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Predictors of Change in Vaccination Decisions Among the Vaccine Hesitant: Examining the Roles of Age and Intolerance of Uncertainty

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Abstract

Background Vaccine hesitancy and resistance pose significant threats to controlling pandemics and preventing infectious diseases. In a group of individuals unvaccinated against the disease caused by the SARS-CoV-2 coronavirus (COVID-19), we investigated how age, intolerance of uncertainty (IU), and their interaction affected the likelihood of having changed one's vaccination decision a year later. We hypothesized that higher IU would increase the likelihood of becoming vaccinated, particularly among individuals of younger age. We predicted that this effect would remain significant, even after controlling for delay discounting and trust in science.

Purpose The goal of this research was to understand the factors influencing changes in vaccination decisions among the vaccine hesitant.

Methods In a larger longitudinal study, ~7,500 participants from Prolific.co completed demographic and vaccination status questions, a delay discounting task, and the Intolerance of Uncertainty Scale in June–August 2021. Approximately 3,200 participants completed a follow-up survey in July–August 2022, answering questions about vaccination status, reasons for vaccination decision, and trust in science. We analyzed data from 251 participants who initially had no intention of getting vaccinated and completed the follow-up survey; 38% reported becoming vaccinated in the intervening year.

Results Data were analyzed using multilevel logistic regression. Over and above other factors related to vaccination decisions (delay discounting, trust in science), younger participants were more likely to change their decision and become vaccinated a year later, especially if they had higher IU, confirming our predictions. Primary reasons for becoming vaccinated were necessity and seeking protection against the virus.

Conclusions These findings highlight the complex interplay between age, uncertainty, and vaccination decisions, and inform health policies by suggesting the need for tailoring interventions to specific concerns in different age groups.

Lay Summary

Vaccine hesitancy and resistance pose significant threats to controlling pandemics and preventing infectious diseases. It is important to understand the factors that influence whether or not unvaccinated individuals change their mind and get vaccinated. We investigated how age and one's intolerance of uncertainty predicted the likelihood of changing one's mind about getting a COVID-19 vaccination in a group of 251 unvaccinated participants. In mid-2021, these individuals indicated they had no intention to get vaccinated; by mid-2022, 38% of them reported that they had been vaccinated. Over and above other factors known to be related to vaccination decisions (delay discounting and trust in science), we found that younger participants were more likely to have changed their minds and become vaccinated a year later, especially if they were less tolerant of uncertainty. Of the reasons provided by participants for having been vaccinated, necessity and seeking protection against the virus were the most common. These findings highlight the complex interplay between age, uncertainty, and vaccination decisions. Importantly, these findings will inform health policies, suggesting the need for tailoring interventions to specific concerns in different age groups.

Key words Intolerance of uncertainty · Public health measures · Vaccination · Vaccine hesitancy · COVID-19

Introduction

Widespread vaccination has been critical to containing the COVID-19 pandemic [1] as well as other infectious diseases [2], but efforts have been threatened by vaccine hesitancy and resistance [3, 4]. Research on predictors of COVID-19 vaccination has considered effects of various factors, including environmental factors (e.g., government regulations and COVID-19 impact severity) [5], and at the level of the individual, both immutable variables (e.g., demographic and personality variables) [6–9], and potentially modifiable variables including psychological (e.g., anxiety and depression) [10] and cognitive mechanisms (e.g., trust in science and delay discounting) [11–13]. Although the intention-behavior relationship has not been empirically demonstrated for all of the public health measures recommended during the COVID-19 pandemic [14], research shows that most, but not all, individuals tend to follow through on their vaccination intentions [15]. From a public health perspective, as protective behaviors become increasingly optional and responsibility for long-term immunity maintenance shifts from official mandates to individual decision-making, it is necessary to identify the factors that contribute to change in people's attitudes, intentions, and behaviors towards vaccines and boosters—particularly in those who are vaccine hesitant. The current longitudinal study investigated whether two factors known to influence health intentions and behaviors—intolerance of uncertainty (IU) and age—predicted decisions to be vaccinated in adults who were initially vaccine hesitant. Understanding the factors contributing to how working-aged adults change their minds about vaccination during a pandemic is crucial for supporting safe return to work (including essential occupations) and school as well as social activities.

