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# Strengthened belief in vaccine effectiveness predicted increased COVID-19 vaccination intention and behaviour: Results from a nationally representative longitudinal survey of U.S. adults from July 2020 to April/May 2021

Ava Kikut [1], Danielle Clark [1], Emma Jesch [*,1], Robert Hornik

*Annenberg School for Communication, University of Pennsylvania, Philadelphia, PA, USA*

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ABSTRACT

Vaccine hesitancy remains a major barrier to ending the COVID-19 pandemic in the United States (U.S.) and an important target for communication interventions. Using longitudinal survey data, we examined whether baseline levels and changes in beliefs about the COVID-19 vaccines predicted change in vaccination intention/behaviour. Repeated measures were collected from a nationally representative sample of U.S. adults ($n$ = 665) in July 2020 and April/June 2021. Linear regressions associated change in COVID-19 vaccination intention/behaviour with changes in beliefs about the COVID-19 vaccines' safety, effectiveness in protecting others from infection, and effectiveness in protecting oneself from infection. Changes in beliefs from T1 to T2 were significantly associated with change in vaccination outcomes for all belief types (safety $B$ = 0.39, SE = 0.07; effectiveness for self $B$ = 0.38, SE = 0.09; effectiveness for others $B$ = 0.43, SE = 0.07). Cross-lagged models suggested a reciprocal causal relationship between pro-vaccine beliefs and vaccination intention/behaviour: Intention to get vaccinated at T1 predicted strengthened safety and effectiveness beliefs at T2. T1 effectiveness beliefs predicted T2 vaccination intention/behaviour, though T1 safety beliefs did not. Communication interventions highlighting the protective benefits of COVID-19 vaccines may be particularly successful in reducing vaccine hesitancy.



Vaccine hesitancy – that is, the "delay in acceptance or refusal of vaccination despite availability of vaccination services" ([1], p. 4163) – has been identified by the World Health Organization as one of the top ten threats to global health [2], and a barrier to ending the COVID-19 pandemic [3]. However, COVID-19 vaccine hesitancy and acceptance have been dynamic in the United States (U.S.): While only 51% of U.S. adults planned to get a vaccine in September 2020 [4], nearly 90% had received at least one dose as of July 7, 2022 [5]. Currently, 106.6 million U.S. adults are eligible for a recommended booster dose, yet only 51% have received one [5]. Identifying factors that decreased initial vaccine hesitancy – and increased acceptance – among the public can inform ongoing COVID-19 vaccine communication efforts. In the present two-wave survey study using a representative sample of U.S. adults, we consider three factors – increased belief in the vaccines' safety, their effectiveness in protecting oneself from infection, and their effectiveness in protecting others. While these beliefs have been shown to be associated with concurrently measured vaccination intention, we examine whether *changes* in beliefs are associated with change in vaccination intention and behaviour, and whether baseline beliefs predict subsequent changes in intention and behaviour. If belief change is associated with reduction in hesitance, evidence is stronger that public health messages targeting these beliefs may be especially effective in encouraging vaccination among those who remain hesitant.

## 1. Literature review

Vaccine hesitancy is multifaceted and context-specific, influenced by convenience (logistics, affordability, and availability); complacency (low perceived risk); and confidence (trust in the medical system, policymakers, and the vaccine itself) [1]. Prior cross-sectional studies and systematic reviews have identified specific factors (other than behavioural beliefs) that are associated with COVID-19 vaccine hesitancy, including socio-demographics;

* Corresponding author at: 3620 Walnut St., Annenberg School for Communication, University of Pennsylvania, Philadelphia 19104, United States.
*E-mail address:* emma.jesch@asc.upenn.edu (E. Jesch).
[1] Co-first authors.

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political affiliation; and conspiratorial ideation. Those who are vaccine hesitant tend to be younger, women – particularly pregnant or breastfeeding mothers – earn a lower income, live in a more rural area, be uninsured, and believe that their healthcare provider would **not** recommend vaccination. They also tend to identify as conservative or Republican, have higher religiosity, express lower trust and altruism, and report higher belief in vaccine conspiracy theories (see [6,7,8,9,10,11,12,13,14,15,16,17]). In the context of the U.S. COVID-19 vaccine rollout, several societal-level changes may have also influenced changes in vaccine hesitancy – including government turnover (e.g., [18,19,20]), widened accessibility (e.g., [21,22,23]), and institutional norms, incentives, and mandates (e.g., [24,25,26]). These factors may directly influence decisions to vaccinate; they may also influence changes in beliefs about the benefits and risks of vaccines, which in turn may influence decisions to vaccinate.

