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Factors influencing Covid-19 vaccine acceptance across subgroups in the United States: Evidence from a conjoint experiment

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ABSTRACT

Public health officials warn that the greatest barrier to widespread vaccination against Covid-19 will not be scientific or technical, but the considerable public hesitancy to take a novel vaccine. Understanding the factors that influence vaccine acceptance is critical to informing public health campaigns aiming to combat public fears and ensure broad uptake. Employing a conjoint experiment embedded on an online survey of almost 2,000 adult Americans, we show that the effects of seven vaccine attributes on subjects' willingness to vaccinate vary significantly across subgroups. Vaccine efficacy was significantly more influential on vaccine acceptance among whites than among Blacks, while bringing a vaccine to market under a Food and Drug Administration Emergency Use Authorization had a stronger adverse effect on willingness to vaccinate among older Americans and women. Democrats were more sensitive to vaccine efficacy than Republicans, and both groups responded differently to various endorsements of the vaccine. We also explored whether past flu vaccination history, attitudes toward general vaccine safety, and personal contact with severe cases of Covid-19 can explain variation in group vaccination hesitancy. Many subgroups that exhibit the greatest Covid-19 vaccine hesitancy did not report significantly lower frequencies of flu vaccination. Several groups that exhibited greater Covid-19 vaccine hesitancy also reported greater concerns about vaccine safety generally, but others did not. Finally, subgroup variation in reported personal contact with severe cases of Covid-19 did not strongly match subgroup variation in vaccine acceptance.

1. Introduction

The human toll of the Covid-19 pandemic has continued unabated. Early questions about how quickly societies would achieve herd immunity have been answered by evidence that even in former hotspots such as Spain, seroprevalence was only about 5% after the first wave in spring 2020 [1]. The combination of ongoing transmission and likelihood that herd immunity will not be reached expeditiously through community infection has led to a commensurate demand for a vaccine to control the spread or intensity of the virus. By early 2021, multiple vaccines showing strong efficacy data from clinical trials have been authorized for public use [2]. Yet even an effective vaccine may have limited public health benefits if significant percentages of the public think the vaccine is unsafe and are unwilling to vaccinate. In recent years, anti-vaccination groups have undermined public uptake of vaccines, leading to recent outbreaks of vaccine-preventable diseases such as measles in Europe and the United States [3]. These groups have already begun mobilizing to challenge uptake of the Covid-19 vaccine, potentially interfering with public health authorities' hopes of widespread immunization. As former Director of the Centers for Disease Control, Thomas Frieden, observed, "This is the first time we've had an anti-vaccine movement before we've had the vaccine [4]."

Early public opinion surveys on vaccine preferences have offered widely varying estimates of vaccine hesitancy among US adults [5]. Most of these surveys are based on generic wording about vaccination that provide little context and no information about the specific attributes of the vaccine. Evidence, first emerging from clinical trials and now from real-world data about approved vaccines, has begun to clarify the nature of the vaccines available to the public. The appropriate public health question to pose is not about generic vaccination, but vaccination conditional on the specifics of the vaccine: its efficacy, side effects, and other characteristics. Further, because the human toll is uneven—minority groups and the elderly have been disproportionately affected—and rarely is vaccine hesitancy population-wide but rather localized demographically [6], understanding the factors that most

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influence vaccine hesitancy among subgroups is crucial for identifying particular vulnerabilities and informing efforts to address them.

Through a conjoint experiment conducted in the United States, we studied the vaccine attributes that affect Americans' willingness to vaccinate against Covid-19 and, critically, how the effects of those attributes vary across demographic subgroups. While previous research has employed conjoint experiments to understand how COVID-19 vaccine attributes would affect vaccine hesitancy [7–10], these studies focus primarily on the effects of vaccine attributes on willingness to vaccinate among the population as a whole, while finding only limited evidence of heterogenous treatment effects [8]. Previous research on other vaccines has shown population subgroups may react differently to the same vaccine attributes [11,12]. Our analysis builds directly on one of the first conjoint experiments into the factors driving US adults' willingness to take a COVID-19 vaccine [7] and investigates heterogeneity in how subgroups respond to different attribute levels. Our findings of heterogeneous effects can aid the targeting and content of public health outreach to specific communities to combat vaccine hesitancy.

2. Material and methods

2.1. Conjoint experiment

To assess the influence of a hypothetical vaccine's characteristics on willingness to vaccinate and how the effects of these attributes vary across important subgroups of the population, we employed a conjoint experiment. Conjoint analysis is a survey-based method commonly used in market research to study how consumers value different attributes of a product or service [13]. The methodological approach has been widely adopted in health research [14], and has been shown to approximate real-world decisions and reasonably predict health behaviors [15]. A fully randomized conjoint is a full factorial design in which all possible combinations may not be observed. However, randomization assures that attributes are orthogonal, which allows the estimation of the marginal effects of each attribute. An advantage of this approach is that it does not rest on an assumed behavioral model of individual decision-making [16]. The estimated treatment effects are nonparametrically identified under a modest set of assumptions, many of which (such as randomization of attribute levels) are guaranteed by the experimental design [17].

2.2. Experimental design

The experiment presented each subject with five pairs of hypothetical vaccine profiles.