The pandemic significantly increased uncertainty in many aspects of life. The sudden and widespread outbreak of COVID-19 caused global disruptions affecting healthcare, employment, education, and social interactions. The rapidly changing nature of the virus [16] and the subsequent implementation of various containment measures such as lockdowns and travel restrictions, created a sense of unpredictability and ambiguity [17–19]. Constantly evolving information, conflicting reports, and misinformation surrounding the effectiveness of preventive measures further contributed to the heightened sense of uncertainty experienced by individuals and communities worldwide [20]. IU, a cognitive bias marked by a fear of, and reduced ability to handle, the unknown [21], is an important factor in understanding the process of behavior change when it comes to overcoming vaccine hesitancy. The construct of IU has recently captured a lot of attention in clinical psychology [22, 23], as it is recognized as global trait that may serve as a transdiagnostic risk factor for emotional psychopathology [24] and emerging IU-focused interventions aim to increase people's tolerance of uncertainty (e.g., through mindfulness and exposure therapy [25]). IU is composed of two factors: *prospective anxiety* that captures cognitive components related to uncertainty and *inhibitory anxiety* that captures certain safety behaviors associated with encountering uncertainty (e.g., avoidance). Interestingly, IU is associated with two potential behavioral outcomes with respect to vaccination. One is to reduce or eliminate the source of uncertainty. There is evidence that higher IU is associated with a higher likelihood of engaging in public health measures as a strategy to mitigate fears of the virus itself [20]. The tendency to engage in coping behaviors, such as checking, repeating, and excessively preparing, with the intention to enhance one's perceived control over a given situation and reduce anxiety, is also well-documented in the literature [26, 27].

On the contrary, others have reported that, despite higher distress about COVID-19, those with higher IU are less likely to get vaccinated due to heightened fears and concerns about unknown risks and efficacy of the vaccine [28]. Gillman et al. [29] similarly report that lower tolerance of ambiguity is associated with vaccine hesitancy, again likely because of uncertainty around efficacy. This phenomenon, known as "uncertainty paralysis" [30], represents another type of coping behavior—avoidance—that has been well-researched in relation to worry and anxiety [31]. Such behavioral avoidance has been found to be predicted by cognitive inflexibility during times of increased uncertainty [32].

In the context of vaccination, two constructs related to IU are trust in science (i.e., the extent to which one trusts in scientists and scientific findings related to vaccines) [11] and delay discounting (i.e., a near-universal tendency to favor smaller immediate rewards over large later rewards) [12]. A previously established negative relationship between uncertainty and trust in health information about COVID-19 [29] suggests that increased IU may be associated with lower trust in science. IU was also found to be positively correlated with delay discounting [33]. It was reasoned that delayed rewards are uncertain, and therefore would require greater tolerance of uncertainty [33, 34].

The factors that determine whether someone with high IU is more likely to engage in behaviors such as vaccination in an effort to reduce feelings of uncertainty or instead become paralyzed and remain unvaccinated remain unclear. Age may be critical to understanding the relation of IU to vaccination decisions under these circumstances. Although younger adults generally show more resistance to vaccination than their older counterparts [35], and COVID-19 vaccination rates are lower amongst younger adults [36], there is also evidence that younger adults tend to be more open [37] and more encouraged [38] to change their health-related behaviors. Moreover, when faced with emotionally salient situations, younger age is associated with increased use of problem-solving strategies to regulate emotions by managing or eliminating the stressor itself [39]. Taken together, we hypothesize that unvaccinated individuals of younger age with higher IU would be more likely to change their mind and decide to get vaccinated as a means to reduce or eliminate their experience of COVID-related uncertainty.

When faced with emotionally salient situations, older age is associated with increased use of passive or avoidant-denial coping strategies [40]. Coupled with less flexibility in the selection of coping strategies [41], it is likely that, as one gets older, higher IU becomes increasingly associated with an avoidant response such as uncertainty paralysis. Therefore, even though age has been one of the most salient clinical indicators monitored in relation to the risk of SARS-CoV-2 exposure [42] and infection [43–45], severity of illness [46], and vaccine availability, we predict that with increasing age, unvaccinated individuals with higher IU would be less likely to decide to become vaccinated.

Given that IU is a trait-like variable and may not tell us about the specific source of uncertainty contributing to health-related decisions during the pandemic, it is important

to also qualitatively assess reasons for vaccination decisions. There are several sources of uncertainty that may contribute to decisions to get vaccinated, including mandates (e.g., requirements for work or school), trust in science (e.g., skepticism about vaccine effectiveness), concerns about health, and possible side effects (of both vaccination and contracting the virus).