According to the reasoned action approach (RAA), behavioural beliefs – or anticipated outcomes of engaging in a given behaviour – are often strong direct predictors of behavioural intentions, which predict the behaviour itself [27]. The RAA, and observed associations between behavioural beliefs and intentions, often forms the basis for health campaign messaging (e.g., [28,29,30]). This model assumes changing – or priming – beliefs that are associated with intention will lead to subsequent intention (and behaviour) change. The RAA incorporates a wider set of predictors than those examined in the current study, including perceived normative information and self-efficacy/perceived behavioural control. In addition, it hypothesizes that attitude mediates the influence of behavioural beliefs on intentions. The current study is informed by only some components of the RAA, focusing on the direct influence of behavioural beliefs on intentions (and behaviour).

Consistent with the RAA, there is growing evidence that COVID-19 vaccination decisions are strongly connected to behavioural beliefs. Some previous studies have identified associations between positive behavioural beliefs pertaining to COVID-19 vaccination (e.g., protection from severe illness or new variants) and vaccination intention (e.g., [9,31,32]). In particular, prior research shows beliefs about vaccine safety and effectiveness are strongly associated with hesitancy – those who do not wish to get vaccinated believe that the vaccine is unsafe or harmful and that it would not protect oneself or others from infection (e.g., [8,12,13]). These previous studies show strong correlations between behavioural beliefs and vaccine intentions. However, most measured belief and intention at the same timepoint, reporting cross-sectional associations. Consequently, inferences that beliefs *influenced* intentions are threatened by concerns that other potential confounders may account for the observed association and uncertainty about causal direction. For example, does one's current beliefs about vaccination predict future intentions and/or does one's current intentions or behaviour predict future beliefs? Further, most studies of COVID-19 behavioural beliefs and intentions were conducted prior to vaccine approval in the U.S. (i.e., before December 2020); as such, they capture beliefs and intentions regarding hypothetical vaccination and may be less relevant now that vaccines are widely available.

There have been some longitudinal studies aimed at understanding shifts in COVID-19 vaccination intention and behaviour from pre-to-post vaccine approval; such studies are diverse in approach, ranging from identifying baseline factors associated with subsequent changes in vaccination intention to asking respondents to describe why they changed their minds. Waszkiewicz et al. [33] surveyed respondents about their vaccination intention at two time points and asked those who were previously vaccine hesitant to disclose the reasons behind their shifting mindset; main factors were increased concern about health and safety and a desire to travel. Evans et al. [34], Harada & Watanabe [35], Hyland et al. [36], and Maciuszeket al. [37] also surveyed respondents over time, identifying potential traits or beliefs at one wave that were associated with changes in vaccination intention at a later wave. Harada & Watanabe [35] found that those who shifted from hesitant to acceptant had higher COVID-19-related anxiety and lower concern for adverse vaccine side effects. Hyland et al. [36] found that those in the "moveable middle" – who had fluctuating vaccination intention throughout the pandemic – tended to be women and expressed lower trust in scientists and doctors. Maciuszeket al. [37] found that those with lower initial vaccine attitudes had higher increases in vaccination intention than those who were consistently acceptant. Conversely, Evans et al. [34] did not find any significant trait differences among initially hesitant healthcare workers who did and did not get vaccinated by follow-up. Although these studies measure shifting intentions, they either focus on socio-demographic predictors alone or treat behavioural beliefs as static. To our knowledge, no prior longitudinal studies have examined whether *changes* in beliefs – specifically, strengthened belief in COVID-19 vaccine effectiveness and safety – have affected change in intention and behaviour, nor have they examined the possibility of reciprocal effects.

We respond to this gap in the present study, leveraging longitudinal survey data from a nationally representative sample of U.S. adults surveyed in July 2020 (T1) and again in April/June 2021 (T2). At both time points, we measure three key behavioural beliefs, chosen from previous studies: that the COVID-19 vaccines are safe, provide effective protection for oneself, and provide effective protection for others. While the RAA and prior studies suggest these beliefs may be promising targets for health communication campaigns, we contribute a unique methodological approach to test this assumption. We measure whether changes in these beliefs led to subsequent adjustments in intention and behaviour over time. First, we examined whether **changes** in each belief from T1 to T2 were associated with **change** in intention/behaviour from T1 to T2. Second, to address issues of causal order, we conducted a series of lagged analyses to assess whether T1 beliefs predicted T2 intention/behaviour, controlling for T1 intention, and similarly whether T1 intention predicted T2 beliefs, adjusting for T1 beliefs.