For each vaccine profile, values of seven vaccine attributes – four about the vaccine itself and three about the political context of vaccine development – were randomly assigned. These attributes were chosen from a review of existing literature on the factors influencing vaccine hesitancy [11,18–23]; interviews with medical experts (n = 4); and a review of secondary literature speculating about the likely characteristics of an eventual Covid-19 vaccine. The vaccine attributes included protection efficacy; protection duration; and the incidence of major and minor side effects. The political attributes included whether the vaccine received full FDA approval or an Emergency Use Authorization; the national origins of the vaccine, and the person or entity endorsing it. Table 1 summarizes the attributes and levels. A sample choice set is presented in the Supporting Information (SI Fig. 1). After viewing each pair of hypothetical vaccine profiles, subjects were first asked to indicate whether they would choose Vaccine A, Vaccine B, or neither. Subjects were then asked to evaluate how likely they would be to accept each vaccine individually on a seven-point ordinal scale from "extremely unlikely" to "extremely likely." Our analysis here focuses on responses to this second measure of vaccination intentions.

Table 1
Considered Attributes and Attribute Levels for Covid-19 Vaccination.

Vaccination Attributes	Levels
Efficacy – protection against severe symptoms	50% 70% 90%
Protection duration	1 year 5 years
Risk of severe side effects (hospitalization or death)	1 in 10,000 1 in 1,000,000
Risk of mild side effects (flu-like symptoms)	1 in 10 1 in 30
Government authorization	FDA emergency use authorization[a] FDA approved and licensed[b]
Vaccine origin	USA China UK
Recommended by	Trump Biden Centers for Disease Control and Prevention World Health Organization

[a] The vaccine has received an emergency use authorization from the US Food and Drug Administration. This allows the expedited use of promising drugs that the FDA has found it reasonable to believe may be effective in combatting the virus.
[b] The vaccine has been approved and licensed by the US Food and Drug Administration.

2.3. Study sample

On July 9, 2020, we recruited an online sample of 1,971 adult Americans via the Lucid Marketplace. The timing of the survey preceded Phase 2/3 safety and efficacy clinical study data; we therefore gauged attitudes prospectively based on attributes identified in previous studies of vaccine hesitancy as opposed to known attributes of Covid-19 vaccines. Lucid contacted 3,708 US adults, of whom 2,000 agreed to participate in the study; 1,971 completed the full questionnaire. Lucid employs quota-based sampling strategies to produce samples matched to the US population on age, gender, ethnicity, and geographic region. The demographic composition of our sample and comparisons to those of prominent social science surveys and U.S. Census American Community Survey statistics are provided in SI Table 1. Past research has shown that experimental effects obtained from Lucid samples closely match those observed using national benchmark probability samples [24]. Our research followed relevant ethical regulations and all protocols were approved by the Cornell University institutional review board (Protocol ID 2004009569).

2.4. Statistical analysis

Estimating treatment effects in a fully randomized conjoint experiment is straightforward. As described in Hainmueller, Hopkins, and Yamamoto [17], the regression coefficients from a baseline ordinary least squares regression with standard errors clustered on respondent are unbiased estimates of the average marginal component effects (AMCEs) for each attribute. The AMCE represents the average difference in a subject choosing a vaccine when comparing two different attribute values – for example 50% efficacy vs. 90% efficacy – averaged across all possible combinations of the other vaccine attribute values.

Our analysis here re-analyzes data from Kreps et al's study [7] to examine how the experimental treatment effects of vaccine attributes on public vaccine acceptance vary across subgroups. To do so, we estimate the same baseline regression, but interact indicator variables identifying each attribute-level with another indicator variable identifying a relevant subgroup (e.g. Americans 60 years of age and older). The regression results themselves are reported in the Supporting Information (SI Tables 2-5). In the text, we illustrate the effects graphically by plotting marginal means at each attribute level for each population subgroup. Comparing marginal means instead of AMCEs offers important advantages in identifying differences in preferences across subgroups and ensuring that any observed differences (or lack thereof) are not an artifact of the chosen baseline level of each attribute [25]. However, the two quantities are directly related; in a fully randomized conjoint, the AMCEs are the differences between marginal means of a given attribute-level and that attribute's baseline level, all else equal.

In this analysis, we look for evidence of differential treatment effects along four dimensions: race/ethnicity; age; gender; and political partisanship. We focus on the first three categories because prior research shows that vaccine hesitancy is likely stronger among people of color [26] and women [27], and because people of color and the elderly are at disproportionate risk from Covid-19. Moreover, a recent study also employing a conjoint analysis reported evidence of heterogeneous treatment effects by age [8]. As a result, understanding what factors increase or decrease vaccine acceptance among these groups and how those effects differ across these critical groups and the rest of the population has important public health implications. Given the increasing partisan polarization of many elements of the response to Covid-19 in the United States [28,29], we also examine whether and how political partisanship moderates the influence of vaccine attributes on willingness to vaccinate.

3. Results

Each vaccine attribute summarized in Table 1 significantly affected willingness to vaccinate in the aggregate [7]. However, this masks significant variation in the effects of different attributes across key demographic subgroups.

3.1. Race/ethnicity

As shown in the left panel of Fig. 1, Blacks were consistently more hesitant to take a Covid-19 vaccine than were whites. Moreover, several vaccine attributes had significantly different effects on uptake across racial and ethnic groups (SI Table 2 presents a pair of statistical models interacting each vaccine attribute with an indicator variable identifying subjects who identified as Black or Latinx). Perhaps most important, we find strong evidence that increasing vaccine efficacy has a weaker effect on vaccine acceptance among Blacks than it does on vaccine acceptance among whites. For example, while an increase in vaccine efficacy from 50% to 90% increased willingness to vaccinate among whites by almost 10%, it produced only a 4% increase among Blacks. Blacks were statistically no more likely to accept a vaccine that was 90% effective than whites were to accept a vaccine that was only 50% effective, all else equal. Blacks were also less sensitive to vaccine protection duration. Increasing protection duration from 1 year to 5 years significantly increased vaccine acceptance among whites ($p < .05$, two-tailed test) by 2%; but the coefficient on the interaction for Blacks is negative, larger than the main effect, and statistically significant ($p < .10$, two-tailed test).