In the current study, we examined data from a subsample of a large longitudinal survey [13], focusing on an adult sample of individuals aged 18 to 69 years who reported being unvaccinated against SARS-CoV-2 in mid-2021. We investigated whether, a year later, they had changed their mind and were vaccinated, and whether IU and age measured at Time 1 interacted to predict change in vaccination status over time, after controlling for two variables related to vaccination decisions: delay discounting [12, 13, 47] and trust in science [11]. We hypothesized that higher IU would be associated with a higher likelihood of changing minds about vaccination with younger age, while the reverse association would be evident with older age.

Methods

Study methods and results are reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for cross-sectional studies [48]. The study was not pre-registered.

Participants

Participants were recruited to participate in a larger study through an online platform (Prolific.co). At *Time 1* (July–August, 2021), we aimed to recruit as many participants as possible to ensure a large enough sample of participants who might remain unvaccinated over time. The final *Time 1* sample comprised 6,926 participants from 13 countries [12, 13]; *n* = 2,890 indicated that they were fully vaccinated, 1,465 that they were partially vaccinated, 2,012 that they were not vaccinated yet but were planning to get vaccinated in the future, and 559 that they were unvaccinated and did not intend to get vaccinated in the future.

At *Time 2*, approximately one year later (July–August, 2022), all participants in the final sample of the larger study were invited to complete a follow-up survey. Of the 3,185 who participated a year later, a subset of individuals (*n* = 251) had indicated at *Time 1* that they had no intention to get vaccinated in the future. Of this sub-sample, 38% reported being vaccinated at *Time 2*.

Participants provided demographic information at *Time 1*. For the sub-sample reported here, mean age was 31.93 years old (*SD* = 10.60); 127 self-identified as female, 124 as male, and 0 as non-binary. Approximately 24% of the sample were residing in the USA, 15% in Poland, 9% in the UK, 8% in Italy, 7% in Canada, 7% in Australia, 6% in Spain, 5% in France, 5% in Mexico, 4% in Germany, 4% in New Zealand, 4% in Portugal, and 1% in the Netherlands. Given the internationality of our sample, we used a subjective measure of relative income where participants estimated their current income relative to others in their own country/region on a sliding scale (0 = low, 50 = average, 100 = high [49, 50]). Average subjective relative income was 37.88 (*SD* = 21.10). Approximately 20% of our sample self-identified as essential workers in occupations supplying critical services during the pandemic: government; health and safety (e.g., healthcare and emergency response); utilities (e.g., water, energy, sanitation, transport, and communications); food (e.g., supermarkets); and manufacturing. In terms of the highest level of education, 38% of the sample reported having a high school education, 47% a university degree (undergraduate degree or professional equivalent), and 15% a postgraduate degree.

We also examined the demographic characteristics of individuals who at *Time 1* expressed no intention to get vaccinated and were invited to participate at *Time 2* but chose not to (Supplementary Table S1). Individuals who returned to participate in the study at Time 2 (*M* = 31.93, *SD* = 10.60) were significantly older than individuals who did not return to participate at Time 2 (*M* = 28.50, *SD* = 9.50). No other significant differences in demographic variables were observed between those who returned to participate in Time 2 of the study and those who did not.

Measures

Intolerance of uncertainty scale-12 ([51])

The intolerance of uncertainty scale-12 (IUS-12) is a 12-item measure of one's difficulties tolerating uncertainty (e.g., "I always want to know what the future has in store for me"). Participants provided responses to items on a six-point scale (0 = Not at all characteristic of me; 5 = Entirely characteristic of me). The *IU* score was the sum of participants' responses to the 12 items, ranging from 0 to 60; the average score was 34.27 (*SD* = 9.61). The scale demonstrated acceptable internal consistency (omega hierarchical = 0.84; Supplementary Materials).

Vaccination status

Participants were asked to indicate their vaccination status at both *Time 1* and *Time 2*. Participants chose between five options in response to the question about their vaccination status: 1 = yes, I have received all necessary doses, 2 = yes, although I require another dose, 3 = no, but I am planning to get vaccinated, 4 = no, I am not planning to get vaccinated, 5 = prefer not to say. As described earlier, only participants with a *Time 1* response of 4 ("no, I am not planning to get vaccinated") were included in this study. From their responses to this question at *Time 2*, a binary *vaccination status* variable was created as the primary outcome variable, distinguishing between those who were vaccinated (fully or partially) or not (including both those who were planning and not planning to get vaccinated in the future).

