Willingness to Vaccinate Against SARS-CoV-2: The Role of Reasoning Biases and Conspiracist Ideation

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Abstract

Background: Widespread vaccine hesitancy and refusal complicate containment of the SARS-CoV-2 pandemic. Extant research indicates that biased reasoning and conspiracist ideation discourage vaccination. However, causal pathways from these constructs to vaccine hesitancy and refusal remain underspecified, impeding efforts to intervene and increase vaccine uptake.

Method: 554 participants who denied prior SARS-CoV-2 vaccination completed self-report measures of SARS-CoV-2 vaccine intentions, conspiracist ideation, and constructs from the Health Belief Model of medical decision-making (such as perceived vaccine dangerousness) along with tasks measuring reasoning biases (such as those concerning data gathering behavior). Cutting-edge machine learning algorithms (Greedy Fast Causal Inference) and psychometric network analysis were used to elucidate causal pathways to (and from) vaccine intentions.

Results: Results indicated that a bias toward reduced data gathering during reasoning may cause paranoia, increasing the perceived dangerousness of vaccines and thereby reducing willingness to vaccinate. Existing interventions that target data gathering and paranoia therefore hold promise for encouraging vaccination. Additionally, reduced willingness to vaccinate was identified as a likely cause of belief in conspiracy theories, subverting the common assumption that the opposite causal relation exists. Finally, perceived severity of SARS-CoV-2 infection and perceived vaccine dangerousness (but not effectiveness) were potential direct causes of willingness to vaccinate, providing partial support for the Health Belief Model's applicability to SARS-CoV-2 vaccine decisions.

Conclusions: These insights significantly advance our understanding of the underpinnings of vaccine intentions and should scaffold efforts to prepare more effective interventions on hesitancy for deployment during future pandemics.

Keywords: SARS-CoV-2, COVID-19, GFCI, conspiracy theories, reasoning, vaccines

General Audience Summary

Large numbers of people routinely refuse or delay vaccinations for themselves and/or their children, leaving individuals and their communities vulnerable to undesirable outcomes (including death) that could be avoided through vaccination. Previous research shows that individuals who believe conspiracy theories, or who are exposed to them, are more likely to delay vaccination or forgo it entirely. While this research links belief in conspiracy theories to reduced willingness to vaccinate, it is unclear whether and how belief in conspiracy theories reduces willingness to vaccinate against SARS-CoV-2 (also referred to as: “COVID-19”). It is also unclear whether tendencies to reason in particular ways (“reasoning biases”), which are thought to encourage belief in conspiracy theories, influence willingness to vaccinate through their impact on conspiracist ideation. Our study involving 554 participants suggested that reduced willingness to vaccinate against SARS-CoV-2 causes belief in vaccine-related conspiracy theories, which contrasts with previous research suggesting that conspiracist ideation reduces willingness to vaccinate (the opposite causal relation). Our study also suggested that reasoning biases, such as a tendency to gather less data before deciding, may influence willingness to vaccinate indirectly, by encouraging paranoia and thereby increasing the perceived dangerousness of vaccines and reducing willingness to vaccinate. Identifying causes of willingness to vaccinate against SARS-CoV-2 is an important first step toward developing interventions that encourage SARS-CoV-2 vaccination. Knowledge provided by our study will therefore help us respond more effectively to the SARS-CoV-2 pandemic and to future infectious disease outbreaks.

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> Mr. Gibbs was convinced that there were a number of medical men…who wanted nothing to be said upon the subject [of the harms associated with smallpox vaccination], and it was therefore his mission to compel them to speak out.
>
> *—The Leeds Mercury (December 3, 1867) describing the commentary of Mr. Gibbs, honorary secretary to the Anti-Vaccination League, Leeds, England*

As the epigraph implies, unwillingness to vaccinate was an obstacle to controlling infectious disease long before the SARS-CoV-2 pandemic. However, this challenge has taken on new urgency as limited personal experience with vaccine-preventable diseases and reduced trust in key figures (governments, scientists, pharmaceutical companies; Dubé et al., 2014) has made adults increasingly hesitant to vaccinate themselves (Ward et al., 2019) and their children (Gowda & Dempsey, 2013; Siddiqui et al., 2013), resulting in clusters of under-vaccination and outbreaks of preventable disease (Siddiqui et al., 2013). This trend led the WHO to declare vaccine hesitancy (the delay in either acceptance or refusal of an available vaccine) a top-ten public health threat in 2019.

Unfortunately, this declaration proved prescient. The full benefits of the safe and highly effective vaccines developed against SARS-CoV-2 remain unrealized, in part because significant numbers of adults hesitate or refuse to vaccinate themselves (Daly et al., 2021; Lazarus et al., 2020) and/or their children (Montalti et al., 2021; Wang et al., 2021). This unwillingness to vaccinate likely impedes establishment of herd immunity (see: Thunström et al., 2020), thereby creating an ongoing risk of vaccine-preventable morbidity and mortality made particularly salient by the progressively increasing virulence of emerging SARS-CoV-2 variants (Fisman & Tuite, 2021).

Belief in conspiracy theories, which tend to proliferate during times of societal crisis (including disease outbreaks; van Prooijen & Douglas, 2017), may have contributed to this public health crisis. Experimental studies showing that exposure to conspiracy theories weakens intentions to vaccinate (Chen et al., 2020; Jolley & Douglas, 2014) strongly support this possibility, as does research indicating that perceived disease risk and perceived vaccine dangerousness mediate the relation between conspiracist ideation and vaccine intentions (Jolley & Douglas, 2014; Romer & Jamieson, 2020). These mediation pathways provide plausible mechanisms by which conspiracist ideation may discourage vaccination: both the aforementioned mediators are highlighted in the Health Belief Model, a prominent theory of medical decision-making positing that vaccination decisions depend upon perceptions of disease vulnerability/severity, as well as the vaccine's perceived dangerousness/effectiveness (Janz & Becker, 1984). More broadly consistent with the possibility that conspiracist ideation causes vaccine intentions, the association between conspiracist ideation and vaccine hesitancy is longstanding (as implied by the epigraph above) and reliable in the general population (Bertin et al., 2020; Romer & Jamieson, 2020; Teovanović et al., 2021). Notably, this association echoes the broader relation between conspiracist ideation and denial of established science findings (Lewandowsky et al., 2013), and is strong relative to other correlates of attitudes toward vaccination (Hornsey et al., 2018).

If conspiracist ideation does encourage vaccine hesitancy and refusal, then causes of conspiracist ideation should exert indirect effects on willingness to vaccinate. Personality traits, including paranoia and locus of control, are one potential cause of belief in conspiracy theories.

Paranoia may cause belief in conspiracy theories by encouraging fear of external agents and the belief that intentions (rather than coincidences) are primary causes of world events (Darwin et al., 2011), explaining its association with SARS-CoV-2 conspiracist ideation (Freeman et al., 2020). External locus of control may also cause conspiracist ideation. Broadly consistent with this notion, evidence suggests that when individuals feel less control over impending threats, they become more likely to believe in conspiracy theories, which may help explain the increase in conspiracy theory endorsement following natural disasters (van Prooijen & Acker, 2015), such as pandemics.

Conspiracist ideation may also be facilitated by reasoning biases. Belief in conspiracy theories is correlated with several reasoning biases, including the tendency to gather less data prior to decision-making (“jumping to conclusions”; Pytlik, Soll, & Mehl, 2020; Sanchez & Dunning, 2020) and the tendency toward lowered decision thresholds (“liberal acceptance”; Kuhn et al., 2021), that have been implicated in the development of other epistemically-suspect beliefs (such as delusions in schizophrenia: Bronstein et al., 2019). Further, manipulating particular reasoning biases, such as the tendency to perceive patterns in data when none are present (“illusory pattern perception”), increases conspiracist ideation (Whitson & Galinsky, 2008). Reasoning biases may cause conspiracist ideation because they influence individuals’ likelihood of endorsing epistemically-suspect alternatives to official accounts, and motivate them to search for these accounts by encouraging paranoid thinking styles and distrust of information authorities, including scientists (see: Pierre, 2020).

Many of the aforementioned factors (belief in conspiracy theories, paranoia, reasoning biases) are highly modifiable (Garety et al., 2021; Steffen Moritz et al., 2014). Accordingly, if they do exert indirect effects on vaccine intentions via conspiracist ideation, they are potential novel targets for interventions aiming to increase vaccine uptake (see: Jolley & Douglas, 2014). Novel interventions that encourage vaccination would be invaluable because commonly-used strategies are frequently ineffective (Pluviano et al., 2017) or backfire – for instance, correcting myths that vaccines cause disease can increase hesitancy (Nyhan & Reifler, 2015). Interventions that reduce belief in conspiracy theories may have the additional beneficial effects of discouraging violence (Moskalenko & Mccauley, 2021) and encouraging pro-social behavior (Jolley & Douglas, 2014; Van der Linden, 2015).

The Present Study

With this literature in mind, the present study tested the pre-registered hypothesis that belief in conspiracy theories reduces willingness to vaccinate against SARS-CoV-2, and that this effect is transmitted (at least in part) via constructs highlighted in the Health Belief Model (such as perceived vaccine dangerousness). Pre-registered hypotheses regarding the interrelations among reasoning biases (see **SI Section S8**) were also tested. Primary tests of these hypotheses were conducted using causal discovery analysis, which leverages machine-learning algorithms to identify potential causal pathways in observational datasets (Shen et al., 2020). This cutting-edge method was used in conjunction with more traditional techniques, such as psychometric network analysis, which offers a more relaxed approach to identifying potential causal effects and provides additional information about their valence and relative magnitude, to identify likely determinants (reasoning biases, personality traits, etc.) of belief in SARS-CoV-2 related conspiracy theories and vaccine intentions. Testing these hypotheses was expected to shed light on the mechanisms underlying willingness to vaccinate and their relationship to belief in conspiracy theories, laying foundations for more effective interventions that could be deployed to combat pandemics in the post-truth era (see: Lewandowsky et al., 2017).

Method

Participants and Recruitment

Data were collected April 1-8, 2021. Participation was restricted to Prolific users ages 18+ who lived in the United States and had access to a desktop or laptop computer. Because past receipt of a SARS-CoV-2 vaccine could influence SARS-CoV-2 vaccine intentions, individuals who endorsed receipt of any such vaccine were excluded using a brief screening survey. 1117 individuals completed the main study. After excluding low-quality responses, the final sample included 554 participants. For demographics and analyses of differential drop-out, see **SI Section S1**.

Data Quality Measures

Several steps were taken to ensure high data quality. Screening survey respondents were not invited to complete the main study if they failed at least two of five attention checks (items placed at random intervals to detect inattentive or low-effort responding), reported a birth date inconsistent with their age, provided demographic information that did not match data collected by Prolific, or completed the screening survey at a speed more than three standard deviations from the mean. Main survey respondents who finished at an especially slow/fast speed, failed at least two of four attention checks, reported a birth date inconsistent with their age, or provided demographic information inconsistent with their screening survey answers were excluded. Finally, a captcha was included in both surveys to deter "participation" by computer programs.

Open Science Practices

The hypotheses and analysis plan for this study was pre-registered (https://osf.io/v6ej2). Anonymized data are available at: https://osf.io/z9cf6/.

