaccine were not vaccinated at follow-up (39/118, 33% negative predictive value).

Table 1. Baseline demographic characteristics of a U.S. population-based sample of 661 participants by COVID-19 vaccine intention and vaccine receipt

	Overall	By COVID-19 Vaccination Status			
		Vaccine Intention		Vaccine Receipt	
		Yes	No	Yes	No
			p-value[a]		p-value[a]
	n (%)	n (%)	n (%)	n (%)	n (%)
Total sample	661 (100%)	543 (82%)	118 (18%)	592 (90%)	69 (10%)
Sex			<0.001		0.03
Male	316 (48%)	279 (51%)	37 (31%)	292 (49%)	24 (35%)
Female	345 (52%)	264 (48%)	81 (68%)	300 (51%)	45 (65%)
Race/Ethnicity			0.08		0.18
Non-Hispanic White	406 (61%)	343 (63%)	63 (53%)	366 (62%)	40 (58%)
Non-Hispanic Black	67 (10%)	48 (9%)	19 (16%)	56 (8%)	11 (16%)
Non-Hispanic Other	61 (9%)	49 (9%)	12 (10%)	58 (10%)	3 (4%)
Hispanic	121 (18%)	98 (18%)	23 (20%)	107 (18%)	14 (20%)
Missing	6 (1%)	5 (1%)	1 (1%)	5 (0.8%)	1 (1%)
Age			0.95		0.24
18-34	213 (32%)	176 (32%)	37 (31%)	189 (32%)	24 (35%)
35-44	149 (23%)	120 (22%)	29 (25%)	128 (22%)	21 (30%)
45-54	160 (24%)	132 (24%)	28 (24%)	148 (25%)	12 (17%)
55+	139 (21%)	115 (21%)	24 (20%)	127 (22%)	12 (17%)
Education			0.001		<0.0001
High school or less	71 (11%)	54 (10%)	17 (14%)	54 (9%)	17 (25%)
Some college/associate	196 (30%)	146 (27%)	50 (42%)	165 (28%)	31 (45%)
Bachelor's degree	247 (37%)	213 (39%)	34 (29%)	230 (39%)	17 (25%)
Graduate degree	139 (21%)	123 (23%)	16 (14%)	137 (23%)	2 (3%)
Missing	8 (0%)	7 (1%)	1 (1%)	6 (1%)	2 (3%)
Income			<0.01		0.008
0-24,999	94 (14%)	73 (13%)	21 (18%)	77 (13%)	17 (25%)
25,000-49,999	100 (15%)	76 (14%)	24 (20%)	86 (15%)	14 (20%)
50,000-99,999	178 (27%)	149 (27%)	29 (25%)	160 (27%)	18 (26%)
100,000-199,999	143 (22%)	119 (22%)	24 (20%)	134 (23%)	9 (13%)
200,000+	66 (10%)	64 (12%)	2 (2%)	64 (11%)	2 (3%)
Missing	80 (12%)	62 (11%)	18 (15%)	71 (12%)	9 (13%)

Table 1. Baseline demographic characteristics of a U.S. population-based sample of 661 participants by COVID-19 vaccine intention and vaccine receipt (*Continued*)

	Overall	By COVID-19 Vaccination Status			
		Vaccine Intention		Vaccine Receipt	
		Yes	No	Yes	No
			p-value[a]		p-value[a]
	n (%)	n (%)	n (%)	n (%)	n (%)
Job status			0.33		0.03
Employed	463 (70%)	388 (72%)	75 (64%)	424 (72%)	39 (57%)
Homemaker	36 (5%)	26 (5%)	10 (9%)	28 (5%)	8 (12%)
Student	40 (61%)	33 (6%)	7 (6%)	35 (6%)	5 (7%)
Not employed/retired	103 (16%)	83 (15%)	20 (17%)	88 (15%)	15 (22%)
Missing	19 (3%)	13 (2%)	6 (5%)	17 (3%)	2 (2%)
COVID-19 vulnerability status			0.04		0.18
Yes[b]	171 (26%)	131 (24%)	40 (34%)	148 (25%)	23 (33%)
No	490 (74%)	412 (76%)	78 (66%)	444 (75%)	46 (67%)