Reasons for vaccination

At *Time 2*, participants had the opportunity to explain their reason(s) for their decision to be vaccinated or not. We first examined the full corpus of responses in the larger study to identify the main reasons mentioned by participants. Reasons for getting vaccinated (or not) were: (i) ending the pandemic (e.g., "it will stop the virus"), (ii) protecting oneself or others from COVID-19 (e.g., "to protect myself and my family"), (iii) (non-) necessity (e.g., "I had to in order to continue being enrolled in college"), (iv) trust (in science, government, or vaccines; e.g., "don't trust the vaccine"), (v) vaccine availability, (vi) health reasons (e.g., "medical complications," "side effects"), or (vii) other (e.g., "afraid of needles"). These categories were then used to classify each participant response provided by the current sub-sample; if multiple reasons were mentioned, the most prominent reason was scored. To establish the inter-rater reliability of this classification, the lead

rater (S.F.C) and two additional raters (R.T. and W.F.) independently classified 100 responses randomly selected from the larger study. Raters had 84–86% agreement on their categorizations of responses, and acceptable inter-rater reliability (Cohen's Kappa ranged from = 0.79–0.81). S.F.C. then scored all of the responses from the participants reported on in this paper.

Trust in science

We used two items designed to measure trust in scientific institutions by asking participants to indicate their confidence in science and in scientists on a scale from 0 = "no confidence at all" to 10 = "a lot of confidence" [52]. Ratings on the two items were added together into a single composite *Trust in Science* variable.

Delay discounting

In this intertemporal choice procedure [12, 13, 53, 54], participants viewed pairs of monetary amounts and were asked to choose between smaller, immediate rewards which varied between trials, and a larger, delayed reward of $2,000. Participants were asked to make six choices at each of seven delays for the larger reward (waiting 1 week, 1 month, 3 months, 6 months, 1 year, 3 years, and 10 years before receiving the $2,000 reward). An iterative, adjusting-amount procedure was used in which the amount of the immediate reward was increased or decreased based on the participant's previous choice at that delay, converging on the amount of the immediate reward equivalent in subjective value to the delayed reward. Degree of discounting was measured by examining the subjective values of reward across the seven delays and computing *Area-under-the-Curve* (AuC), a single, theoretically-neutral measure of discounting [55]. The scores range from 0 to 1, with lower AuC representing a greater discounting rate (i.e., greater tendency to choose smaller immediate rewards over larger later rewards).

Attention checks

To identify random responders, three items from the Conscientious Responder Scale [56] were included at select points within the survey at *Time 1* (e.g., "To answer this question, please choose option three, neither agree nor disagree"). At *Time 2*, only one item was used given that the survey was much shorter. None of the participants in the current subsample failed the attention check.

Procedure

Data were collected longitudinally using two online Qualtrics surveys as part of a larger study. At *Time 1*, participants provided informed consent and, among other measures (see Halilova et al., [12, 13]), provided demographic information (including age and country of residence), completed the IUS-12 [51] and the delay discounting task, and answered questions about their COVID-19 vaccination status. At *Time 2*, participants completed a series of COVID-related questions, including vaccination status and their reasons for their vaccination decision, as well as questions regarding their trust in science.

Statistical Analysis

We computed Pearson's product moment correlations between the variables of interest. Multilevel logistic regression models were constructed using R packages *lme4* [57] and *lmerTest* [58]. First, we constructed the model with vaccination status at *Time 2* (unvaccinated vs. vaccinated) as the outcome variable, and age (*Time 1*), IUS-12 (*Time 1*), and age × IUS-12 interaction as predictors. Each participant's vaccination status at *Time 2* (Level 1) was nested within country (Level 2) to account for possible systematic differences across countries. A likelihood ratio test showed that the model including age × IUS-12 interaction accounted for significantly more variance in the data compared to an intercept-only model, $\chi^2(3) = 16.91$, $p < .001$. The model was then expanded to include AuC (*Time 1*) and Trust in Science (*Time 2*) as covariates to test whether the age × IUS-12 interaction remains significant after controlling for these variables.

Results

Descriptive Statistics

Of those who completed *Time 2* ($n = 251$), 38% reported that they were now vaccinated. Descriptive statistics for the key variables of interest are presented in Table 1, broken down by vaccination status. Supplementary Figure S1 shows the distribution of age across the sample. The correlations between the variables are reported in Table 2.