Protocol

This study was approved by the University of Minnesota Institutional Review Board. During the screening survey, participants reported demographic information and then completed the Belief in Conspiracy Theories Inventory (BCTI; Swami et al., 2010). While the pre-registered recruitment plan involved stratified sampling of participants for the main study based on this measure, after excluding low-quality responses the screened sample approached the size that our power analyses suggested was necessary to detect hypothesized effects. Thus, all participants with sufficient data quality were invited to the main study. During the main study, participants completed measures of vaccine intentions, constructs from the Health Belief Model (perceived vaccine dangerousness and effectiveness, perceived severity of SARS-CoV-2 infection), belief in SARS-CoV-2 vaccine-related conspiracy theories, paranoia, locus of control, and epistemic trust in scientists. They also completed tasks that measured reasoning biases linked to conspiracist ideation in past research, including jumping to conclusions, liberal acceptance, denominator neglect, and illusory pattern perception. All tasks and measures were completed in randomized order. Participants received $9 remuneration for completing the entire study.

Measures

Participants completed the measures listed below. All measures had good-to-excellent internal consistencies, as evaluated using Omega Total (McDonald, 1999; see: **SI Section S2**). For full versions of measures developed for this study, see **SI Section S3**.

Self-report Measures

SARS-CoV-2 Vaccine Intentions were measured using a five-item scale developed for the present study (a sixth item was excluded, see: **SI Section S3**). Items were inspired by those used in past research on vaccine intentions (Powell et al., 2018; Shapiro et al., 2018). Participants rated their agreement with all items (example: “I am confident that getting the [Pfizer/Moderna] vaccine this week would be the right thing to do”) on a 7-point scale (1=“completely disagree, 7=“completely agree”). Ratings were initially made with respect to participants’ own willingness to vaccinate. These ratings are the main focus of the present study. For exploratory reasons, participants with children were asked to re-rate the items to indicate willingness to vaccinate their children (for results involving these ratings, see **SI Section S7**). In each case, total scores for each participant were computed as the sum of all ratings for the five scale items (after reverse scoring, as appropriate). Prior to rating the items, participants were randomly assigned to read the Emergency Use Authorization (EUA) fact sheet for either the Pfizer or Moderna vaccine against SARS-CoV-2 (for comparison of intentions on this basis, see: **SI Section S8**). Thus, the present study measured willingness to receive a specific SARS-CoV-2 vaccine authorized by the US Food and Drug Administration (FDA), an approach which is both externally valid and may limit variability due to participants imagining vaccines with different safety and efficacy profiles. To limit the effects of socioeconomic barriers to vaccination on vaccine intentions, participants were asked to imagine that the vaccine would be free and provided at a time convenient for them.

Perceived Vaccine Dangerousness was measured using a seven-item scale developed for the present study. Items were either drawn from previous measures of vaccine dangerousness (Powell et al., 2018) or based on common vaccine-related fears and myths noted by Reid (2020) and by the WHO. Respondents rated their agreement with each item (example: “Vaccines cause people to develop allergies”) on a seven-point scale (1=“completely disagree, 7=“completely agree”). Ratings were summed to produce a total score for each participant. In previous research, reduced willingness to vaccinate against SARS-CoV-2 has been observed among individuals who view vaccines as more dangerous (Romer & Jamieson, 2020).

Perceived Vaccine Effectiveness (Powell et al., 2018) was measured by having respondents rate four items (example: “vaccines are one of the most effective medical treatments”) on a seven-point scale (1=“strongly disagree”, 7=“strongly agree”). Ratings were summed to produce a total score for each participant. This measure, which had good internal consistency (α=.84) in past research (Powell et al., 2018), was included because reduced willingness to vaccinate has been repeatedly observed among individuals who view vaccines as less effective (Brewer & Fazekas, 2007; Powell et al., 2018).

Perceived Severity of SARS-CoV-2 Infection was measured using an eight-item scale developed for this study. Participants were asked to indicate how likely a person infected with SARS-CoV-2 was to experience various outcomes (examples: “be hospitalized” and “die”) on a seven-point scale (1=“Extremely Unlikely”, 7=“Extremely Likely”). Ratings were summed to produce a total score for each participant (after reverse scoring as appropriate). In previous research, reduced willingness to vaccinate against SARS-COV-2 was associated with perceiving infection as likely to produce less severe illness (Schwarzinger et al., 2021).

Belief in SARS-CoV-2 vaccine conspiracy theories was measured using a six-item scale developed for the present study. Items were either based on misinformation aggregated by newsguardtech.com or adapted from previous research (e.g., Freeman et al., 2020). Each item described a different conspiracy theory targeting SARS-CoV-2 vaccines (example: “The [SARS-CoV-2] vaccine contains a microchip that will be used in a global tracking system”). Participants were asked to rate the accuracy of each item on a nine-point scale (1=“Completely False”, 9=“Completely True”). Ratings were summed to produce a total score for each participant. Belief in conspiracy theories has been repeatedly related to reduced willingness to vaccinate against SARS-CoV-2 (Bertin et al., 2020; Romer & Jamieson, 2020).

Generalized Conspiracist Ideation was measured using the Belief in Conspiracy Theories Inventory (BCTI; Swami et al., 2010). Respondents rated 14 items (example: "The Apollo moon landings never happened and were staged in a Hollywood film studio") on a nine-point scale (1="Completely False", 9="Completely True"). One item from the original BCTI was excluded because it dealt with UK government distribution of drugs to racial/ethnic minorities and was deemed less relevant to our US-based participants. As in previous research, ratings were averaged to obtain a total score. This measure, which was selected because it has favorable psychometric properties in relation to other measures of general conspiracist ideation (Swami et al., 2017), was included to allow exploration of whether the pathways from reasoning biases to conspiracy theories would be similar when the criterion variable was generalized vs. specific (to SARS-CoV-2) conspiracist ideation.

Paranoia was measured using the Revised Green et al. Paranoid Thoughts Scale (R-GPTS; Freeman et al., 2019). This measure consists of two subscales: Ideas of Reference (GPTS-A) and Persecutory Ideation (GPTS-B). The latter subscale was the focus of the present study because of its strong association with SARS-CoV-2 related conspiracist ideation in past research (Freeman et al., 2020). This subscale has favorable psychometric properties, including item invariance by age and gender, and the fact that Item Response Theory suggests that all subscale items are highly discriminative of latent trait persecutory ideation (Freeman et al., 2019). Participants rate the ten subscale items (example: "I was sure someone wanted to hurt me") on a five-point scale (0="Not at all", 4="Totally") to indicate how well it reflects their thoughts and feelings over the last month.

Epistemic Trust in Scientists was measured using the Muenster Epistemic Trustworthiness Inventory (METI; Hendriks, Kienhues, & Bromme, 2015). The METI asks respondents to indicate how well 14 opposing adjective pairs describe an expert (in this case, scientists as a group) using a seven-point scale anchored by the adjective pairs (example: I consider scientists to be: 1="Competent", 4="In the middle", 7="Incompetent"). Adjective pairs were designed to address perceptions (of the expert's integrity, benevolence, and expertise) that may impact decisions to place epistemic trust in and defer to the expert. Ratings were summed to produce a total score for each participant, and then reversed so that higher scores reflected greater trust in scientists. Scientists were selected as the focus of the measure because research indicates that trust in scientists is associated with belief in SARS-CoV-2 conspiracy theories (Freeman et al., 2020), and because trust in scientists may be a particularly important determinant of willingness to accept SARS-CoV-2 vaccines given their unique features (e.g., that they inject mRNA to generate protein antigens, a mechanism of action that is poorly understood by the general public).

Locus of Control was measured using Levenson's Locus of Control scale (Levenson, 1981). Respondents rate their agreement with 24 items on a six-point scale (1="Strongly Disagree", 6="Strongly Agree"). Item ratings were summed to produce scores on three subscales: internal and external locus of control, and control by chance. This measure was included because more external locus of control and loss of personal (internal) control have been related to belief in conspiracy theories (Hamshire et al., 1968; Whitson & Galinsky, 2008).

Task-based Measures of Reasoning Biases

Data Gathering was measured using the Box Task (Steffen Moritz et al., 2017). Participants were presented with an array of twelve white boxes and were asked to determine whether they were primarily black or yellow inside. In each trial of the task, participants could either decide which color was more prevalent or ask for additional information. If participants opted to decide, they then rated their post-decision confidence on a seven-point scale (1="I was guessing", 7="Certain I was right"). If participants instead asked for additional information, they were shown the inside of another box (whose location in the display was chosen at random). Prior to revealing the color of the new box, participants indicated (on an 11-point scale: 1="100% sure black", 11="100% sure yellow") whether they believed the open boxes in the resulting display would be primarily black or yellow. Participants were allowed to open a maximum of nine boxes before deciding. While participants were unaware of the exact limit, they were told that they would be required to decide before all boxes were opened. The sequence of colors revealed was randomized, but used the same color ratio (5[black]:4[yellow]) as that employed in two previous studies (Steffen Moritz et al., 2017, 2020). The key metric derived from this task was the number of data points requested before a decision was made ("draws to decision"). Reduced data gathering has previously been associated with endorsement of SARS-CoV-2 conspiracy theories (Kuhn et al., 2021).

Decision Thresholds were measured by having participants complete a multiple-choice quiz where they attempted to identify the titles of paintings. Paintings were taken from a prior study using this strategy to measure decision thresholds (Moritz et al., 2009) and from the websites of major art museums. As in this previous study, paintings and possible titles were selected such that the answers would be ambiguous. For each painting, participants rated the plausibility of all four possible titles (on a 0-100 scale, with higher numbers suggesting more plausible options). After making these ratings, participants could either decide that one of the titles was correct or report that they did not feel ready to decide. The key metric derived from the task was the average plausibility rating for titles that the participant decided were correct. In previous research, lower decision thresholds have been related to endorsement of SARS-CoV-2 conspiracy theories (Kuhn et al., 2021).

Illusory Pattern Perception was measured using the Snowy Pictures Task (Whitson & Galinsky, 2008). Participants were presented with 24 pictures with significant visual noise. Half contained a difficult-to-perceive object, half did not. Participants were asked to indicate whether or not an object was present, and then rate their confidence in their decisions on a seven-point scale (1="I was guessing", "7=Certain I'm right"). Stimuli were taken from a previous study of illusory pattern perception (Walker et al., 2019). False alarm rates ("detection" of an object where none was present) were the key metric derived from the task. In past research, manipulations that increase illusory pattern perception also increase conspiracist ideation (Whitson & Galinsky, 2008), suggesting that illusory pattern perception may cause endorsement of conspiracy theories.

Denominator Neglect was measured using an urn gambling task (Sanchez & Dunning, 2020). Participants were asked to imagine that they could win $10 by drawing a red ball from one of the urns. Each urn had a different ratio of red to black balls. Participants rated (on a seven-point scale: 1="Definitely Urn A", 7="Definitely Urn B") their preference for drawing a ball from one urn over the other. Seven pairs of urns were presented. Urn A always had one red and nine black balls. Urn B always had 100 total balls, of which between seven and thirteen were red. Thus, in three cases Urn B had more red balls (a higher numerator) than Urn A, but offered a poorer chance of winning when the denominator (total balls in the urn) was accounted for. As in previous work (Sanchez & Dunning, 2020), denominator neglect was calculated by averaging participants' preference ratings across these three cases. Denominator neglect may discourage vaccination by causing over-estimation of side-effect risks (Reyna, 2004), and is associated with belief in conspiracy theories (Sanchez & Dunning, 2020).