The effect of vaccine origin on acceptance also varied across racial groups. A vaccine developed in the UK did not have a significantly different effect on vaccine attitudes among whites and Blacks. However, whites were significantly less likely to take a vaccine developed in China. Among whites, a Chinese vaccine decreased willingness to vaccinate by 12% from the US-developed vaccine baseline. Among Blacks, the decrease was much smaller, just 3%.

Blacks also reacted differently to various endorsements of a Covid-19 vaccine than did whites. Among Blacks, vaccine acceptance was significantly lower when President Trump endorsed the vaccine than among any other endorsement group ($p < .05$, two-tailed test). Moreover, among Blacks, there were no significant differences across the Biden, CDC, and WHO treatments. By contrast, among whites, there was no difference across the Trump and Biden treatments, and both the CDC and WHO treatments produced greater vaccine acceptance than either of the political endorsements ($p < .05$, two-tailed test).

We find little evidence that vaccine attributes had significantly different effects on the vaccination intentions of Latinos vs. whites. As seen in the right panel of Fig. 1, the general pattern of effects is quite similar, with the only exception being protection duration. A longer protection duration significantly increased willingness to vaccinate among whites, but had no effect among Latinos.

3.2. Age

Older Americans in our study were consistently more reluctant to accept a Covid-19 vaccine than were younger Americans. This baseline finding is somewhat surprising as many surveys have shown that older Americans are less hesitant than younger cohorts; however, the result is consistent with a pair of recent studies also employing conjoint experiments [8,30]. We address this in further detail in the Discussion. However, our main focus here is on how age moderated the effects of vaccine attributes on willingness to vaccinate. The gap between older and younger Americans narrowed somewhat as vaccine efficacy increased (see Fig. 2); the gap was 9% for a vaccine with 50% efficacy versus 6% for a vaccine with 90% efficacy; however, the differences in effect sizes are not statistically significant (SI Table 3). Older and younger Americans responded similarly to information about the vaccine's protection duration, as well as the incidence of major and minor side effects. However, approving a vaccine by FDA Emergency Use Authorization had a particularly strong adverse effect on vaccine willingness among older Americans. Among those under 60, an EUA only modestly decreased vaccine acceptance by about 1.5%. Among those 60 and older, the effect was almost three times greater.

Vaccine origin had a stronger negative effect on older people than younger people. Americans of all age cohorts were significantly less likely to take a vaccine developed in China than one developed in the United States; however, the negative effect was much larger on the vaccination intentions of older Americans (−15% vs. −9% for subjects under 60).

Finally, older Americans were more responsive to vaccine endorsements than were younger Americans. Among those 60 and over, an endorsement by the CDC increased vaccine acceptance by 14% from the Trump endorsement baseline. By contrast, the CDC endorsement only increased the marginal mean willingness by 5% vs. the Trump baseline among subjects under 60. Older Americans were also more responsive to an endorsement from the CDC than from the WHO. The marginal mean willingness to vaccinate among US adults under 60 was no different in the CDC and WHO treatments. However, among adults 60 and over, vaccine acceptance was significantly lower when the vaccine was endorsed by the WHO than when endorsed by the CDC, all else equal.