## 2. Methods

### 2.1. Survey sample

Survey data were collected for a separate study from a nationally representative sample of U.S. adults previously recruited by Social Science Research Solutions (SSRS). Surveys were conducted in English or Spanish online or by phone. Respondents were asked questions about their COVID-19 related beliefs and behaviours, as well as other personal characteristics. The study was approved by the authors' Institutional Review Board; study subjects provided prior consent to participate in the SSRS OpinionPanel. Survey weights were developed by SSRS to ensure participants matched the U.S. population on important demographic variables.

The present study uses survey data collected on July 15–21, 2020 (T1) and 9–11 months later (T2; as part of the larger project, respondents were randomly assigned to complete T2 surveys on either April 12–20, 2021 or June 8–30, 2021). While the larger project collected data in May/June 2020 (T0; $n = 1074$, cooperation rate 54 %; recruitment rate for the ongoing panel varies between 2 and 4 %), the initial survey instrument did not include vaccine-related questions. Thus, data collected from this prior wave were not relevant to the present study. In total, 83 % of T0 respondents ($n = 889$) responded at T1 and 70 % of T0 respondents ($n = 750$) responded at T2. The present study sample includes the 665 respondents who participated at both T1 and T2. While the

analytic sample had some differences with the original baseline sample (T0), weighting procedures meant that the analytic sample represented the population in a similar way (see Table 1).

### 2.2. Dependent variable: Change in vaccination intention and behaviour

The primary outcome variable for this study was change in COVID-19 vaccination intention and behaviour from T1 to T2. Intention/behaviour was measured from 1 (low) to 4 (high). At T1, all participants were asked: "If you were able to get a vaccine for coronavirus today, what is the likelihood that you would get vaccinated?" (*4 = very likely; 3 = somewhat likely; 2 = somewhat unlikely; 1 = very unlikely*). At T2, participants who did not claim to be vaccinated were asked the same question.

Because vaccines became available to U.S. adults between waves, vaccination behaviour was only measured at T2. Respondents were asked: "Have you received at least one dose of any of the COVID-19 or coronavirus vaccines?" (*Yes/No*). The T2 outcome measure combined the T2 intention measure with the T2 self-report of vaccination status. This decision to merge vaccinated respondents with unvaccinated respondents who reported "very likely" reflected two considerations: as noted above, the T2 sample was collected over two (randomly selected) periods (April and June); this meant that some members of the sample had two more months to become vaccinated than others, so current reported vaccination status did not reflect the same meaning for all respondents. As such, 64 % of respondents reported being vaccinated in the June sample, while only 54 % had reported being vaccinated in April. In addition, and consistent with the RAA [27], intention at T1 was strongly linked with behaviour at T2 (82 % of respondents who were "very likely" at T1 had received at least one dose of the vaccine at T2, while only 23 % of those who described themselves as "very unlikely" at T1 reported being vaccinated at T2). This justifies the assumption that nearly all of the "very likely" respondents at T2 would be vaccinated if they had enough time. In the interest of creating a T2 measure parallel to the T1 intention score, allowing for the inclusion of the full sample of respondents, those vaccinated at T2 were merged with unvaccinated T2 "very likely" respondents in the T2 intention/behaviour score. Respondents were assigned a "4" at T2 if they reported being either "very likely" to get vaccinated or if they had already received a first dose. A change in intention/behaviour variable was created by subtracting T1 intention scores from T2 intention/behaviour scores.

### 2.3. Independent variable: Changes in beliefs

Three beliefs about COVID-19 vaccines were measured at both T1 and T2. Items were adapted from the vaccine hesitancy scale developed by the SAGE Working Group on Vaccine Hesitancy [38] and validated by Shapiro et al. [39]. At T1, respondents were asked to rate their agreement with a battery of items starting with the stem, "If you were to receive a potential coronavirus vaccine…". Items included: …you would suffer bad side effects from the vaccine (safety); you would be well protected from getting infected with the coronavirus (effectiveness for self); you would be protecting others in your community from getting infected (effectiveness for others) (*1 = strongly disagree; 2 = somewhat disagree;*