Analyses

Preliminary tests of study hypotheses (e.g., examining whether it was plausible that Health Belief Model constructs might mediate the relations between conspiracist ideation and vaccine intentions) were conducted using bootstrapped mediation models (**SI Section S8**).

Causal Discovery Analysis

Causal discovery analyses were used as the primary test of study hypotheses. Although traditional wisdom holds that patterns of causation cannot be inferred from cross-sectional, observational data, this perspective neglects the fact these data carry information (e.g., in patterns of partial correlation) regarding which potential causal relations are more or less plausible (**Figure 1**). An emerging class of machine learning algorithms, collectively called causal discovery analyses, leverage this information to identify likely causal relations in a given dataset. These analyses have been successfully used to recover complex causal pathways, such as those involved in the pathophysiology of Alzheimer's disease (Shen et al., 2020), from observational data.

In the present study, one such algorithm, Greedy Fast Causal Inference (GFCI) was employed to infer a set of empirically plausible causal relations between SARS-CoV-2 vaccine intentions, belief in SARS-CoV-2 conspiracy theories, and other relevant individual-difference variables (e.g., reasoning biases, perceptions of vaccine dangerousness). The GFCI algorithm searches the space of penalized likelihood scores of all possible acyclic causal relations among the measured variables to produce a preliminary assessment of likely causal pathways. This preliminary result is then iteratively refined by ruling out causal models that imply patterns of conditional independence inconsistent with the data. The output of this procedure is a partial ancestral graph (PAG), with the edge type (**Table 1**) varying depending on the set of directed edges that were present across all remaining plausible causal models (e.g., a directed edge [→] is present if, and only if, all models not containing that edge were removed during the steps outlined above). A particular strength of the GFCI model is its ability to identify situations where unmeasured variables confound the relation between two measured variables, making it particularly well-suited to analyses of data from human research studies (where practical concerns, such as time limitations, constrain measurement of all relevant variables).

To better ensure graph stability, the GFCI algorithm was repeated on 1000 jackknifed re-samples of the study data (1000 re-samples, rather than 10,000 as preregistered, were used to limit computational requirements). The original dataset was included as an additional re-sample. Results were aggregated into a single, consensus PAG by depicting the edge type (including: "no edge") and orientation most commonly present in the PAGs created from the jackknifed re-samples. The full FCI rule set was employed. Default values for remaining parameters were used. For example, the penalty discount (c) used for generating the initial likelihood scores (BIC) was set to 1, the alpha value used in conjunction with Fisher's *z* tests to determine conditional independence and refine the preliminary results was set to .010, and one-edge faithfulness was not assumed. Because causal discovery algorithms recover causal pathways more effectively when they are provided with prior knowledge (Shen et al., 2020), the algorithm was given a set of forbidden edges: 1) age and sex could not be caused by any other variable, and 2) vaccine-related variables, such as belief in SARS-CoV-2 conspiracy theories, could not cause locus of control, as this was deemed implausible.

To provide information about the size of potential causal effects identified by GFCI, structural equation models featuring the edges GFCI suggested were fit to the data (using lavaan; Rosseel, 2019). Standardized structure coefficients were then added to the PAG. In cases where the voting ensemble preferred one edge orientation (→) to its opposite (←) by a slim margin (<10%), or when an edge orientation did not match that suggested by prior literature, Vuong's test (Vuong, 1989) was used to compare the model suggested by GFCI to that with the edge in question reversed. Significant results indicate support for GFCI's conclusion about the edge orientation over the alternative.

Psychometric Network Analysis

As a complement to this casual discovery analysis, a psychometric network analysis was conducted. This analysis affords a more relaxed approach to identifying potential causal relations between SARS-CoV-2 vaccine intentions, belief in SARS-CoV-2 conspiracy theories, reasoning biases, and other relevant individual-difference variables. It also conveys information about the valence and relative magnitude of these relations.

In this psychometric network analysis, edges were calculated using partial correlations, and the least absolute shrinkage and selection operator (LASSO; Tibshirani, 2016) was used to regularize the resulting network. The tuning parameter for LASSO (λ) was selected to minimize the Extended Bayesian Information Criterion (EBIC; Chen and Chen, 2008), as this technique is beneficial for retrieving the true network structure (Foygel Barber and Drton, 2015). Following the recommendations of Foygel and Drton (2010), the EBIC hyper-parameter (γ) was set to 0.5 to prioritize avoidance of Type I errors. The resulting undirected graphs of regularized partial-correlation networks were visualized using *R's qgraph* package, version *1.6.9* (Epskamp, 2020).

Because network analysis assumes that nodes represent distinct entities (Meier et al., 2019), variables included in each network analyses were evaluated for potential redundancy using *R's networktools* package, version *1.2.3* (Jones, 2020). In keeping with prior research, a given pair of variables was considered potentially redundant if (1) zero-order correlation between the variables exceeded .70 (indicating at least 50% overlapping variance; following the threshold adopted in Elliott, Jones, and Schmidt, 2020) and (2) correlations between each member of the pair and all remaining variables in the network were not statistically significantly different in more than 75% of cases (Marchetti, 2020; Meier et al., 2019).

Network Inference

After the network was estimated, node centrality and predictability were examined for exploratory purposes. Node predictability was computed using *R's mgm* package, version *1.2.12*. Predictability indexes how much variance in a given node is explained by the nodes that are connected to it in the network (Haslbeck and Fried, 2017), and can be understood as an upper bound on controllability (Fried et al., 2018).

Node centrality was measured using one-step expected influence (in networks with positive and negative edges, this measure of centrality may be preferable; see: Robinaugh, Millner, and Mcnally, 2016). One-step expected influence was calculated as the sum of the value of all edges extending from a given node, taking the mathematical sign of each edge into account. Expected influence was calculated using *networktools* (Jones, 2020).

Because it is possible that unequal variances of the nodes in the network affect their centrality estimate, thereby influencing the observed network structure (Terluin, De Boer, and De Vet, 2016), correlations between expected influence values and standard deviations (SDs) of the individual nodes were examined. The correlations between expected influences and means of individual nodes were also examined to better ensure that differences in severity did not explain node centrality or network structure.

Exploratory statistical tests of the differences between edge weights and node centrality measures were carried out using a non-parametric bootstrapping procedure conducted using *R's bootnet* package, version *1.4.3* (Epskamp, 2020). Data were bootstrapped 1000 times for this purpose. If the 95% confidence interval for the difference between two edge weights or node centrality metrics did not overlap with zero, the difference was considered statistically significant.

Network Accuracy and Stability

Network accuracy and stability were also estimated using *bootnet* and 1000 bootstrapped re-samples. The accuracy of edge weights was quantified using the 95% confidence intervals generated from this bootstrapping procedure. Narrower confidence intervals indicate greater precision in edge weight estimates. Stability of centrality measures was quantified using the correlation stability coefficient (CS-coefficient; Epskamp, Borsboom, and Fried, 2018), which denotes the proportion of cases that can be dropped such that the set of stability measures obtained using the full and reduced data-sets are correlated above a certain threshold (.70 in the present study) with 95% probability. Following the recommendations of (Epskamp et al., 2018), metrics were considered stable if the CS-coefficient exceeded .25.

Outliers and Missing Data

Outliers were detected using the method of Hubert and Van Der Veeken (2008), as pre-registered, because this method was designed for detecting outliers in skewed data; several variables in the present study, including belief in SARS-CoV-2 vaccine conspiracy theories, were right skewed. Detected outliers were winsorized (Fuller, 1991). For additional information, see **SI Section S4.** Participants with missing data were included in path analyses given that the selected parameter estimation method (FIML) handles these data effectively. All other analyses were conducted after excluding participants with missing data list-wise.

Demographic Covariates

Small differences were observed on SARS-CoV-2 vaccine intentions as a function of demographic variables. For example, older individuals were less willing to vaccinate against SARS-CoV-2, rho(552)=-0.17, *p*<.001, as were women (*M*=25.13, *SD*=9.48 vs. men: *M*=27.00, *SD*=8.40). For this reason, age and sex are included as covariates in all analyses (other than zero-order correlations).

Results

Evaluation of Novel Measures

Novel measures were created for the present study to assess SARS-CoV-2 vaccine intentions and belief in SARS-CoV-2 conspiracy theories. Support for the validity of both measures was found. The measure of intentions correlated as expected with past vaccination behavior (see: **SI Section S3**). For example, individuals were more willing to vaccinate themselves (*t*(504.72)=7.35, *p*<.001) and their children (*t*(97.72)=3.54, *p*<001) if they/their children had received an influenza vaccine in the last two years. The measure of SARS-CoV-2 specific conspiracy theories correlated as expected with a generalized measure of conspiracist beliefs (the BCTI), rho(552)=.59, *p*<.001.

After these initial checks, the measure of SARS-CoV-2 vaccine intentions (targeting adults' willingness to have themselves vaccinated) was subjected to additional scrutiny. First, Mokken analysis and Principal Component Analysis (PCA) were used to determine whether this measure was unidimensional (i.e., that it captured a single underlying trait). After confirming that the measure was unidimensional, it was examined with Item Response Theory to investigate whether it discriminated well between individuals with differing willingness to vaccinate and whether it provided sufficiently reliable estimates of willingness to vaccinate within the usual range of this trait in the general population.

The results of PCA and Mokken analysis suggested that while the first five items of the measure loaded strongly on a single dimension and exhibited strong scaling properties (allowing total scores to be calculated by summing item ratings), the sixth item loaded less strongly on this dimension and exhibited weaker scaling properties. Thus, this item is excluded in the present study. The remaining five items were highly discriminative of participants' willingness to vaccinate, with difficulty levels suggesting that individuals providing the lowest ratings on each of these items were likely to have a willingness to vaccinate that was at least a standard deviation below the population mean, and that individuals providing the highest ratings on each of these items were likely to be slightly above the population mean on willingness to vaccinate. The analysis also suggested that the measure as a whole would be sufficiently reliable for individuals within approximately two standard deviations of the population mean willingness to vaccinate, and that it would provide the most information about willingness to vaccinate for individuals who were approximately one standard deviation above to two standard deviations below the population mean in this trait. Thus, the final five-item measure was deemed sufficient for investigating SARS-CoV-2 vaccine intentions in the present study. For additional information on these analyses, see **SI Section S3**.

Descriptive Statistics

Our measure of intent to vaccinate against SARS-CoV-2 had a theoretical maximum of 35 and a theoretical minimum of five. The mean level of adults' intentions (26.11) suggested that, on average, unvaccinated adults were rather willing to vaccinate. The distribution of adults' vaccine intentions was left-skewed, with fewer individuals being increasingly unwilling to vaccinate. The distribution for adults' willingness to vaccinate their children against SARS-CoV-2 was comparatively platykurtic. The mean for this distribution (19.37) was significantly lower ($t(147.78)=6.22$, $p<.001$, 95%CI=[4.60 8.87]) than that for adults, perhaps due to the fact that at the time of the survey the vaccine had not been approved for emergency use in children.

Our measure of belief in SARS-CoV-2 conspiracy theories had a theoretical maximum of 54 and a theoretical minimum of 6. The mean for this measure (13.54) indicated that, on average, participants did not strongly believe in these theories. The distribution of this measure was right-skewed, with fewer individuals providing increasingly strong endorsements of these conspiracy theories. To better ensure that our selection criteria (especially, selecting only unvaccinated individuals) did not result in a sample that endorsed conspiracy theories to a degree that is not representative of the general population, average endorsement of generalized conspiracy theories (on the BCTI) was compared between this and previous studies. Average endorsement of these theories was comparable. For instance, the mean for this study was 3.76, and for a previous general population study (Georgiou et al., 2019) it was 3.56. For additional descriptive statistics, see **SI Section S2**.