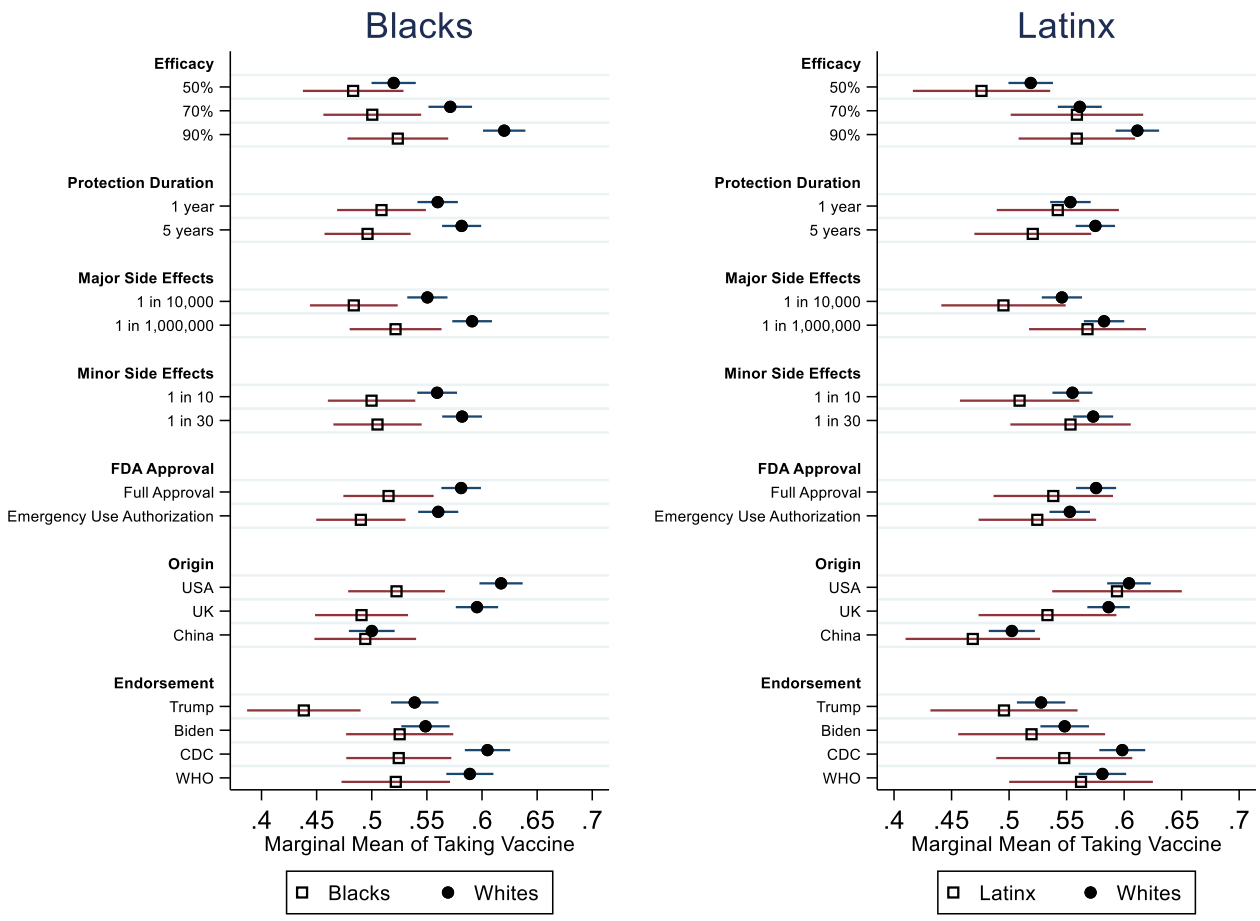

Fig. 1. Differential Effects by Race/Ethnicity. *Note:* Each marker indicates the marginal mean for each group at each attribute/level. Bars indicate 95% confidence intervals.

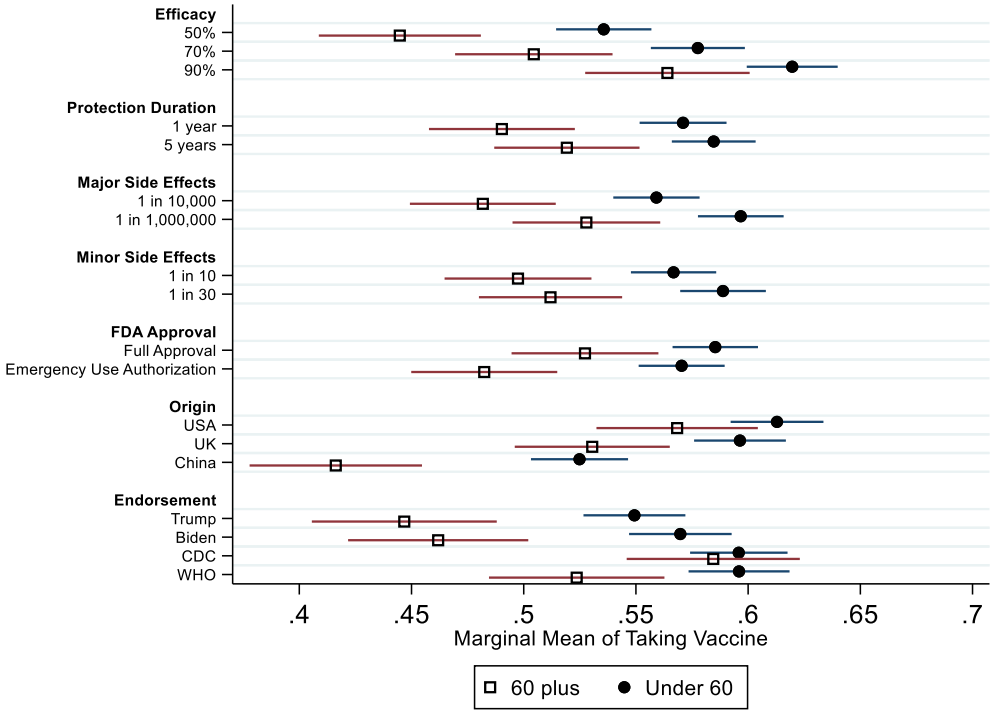

Fig. 2. Differential Effects by Age (60 Plus vs. Under 60). *Note:* Each marker indicates the marginal mean for each group at each attribute/level. Bars indicate 95% confidence intervals.

3.3. Gender

As Fig. 3 shows, there were large and statistically significant gaps in vaccine acceptance between men and women at each attribute-level in our experiment. Women were systematically less willing to accept a Covid-19 vaccine in our survey than were men. For example, both men and women responded to higher levels of vaccine efficacy by becoming more willing to get vaccinated. However, the gender gap remained roughly constant at every level.

Moreover, gender significantly moderated the influence of several factors on vaccine acceptance. For example, a longer protection duration had a greater positive effect on willingness to vaccinate among women than it did among men (SI Table 4). An FDA Emergency Use Authorization significantly reduced vaccine acceptance among women by 4%. Among men, the difference was roughly 0.5% and not statistically significant (the difference in effect sizes is statistically significant: see SI Table 4). Among men, CDC and WHO endorsements both significantly increased vaccine acceptance versus that observed in the Biden and Trump treatments ($p < .05$, two-tailed test) and acceptance was statistically indistinguishable across these treatments. By contrast, among women vaccine acceptance was highest in the CDC treatment; acceptance in the WHO treatment was significantly lower than in the CDC treatment ($p < .05$ two-tailed test), but significantly higher than in either of the political endorsement treatments ($p < .05$, two-tailed test).