**Table 1**
Descriptive data of study participants.

| | | **Analytic Sample** | | **Baseline Sample** | |
|---|---|---|---|---|---|
| | | T1 & T2 ($n$ = 665) | | T0 ($n$ = 1,074) | |
| | | Weighted M (SD) or % | Unweighted M (SD) or % | Weighted M (SD) or % | Unweighted M (SD) or % |
| Female | | 51.67 % | 51.89 % | 51.31 % | 51.45 % |
| Has kids < 18 in household | | 31.89 % | 30.53 % | 32.28 % | 30.17 % |
| Has partner/spouse | | 64.47 % | 64.51 % | 62.49 % | 61.55 % |
| Works away from home | | 23.89 % | 22.86 % | 24.49 % | 22.83 % |
| Own home | | 67.21 % | 71.88 % | 64.43 % | 67.41 % |
| Had COVID-19 (T2) | | 8.03 % | 7.82 % | – | – |
| Has health insurance | | 87.93 % | 93.52 % | 88.58 % | 92.17 % |
| Region | Northeast | 17.83 % | 19.88 % | 17.66 % | 19.40 % |
| | Northcentral | 20.91 % | 24.40 % | 20.90 % | 22.59 % |
| | South | 37.13 % | 35.54 % | 37.25 % | 36.27 % |
| | | 24.13 % | 20.18 % | 24.20 % | 21.74 % |
| Income | <$20 K | 15.82 % | 9.03 % | 16.76 % | 11.95 % |
| | $20 K to <$30 K | 9.37 % | 7.88 % | 9.98 % | 8.58 % |
| | $30 K to <$40 K | 9.27 % | 7.72 % | 10.64 % | 8.48 % |
| | $40 K to <$50 K | 8.23 % | 8.87 % | 10.44 % | 11.24 % |
| | $50 K to <$60 K | 10.83 % | 9.03 % | 9.12 % | 8.38 % |
| | $60 K to <$70 K | 8.74 % | 9.03 % | 7.03 % | 7.76 % |
| | $70 K to <$100 K | 14.77 % | 19.05 % | 13.28 % | 16.55 % |
| | $100 K to <$150 K | 15.68 % | 18.56 % | 13.93 % | 16.14 % |
| | $150 K or more | 7.29 % | 10.84 % | 8.83 % | 10.93 % |
| Race/Ethnicity | Black | 11.42 % | 14.59 % | 11.31 % | 14.99 % |
| | White | 71.53 % | 73.08 % | 71.38 % | 70.11 % |
| | Latinx | 16.40 % | 8.27 % | 16.56 % | 9.96 % |
| Political Party | Republican | 24.31 % | 24.66 % | 24.05 % | 23.74 % |
| | Democrat | 35.76 % | 38.20 % | 35.77 % | 37.43 % |
| | Independent | 31.98 % | 30.98 % | 33.00 % | 32.77 % |
| Education (years) | | 13.94 (2.75) | 14.99 (2.70) | 14.02 (2.82) | 14.77 (2.76) |
| Household size | | 2.76 (1.39) | 2.62 (1.42) | 2.87 (1.59) | 2.66 (1.51) |
| Age | | 47.36 (17.54) | 49.82 (16.48) | 47.76 (17.98) | 49.85 (17.17) |
| Changes in beliefs (T2-T1) Effectiveness for self | | 0.17 (0.93) | 0.22 (0.88) | – | – |
| | Effectiveness for others | 0.24 (0.96) | 0.30 (0.91) | – | – |
| | Safety | 0.58 (1.08) | 0.68 (1.00) | – | – |

*Note.* M indicates mean, % indicates percentage and SD indicates standard deviation. Changes in beliefs were measured by subtracting belief at T1 from the matched belief at T2. Belief items at T1 and T2 were measured on 1–4 scale. The weighted means and standard deviations use weights developed to represent the U.S. population. Panel descriptive data was measured in a wave preceding T1 of this study (T0; May/June 2020) unless otherwise indicated.

*3 = somewhat agree; 4 = strongly agree*). These items were presented in random order.