Zero-order Correlations Between Study Variables

Non-parametric correlations (Spearman's rho) were used to account for non-normality. Confidence intervals were calculated using R's spearmanCI package, version 1.0. Notably, SARS-CoV-2 vaccine intentions were correlated with belief in SARS-CoV-2 vaccine conspiracy theories (rho(552)=-.61, $p<.001$, 95%CI=[-0.67 -0.55]) and with constructs from the Health Belief Model, including the perceived severity of SARS-CoV-2 infection (rho(552)=.23, $p<.001$

, 95%CI=[0.14 0.31]), as well as general perceptions of vaccine dangerousness (rho(552)=-.61, p<.001, 95%CI=[-.66 -.55]), but not effectiveness (rho(552)=.06, p=.183, 95%CI=[-0.03 0.14]). These results are broadly consistent with Hypothesis 1's assertion that conspiracist ideation and Health Belief Model constructs impact SARS-CoV-2 vaccine intentions.

Belief in SARS-CoV-2 vaccine conspiracy theories was associated with several reasoning biases, including increased denominator neglect (rho(552)=.21, p<.001, 95%CI=[0.12 0.29]), higher rates of illusory pattern perception (rho(552)=.11, p=.013, 95%CI=[0.02 0.19]), and (marginally) less data gathering (rho(552)=-.09, p=.042, 95%CI=[-0.17 0.00]). These results are compatible with possibility that reasoning biases might contribute to belief in conspiracy theories.

For the full set of zero-order correlations between study variables, see **SI Section S5**.

Causal Discovery Analyses

The consensus PAG generated via causal discovery analysis is depicted in **Figure 2**. A structural equation model featuring the relations suggested by this PAG was an adequate fit to the data, RMSEA=.07, CFI=.87, SRMR=.07. Vuong's test supported this model over alternative models with the edges between the following variables reversed: vaccine conspiracist ideation and vaccine intentions (z=1.55, p=.061), trust in scientists and vaccine intentions (z=2.34, p=.010), and vaccine conspiracist ideation and perceived vaccine dangerousness (z=2.07, p=.019), suggesting that GFCI's edge orientations were more likely correct than their reversed counterparts. This result is notable given that the examined edges' orientation in the PAG differed from that expected from prior literature (see Discussion section).

The PAG generated by GFCI was only partially consistent with the hypothesis that conspiracist ideation causes vaccine intentions via Health Belief Model constructs. In this PAG, perceived disease severity and vaccine dangerousness (but not effectiveness) directly caused vaccine intentions, supporting the existence of the latter leg ("path b") of the hypothesized indirect effect. However, perceived disease severity (indirectly, via vaccine intentions) and vaccine dangerousness (directly, and/or indirectly via vaccine intentions) were identified in the PAG as causes of belief in SARS-CoV-2 conspiracy theories, implying that they are not, as predicted, caused by this belief. Moreover, the PAG indicated that belief in SARS-CoV-2 conspiracy theories was (directly) caused by vaccine intentions, but not vice-versa, as hypothesized.

Because belief in SARS-CoV-2 conspiracy theories did not function as hypothesized, the PAG was inspected for potential causal pathways leading from reasoning biases to vaccine intentions through other variables. Two such pathways were identified. Lowered decision thresholds and reduced data gathering were both causal ancestors of persecutory ideation, which caused perceptions of vaccine dangerousness and, in turn, vaccine intentions. Thus, even if belief in conspiracy theories does not cause vaccine intentions, reasoning biases associated with this belief may modulate intentions via their effects on paranoia. However, it should be noted that GFCI indicated that the role of these reasoning biases as a causal ancestor of paranoia (and, in turn vaccine intentions and conspiracist ideation) may be due to an unmeasured confounder. This possibility should be investigated in future research, especially as it is consistent with theoretical frameworks describing the relation between reduced data gathering and more extreme (delusional) forms of paranoia (Bronstein et al., 2019).

On a more exploratory basis, the relations between epistemic trust in scientists, conspiracist ideation, and willingness to vaccinate was inspected. The PAG indicated that belief in SARS-CoV-2 conspiracy theories (directly) and vaccine intentions (directly, or indirectly, via belief in SARS-CoV-2 conspiracy theories) caused epistemic trust in scientists, implying that trust in scientists is (perhaps counterintuitively) not a direct cause of vaccine intentions.

Exploratory Analyses involving Psychometric Networks

Although these results grant insight into potential causal pathways leading to (and from) vaccine intentions, they are limited in that they provide no information about the valence and relative magnitude of potential causal effects. Moreover, because causal discovery analyses identify potential causal relations using a stringent rule set, they may overlook relations worthy of further investigation. Psychometric network analyses that use partial correlation to draw network edges address these limitations by taking a more relaxed approach to identifying potential causal relations (identifying associations that persist after controlling for multiple possible confounds), and by providing a visualization of potential causal relations' valence and relative magnitudes. Accordingly, for exploratory purposes a partial correlation network was constructed from the same set of variables subjected to causal discovery analysis.

Network Estimation

The goldbricker function (*networktools*) suggested that none of the nodes in the resulting network (**Figure 3**) were redundant. In the regularized network, vaccine intentions were strongly (negatively) related to perceived dangerousness of vaccines, and were more moderately (positively) associated with perceived severity of SARS-CoV-2 infection. Both these variables were identified as possible causes of intentions in the causal discovery analyses. Vaccine intentions were also strongly (negatively) associated with belief in SARS-CoV-2 conspiracy theories and were more moderately (positively) associated with epistemic trust in scientists. Vaccine intentions were identified as a likely cause of both these variables by GFCI.

Belief in SARS-CoV-2 conspiracy theories was strongly (positively) associated with perceived vaccine dangerousness. In our causal discovery analysis, it was ambiguous whether the relation between these variables was direct, indirect (via vaccine intentions), or both. The presence of this edge in a network controlling for vaccine intentions (and its statistical significance in the structural equation model fit to the PAG produced via causal discovery analysis) provides preliminary support for the presence of a direct relation (in addition to the indirect one) between perceived dangerousness and SARS-CoV-2 conspiracist ideation. Belief in SARS-CoV-2 conspiracy theories was more moderately (and negatively) associated with epistemic trust in scientists, potentially because belief in these theories discourages this form of trust (as indicated in the causal discovery analysis). Belief in SARS-CoV-2 conspiracy theories was also (positively) associated with several reasoning biases, including illusory pattern perception and denominator neglect. While these biases were not identified as possible causes of conspiracist ideation by GFCI, previous literature providing evidence of a causal relation between these variables (Sanchez & Dunning, 2020; van Prooijen et al., 2018; Whitson & Galinsky, 2008) suggests that additional exploration of the role of these biases may be warranted. Belief in SARS-COV-2 conspiracy theories was also associated (positively) with persecutory ideation (which GFCI suggested was causally upstream of belief in conspiracy theories) and epistemic trust in scientists (which GFCI suggested was reduced by belief in SARS-CoV-2 conspiracy theories).

Network Inference

In addition to providing information about the absolute strength and valence of relations identified by GFCI, network analysis provides information about the relative strength of potentially causal effects. There were several significant differences among edge weights in the network (**Figure S5: top**). Notably, the negative edges connecting vaccine intentions to belief in

SARS-CoV-2 conspiracy theories and perceived vaccine dangerousness were stronger than every other negative edge in the network. This result indicates that among the causal effects suggested by GFCI, the effect of perceived dangerousness on vaccine intentions and the effect of vaccine intentions on belief in SARS-CoV-2 conspiracy theories are likely to be the strongest (most negative). Other edges stronger than most others in the network included those connecting belief in SARS-CoV-2 conspiracy theories to epistemic trust in scientists and perceived vaccine dangerousness, as well as the edge connecting vaccine intentions to epistemic trust in scientists. GFCI suggested that all of these edges were reflective of causal relations.

For information about the one-step expected influence and predictability of nodes in the network, as well as overall network accuracy and stability (which was quite good), see **SI Section S6**.

Discussion

The present study extends previous research on willingness to vaccinate against SARS-CoV-2 by using machine learning algorithms and psychometric network analysis to elucidate relations between reasoning biases, conspiracist ideation, and vaccine intentions. Several key insights into these relations were generated. Causal discovery analyses suggested that SARS-CoV-2 vaccine intentions and perceived vaccine dangerousness caused belief in SARS-CoV-2 vaccine conspiracy theories (but not vice-versa). This suggestion is inconsistent with our pre-registered hypothesis that there would be an indirect effect of these beliefs on vaccine intentions via constructs highlighted in the Health Belief Model. Stronger support was observed for the specific prediction that Health Belief Model constructs influence adults' intentions to vaccinate themselves (and their children, **SI Section S8**). Two constructs from this model – perceived disease severity and perceived vaccine dangerousness – were implicated as direct causes of

SARS-CoV-2 vaccine intentions. Finally, reasoning biases, such as the tendencies to gather less data and adopt lower decision thresholds, were identified as causal ancestors of conspiracist ideation and vaccine intentions, expanding our knowledge of the cognitive underpinnings of these processes.

The lack of support for our hypothesis that conspiracist ideation indirectly causes vaccine intentions is surprising given previous experimental (Chen et al., 2020; Jolley & Douglas, 2014) and observational (Romer & Jamieson, 2020) studies consistent with this hypothesis. The discrepancy between our results and those of these previous studies may stem from our use of GFCI to uncover potential causal pathways. GFCI assumes that causal graphs are acyclic, and may therefore fail to capture complex causal patterns, such as reciprocal causation. With this in mind, GFCI's suggestion that the causal relation between conspiracist ideation and vaccine intentions is opposite that suggested by previous literature can be interpreted as evidence that this relation is, in fact, bidirectional. Future research could test this conclusion by examining the dynamic interplay between conspiracist ideation and vaccine intentions across multiple measurement occasions. Regardless of the outcome of this future work, the present study's suggestion that reduced willingness to vaccinate causes belief in conspiracy theories (perhaps as a confirmatory strategy, see: Bertin et al., 2020) lends new urgency to efforts to address vaccine hesitancy and refusal because belief in conspiracy theories is associated with undesirable outcomes, including reduced engagement in prosocial behavior (Van der Linden, 2015) and decreased epistemic trust in scientists (**Figure 2**), which may hinder efforts to combat infectious disease outbreaks (Mulukom, 2021).

Although the present study found no evidence for the hypothesized indirect effect of conspiracist ideation, significant support was found for the notion that the hypothesized mediators influence vaccine intentions. Two constructs from the Health Belief Model, perceived vaccine dangerousness and perceived severity of SARS-CoV-2 infection, were implicated as direct causes of willingness to vaccinate against SARS-CoV-2. However, a third construct from this model, perceived vaccine effectiveness, was not identified as a cause of vaccine intentions. Indeed, in our psychometric network, perceived effectiveness was only associated with vaccine intentions indirectly, via perceived disease severity and vaccine dangerousness, and perceived effectiveness did not correlate with intentions at zero-order. Given that manipulating perceived effectiveness impacts willingness to vaccinate (e.g., against HPV; Bigman et al., 2010), this null result may be a Type II error (particularly given that the majority of individuals scored within a three-point range on our measure of effectiveness). Accordingly, future research should clarify whether there is a causal relation between perceived vaccine effectiveness and SARS-CoV-2 vaccine intentions, and whether any such relation is direct or, as suggested by our network analysis, indirect (via perceived vaccine dangerousness and/or disease severity).