3.4. Political partisanship

In previous research we found that Democrats were moderately more willing to vaccinate than were Republicans, all else being equal [7]. However, acceptance varied significantly across attribute levels, as partisanship significantly moderated the effect of several vaccine attributes on acceptance (see Fig. 4). For example, at the 50% efficacy level the marginal mean vaccine acceptance was actual higher for Republicans than for Democrats, though the difference was not statistically significant. However, increasing efficacy to 70% significantly increased vaccine acceptance among Democrats by 7% versus <2% for Republicans. Similarly, an increase from 50% to 90% vaccine efficacy increased Democrats' willingness to vaccinate by 11% versus just 6% for Republicans. Both partisan differences in effect sizes are statistically significant (SI Table 5).

Partisanship also significantly moderated the effects of endorsements on vaccine acceptance. Unsurprisingly, Republicans were significantly more likely to vaccinate when the vaccine was endorsed by President Trump than by then-former Vice President Biden, and vice versa for Democratic respondents. Democrats were also significantly more likely to accept vaccination than Republicans when the vaccine was endorsed by the CDC.

3.5. Exploring the forces underlying demographic differences

To shed light on why vaccine attributes affect vaccine acceptance differently across subgroups and to explore several possible explanations for aggregate differences in acceptance across subgroups, we conducted several additional analyses examining responses to other questions included on the survey. Overall, we sought to unpack the basis of vaccination attitudes among the subgroups that we identified as more hesitant to vaccinate by investigating whether these groups are also those who reported being less likely to vaccinate for the flu and more concerned about vaccine safety in general. We also examine self-reported contact with individuals who were hospitalized or died from Covid-19 to see if this differential exposure corresponds to demographic variation in vaccine acceptance.

First, we examine whether groups that were more hesitant to take a Covid-19 vaccine in our experiment also reported less frequent histories of vaccination against influenza; this provides an initial assessment of the extent to which variation in attitudes toward a Covid-19 vaccine are unique. Second, we investigated the degree to which different demographic groups' concerns about vaccine safety, which has been found to be a reason why people do not vaccinate for other viruses [31], may map onto variation in Covid-19 vaccine hesitancy. Third, we examine whether variance in personal contact with Covid-19 corresponds to demographic patterns in Covid-19 vaccine hesitancy. Previous research shows that individuals make vaccination decisions based on their perception of threat, for example whether they believe that the likelihood that they will be infected or that the severity of the virus is high [32].

Table 2 below presents a series of ordered logit and logit regressions examining the relationship between demographic factors and past flu vaccination frequency (never; once or twice; most years; every year); attitudes about vaccine safety (extremely safe; very safe; somewhat safe; or not safe at all); and whether they know someone who had been hospitalized or died as a result of Covid-19 (yes; no), a proxy for whether individuals believe that they themselves might be adversely affected by Covid-19.

The first model of Table 2 shows that older Americans were more likely to report frequent flu vaccinations, even though they were less likely to accept a Covid-19 vaccine in our experiment, all else equal. Similarly, after including a range of additional demographic controls we found no evidence that Blacks or women were less likely to report frequent flu vaccination, even though both groups were more vaccine hesitant with respect to Covid-19 across a range of hypothetical vaccine profiles. Collectively, these results suggest that demographic variations in Covid-19 vaccine hesitancy do not map neatly onto demographic differences in self-reported past experience with flu vaccinations.

Variation in general concerns about vaccine safety map more closely onto subgroup variation in acceptance of a Covid-19 vaccine in our study. Blacks and women were significantly more concerned about general vaccine safety, on average, than whites and men; this corresponds with the greater vaccine hesitancy concerning Covid-19 among Blacks and women. However, none of these groups report being significantly less likely to vaccinate against the flu (model 1), which cuts against studies showing that those who question vaccine safety are less likely to vaccinate generally [33]. Moreover, Latinos were significantly more skeptical of vaccine safety in our sample than whites, but they were only marginally less likely to vaccinate against Covid-19 in our experiment. Older Americans were significantly more confident in general vaccine safety than were younger Americans, and yet they were more hesitant to take a Covid-19 vaccine in our study.

While we did find that women were both more skeptical of vaccine safety in general and more hesitant to take a Covid-19 vaccine, recent research suggests that a primary driver of this hesitancy among women may be online misinformation baselessly alleging that Covid-19 vaccines can jeopardize fertility [34]. If this is the dominant force behind the gender gap, we would expect the gender gap to be greater among women and men of child-bearing age than between older men and women. Fig. 5 offers little support for this hypothesis. The gender gap between men and women under 40 is, if anything, slightly smaller than the corresponding gender gap for those 40 and over.[2]

Finally, we might expect differential personal exposure to the human toll of Covid-19 to be correlated with subgroup variation

[2] We chose 40 as the cut-off because the 2018 birth rate for women 40–44 was 11.8 per 1,000 and for women 45–49 just 0.9 per 1,000, vs. 52.6 per 1,000 for women 35–39 [48]. Alternate cut-offs yield similar results.