[a] Pearson's Chi-squared Test

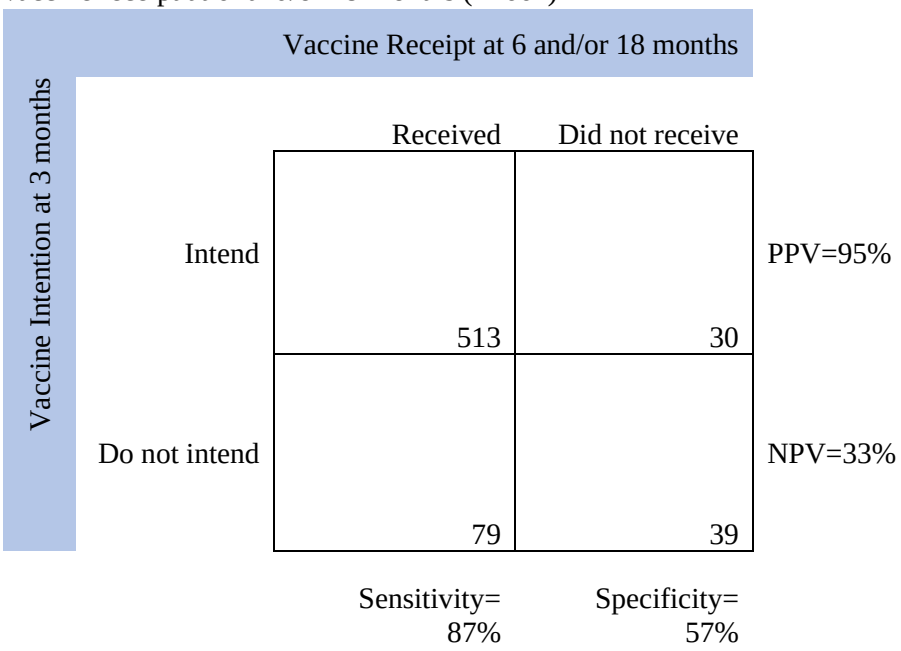
[b] Healthcare workers, persons living in long-term care facilities, essential workers, persons ages 65+, persons with high-risk medical conditions

Table 2. Logistic regression of theoretical variables by COVID-19 vaccine intention and vaccine receipt among 661 participants in a U.S. population-based sample

	Univariable		Multivariable	
	Vaccine Intention	Vaccine Receipt	Vaccine Intention	Vaccine Receipt
HBM Constructs	OR (95% CI)	OR (95% CI)	aOR (95% CI)[a]	aOR (95% CI)[a]
Self-efficacy	1.2 (1.0, 1.3)[b]	1.2 (1.0, 1.4)[b]	0.9 (0.8, 1.1)	0.9 (0.7, 1.1)
Perceived susceptibility	2.0 (1.5, 2.6)[b]	2.0 (1.4, 2.8)[b]	1.6 (1.1, 2.3)[b]	1.5 (1.0, 2.3)
Perceived benefits	4.9 (3.6, 6.6)[b]	4.1 (3.0, 5.7)[b]	2.2 (1.4, 3.4)[b]	1.7 (1.1, 2.8)[b]
Perceived barriers	0.2 (0.2, 0.3)[b]	0.2 (0.1, 0.3)[b]	0.8 (0.5, 1.2)	0.6 (0.3, 1.0)
Expected employer mandated vaccination				
No	Ref	Ref	Ref	Ref
Yes	1.9 (0.8, 4.3)	4.0 (1.0, 16.7)	1.8 (0.7, 4.7)	5.2 (1.0, 26.2)[b]
TPB Constructs				
Subjective norm	2.1 (1.7, 2.4)[b]	2.1 (1.7, 2.5)[b]	1.1 (0.8, 1.4)	1.3 (1.0, 1.7)[b]
Positive attitude	3.4 (2.7, 4.2)[b]	3.0 (2.3, 3.8)[b]	1.9 (1.3, 2.7)[b]	1.5 (1.0, 2.3)[b]
Other variables				
Perceived access	1.0 (0.8, 1.1)	1.2 (0.9, 1.4)	0.9 (0.7, 1.2)	1.2 (0.9, 1.6)
Knowledge of COVID-19	0.8 (0.6, 1.1)	0.8 (0.5, 1.1)	0.9 (0.6, 1.2)	0.9 (0.6, 1.4)