Belief items were modified at T2 to acknowledge the (no longer hypothetical) availability of the vaccine, with items phrased based on participants' reported vaccination behaviour. For those who were not yet vaccinated, the conditional tense was used (e.g., "How much do you disagree/agree that if you were vaccinated against the coronavirus. . .you *would* be protecting others in your community from getting infected"). For those who had received at least one dose of a vaccine, the present or past tense was used (e.g., "Thinking about your experience getting vaccinated against the coronavirus, how much do you disagree/agree. . . you *are* protecting others in your community from getting infected."). In addition, the safety belief item at T2 was re-worded to the following: "You [would experience / experienced] serious side effects for longer than a few days." Those who had not been vaccinated were asked about anticipated future side effects (would experience); those who had been vaccinated were asked about their experienced side effects (experienced). The safety item was reverse-coded so higher scores indicated stronger pro-vaccine beliefs. To measure changes in beliefs, we subtracted the T1 belief from the matched T2 belief.

### 2.4. Analyses

Using Stata 15 [40], we estimated linear regressions examining the association between change in COVID-19 vaccination intention/behaviour and changes in beliefs about vaccine safety, effectiveness for self, and effectiveness for others. To check for potential confounders, we re-ran analyses controlling for demographic variables – including age, income, education, working outside the home, household size, having health insurance, race/ethnicity, and political party. We considered these variables to be potential confounders because they were significantly correlated with change in at least one of the three vaccine beliefs. Next, recognizing causal order as a possible threat to inference, we conducted longitudinal analyses, fitting cross-lagged panel correlation models predicting intention and beliefs at T2 from T1 measures of those variables. Subsamples were separately weighted to represent the U.S. population. Analyses incorporate corrected standard errors using the Stata svy command.

## 3. Results

### 3.1. Descriptive data

Table 1 shows descriptive data for all variables included in the main analysis, as well as demographic characteristics. Among the weighted analytic sample at T2, 58 % of respondents had received at least one dose of a COVID-19 vaccine. Between T1 and T2, mean vaccination intention/behaviour (1–4) increased from 2.78 to 3.18. Among respondents who did not intend to get vaccinated at T1 (somewhat unlikely or very unlikely) ($n = 244$), approximately 45 % shifted to intending to get vaccinated (somewhat likely/very likely/vaccinated) by T2. Overall, beliefs became more favourable toward COVID-19 vaccines. On 1–4 scales, the mean belief in safety shifted from 2.48 to 3.06, belief in effectiveness for others shifted from 2.90 to 3.15, and belief in effectiveness for self shifted from 2.69 to 2.86. The three vaccine beliefs at both time points, intention at T1 and intention/behaviour at T2 were significantly correlated with each other (see Table 2).

### 3.2. Main results

We assessed the relationship between changes in pro-vaccine behavioural beliefs and changes in pro-vaccination intention/behaviour. Linear regressions showed belief change from T1 to T2 was significantly associated with intention/behaviour change for all three belief types (effectiveness for self $B = 0.38$, SE = 0.09; effectiveness for others $B = 0.43$, SE = 0.07; safety $B = 0.39$, SE = 0.07). These results are shown in Table 3. Adjusting for potential confounders did not decrease the size of coefficients.

While initial analyses showed changes in beliefs were *associated* with change in intention/behaviour, they do not establish causal order. Did beliefs influence subsequent intention/behaviour or did the experience of getting vaccinated between T1 and T2 influence subsequent beliefs? We were limited to two waves of data and could not directly test whether prior changes in beliefs (e.g., from T1 to T2) affected subsequent change in intention (e.g., from T2 to T3). However, we could examine whether (1) baseline beliefs at T1 predicted future intention/behaviour at T2 controlling for intention at baseline and (2) whether baseline intention predicted future beliefs controlling for beliefs at baseline. Fig. 1 (belief in vaccine effectiveness in protecting oneself), Fig. 2 (belief in vaccine

**Table 3**
Linear regression: Change in COVID-19 vaccination intention/behaviour on changes in pro-vaccine beliefs.

| Changes in beliefs | *B* (SE) | *B* (SE) | *B* (SE) |
|---|---|---|---|
| Effectiveness for self | 0.38*** (0.088) | | |
| Effectiveness for others | | 0.43*** (0.069) | |
| Safety | | | 0.39*** (0.066) |
| Constant | 0.34*** (0.066) | 0.29*** (0.061) | 0.17* (0.074) |
| $R^2$ | 0.1006 | 0.1411 | 0.1435 |
| *N* | 659 | 654 | 658 |

*Note.* Standard errors in parentheses; Weights developed to represent the U.S. population. * p < 0.05, ** p < 0.01, *** p < 0.001.