The results of the present study were clearer concerning the potential for reasoning biases to influence vaccine intentions and conspiracist ideation. In our network analysis, denominator neglect and illusory pattern perception were directly associated with belief in SARS-CoV-2 conspiracy theories, in accordance with previous research on generalized conspiracist ideation (Sanchez & Dunning, 2020; Whitson & Galinsky, 2008). Although neither of these biases was identified as a cause of conspiracist ideation in the present study, two other reasoning biases (lowered decision thresholds and the tendency to gather less data prior to decision making) were identified as potential causal ancestors of belief in SARS-CoV-2 related conspiracy theories, building on previous research showing an association between these variables (Kuhn et al., 2021). Both of these reasoning biases were involved in causal pathways that increased paranoia and the perceived dangerousness of vaccines, thereby reducing vaccine intentions and encouraging conspiracist ideation. Given this potential pathway, future research should investigate whether existing intervention that target these biases and/or paranoia, such as SlowMo and Metacognitive Training (Garety et al., 2021; Moritz et al., 2014), might be adapted to encourage vaccination and reduce conspiracist ideation. The possibility that these interventions might have these effects is particularly exciting given that existing interventions on vaccine intentions are frequently ineffective (Pluviano et al., 2017) or backfire (Nyhan & Reifler, 2015).

The results of the present study also clearly implicate locus of control in conspiracist ideation and reduced willingness to vaccinate. Causal discovery analyses indicated that locus of control (by others) indirectly encourages vaccine-related conspiracist ideation via its influence on persecutory ideation, and, in turn, perceived vaccine dangerousness and vaccine intentions. Network analyses implied that these effects are strong relative to other influences on conspiracist ideation and vaccine intentions. By identifying this causal pathway from locus of control to conspiracist ideation, this study extends past research showing that threats to personal control motivate generalized conspiracist ideation (van Prooijen & Douglas, 2017; Whitson & Galinsky, 2008).

In addition to these findings, the present study paves the way for future work on this topic through its creation of a multi-item, unidimensional measure of SARS-CoV-2 vaccine intentions with discriminative items that is reliable and highly informative for individuals with latent trait intentions within approximately two standard deviations of the population mean. Beyond its favorable psychometrics, the measure has several other useful properties. It explicitly tells participants to assume that the vaccine will be free and delivered at a time convenient for them, which may reduce variance in intentions due to factors not directly related to the vaccine itself, such as socioeconomic status. Further, the measure asks participants to rate their intentions after reading the Emergency Use Authorization (EUA) fact sheet for a specific SARS-CoV-2 vaccine. This provides a platform for future experimental manipulation (e.g., alterations to the fact sheet could be used to test the impacts of health communication on vaccine intentions) and adaptation to studies examining willingness to vaccinate against other diseases (by inserting the appropriate EUA and making minor wording changes to the measure itself).

By providing researchers with this rigorously evaluated measure (**SI Section S3**), we hope to move the field toward a consensus metric of willingness to vaccinate against SARS-CoV-2 and other highly-infectious microbes. Thus far, the majority of studies on this topic (for example: Daly et al., 2021; Romer & Jamieson, 2020) have employed single-item measures of intentions with varying wording and types of rating scales. While this strategy was appropriate given the need for rapid insight into a global pandemic, at this time moving toward a multi-item, consensus measure that has been rigorously evaluated confers multiple advantages, such as allowing for easier comparison of study results as well as potentially affording better coverage of the vaccine intentions construct and better prediction of actual vaccination behavior.

The implications of the present study should be considered in the context of several limitations. First, participants were required to deny receipt of any SARS-CoV-2 vaccine. This criterion excluded approximately 30% of the US population (New York Times Vaccine Tracker) at the time of data collection (early April, 2021). Excluded individuals may differ systematically from those allowed to participate (e.g., they may have gotten a vaccine dose due to pre-existing medical condition, higher SES, etc.), potentially in ways that could impact the pattern of causal relations observed here-in. Future research should therefore reexamine these relations in samples recruited closer in time to the release of novel vaccines, when selection effects are less likely to bias study results. A second limitation of the present study is that its analyses employed cross-sectional datasets. Casual discovery analyses may more accurately recover casual relations when temporal information is provided (Shen et al., 2020). Moreover, the set of contemporaneous causal relations between variables may differ from that unfolding across time. Future research should address this limitation by using causal discovery analyses to examine the relations between conspiracist ideation, reasoning biases, Health Belief Model constructs, and vaccine intentions in longitudinal datasets. A final limitation of the present study is that it examined the causes and correlates of willingness to vaccinate, rather than vaccination behavior. While intentions generally explain a moderate amount of variance in ultimate behaviors (approximately 22%, on average; Armitage & Conner, 2010), future research should examine whether receipt of a SARS-CoV-2 vaccine is subject to the same causal influences as those suggested by the present study of intentions.

Conclusion

The longstanding trend of disease outbreaks exacerbated by vaccine hesitancy and refusal (Dyer, 2017; Siddiqui et al., 2013) has continued during the SARS-CoV-2 pandemic. Gaining insight into the causal pathways leading to (and from) willingness to vaccinate should scaffold more effective responses to this ongoing crisis. While this study supports certain conventional views of these pathways – for example, by implicating perceived disease severity and vaccine dangerousness as direct causes of vaccine intentions – it challenges others – by, for instance, indicating that belief in SARS-CoV-2 conspiracy theories and epistemic trust in scientists are caused by reduced willingness to vaccinate (but not vice-versa). The present study also broadens our understanding of these pathways by implicating reasoning biases, such as reduced data gathering, as potentially modifiable targets that are causally upstream of vaccine intentions.

These insights provide exciting new directions for future research that could make use of the rigorously evaluated measure of SARS-CoV-2 vaccine intentions developed in the present study.

Author Contributions

M.V. Bronstein developed the study design and concept, which S. Vinogradov helped refine. M.V. Bronstein analyzed the data. E. Kummerfeld provided expertise surrounding causal discovery analyses. M.V. Bronstein drafted the manuscript. A. MacDonald and S. Vinogradov provided critical revisions. All authors approved the final manuscript for submission.

Conflicts of Interest

Conflicts of Interest: None

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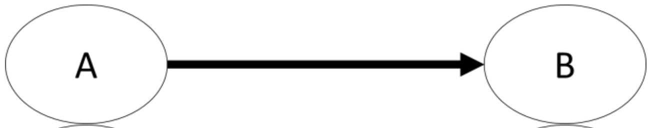
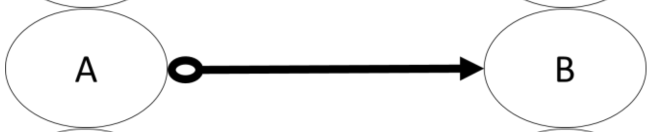
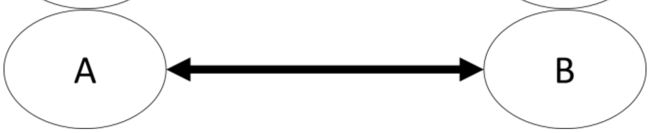
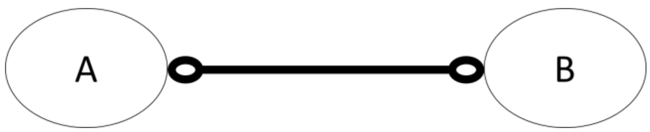
Table 1.

Edge Types in a Partial Ancestral Graph Convey Information about Potential Causal Relations

Edge Type	Information Conveyed
	A is a direct or indirect cause of B. A and B are potentially confounded. B is not a cause of A.
	Either A is a cause of B or there is an unmeasured confounder of A and B, or both. B is not a cause of A.
	There is an unmeasured confounder (L) of A and B. There may be measured variables along the causal pathway from L to A or B.
	Exactly one of the following holds: 1. A is a cause of B 2. B is a cause of A 3. There is an unmeasured confounder of A and B 4. Both a and c 5. Both b and c

Note. In addition to the above, if an edge is **bold** (thickened), then the relation is definitely direct. Else, it is possibly indirect. If an edge is green, there is no latent confounder of the relation; if it is blue, there may be a latent confounder.

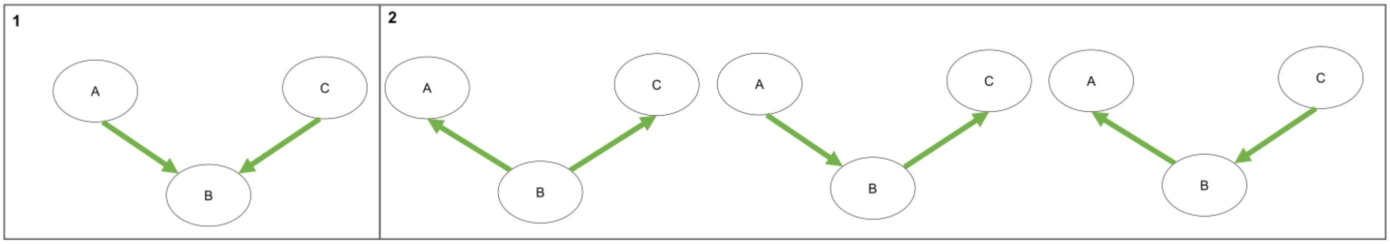


Figure 1. **Patterns of conditional relations convey information about causal orientations.** The absence of an arrow denotes the absence of a causal relation. Green arrows denote causal relations between variables (see **Table 1**). **Panel 1:** A "collider" graph (A and C directly cause B, no edge between A and C). A is unconditionally independent of C, and A is dependent on C conditional on B. **Panel 2:** However, in all other possible relations between A, B, and C (where no edge is present between A and C), a different pattern of conditional relations emerges: A is unconditionally dependent on C, and A is independent of C conditional on B. Given the differential pattern of conditional relations between the graphs in **Panel 1** and **Panel 2**, examining conditional relations can support inference about whether a collider or some other causal process generated the observed data. Greedy Fast Causal Inference uses cases like that illustrated above to determine the direction of causal edges and to rule in/out latent confounds of the relations between variables.