Vaccination Status

The logistic multilevel model without AuC and Trust in Science as covariates showed a significant age × IUS-12 interaction on the likelihood of change in vaccination status a year after expressing no intention of getting vaccinated, $b = -0.06$, SE = 0.02, $z = -3.00$, OR = 0.95, 95% CI [0.91, 0.98], $p = .003$. This interaction remained significant even after controlling for the effects of AuC and Trust in Science (Table 3; Fig. 1). Specifically, the younger the age of the participant, the higher the odds of change in vaccination status a year later with higher IU, $OR = 1.05$, $p = .006$. Controlling for age, AuC and Trust in Science, higher IU was associated with increased odds of being vaccinated, $OR = 6.60$, $p < .001$. Similarly, controlling for IU, AuC, and Trust in Science younger age was a significant predictor of higher odds of being vaccinated a year after reporting no intention to get vaccinated, $OR = 1.05$, $p = .006$.

Also of interest were the effects of the predictors that were not a primary focus of our hypotheses: Trust in Science and delay discounting (AuC). After controlling for the effects of IUS, age, and AuC, greater Trust in Science predicted an

Table 1 Descriptive Statistics for Variables of Interest

	Vaccinated	Unvaccinated
n	95	156
Mean age (years)	29.52 (9.79)	33.40 (10.83)
Age range (years)	18–69	18–64
Mean IUS-12 score	35.89 (9.21)	33.28 (9.75)
IUS-12 range	15–59	12–58
Mean AuC	0.36 (0.27)	0.40 (0.25)
AuC range	0.01–0.99	0.01–0.99
Mean Trust in Science score	13.79 (4.07)	11.03 (4.97)
Trust in Science range	0–20	0–20

Standard deviation is shown in parentheses. *AuC* = Area-under-the-Curve; and *IUS-12* = Intolerance of Uncertainty Scale-12.

increased likelihood of getting vaccinated, $OR = 1.14$, $p < .001$. After controlling for the effects of IU, age, and Trust in Science, AuC was not a significant predictor of vaccination, $OR = 0.77$, $p = .683$.

Vaccination reasons

At *Time 2*, participants could provide reasons for their decision to become vaccinated or not. Approximately 94% of participants who provided qualitative responses identified a single reason for their decision. Of the 95 participants who changed their mind about vaccination one year later, $n = 49$ provided reasons for their decision: 45% felt it necessary to get vaccinated (8% for social reasons, 18% for work, and 18% for other reasons), of which 95% explicitly mentioned the influence of government mandates; 29% sought protection against the virus (16% for themselves, 10% for their family, and 2% for others), of which 21% specifically mentioned preventing severe illness or death; 8% based their decision on trust in vaccines and 2% trust in science; 2% were influenced by vaccine availability; 2% had a desire to contribute to ending the pandemic; and 12% were scored as other (e.g., peer pressure). Out of 157 participants who did not change their mind and remained unvaccinated a year later, $n = 109$ provided reasons for their decision: 43% based their decision on mistrust (24% in vaccines, 10% in government, 5% in science, and 5% other); 31% said vaccination was not necessary for them; and 16% said they were protecting themselves from experiencing other health complications or side effects; and 10% mentioned "other" reasons for remaining unvaccinated, referring primarily to personal circumstances (e.g., "afraid of needles") or personal opinions (e.g., "don't like vaccines").

Table 2 Correlations Between Variables of Interest

	IUS-12	Age	AuC
IUS-12	–		
Age	−0.17	–	
AuC	−0.06	−0.11	–
Trust in Science	0.04	−0.28	−0.06

AuC = Area-under-the-curve; and *IUS-12* = Intolerance of Uncertainty Scale-12.

Discussion

This longitudinal investigation assessed the contributions of age and IU to the process of changing one's mind about getting vaccinated a year after reporting no intention to get vaccinated, over and above well-established predictors of vaccination, such as delay discounting and trust in science. We found that IU significantly interacted with age in predicting the likelihood of changing one's mind about vaccination: with younger age, those who were more intolerant of uncertainty in 2021 were more likely to be vaccinated in 2022. Thus, while younger adults may have shown greater resistance to vaccination throughout the pandemic [59], our findings suggest that younger adults with higher IU were more likely to change their minds about vaccination over the course of a year.