[a] Controlling for sex
[b] Significant at $p < 0.05$

Figure. COVID-19 vaccine intention at 3-months and COVID-19 vaccine receipt at 6- and/or 18-months (n=661)



Discussion

Our study found that vaccine intention was only moderately correlated with vaccine receipt. Moreover, the theoretical domains that predicted vaccine intention and vaccine receipt had relatively little overlap. Factors associated with vaccine intention, such as perceived susceptibility, perceived benefits, and positive attitude, had attenuated or insignificant relationships with vaccine receipt. Conversely, employer mandated vaccination and subjective norms, the factors most associated with vaccine receipt, were not significantly associated with vaccine intention. This instance of different theoretical predictors being associated with vaccine intention versus vaccine receipt provides support for observations in previous studies of differences between intention and behavior, the "intention-behavior gap."

Conventionally, the intention-behavior gap describes how intentions often fall short of enacted health behaviors, (e.g., intention to be on a diet may not lead to differences in food consumption) [20]. In this study, the inverse of the intention-behavior gap was observed: intention *underestimated* future vaccine receipt. Somehow, more individuals received the COVID-19 vaccine than had previously intended. Both the dynamic and pervasive nature of COVID-19 and the one-time health behavior of vaccination measured in this study, compared to repeated lifestyle change behaviors that are often described by the intention-behavior gap, could be facilitating this opposing outcome. If repeated vaccination was instead examined, our findings might change.

Another factor facilitating the intention-behavior gap could be the saturation and widespread availability of the COVID-19 vaccine. The strain placed on the healthcare system compelled this widespread access, creating an environment in which receiving a COVID-19 vaccine was often highly convenient. Some places went to greater extends and made it inconvenient to remain unvaccinated through vaccine requirements in schools, workplaces, and other public places. For instance, New York City implemented a vaccine requirement for indoor dining [32]. Vaccine mandates and facilitating environments follows a shift in public health practice towards factors external to the individual, such as access, rules and regulations, and influential persons. Our study supports environmental factors as critical to decision making, with the strongest predictor of vaccination being workplaces that require it.

Our finding of the association between vaccine receipt and subjective norm is congruent with prior research showing an association between COVID-19 vaccine receipt and social norms, including when encouragement to become vaccinated came from members of one's social circle [27, 33]. In accordance with previous findings that those with higher levels of knowledge are no more likely to receive the HPV vaccine [34], our study found that knowledge was not correlated with COVID-19 vaccine intention or receipt. Prior exploration into knowledge being insufficient alone to facilitate behavior change is supported [35]. For future pandemics, a continued focus on external factors including social and workplace environments is likely to yield the highest levels of vaccination.

A potential limitation to the generalizability of our study is the higher proportion of vaccinated individuals compared to the equivalent U.S. population. 90% of our sample had received at least one vaccine dose, while 80% of the U.S. population ages 18 or older had received at least one vaccine dose during the equivalent time period of the 18-month survey (April to May 2022). While measuring health beliefs prior to vaccination allowed for causal order to be established, there is still the potential that health beliefs could have changed between vaccine intention and vaccine receipt. Additionally, participant exclusion due to missing data (n=291) has a potential unmeasured impact on the validity of our findings. Finally, while use of self-reported vaccine receipt could be assumed to be a limitation, it has been shown to be a valid metric through an analysis comparing anti-spike IgG seroprevalence with self-reported COVID-19 vaccine receipt [24].