**Table 2**
Descriptive data and correlation matrix for COVID-19 vaccination intention/behaviour and pro-vaccine beliefs at T1 and T2.

| | | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time 1 | 1. Intention | 2.78 | 1.19 | | | | | | | |
| | 2. Belief in effectiveness for self | 2.69 | 0.86 | 0.59*** | | | | | | |
| | 3. Belief in effectiveness for others | 2.90 | 0.99 | 0.65*** | 0.74*** | | | | | |
| | 4. Belief in safety | 2.48 | 0.84 | 0.51*** | 0.40*** | 0.35*** | | | | |
| Time 2 | 5. Intention/behaviour | 3.18 | 1.22 | 0.58*** | 0.54*** | 0.55*** | 0.37*** | | | |
| | 6. Belief in effectiveness for self | 2.86 | 0.97 | 0.41*** | 0.48*** | 0.43*** | 0.27*** | 0.65*** | | |
| | 7. Belief in effectiveness for others | 3.15 | 0.97 | 0.48*** | 0.50*** | 0.52*** | 0.28*** | 0.73*** | 0.67*** | |
| | 8. Belief in safety | 3.06 | 1.03 | 0.36*** | 0.37*** | 0.36*** | 0.35*** | 0.62*** | 0.56*** | 0.55*** |

*Note.* $n = 665$. M indicates mean and SD indicates standard deviation. Weights developed to represent the U.S. population. All items measured on 1–4 scale. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

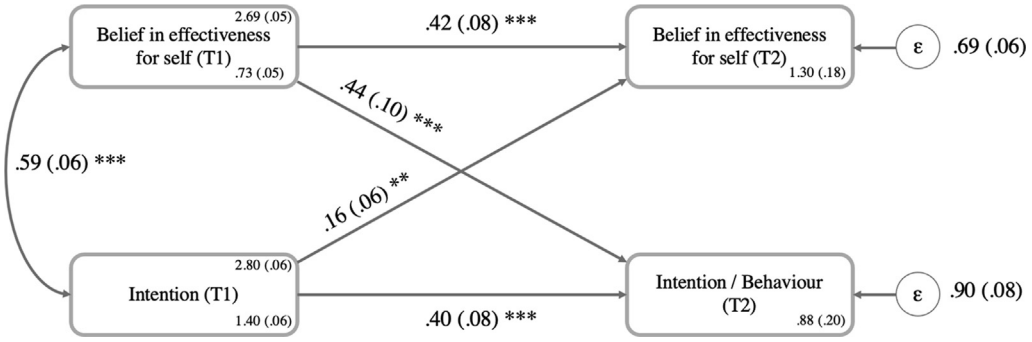


**Fig. 1. Cross-lagged model: Belief in COVID-19 vaccine effectiveness for protecting oneself.** *Note.* $n$ = 659. Standard errors in parentheses; weights developed to represent U.S. population. * p < 0.05, ** p < 0.01, *** p < 0.001.

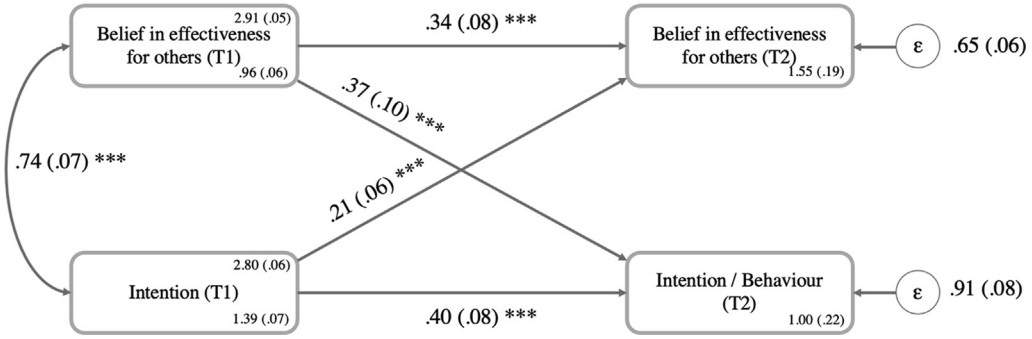


**Fig. 2. Cross-lagged model: Belief in COVID-19 vaccine effectiveness for protecting others.** *Note.* $n$ = 654. Standard errors in parentheses; weights developed to represent U.S. population. p < 0.05, ** p < 0.01, *** p < 0.001.