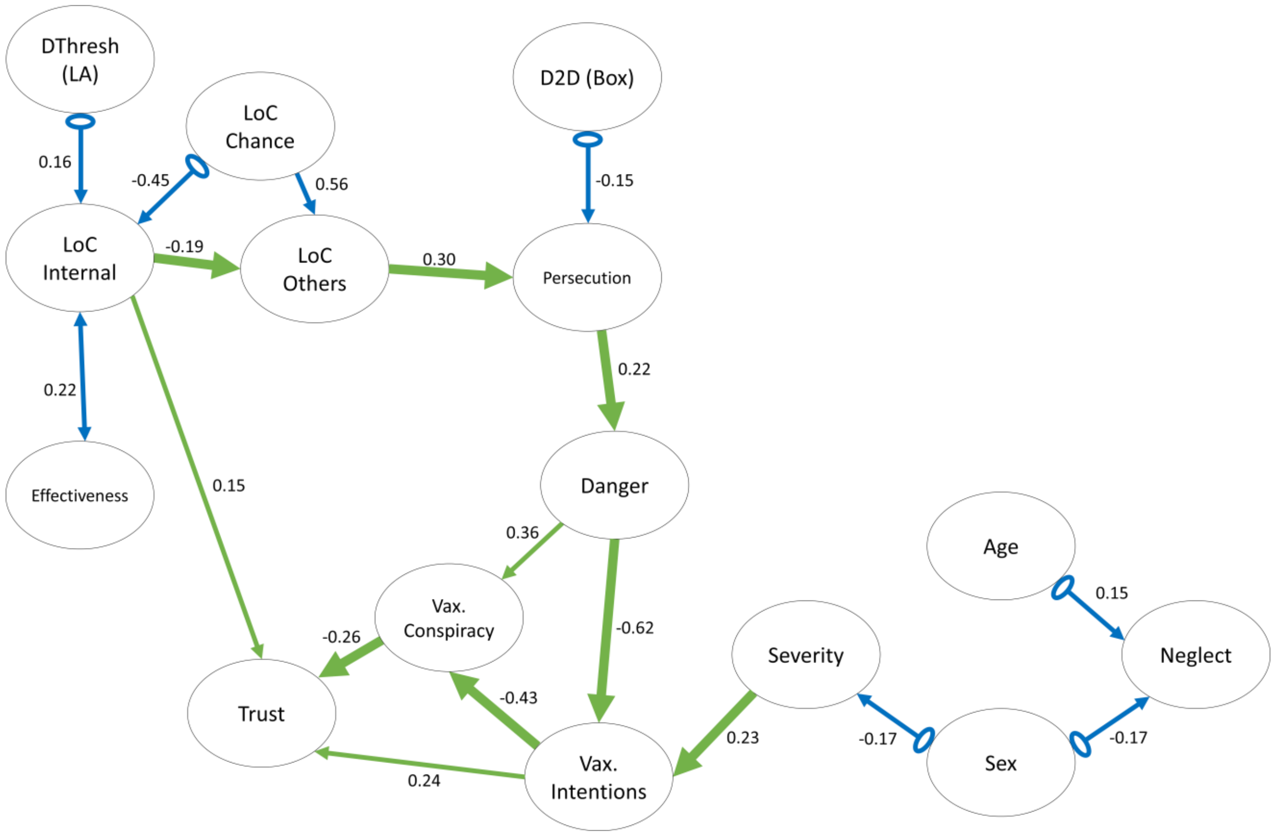


Figure 2. Directed Acyclic Graph suggested by the Greedy Fast Causal Inference (GFCI) causal discovery algorithm. See **Table 1** for a description of possible edge types. Variables are not depicted if GFCI could not determine a potential causal relation between them and another variable included in the analysis. Refer to **Figure 3** for information about the valence (positive/negative) and relative strength of potential causal effects depicted here. Numbers adjacent to edges are standardized parameter estimates from a structural equation model of the causal structure suggested by GFCI. Neglect=Denominator Neglect. Trust=Epistemic Trust in Scientists. Vax.=Vaccine. LoC=Locus of Control. D2D=Draws to Decision. DThresh=Decision Threshold. Sex is coded as the effect of being male (vs. female).

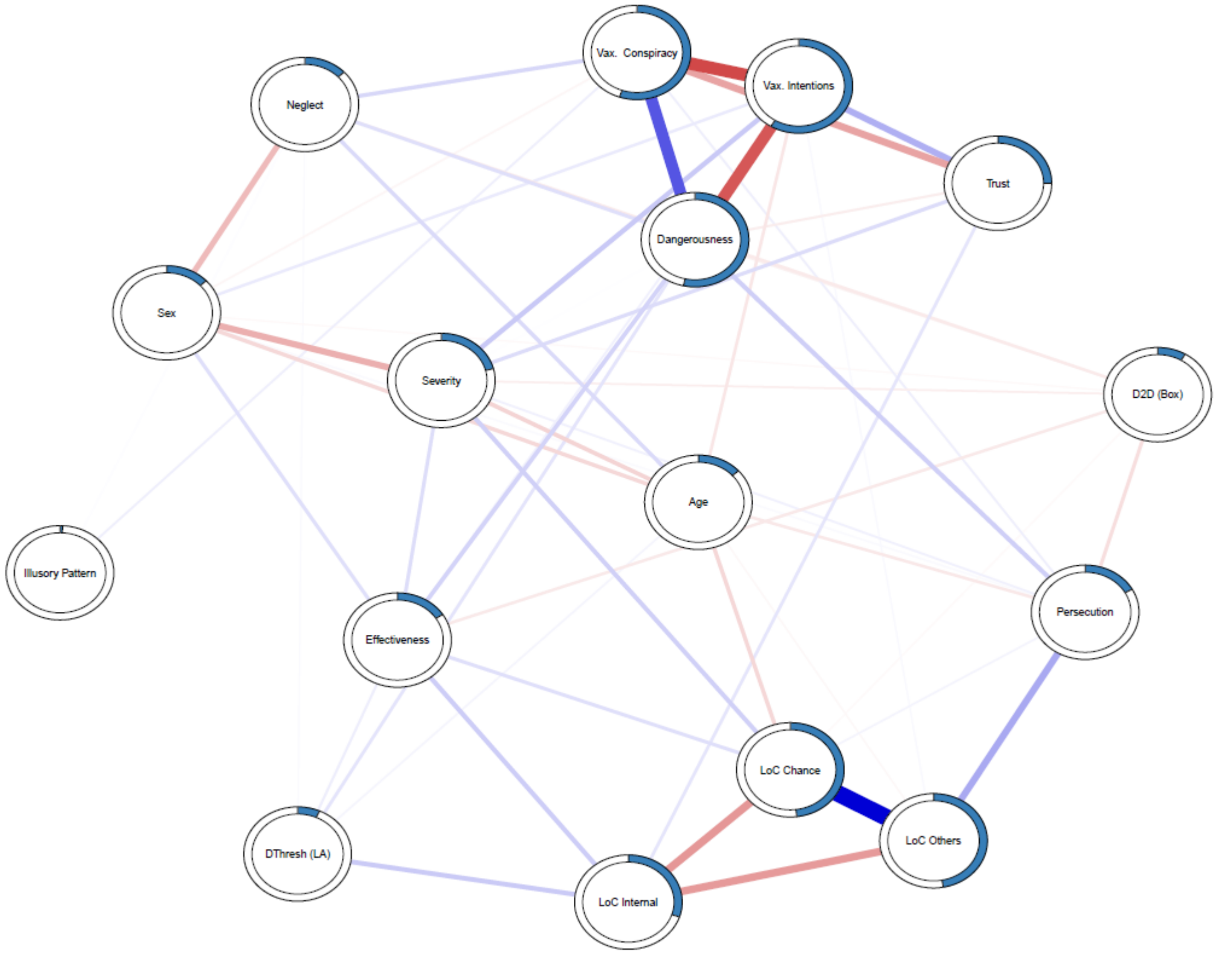


Figure 3. Regularized partial correlation network. Annulus surrounding each node denotes predictability (more filled=more predictable). Red=negative association. Blue=positive association. Neglect=Denominator Neglect. Trust=Epistemic Trust in Scientists. Vax.=Vaccine. LoC=Locus of Control. D2D=Draws to Decision. DThresh=Decision Threshold. Sex is coded as the effect of being male (vs. female).

Supplementary Material for:

SARS-CoV-2 Vaccine Intentions, Reasoning Biases, and Conspiracist Ideation

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Table of Contents

Section S1. Demographic Information

Table S1.

Demographic Information

Demographic	Screener	Main Study
N	1117	554
Age [*M* (*SD*)]	32.79 (11.46)	33.79 (11.48)
Gender Identity		
Male	590	289
Female	512	252
Non-binary	15	11
Sex Assigned at Birth		
Male	592	290
Female	525	262
Intersex	0	0
Race		
White/Caucasian	705	352
Black/African American	82	38
Asian	167	72
Pacific Islander	4	2
Middle Eastern/North African	2	2
Native American/Alaska Native	1	0
Other	6	3
Hispanic	Yes: 67 | No: 1050	Yes: 38 | No: 521
Level of Education		
Some High School, no Diploma	17	9
GED or High School Graduate	164	90
Some College, No Degree	278	122
Associate's Degree	105	48
Bachelor's Degree	416	207
Master's Degree	113	65
PhD/Prof. Degree	24	11
Marital Status		
Single, Never Married	666	323
Married/Domestic Partnership	384	192
Widowed/Widower	7	3
Divorced	48	29
Separated	12	5
Had COVID-19	--	Yes: 45 | No: 509
Got a Flu Vaccine (last 2 years)	--	Yes: 195 | No: 359
Experienced vaccine-related SAE	--	Yes: 3 | No: 550
Has Children Under 18	--	Yes: 115 | No: 439
Child had COVID-19	--	Yes: 5 | No: 110
Child got Flu Vaccine (Last 2 Years)	--	Yes: 47 | No: 68
Chose not to have child vaccinated	--	Yes: 25 | No: 90

Note. Individuals could opt not to answer demographic questions, and were able to select more than one option for race/ethnicity. For the main study, demographic information refers to participants included in the final sample for analysis.

Differential Drop-out

Just over half of the individuals (55%) who were invited to participate in the main study did so. To examine the possibility of differential drop-out, individuals who were invited to participate in the main study and accepted that invitation were compared to individuals who were invited but declined on variables recorded during the screening survey. People who accepted (age: M = 34.09, SD = 11.79) vs. declined (age: M = 31.19, SD = 10.81) the invitation were slightly older ($t(1105.6) = 4.28$, $p < .001$), and had a pattern of educational attainment different from that expected by chance ($\chi^2(7) = 15.03$, $p = .027$; more individuals who accepted than expected had master's degrees, and fewer than expected had a GED or "some college"). People who accepted vs. declined the invitation did not differ in terms of sex ($\chi^2(1) = 1.01$, $p = .313$), gender ($\chi^2(2) = 4.81$, $p = .090$), or generalized conspiracist ideation ($t(1092.8) = 1.29$, $p = .198$). Thus, our two-stage recruitment method may have systematically selected for individuals in a manner that may make this study less generalizable to less educated and younger individuals.

Section S2. Internal consistency and descriptive statistics of study measures

Table S2.

Internal Consistency and Descriptive Statistics of Study Measures

Measure	*M* (*SD*)	Omega Total
Vaccine Intentions (Adults)	26.11 (8.97)	.98
Vaccine Intentions (Children)	19.37 (10.89)	.98
Perceived Vaccine Dangerousness	23.06 (6.77)	.92
Perceived Vaccine Effectiveness	16.47 (2.27)	.84
Perceived SARS-CoV-2 Severity	32.69 (8.22)	.89
SARS-CoV-2 Vaccine Conspiracist Ideation	13.54 (10.99)	.96
Generalized Conspiracist Ideation (BCTI)	3.76 (1.54)	.92
Ideas of Reference (GPTS-A)	4.57 (5.37)	.91
Paranoia (GPTS-B)	3.87 (6.35)	.94
Epistemic Trust in Scientists (METI)	81.06 (11.27)	.95
Locus of Control – Internal (Levenson)	33.62 (5.29)	.81
Locus of Control – Chance (Levenson)	25.36 (6.15)	.87
Locus of Control – Others (Levenson)	25.40 (6.48)	.86
Box Task – Draws To Decision	7.52 (3.50)	--
Box Task – Decision Threshold	5.89 (1.78)	--
Box Task – Decision Confidence	3.98 (1.67)	--
Box Task – Decision Accuracy	.66 (.47)	--
Denominator Neglect	2.34 (1.54)	--
Illusory Pattern Perception – d’ (sensitivity)	-0.02 (1.02)	--
Illusory Pattern Perception – c (criterion)	-0.01 (0.84)	--
Illusory Pattern Perception – Confidence Gap	0.93 (0.75)	--
Painting Task – Decision Threshold	68.55 (16.23)	--
Painting Task – Number of Decisions	24.15 (8.07)	--

Note. Descriptive statistics and internal consistencies for outlier filtered data.