The majority of studies have only investigated vaccine intention, and our study indicates that this is a flawed strategy that is unlikely to produce results that will appropriately inform public health action. If only the results from vaccine intention were incorporated, we might develop interventions focusing on the risks associated with COVID-19 infection, the benefits associated with COVID-19 vaccination, and creating positive attitudes towards vaccination. Conversely, if interventions were developed based on vaccine receipt, we would focus on employer mandated vaccination and increasing subjective norms towards COVID-19 vaccination.

Conclusion

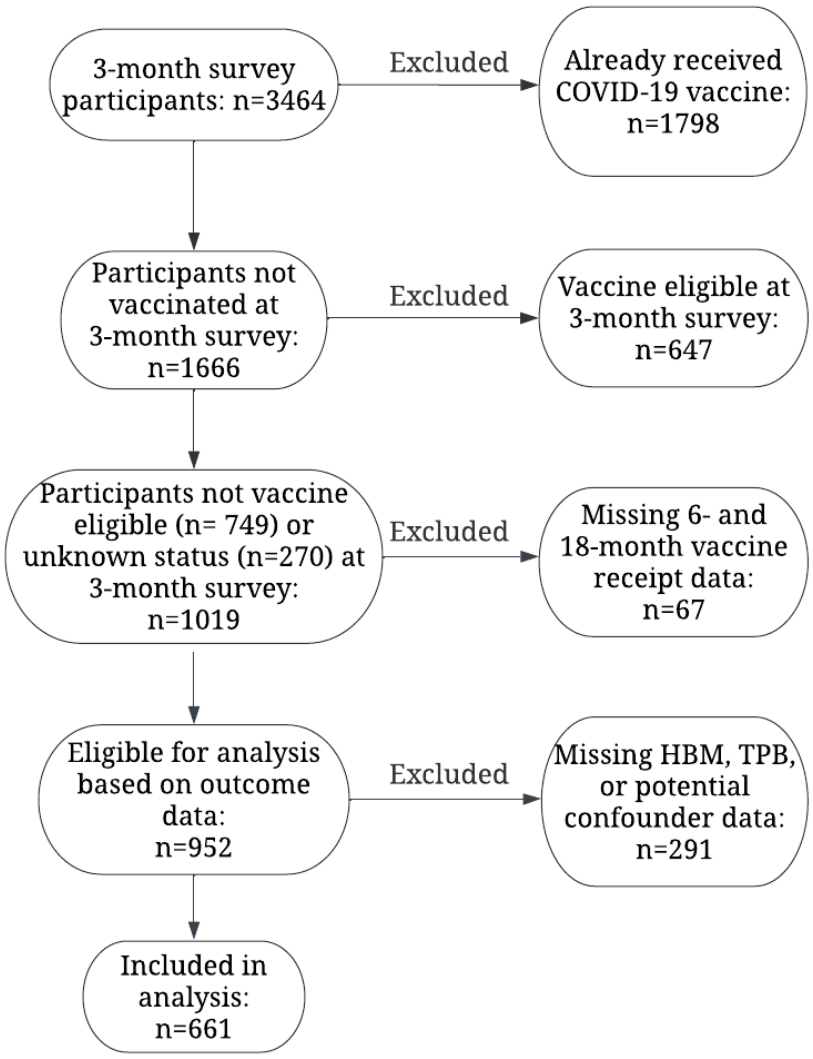
This study fills a gap in the literature by longitudinally examining vaccine intention and vaccine receipt in a U.S. sample, and exhibits support for the value of COVID-19 vaccine mandates and of fostering a culture of vaccination within social groups to increase COVID-19 vaccine receipt.