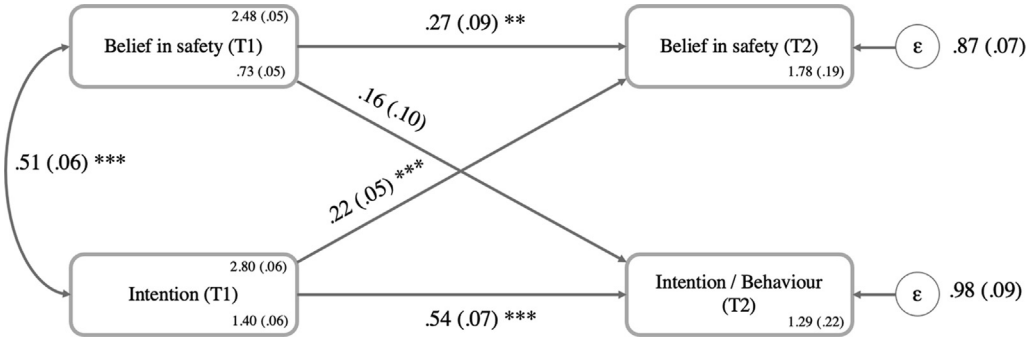


**Fig. 3. Cross-lagged model: Belief in COVID-19 vaccine safety.** *Note.* $n$ = 658. Standard errors in parentheses; weights developed to represent U.S. population. * p < 0.05, ** p < 0.01, *** p < 0.001.

effectiveness for protecting others) and Fig. 3 (belief in vaccine safety) present weighted cross-lagged panel models. As shown in Figs. 1 and 2, both T1 vaccine effectiveness beliefs (self and others) predicted T2 intention/behaviour, adjusting for T1 intention (effectiveness for self $B$ = 0.44, SE = 0.10; effectiveness for others $B$ = 0.37; SE = 0.10). However, as shown in Figure 3, T1 safety beliefs were not significantly predictive of T2 intention/behaviour adjusting for T1 intention ($B$ = 0.16, SE = 0.10). In short, prospective beliefs about the vaccine's safety – anticipated serious side effects – did not influence subsequent intentions or behaviour. There was also evidence for reverse influence of intention on all three beliefs. T1 intention predicted T2 beliefs, adjusting for T1 beliefs (effectiveness for self $B$ = 0.16, SE = 0.06; effectiveness for others $B$ = 0.21, SE = 0.06; safety $B$ = 0.22, SE = 0.05). As such, one's baseline intention to get vaccinated – and their likely uptake of the vaccine between waves 1 and 2 – predicted **future** beliefs about vaccine safety and effectiveness.

## 4. Discussion

Identifying factors that increase vaccination intention, particularly among those who are initially hesitant, is important for public health. In this longitudinal survey study, we found strengthened beliefs in favour of the safety and effectiveness of COVID-19 vaccines from July 2020 to April/June 2021 were significantly associated with increased vaccination intention and behaviour over the same period. Additional analyses addressed the issue of causal order, recognizing that the observed association of simultaneous changes in beliefs and intentions could reflect the effects of belief on

intention, of intention on belief, or both. Cross-lagged analyses suggested effectiveness beliefs predicted subsequent vaccination intention/behaviour; believing a vaccine would protect oneself and others from infection in July 2020 predicted vaccination (or strongly intending to get vaccinated) in April/June 2021, controlling for prior intention. In contrast, the belief that vaccines would be safe did not appear to predict subsequent intention/behaviour.

There was complementary evidence that prior intention predicted changes in all three beliefs. Indeed, the evidence suggests that there is reciprocal influence for the belief and intention variables, with one exception: baseline belief in vaccine safety does not predict subsequent change in intention/behaviour. We speculate that baseline safety beliefs did not predict follow-up change in intention because the anticipated safety concerns expressed at T1 (before the vaccine was available) were not relevant to the experienced or publicly known information about vaccination safety available by T2. Respondents may have initially feared side effects – for a vaccine that was merely hypothetical at baseline – but by follow-up, reported few or no severe side-effects.