Section S3. Measures Developed for the Present Study

Several measures were developed for the present study. Items from these measures can be found in the table below:

Table S3.

Novel Measures and Associated Content

Measure	***Item***
Vaccine Intentions	1. *I am confident that getting the (Pfizer/Moderna) vaccine this week would be the right thing to do* 2. *Getting the (Pfizer/Moderna) vaccine this week would be good for my health* 3. *Getting the (Pfizer/Moderna) vaccine this week would protect me from COVID-19* 4. *Getting the (Pfizer/Moderna) vaccine this week would protect vulnerable people in my community from COVID-19* 5. *The benefits of getting the (Pfizer/Moderna) vaccine this week would outweigh the risks* 6. *If I received the (Pfizer/Moderna) vaccine this week, I would wait longer than the recommended (three weeks/one month) to get the second dose of the vaccine**+
Perceived Disease Severity	1. *...suffer permanent negative effects on their health (e.g., reduced lung function, heart damage, altered sense of taste or smell)* 2. *...die* 3. *...be hospitalized* 4. *...be sick for over two weeks* 5. *...be unable to do basic household tasks (e.g., cook for oneself) for some period of time* 6. *...be unable to get out of bed for a period of time* 7. *...be sicker than they would have been if they had instead contracted influenza ("the flu")* 8. *...be asymptomatic (experience no detectable symptoms)**
Perceived Vaccine Dangerousness	1. *Formaldehyde in vaccines is harmful to human health* 2. *Vaccines cause autism* 3. *Vaccines cause people to develop allergies* 4. *Vaccines are a very safe medical treatment* 5. *Many people have severe adverse reactions to vaccines*

	6. *Giving infants too many vaccines too soon can overwhelm their immune systems* 7. *Vaccines often cause individuals to become severely ill with the very diseases they claim to protect against*
SARS-CoV-2 Vaccine Conspiracy Theories	1. *The COVID-19 vaccine contains a microchip that will be used in a global tracking system* 2. *COVID-19 was created in a lab with the goal of forcing individuals to get vaccinated* 3. *The pharmaceutical industry created the coronavirus to increase sales of its drugs and vaccines.* 4. *The government is hiding the fact that the COVID-19 vaccine will change your DNA* 5. *Military scientists designed the COVID-19 vaccine to alter the virus so that it can be reactivated later by 5G signals* 6. *Pharmaceutical companies have worked together to cover up deaths caused by the COVID-19 vaccine*

Note. *=reversed. +This item was excluded after examining the item functioning using Item Response Theory (see below). The adult version of the vaccine intentions measure is depicted. In the child version, each item was altered to focus on the respondent's children (ex: "getting my children the [Pfizer/Moderna] vaccine this week…"). The stem for the perceived disease severity questions was: "How likely is a person who is infected with COVID-19 to…"

Measure Validity

The validity of the present study's measure of SARS-CoV-2 vaccine intentions was investigated by examining its association with past vaccination behaviors, as previous research has shown that history of vaccination predicts vaccine intentions (Crowley Rpa-C et al., 2009). In support of the measure's validity, previous vaccination behaviors were consistently associated with SARS-CoV-2 vaccine intentions. Individuals who received an influenza vaccine in the last two years were more willing to vaccinate against SARS-CoV-2 (M = 29.46, SD = 6.91) than their counterparts who had not (M = 24.30, SD = 9.43), $t(504.72) = 7.35$, $p < .001$. Moreover, parents were more willing to vaccinate their child against SARS-CoV-2 if their child had been vaccinated against influenza in the last two years (M = 23.51, SD = 10.50) than if their child had not received the influenza vaccine during this time period (M = 16.51, SD = 10.28), $t(97.72) = 3.54$, p < 001. Parents were also more willing to vaccinate their child against

SARS-CoV-2 if they had not previously refused a vaccine for their child (*M* = 21.92, *SD* = 10.43), versus if they had refused a vaccine for their child in the past (*M* = 10.20, *SD* = 6.92), $t(57.70) = 6.63$, $p < .001$.

The validity of the present study's measure of SARS-CoV-2 vaccine conspiracy theories was investigated by examining its association with a measure of generalized conspiracist ideation (the BCTI). In support of the validity of our measure of SARS-CoV-2 vaccine conspiracy theories, belief in these theories and generalized conspiracist ideation were highly correlated, rho(552) = .59, $p < .001$.

Examining Our Vaccine Intentions Measure Using Item Response Theory

Many studies have relied on measures of SARS-CoV-2 vaccine intentions that have not been subjected to rigorous psychometric evaluation (in particular, many have used novel single-item measures, which may have psychometric disadvantages relative to multi-item measures). While the use of these measures was understandable given the urgency of learning about factors underlying SARS-CoV-2 vaccine intentions, the resulting situation has several disadvantages. Without access to psychometric information about the measures used in the literature on SARS-CoV-2 vaccine intentions, researchers are unable to take important contextual information (such as whether measures used in the literature discriminate well between individuals with true scores spanning the spectrum of vaccine intentions) into account when interpreting published findings. Moreover, these researchers may have difficulty selecting the best measure to use in their studies of SARS-CoV-2 vaccine intentions, leading to heterogeneity of selected measures that might contribute to disparate results across studies, further complicating interpretation of the literature. To remedy this situation, the psychometric properties of the measure of vaccine intentions used in the present study were systematically evaluated.

To determine how well items differentiated between individuals who differed on willingness to vaccinate against SARS-CoV-2, a two parameter graded-response model (Samejima, 1968) based on Item Response Theory was fit to the data (using R's mirt package version 1.33.2). Item Response Theory makes several assumptions, including that the scale is unidimensional (representing a single latent trait ability, theta). To test this assumption, Mokken analysis and principal component analysis (PCA) were employed. PCA (conducted using R's psych package, version 2.1.6) suggested that the vaccine hesitancy scale was unidimensional (a single component explained 73% of the item variance, and the model fit the data well, $\chi 2= 30.33$, $p < .001$, RMSR =.04). This was confirmed with parallel analysis (conducted with R's paran package, version 1.5.2). However, the communality (proportion of variance in items explained by the principal components) for item 6 was low (0.02), suggesting that relatively little variance was shared between the underlying scale dimension and responses to item 6. Mokken analysis was conducted using R's Mokken package version 3.0.6. Items with Loevinger's H above 0.3 were considered to be part of a unidimensional scale (Stochl et al., 2012). Items 1-5 had H values above .70, but Item 6 had an H value (.09) below the critical threshold. This suggested that Item 6 should be excluded prior to fitting the IRT model. With this item excluded, the scale's overall H was .87 (SE = .01), indicating strong scaling properties (Stochl et al., 2012). Furthering the suggestion that Item 6 should be excluded from the IRT-based analysis (and the scale itself), when Item #6 was included, it had an unacceptable discrimination parameter, 0.35, and difficulty parameters suggesting that the majority of response options required levels of latent willingness to vaccinate that were seven or more standard deviations outside the mean.

With this in mind, the remaining five items were modeled. The model was an excellent fit to the data, RMSEA = 0, CFI = 0. The resulting parameters describing each item are depicted in **Table S4**. The first of these parameters, α, quantifies the ability of the item to discriminate between individuals with different latent trait willingness to vaccinate against SARS-CoV-2 (θ). Higher values of α indicate greater increases in the degree of item endorsement with small changes in θ. Values of α exceeding one reflect highly discriminative items (Baker & Kim, 2017). For each item, difficulty parameters denote the level of θ necessary to have a 50% chance of endorsing either of two adjacent response options (example: for item 1, a person with a latent willingness to vaccinate 1.27 standard deviations below the population mean would have a 50% chance of providing a rating of one and a 50% chance of providing a rating of two). Larger values of the difficulty parameter indicate that endorsement of the item at that level is indicative of greater latent trait willingness to vaccinate (θ). All items were sufficiently discriminative. Item difficulties varied between –1.75 and 0.54, suggesting that the test would mainly provide information about individuals whose willingness to vaccinate was somewhat less than the population mean.

The test information curve (**Figure S1, left**) suggested that the measure would provide the most information about willingness to vaccinate for individuals who were slightly above (approximately 1SDs) to moderately below (approximately -2SDs) the population mean in this trait. **Figure S1** (right) illustrates how the test score is sensitive to changes in theta within this range, but does not change once θ becomes more extreme, limiting ability to discriminate between individuals with more extreme vaccine intentions. The plot of standard errors suggested that the test would be reliable for individuals in the likely range (+/- 2SDs of the population mean) of willingness to vaccinate for most studies of the general population. Given these results, it may be worthwhile for future studies to add one or two items that can discriminate well between individuals who are at least moderately willing to vaccinate. This would help the measure be useful in studies attempting to identify factors that promote willingness to vaccinate, as well as those focused on vaccine hesitancy/refusal (like the present study).

Table S4.

Discrimination Parameters and Item Difficulties for Vaccine Intentions Scale

Item	α	b1	b2	b3	b4	b5	b6
1	7.39 [6.22 8.56]	-1.27 [-1.42 -1.12]	-0.93 [-1.05 -0.80]	-0.76 [-0.88 -0.64]	-0.37 [-0.47 -0.27]	-0.09 [-0.19 0.01]	0.33 [0.22 0.43]
2	9.54 [7.74 11.33]	-1.36 [-1.52 -1.21]	-1.01 [-1.14 -0.89]	-0.86 [-0.97 -0.74]	-0.39 [-0.49 -0.28]	-0.12 [-0.22 -0.02]	0.34 [0.25 0.45]
3	3.40 [2.95 3.85]	-1.75 [-1.96 -1.54]	-1.40 [-1.57 -1.22]	-1.17 [-1.33 -1.02]	-0.63 [-0.75 -0.50]	-0.17 [-0.28 -0.06]	0.54 [0.42 0.66]
4	4.16 [3.60 4.72]	-1.67 [-1.87 -1.48]	-1.34 [-1.50 -1.17]	-1.15 [-1.30 -1.00]	-0.70 [-0.82 -0.58]	-0.22 [-0.33 -0.11]	0.36 [0.25 0.47]
5	8.37 [6.92 9.82]	-1.34 [-1.49 -1.19]	-1.05 [-1.18 -0.92]	-0.86 [-0.98 -0.74]	-0.46 [-0.57 -0.36]	-0.15 [-0.25 -0.05]	0.20 [0.10 0.30]

Note. Numbers in brackets are 95% CIs. For actual items, see **SI Table S3.** Item #6 was excluded, as explained above, because it did not strongly tap the same underlying dimension as the other scale items.