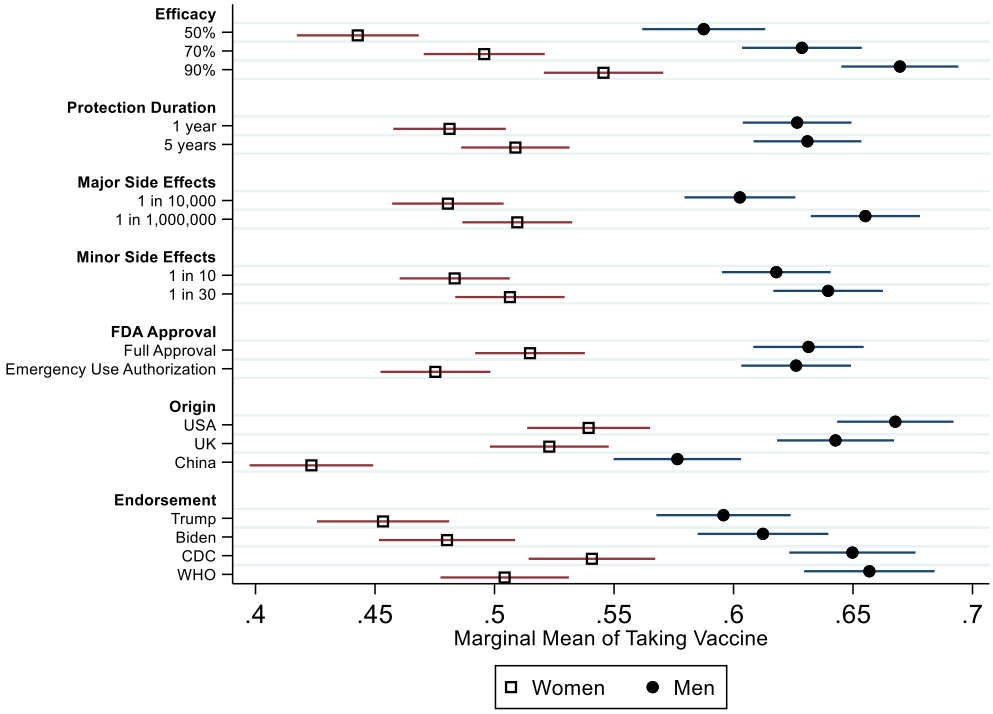

Fig. 3. Differential Effects by Gender (Men vs. Women). *Note:* Each marker indicates the marginal mean for each group at each attribute/level. Bars indicate 95% confidence intervals.

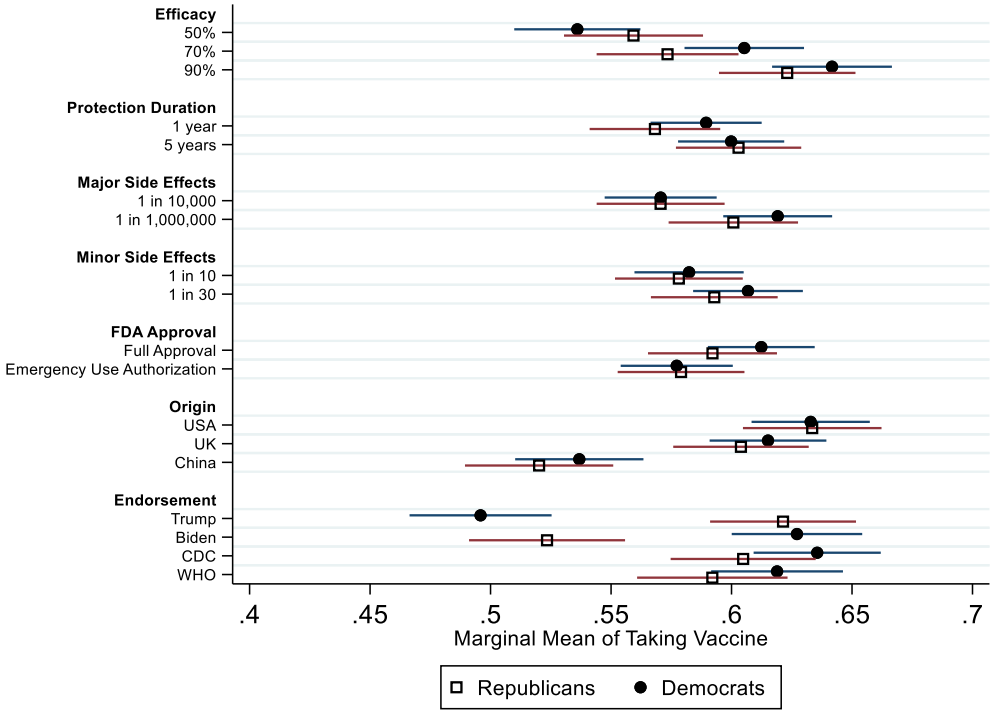

Fig. 4. Differential Effects by Party (Democrats vs. Republicans). *Note:* Each marker indicates the marginal mean for each group at each attribute/level. Bars indicate 95% confidence intervals.

in vaccine acceptance. Consistent with statistics showing that Covid-19 has disproportionately affected communities of colors [35], both Blacks and Latinos were significantly more likely than other Americans to report knowing someone who has been hospitalized with or died from Covid-19 (model 3). However, that personal contact has not closed the gap between Blacks and whites in terms of willingness to vaccinate. Women and older Americans were, surprisingly, both less likely to report knowing someone who had been hospitalized or died of Covid-19. However, both groups also reported greater vaccine hesitancy in our experiment. Republicans were no more or less likely to report personal contact with a severe case of Covid-19 than were Democrats (a Wald test shows

Table 2
Predictors of Flu Vaccination Frequency, Perceived Vaccine Safety, and Self-Reported Contact with Severe Covid-19 Case.