These findings build on extant literature emphasizing the role of IU in health behaviors, such as vaccination. IU is commonly associated with behavioral avoidance of situations that are uncertain. In the context of COVID-19, however, exposure to uncertainty was unavoidable, given the rapidly changing situation in terms of the threat of SARS-CoV-2 (e.g., waves of infection and new variants) as well as the changing policies and mandates designed to contain its impact. In those who experience higher levels of anxiety when encountering uncertainty (i.e., individuals who are highly intolerant of uncertainty), younger age was associated with an increased likelihood of changing one's mind. This finding is broadly consistent with previous work showing that younger adults have more flexible coping styles [40, 41] and are more likely to take action—in this case, getting vaccinated—as a means to eliminate stressors [39]. The findings are also consistent with previous research indicating a functional role of anxiety in health-related behaviors, showing that decisions to not get vaccinated are associated with a decrease in fear of COVID-19 [60].

Among those participants who changed their vaccination status a year after stating no intention to get vaccinated, the most commonly provided reason for doing so (approximately 45%) was because of government mandates related to work and social activities; the second most common reason (29%)

Table 3 Results of the Logistic Multilevel Model Predicting the Likelihood of Change in Vaccination Status a Year After Initially Expressing No Intention to Get Vaccinated

Fixed effects	*b*	*SE*	*z*	*p*	*OR*	95% CI
Intercept	−0.27	0.92	−0.29	.774	0.77	[0.13, 4.68]
Trust in Science	0.13	0.04	3.30	<.001	1.14	[1.05, 1.22]
AuC	−0.26	0.63	−0.41	.683	0.77	[0.23, 2.65]
Age	−0.05	0.02	−2.72	.006	0.95	[0.92, 0.99]
IUS-12	1.89	0.63	3.01	.003	6.60	[1.93, 22.57]
Age × IUS-12	−0.05	0.02	−2.73	.006	0.95	[0.91, 0.99]

Random effects	Estimate	SD
Intercept error variance (country)	0.75	0.87

Age, IUS, and AuC were measured at *Time 1*. Trust in Science and vaccination status (the outcome variable) were measured at *Time 2*. Age is measured in years. IUS-12 = Intolerance of Uncertainty-12 total score; *AuC* = Area-under-the-Curve *CI* = Confidence interval; *OR* = odds ratio; *SD* = standard deviation; and *SE* = standard error of the mean.

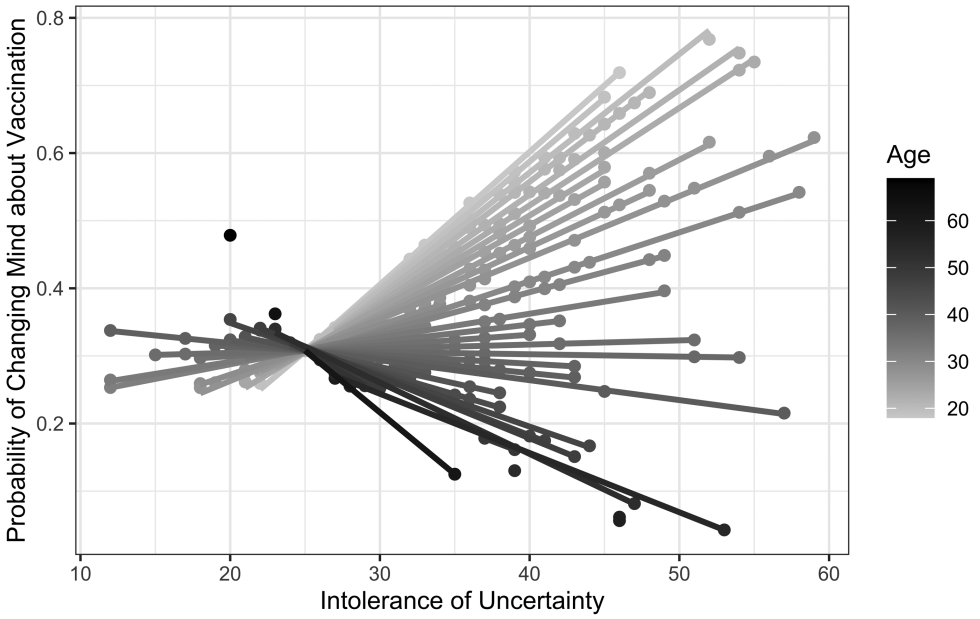

Fig. 1. The likelihood of being vaccinated (0 = unvaccinated and 1 = vaccinated) at *Time 2*, a year after reporting no intention to get vaccinated, plotted by age and total score on the Intolerance of Uncertainty Scale at *Time 1*. The plot indicates that younger age (shown in lighter shades) is associated with greater likelihood of change in vaccination status a year later in individuals with higher intolerance of uncertainty.