References

1. Cucinotta, D. and M. Vanelli, *WHO Declares COVID-19 a Pandemic.* Acta Biomed, 2020. **91**(1): p. 157-160.
2. *WHO Coronavirus (COVID-19) Dashboard*. [cited 2022 September 3]; Available from: https://covid19.who.int/.
3. Baden, L.R., et al., *Efficacy and Safety of the mRNA-1273 SARS-CoV-2 Vaccine.* New England Journal of Medicine, 2021. **384**(5): p. 403-416.
4. Polack, F.P., et al., *Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine.* New England Journal of Medicine, 2020. **383**(27): p. 2603-2615.
5. Dooling, K., et al., *The Advisory Committee on Immunization Practices' Updated Interim Recommendation for Allocation of COVID-19 Vaccine — United States, December 2020.* MMWR. Morbidity and Mortality Weekly Report, 2021. **69**(5152): p. 1657-1660.
6. *COVID Data Tracker*. [cited 2022; Available from: https://covid.cdc.gov/covid-data-tracker/#vaccinations_vacc-total-admin-rate-total.
7. Mathieu, E., et al., *A global database of COVID-19 vaccinations.* Nature Human Behaviour, 2021. **5**(7): p. 947-953.
8. MacDonald, N.E., *Vaccine hesitancy: Definition, scope and determinants.* Vaccine, 2015. **33**(34): p. 4161-4.
9. *Ten threats to global health in 2019*. [cited 2022 September 3]; Available from: https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019.
10. Li, L., C.E. Wood, and P. Kostkova, *Vaccine hesitancy and behavior change theory-based social media interventions: a systematic review.* Translational Behavioral Medicine, 2022. **12**(2): p. 243-272.
11. Rosenstock, I.M., *Historical Origins of the Health Belief Model.* Health Education Monographs, 1974. **2**(4): p. 328-335.
12. Ajzen, I., *The theory of planned behavior.* Organizational Behavior and Human Decision Processes, 1991. **50**(2): p. 179-211.
13. Guidry, J.P.D., et al., *Willingness to get the COVID-19 vaccine with and without emergency use authorization.* American Journal of Infection Control, 2021. **49**(2): p. 137-142.
14. Shmueli, L., *Predicting intention to receive COVID-19 vaccine among the general population using the health belief model and the theory of planned behavior model.* BMC Public Health, 2021. **21**(1).
15. Hossain, M.B., et al., *Health Belief Model, Theory of Planned Behavior, or Psychological Antecedents: What Predicts COVID-19 Vaccine Hesitancy Better Among the Bangladeshi Adults?* Front Public Health, 2021. **9**: p. 711066.
16. Chu, H. and S. Liu, *Integrating health behavior theories to predict American's intention to receive a COVID-19 vaccine.* Patient Educ Couns, 2021. **104**(8): p. 1878-1886.
17. Berg, M.B. and L. Lin, *Predictors of COVID-19 vaccine intentions in the United States: the role of psychosocial health constructs and demographic factors.* Translational Behavioral Medicine, 2021. **11**(9): p. 1782-1788.
18. Li, J.B., E.Y.H. Lau, and D.K.C. Chan, *Why do Hong Kong parents have low intention to vaccinate their children against COVID-19? testing health belief model and theory of planned behavior in a large-scale survey.* Vaccine, 2022. **40**(19): p. 2772-2780.
19. Patwary, M.M., et al., *Determinants of COVID-19 Vaccine Acceptance among the Adult Population of Bangladesh Using the Health Belief Model and the Theory of Planned Behavior Model.* Vaccines, 2021. **9**(12): p. 1393.
20. Faries, M.D., *Why We Don't "Just Do It": Understanding the Intention-Behavior Gap in Lifestyle Medicine.* Am J Lifestyle Med, 2016. **10**(5): p. 322-329.