	Flu Vaccination	Vaccine Safety	Contact w/Severe Covid
Democrat	0.22*	0.58***	0.37**
	(0.13)	(0.14)	(0.19)
Republican	−0.05	0.43***	0.48**
	(0.13)	(0.14)	(0.19)
Black	0.07	−0.86***	0.34**
	(0.12)	(0.14)	(0.16)
Latino	0.14	−0.58***	0.39**
	(0.14)	(0.15)	(0.18)
Female	0.11	−0.48***	−0.32***
	(0.08)	(0.09)	(0.11)
Age	0.02***	0.01***	−0.02***
	(0.00)	(0.00)	(0.00)
Education	0.12***	0.16***	0.23***
	(0.02)	(0.03)	(0.03)
Contact w/Severe Covid		0.38***	
		(0.10)	
Constant			−1.74***
			(0.28)
Observations	1,971	1,859	1,971

Note: Table presents results of ordered logit models for flu vaccination and vaccine safety and logit model for personal contact with someone who was hospitalized or died from Covid-19. Standard errors in parentheses. All significance tests are two-tailed.
*** p < 0.01, ** p < 0.05, * p < 0.10

that the two coefficients are not significantly different from one another p < .05, two-tailed). And yet, Democrats were more willing to accept a Covid-19 vaccine, on average, than were Republicans. The inconsistent findings suggest that variation in personal contact with severe Covid-19 cases is not a major driver of the significant subgroup differences observed in our study.

4. Discussion

In a commentary about the Covid-19 vaccine, former CDC Director Tom Frieden observed that "The biggest challenge to getting a Covid-19 vaccine into enough people's arms won't be scientific, technical or logistical; it will come from a lack of trust." He observed that low levels of trust in the vaccine, whether because of where it is made, whether it is effective, or how long the protection lasts, would lead to vaccine hesitancy and potentially sabotage the vaccination campaign [36]. While most previous studies and polls have queried overall levels of support for Covid-19 vaccination in the community, our approach of examining the demographic pockets of hesitancy and how subgroups respond differently to different vaccine attributes can more effectively target outreach efforts. Our findings suggest that certain groups will need more outreach and mobilization because of higher levels of vaccine hesitancy. Even more important, our findings also point to the particular attributes that public health campaigns might emphasize to reach particular subgroups, an inherently difficult task [37–39].

Past research has shown stark partisan divides on Covid-19 related policies, from whether to wear masks (Democrats are twice as likely as Republicans to think that masks should always be worn), to beliefs that individual behaviors affect the spread of the virus, and the extent to which Americans are concerned about the health impacts of the virus [40]. Partisanship also influences