was related to prevention of serious illness. Even though all of these participants were vaccinated at *Time 2*, these different catalysts may reflect different forms of behavior change. On the one hand, individuals who described getting vaccinated because they were mandated to do so might have changed their behavior (i.e., became vaccinated) without changing their mind about vaccination (e.g., "I was planning to travel abroad so needed to be fully vaccinated. Otherwise I wouldn't have gotten the vaccines"). It can be reasoned that these individuals may be less likely to engage in these efforts voluntarily—an important observation now that the pandemic has been declared over and responsibility for maintaining long-term immunity via booster vaccine doses has gradually shifted from government mandates to individual decision-making. On the other hand, individuals who stated that they got vaccinated to protect themselves against severe illness may be more likely to receive future doses for long-term immunity maintenance because of the apparent change in their belief about vaccination. Future research should focus on investigating the long-term maintenance of behavior change and how to combine short- and long-term interventions to influence both rapid and sustained uptake of protective health behaviors.

Older age was associated with a lower likelihood of changing one's mind about vaccination, particularly among those who endorsed higher IU. This finding is consistent with research on uncertainty paralysis (i.e., inaction in the face of uncertainty about the outcome), both in relation to COVID-19 protective behaviors [28] and when faced with other health-related issues [61, 62]. Our results suggest that uncertainty paralysis may be a more prevalent response among individuals of older age when coping with uncertain situations, and may reflect the adoption of more avoidant coping strategies [40]. The findings are also consistent with previous research showing that as adults age, they tend to become less flexible, are more resistant to change, and display an increased preference for stability and familiarity [63]. This highlights the importance of targeted communication strategies, suggesting that approaching individuals of older age with messages that instill certainty (e.g., clear and easy-to-understand content from a trusted source, like a family doctor) [64] may be more effective in changing their mind about vaccination. Other intervention approaches may also involve psychoeducation and behavioral approaches (e.g., exposure) [65] focused on introducing strategies to reduce IU.

Another explanation for the moderating effect of age on the relationship between IU and changing one's mind about vaccination is the age differences in beliefs about uncertainty and worry. IU diminishes as people transition from young adulthood to middle and advanced age, as they learn that excessive worrying about the unknown is counterproductive and as their belief in the functional value of worry weakens [66]. It is possible that, compared to their older counterparts, younger individuals were more motivated to get vaccinated and reduce feelings of uncertainty because they experienced more worries about potential consequences of not getting vaccinated. This possibility is consistent with research showing that age moderates the relationship between COVID-19 worries and anxiety: among individuals aged 50+ years, anxiety was unrelated to perceived likelihood of contracting COVID-19, whereas among younger ages (18–49 years), these variables were positively correlated [67].

It is notable that the interaction between IU and age accounted for a significant amount of variance in likelihood of change in vaccination status, over and above other well-established cognitive predictors of vaccination, such as trust in science [11] and delay discounting [12, 13, 47]. These findings are supported by participants' qualitative reasons for their decisions, which revealed evidence of mistrust in science (e.g., "COVID vaccine is ineffective"), delay discounting (e.g., "I don't think the benefits outweighed the long-term unknown and known short-term risks"), as well as uncertainty (e.g., "I'm just worried about how my body will handle it. I mostly trust the vaccine, just not for myself."; "I needed it to travel, but I'm not sure about it so I won't get the third dose.").

Interestingly, we did not find a significant association between delay discounting, a well-established predictor of vaccination [12, 13, 15], and the likelihood of changing mind about vaccination among vaccine-hesitant individuals. The finding suggests that the process of changing mind about vaccination in this population likely relies on a different set of predictors compared to the initial decision to get vaccinated in the general population. The range of qualitative responses confirm the complexity of the decision-making process when it comes to getting vaccinated. It is possible that more effective interventions for encouraging people to engage in protective behaviors would have to carefully assess their stage of readiness for change [68]. For example, individuals in the *preparation* stage (i.e., have decided to change and are planning to take the first steps) may benefit from interventions involving individual nudges [69, 70]. In our sample, one participant stated "I've been too busy" as their reason for not getting vaccinated. It is possible that someone who is generally not opposed to vaccines but is struggling to find time to follow through on their intentions may respond well to nudges to get vaccinated through personal messages. However, the same intervention may not be effective for individuals in the *precontemplative* stage (i.e., not yet considering change), as was evident from a study showing ineffectiveness of nudges in a vaccine-hesitant population [71]. A number of participants in our sample who expressed concerns about vaccines (e.g., "I don't trust that it will not adversely affect me") may not be as receptive to the nudge messages. Incorporating alternative interventions (e.g., motivational interviewing) [72] for the individuals in the precontemplative stage may be necessary to facilitate change.