Our results are consistent with the examined component of the RAA, showing that certain behaviour-specific beliefs can be strong predictors of intention and behaviour (e.g., [8,12,13]). Specifically, the increased belief that vaccines will be effective in protecting oneself and others from infection was strongly associated with subsequent decreased vaccine hesitancy. While prior studies have examined the relationship between behavioural beliefs and intention/behaviour cross-sectionally, this longitudinal survey study, to our knowledge, is the first to consider *changes* in beliefs and intention/behaviours over time. We show that it is possible for beliefs about the effectiveness of vaccines to shift, and that such shifts may increase openness to vaccination. Importantly, changes in behavioural beliefs may be driven by thoughtful and deliberate communication campaigns; they may also be driven by shifts in peer norms; equitable allocation and distribution strategies; collaboration with trusted stakeholders; and improved accessibility [41]. Communication efforts in tandem with structural changes may be integral to increasing vaccine uptake.

### 4.1. Implications

The results of this study are promising. First, aligning with other longitudinal survey studies, among respondents in our sample who were initially hesitant about COVID-19 vaccines in July 2020, 45 % were vaccinated or intending to vaccinate in April/June 2021 [4,5]. Our study findings indicate that increased belief in vaccine effectiveness may – at least partially – explain this change in intention and behaviour. We recognize that the effectiveness measures used in this study – which centre on protection from infection, rather than severe illness or hospitalization – may limit inferences. All of our data were collected before the spread of the Omicron variant and breakthrough infections [42]. Nevertheless, this finding is important for ongoing vaccine efforts. Vaccine hesitancy remains a challenge for continued immunization (23 % of vaccinated U.S. adults definitely do not intend to get a recommended booster dose) and child vaccination (27–32 % of parents with children under 18 report they definitely do not intend to get their child vaccinated) [43]. Yet we show that beliefs about the vaccines continued to shift, and these belief changes have predicted changed vaccination decisions. Public health messages which contribute to increased pro-vaccine beliefs can play a critical role in influencing vaccination uptake. As recommendations and eligibility criteria evolve, public health messages that focus on the protective benefits of vaccination (both for oneself and for others) may be particularly effective in decreasing hesitance.

### 4.2. Strengths & limitations

This study has several strengths, including the use of a large, nationally representative sample and longitudinal analyses. Surveying the same participants in both waves permitted analysis of the association between changes in individuals' beliefs and vaccination intention over time. Cross-lagged analyses help strengthen causal claims by providing evidence that prior behavioural beliefs predict future vaccination intention/behaviour.

Cross-lagged analyses were particularly important in establishing that causal order may differ based on belief type. Our results are consistent with a claim that perceptions of vaccine effectiveness influenced vaccination while all three beliefs were *influenced by* vaccination intention. At T2, the safety belief item asked about experienced side effects rather than anticipated side effects as at T1. We speculate that the lack of influence of T1 safety beliefs on T2 outcomes in the cross-lagged model may reflect the fact individuals did not experience and did not hear about the bad side effects they expected at T1. These findings illustrate the importance of using cross-lagged models to support causal claims.

The present study faces limitations common to survey-based research designs, including a reliance on self-reported outcomes and the potential for unmeasured confounders with different lags of effect on the focus variables to bias estimates of effects. Despite our efforts to strengthen causal claims through the use of longitudinal data and cross-lagged analyses, some threats to inference are inevitable in the absence of a true experimental design. Our study was also limited to two waves of data that were collected as part of a larger research project. Additional time points would strengthen our ability to make causal inferences about whether prior changes in belief influenced future changes in vaccination intention. In addition, we chose to focus on just three potential belief targets – safety, effectiveness for self, and effectiveness for others – utilizing a subset of the RAA. This approach is by no means definitive; for example, other models of health behaviour change (e.g., the health belief model) integrate elements of risk (e.g., perceived severity and susceptibility to disease). Future research could consider other components of the RAA by examining the relationship between changes in normative and control beliefs and change in vaccination intention.

## 5. Conclusions

Vaccine hesitancy remains a barrier to ending the COVID-19 pandemic. However, many who were initially hesitant have since become vaccinated. Understanding the factors that contribute to changes in vaccine hesitancy is important for informing public health communication efforts moving forward. The findings of this study suggest that individuals who did not intend to get a COVID-19 vaccine in July 2020 were more likely to be vaccinated 9 to 11 months later if they became more convinced of the vaccines' effectiveness. Communication interventions highlighting the ability of COVID-19 vaccines to protect oneself and others may be particularly effective in reducing vaccine hesitance.

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## CRediT authorship contribution statement

AK, DC, and EJ co-led the study; and contributed to the conceptualization, formal analysis, investigation, methodology, and writing and revising the original and revised draft. RH supervised the

study; contributed to study methodology; provided resources; and wrote and reviewed drafts.

## 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.

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