21. Ng, T.W.Y., et al., *Testing an integrative theory of health behavioural change for predicting seasonal influenza vaccination uptake among healthcare workers.* Vaccine, 2020. **38**(3): p. 690-698.
22. Fall, E., M. Izaute, and N. Chakroun-Baggioni, *How can the health belief model and self-determination theory predict both influenza vaccination and vaccination intention ? A longitudinal study among university students.* Psychol Health, 2018. **33**(6): p. 746-764.
23. Vermandere, H., et al., *Uptake of the human papillomavirus vaccine in Kenya: testing the health belief model through pathway modeling on cohort data.* Globalization and Health, 2016. **12**(1).
24. Siegler, A.J., et al., *Trajectory of COVID-19 Vaccine Hesitancy Over Time and Association of Initial Vaccine Hesitancy With Subsequent Vaccination.* JAMA Netw Open, 2021. **4**(9): p. e2126882.
25. Nguyen, K.H., et al., *Changes in COVID-19 vaccination receipt and intention to vaccinate by socioeconomic characteristics and geographic area, United States, January 6 – March 29, 2021.* Annals of Medicine, 2021. **53**(1): p. 1419-1428.
26. Rane, M.S., et al., *Determinants and Trends of COVID-19 Vaccine Hesitancy and Vaccine Uptake in a National Cohort of US Adults: A Longitudinal Study.* Am J Epidemiol, 2022. **191**(4): p. 570-583.
27. Yan, E., et al., *Predictors of COVID-19 actual vaccine uptake in Hong Kong: A longitudinal population-based survey.* SSM Popul Health, 2022. **18**: p. 101130.
28. Siegler, A.J., et al., *Protocol for a national probability survey using home specimen collection methods to assess prevalence and incidence of SARS-CoV-2 infection and antibody response.* Ann Epidemiol, 2020. **49**: p. 50-60.
29. Myers, L.B. and R. Goodwin, *Determinants of adults' intention to vaccinate against pandemic swine flu.* BMC Public Health, 2011. **11**(1): p. 15.
30. Ranganathan, P., C.S. Pramesh, and R. Aggarwal, *Common pitfalls in statistical analysis: Logistic regression.* Perspect Clin Res, 2017. **8**(3): p. 148-151.
31. von Elm, E., et al., *The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.* Int J Surg, 2014. **12**(12): p. 1495-9.
32. Fitzsimmons, E.G. *New York City Is Rolling Back Pandemic Restrictions. Is It Too Soon?* 2022 [cited 2023 March 20]; Available from: https://www.nytimes.com/2022/02/28/nyregion/nyc-vaccine-mask-mandates.html.
33. Latkin, C., et al., *A longitudinal study of vaccine hesitancy attitudes and social influence as predictors of COVID-19 vaccine uptake in the US.* Human Vaccines & Immunotherapeutics, 2022. **18**(5): p. 1-9.
34. Fishman, J., et al., *Parent and adolescent knowledge of HPV and subsequent vaccination.* Pediatrics, 2014. **134**(4): p. e1049-56.
35. Brewer, N.T. and K.I. Fazekas, *Predictors of HPV vaccine acceptability: a theory-informed, systematic review.* Prev Med, 2007. **45**(2-3): p. 107-14.

Supplementary Figure 1. Participant inclusion flow diagram



Supplementary Table 1. Items, response scales, and internal consistency of main study variables