The choice of intervention should also consider the context. When a rapid change in behavior is required for short-term virus containment, government mandates seem to be the most effective, as suggested by participants' qualitative responses (e.g., "I needed the vaccine for employment") and supported by prior research [73, 74]. The pervasive uncertainty associated with the pandemic, reflected in government policies (e.g., lack of a clear timeline for easing restrictions, ambiguity about future travel, and social activity constraints), may motivate individuals to take action and get vaccinated. Conversely, if the objective is to promote long-term immunity maintenance (e.g., increasing willingness to receive vaccine booster doses), it will be essential to concentrate on programs aimed at changing people's attitudes in the long run, rather than immediately altering their behavior.

Limitations and Future Directions

The study has a number of limitations. First, our sample at *Time 2* was significantly older compared to those *Time 1* participants who were eligible for *Time 2* but lost to attrition (Supplementary Table S1). Although this finding may suggest that the *Time 2* sub-sample was not representative of *Time 1* participants who expressed no indication to get vaccinated, it should be noted that this age difference was small (mean ages of 29 vs. 32 years). Second, the majority of the participants in the current study were aged under 50 years old. Given the purpose of this research was to investigate the effect of age as a continuous variable (i.e., not to compare younger vs. older adults), it should be noted that the age range of our sample was sufficiently wide to investigate the effect of age (18–69 years; Supplementary Fig. S1). Nevertheless, additional studies replicating the effect and extending it into older-aged participants would help consolidate the findings reported here. Third, it is important to note that although the participants in this study are from 13 countries, the relatively small sample size ($N = 251$) meant we were unable to explore country-related differences. Lastly, the cross-sectional nature of this study does not allow for causal inferences about the effect of IU on individuals' decisions to get vaccinated. The field would benefit from further work testing the effect of uncertainty interventions on the process of changing mind about vaccination in vaccine-hesitant individuals. Moreover, future research in this area can benefit from studies focused exclusively on vaccine-hesitant individuals, allowing for a more nuanced investigation of the decision-making process in this population.

Conclusion

Overall, this study showed a significant interaction between age and IU on the decision to get vaccinated a year after initially expressing no intention to do so, over and above the effects of delay discounting and trust in science. In the context of this research, we also explored participants' own reasoning about their vaccination decisions. Future research could further examine various factors of people's uncertainty regarding vaccination. Unlike studies investigating predictors of vaccination during COVID-19 at a single time point, this longitudinal investigation of the process of changing one's mind about vaccination in vaccine-hesitant populations allows for a better understanding of the dynamic nature of vaccine hesitancy and when it might shift into vaccine willingness. By recognizing the influence of age and IU on changes in vaccine decisions, public health campaigns can tailor their messages to address specific concerns and uncertainties (e.g., trust in science vs. uncertainty about future mandates) in different age groups. Additionally, future longitudinal research will inform development of targeted interventions aimed at reducing vaccine hesitancy over time, emphasizing the importance of building trust in vaccines and healthcare systems. Recognizing the complex interplay between age, uncertainty, and vaccination decisions can contribute to more effective strategies to promote vaccine uptake and ultimately inform public health measures in preparation for future pandemics or other health crises.

Supplementary Material

Supplementary material is available at *Annals of Behavioral Medicine* online.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest (individual DOI forms were signed and submitted by every author).

Authors' Contributions Julia G. Halilova (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing—original draft, Writing—review & editing), Samuel Fynes-Clinton (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing—review & editing), Donna Rose Addis (Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing—original draft, Writing—review & editing), and R. Shayna Rosenbaum (Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing—original draft, Writing—review & editing)

Statement on the Welfare of Animals This article does not contain any studies with animals performed by any of the authors.

Statement of Human Rights and Ethics Approval The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The research was approved by the York University and Baycrest Research Ethics Boards REB# 19-07.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Transparency Statement

(1) This study was not formally registered. (2) The analysis plan was not formally pre-registered. (3, 4) De-identified data from this study and analytic code used to conduct the analyses presented in this study are available in a public archive Open Science Framework https://osf.io/8g5ue/?view_only=f6480e76660046f7aa87b1d20528fbb3. (5) All materials used to conduct the study are publicly available.

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