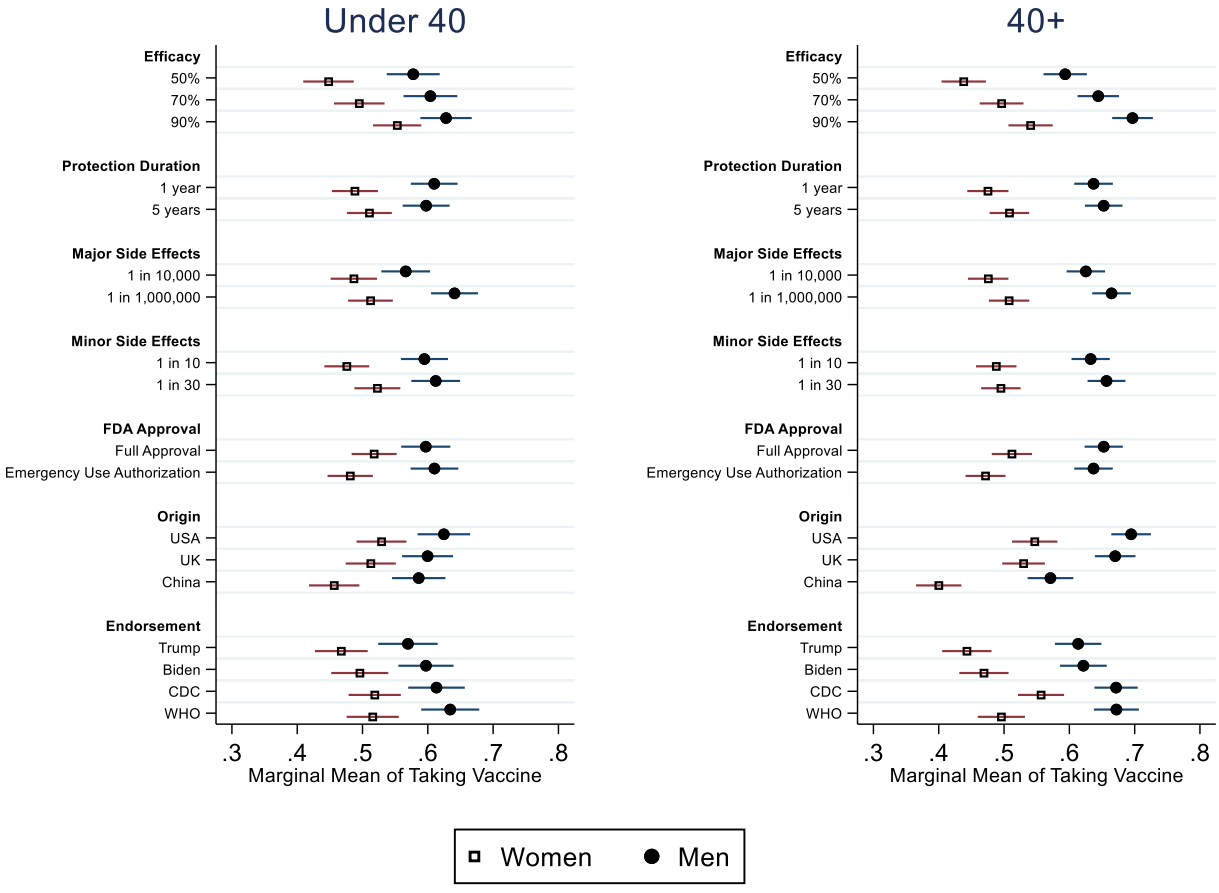

Fig. 5. Gender Gap by Age. *Note:* Each marker indicates the marginal mean for each group at each attribute/level. Bars indicate 95% confidence intervals.

vaccine intentions. Republicans are less likely to vaccinate, all else equal, than are Democrats [7]. Partisanship also moderates the effects of several attributes on vaccine acceptance. Increasing vaccine efficacy is less influential in building support for vaccination among Republicans than among Democrats, and Republicans are also less likely to be persuaded by endorsements from the CDC.

Similarly, race also significantly moderated the effect of multiple vaccine attributes on willingness to vaccinate. Perhaps most importantly, increasing vaccine efficacy had a weaker effect on vaccine acceptance among Blacks than it did among whites. Race also moderated the influence of protection duration, national vaccine origin, and political/organizational endorsements on vaccine acceptance. A number of studies have shown that ethnic and racial minority groups are generally less likely to vaccinate than whites [41]. Safety concerns and distrust of doctors who recommend vaccines are often cited as the reasons for reluctance [31]. Follow-up analyses show that Blacks and Latinos also have lower perceptions of vaccine safety in general [42]. Public health education campaigns should acknowledge the lower levels of trust in vaccine safety and reinforce the benefit of the vaccine and risk of the virus, perhaps deploying religious leaders in these groups to legitimate Covid-19 vaccination.

Our research corroborates studies on other viruses that find lower vaccination rates for women versus men [27] and emerging evidence about Covid-19 vaccine preferences [5]. Vaccine safety has been cited as a cause of concern [43], and indeed our analysis shows that women tend to view vaccines as less safe than men. However, additional analysis suggests that concerns about the Covid-19 vaccine's effects on fertility cannot fully explain the gender gap in vaccine acceptance. The gender gap between older women and men was just as if not larger than the gender gap among younger subjects. An EUA had a greater negative effect on vaccine acceptance among women than among men. Outreach efforts to women could concentrate on addressing fears that the approval process was rushed or based on incomplete data. Further research should also investigate the effect of exposure to anti-vaccine conspiracy theories on intention to vaccinate against Covid-19, as previous research has shown that anti-vaccine conspiracies can torpedo intentions to vaccinate [44].

From a public health perspective, the most significant disconnect between Covid-19 susceptibility and vaccination preferences is the older population. Older Americans comprise a widely disproportionate share of Covid-19 deaths [45], but were less willing to vaccinate in our study, all else equal. This inverse relationship between age and willingness to vaccinate is also surprising, though additional analyses (SI Table 6) show that the relationship between age and vaccine acceptance in our study was curvilinear. Most opinion surveys find older adults are more likely to vaccinate than younger adults [5]. However, most of these survey questions ask about willingness to take a generic vaccine. The relationship here is consistent with a pair of additional studies that also recruited subjects from the Lucid platform and employed a conjoint experiment to examine the effects of vaccine attributes on public willingness to vaccinate [8,30]. The framing of vaccination intention questions affects responses [5], and it could be that the conjoint design presented difficulties for older respondents, depressing reported willingness to vaccinate versus levels observed in more generic survey questions. Future research could explore whether these divergent results are a product of the characteristics of the sample or of the methodological design in which subjects have much more information about the vaccines when indicating their vaccination preferences. Another possibility is that the questions in our study were prospective and asked before vaccines were available. Vaccination rates among older Americans had reached 70% by March 2021. We recommend further study to understand how how these rates exceeded the stated preferences to glean lessons for approaches that might prove successful for other demographics or perhaps for booster shots.

More importantly, our findings show that some vaccine attributes were more important to older than younger Americans. For example, older Americans were particularly troubled by the EUA process versus a vaccine receiving full FDA approval. This suggests that outreach efforts to combat hesitancy among older Americans might be particularly effective if they address concerns that the approval process was rushed or incomplete. Explaining the rigorous standards of the clinical trials and the large numbers of individuals enrolled in those trials might combat an important source of concern among many older adults. Similarly, we found that CDC endorsements were particularly effective in boosting vaccine acceptance among older individuals. The messenger matters, and our results show that older Americans were even more responsive than younger Americans to endorsements from public health officials versus endorsements from politicians.

Since subgroups vary considerably in their hesitancy and response to different vaccine attributes, subgroup-specific mobilization cues should be considered. For example, public health authorities should develop outreach strategies that reassure and incentivize individuals in these subgroups [46], whether through dialogue-based strategies that deploy religious or traditional leaders in these groups, incentive-based strategies that provide food or other goods as an incentive, or reminders by phone or mail [47]. Recognizing these subgroup differences can help identify and then craft those subgroup-specific policies.

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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Data statement

All data files and statistical code to produce the tables and figures reported in the manuscript will be published on the Harvard Dataverse upon acceptance for publication at: https://doi.org/10.7910/DVN/6BSJYP.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2021.04.044.

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