Outcome Variables	Scale	Cronbach α
Vaccine intention measured at 3 months		n/a
Unsure, somewhat, or very unlikely classified as not intending; somewhat or very likely classified as intending	Y/N	
Vaccine receipt measured after 3 months (6 and/or 18 months)		n/a
Greater than or equal to one COVID-19 vaccine dose classified as received vaccine	Y/N	
Health Belief Model		
High self-efficacy towards COVID-19 vaccination		n/a
Can easily get the COVID-19 vaccine once eligible	1~7	
High perceived susceptibility towards COVID-19 infection		0.65
Chance of getting COVID-19 in the next few month	1~5	
Worry about getting COVID-19 in the near future	1~5	
Possibility of getting COVID-19	1~5	
Worry about new variants	1~5	
High perceived benefits towards COVID-19 vaccination		0.81
Decrease chance of COVID-19 infection or complications	1~5	
Decrease likelihood of hospitalization if infected	1~5	
Vaccine will protect friends and family	1~5	
High perceived barriers towards COVID-19 vaccination		0.65
Scared of needles	1~5	
Vaccine side effect concerns	1~5	
Safety concerns due to rushed vaccine development	1~5	
Vaccine will not protect against new coronavirus variants	1~5	
Don't need vaccine due to previous COVID-19 infection	1~5	
Expected employer mandated COVID-19 vaccination		n/a
Expectation of employer or place of work to require COVID-19 vaccination	Y/N	
Theory of Planned Behavior		
High subjective norm towards COVID-19 vaccination		0.82
Approval from family members of COVID-19 vaccination	1~7	
Approval from friends of COVID-19 vaccination	1~7	
Approval from other important people of COVID-19 vaccination	1~7	
Positive attitude towards COVID-19 vaccination		0.78
COVID-19 vaccine is wise or foolish	1~7	
COVID-19 vaccine is worthless or valuable	1~7	
COVID-19 vaccine is satisfactory or unsatisfactory	1~7	
COVID-19 vaccine is bad or good	1~7	
COVID-19 vaccine is difficult or easy	1~7	

Supplementary Table 1. Items, response scales, and internal consistency of main study variables (*Continued*)

Other variables	Scale	Cronbach α
High perceived access towards COVID-19 vaccination		n/a
Commonly visited places are offering COVID-19 vaccines	1~5	
High knowledge of COVID-19 and mitigation strategies		n/a
Knowledge of cloth face-mask efficacy against COVID-19	Y/N	
Knowledge of precautions needed for children/young adults against COVID-19	Y/N	
Knowledge COVID-19 symptoms	Y/N	
Knowledge of airborne transmission of COVID-19	Y/N	

Supplementary Table 2. Theoretical variables by COVID-19 vaccine intention and vaccine receipt among 661 participants in a U.S. population-based sample

	Overall	Vaccine Intention		Vaccine Receipt	
		Yes	No	Yes	No
HBM Constructs	Mean/n (SD/%)	Mean/n (SD/%)		Mean/n (SD/%)	
Self-efficacy	5.0 (1.5)	5.0 (1.5)	4.7 (1.6)[a]	5.0 (1.5)	4.6 (1.4)[a]
Perceived susceptibility	3.1 (0.7)	3.2 (0.7)	2.8 (0.7)[c]	3.2 (0.7)	2.8 (0.7)[b]
Perceived benefits	4.2 (0.8)	4.4 (0.6)	3.4 (1.0)[c]	4.4 (0.7)	3.3 (1.0)[c]
Perceived barriers	2.6 (0.7)	2.5 (0.7)	3.1 (0.6)[c]	2.5 (0.7)	3.2 (0.5)[c]
Expected employer mandated vaccination					
No	596 (90%)	485 (89%)	111 (94%)	529 (89%)	67 (97%)
Yes	65 (10%)	58 (11%)	7 (6%)	63 (11%)	2 (3%)
TPB Constructs					
Subjective norm	6.3 (1.2)	6.5 (1.0)	5.3 (1.5)[c]	6.4 (1.0)	5.0 (1.5)[c]
Positive attitude	5.6 (1.1)	5.9 (0.9)	4.4 (1.3)[c]	5.8 (1.0)	4.3 (1.3)[c]
Other variables					
Perceived access	3.0 (1.2)	2.9 (1.2)	3.0 (1.0)	3.0 (1.2)	2.8 (1.1)
Knowledge of COVID-19	2.9 (0.7)	2.9 (0.7)	3.0 (0.7)	2.9 (0.7)	3.0 (0.8)

[a] Pearson's Chi-squared test or Two-sample t-test, significant at $p < 0.05$

[b] Pearson's Chi-squared test or Two-sample t-test, significant $p < 0.005$

[c] Pearson's Chi-squared test or Two-sample t-test, significant at $p < 0.0005$