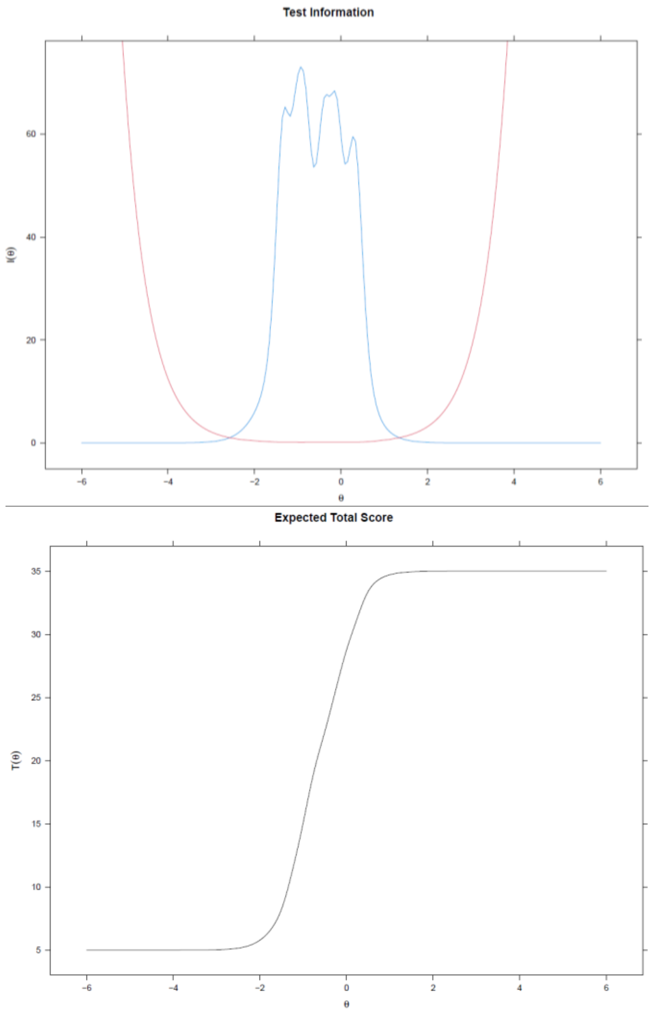

Figure S1. Left: Test Information Curve (Blue) and standard errors (Red). Right: Expected total score on the measure as a function of latent trait willingness to vaccinate (θ).

Section S4. Note on Outlier Filtering

Summary scores for measures of interest were checked for univariate outliers using the method of Hubert and Van Der Veeken (2008), which is designed for filtering skewed data. A total of 68 univariate outliers were detected across the following variables: perceived vaccine effectiveness, epistemic trust in scientists, internal locus of control, chance locus of control, the sensitivity and confidence gap metrics derived from the illusory pattern perception task, and the decision threshold for the Box Task. Multivariate outliers were checked for by visualizing bivariate relations between key variables of interest. No such outliers were observed. The results of the present study did not differ qualitatively when outliers were included vs. not included in the dataset.

Section S5. Zero-order correlations

Table S5.
Zero-order correlations

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-.61*	.06	.23*	-.62*	-.41*	-.04	.42*	.01	.10^{+}	.05	.04	-.17*	-.04	-.01
2		.16*	.02	.63*	.48*	.19*	-.30*	.04	.06	.06	-.12*	.22*	.09^{+}	.13*
3			.14*	.12*	.14*	.08	.02	.13*	.11*	.08	-.11*	-.03	.04	.10^{+}
4				-.09^{+}	.06	.13*	.15*	-.10^{+}	.19*	.13*	-.12*	.04	.07	.06
5					.59*	.15*	-.36*	.01	.07	.07	-.09^{+}	.21*	.11^{+}	.07
6						.16*	-.22*	-.04	.15*	.14*	-.08	.21*	.11^{+}	.07
7							-.05	-.17*	.29*	.34*	-.14*	.04	.05	-.01
8								.17*	-.02	-.10^{+}	.01	-.15*	-.02	.10^{+}
9									-.43*	-.40*	-.03	-.02	.00	.19*
10										.62*	-.11*	-.02	.05	-.02
11											-.01	-.03	.01	-.10^{+}
12												-.08	.00	-.05
13													.07	.05
14														-.01

1=Vaccine Intentions (Adults), 2=Perceived Vaccine Dangerousness, 3=Perceived Vaccine Effectiveness, 4=Perceived SARS-CoV-2 Severity, 5=SARS-CoV-2 Vaccine Conspiracist Ideation, 6=Generalized Conspiracist Ideation, 7=Paranoia (GPTS-B), 8=Epistemic Trust in Scientists, 9=Locus of Control (Internal), 10=Locus of Control (Chance), 11=Locus of Control (Others), 12 = Draws to Decision (Box Task), 13=Denominator Neglect, 14=Illusory Pattern Perception (False Alarms), 15=Decision Threshold (Painting Task). All correlations are non-parametric (Spearman's rho), df=552. $^{+}$=p<.05, *=p<.01.

Section S6. Network Stability, Accuracy, and Difference Tests

This section depicts results regarding the stability and accuracy of the network depicted in the main text, as well as tests for significant differences among edges and centrality measures.

Significant differences were observed between nodes' expected influence (**SI Figure S4: bottom**). The node with the strongest (negative) expected influence was SARS-CoV-2 vaccine intentions, suggesting that improving vaccine intentions would have a substantial impact on other variables in the network (such as belief in SARS-CoV-2 conspiracy theories and epistemic trust in scientists). Perceived vaccine effectiveness had the third strongest positive expected influence; other Health Belief Model constructs had more moderate positive expected influences. Belief in SARS-CoV-2 conspiracy theories had a relatively small negative expected influence.

There was no correlation between the standard deviation of a node and its expected influence, rho(14)=.02, p=.952, 95%CI=[-.53 .62]. There was also no correlation between node means and their expected influences, rho(14)=.08, p=.780, 95%CI=[-.43 .64]. Thus, the relative average levels of conspiracist ideation/vaccine intentions and differential node informativeness were not capable of explaining the centrality of nodes in the network.

Variance in nodes was generally well explained by their neighbors. The average predictability across nodes was .27, indicating that just over one quarter of variance in the network could be accounted for. However, 63% of the variance in the network remained unexplained and may be attributable to unmeasured variables. The three best explained nodes in the network were SARS-Cov-2 vaccine intentions (predictability=.59), belief in SARS-CoV-2 conspiracy theories (predictability=.55), and perceived dangerousness of vaccines (predictability=.54).

Network Accuracy and Stability

Bootstrapped confidence intervals suggested that the precision of network edges was acceptable (**SI Figure S3**). Edges were sufficiently stable, with a correlation-stability coefficient of .75. The one-step expected influence was less stable (CS-coefficient=.59), but still above the recommended cutoff (0.5; Epskamp et al., 2018). Consequently, findings regarding these metrics could be interpreted.

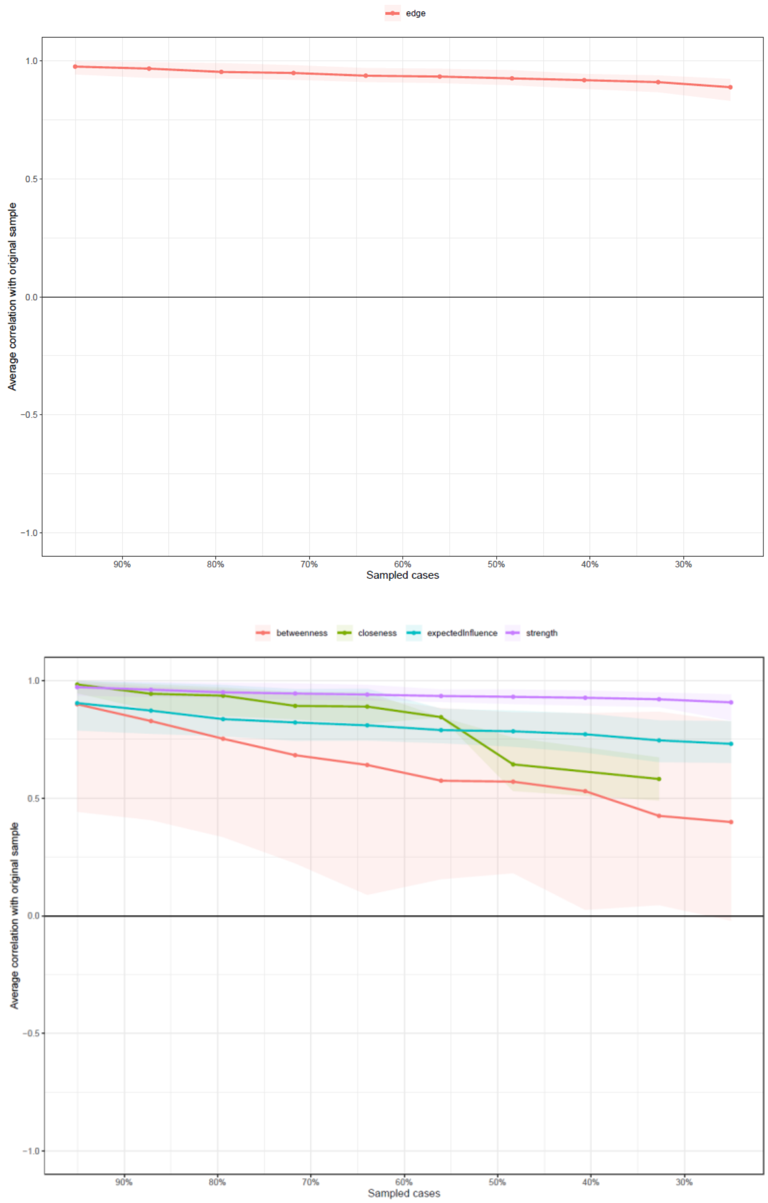

Figure S2. Stability of edge weights and centrality metrics, computed using a case-drop bootstrapping procedure. Clouds represent 95% CIs.

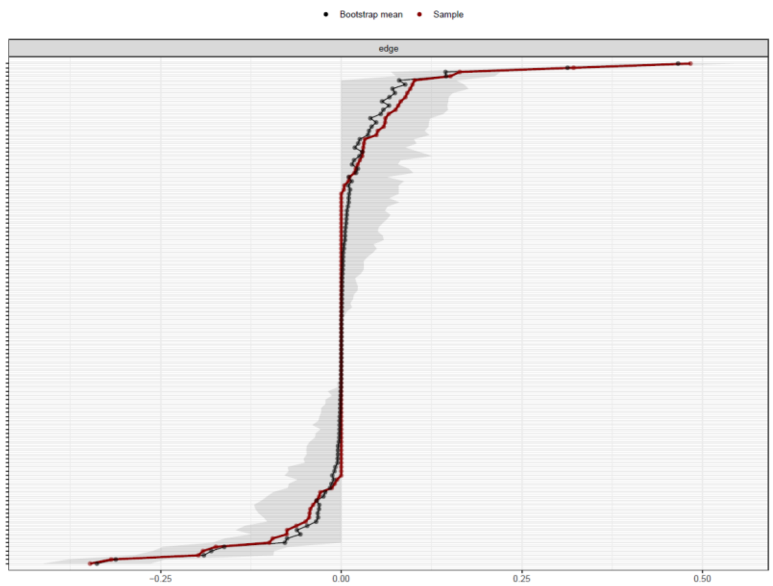

Figure S3. Bootstrapped confidence intervals for edge weights. Red = sample means, black = bootstrapped means. Grey = 95% CI. Edges are ordered by weight, with ties broken by bootstrapped sample means. Y-axis labels omitted as is customary.

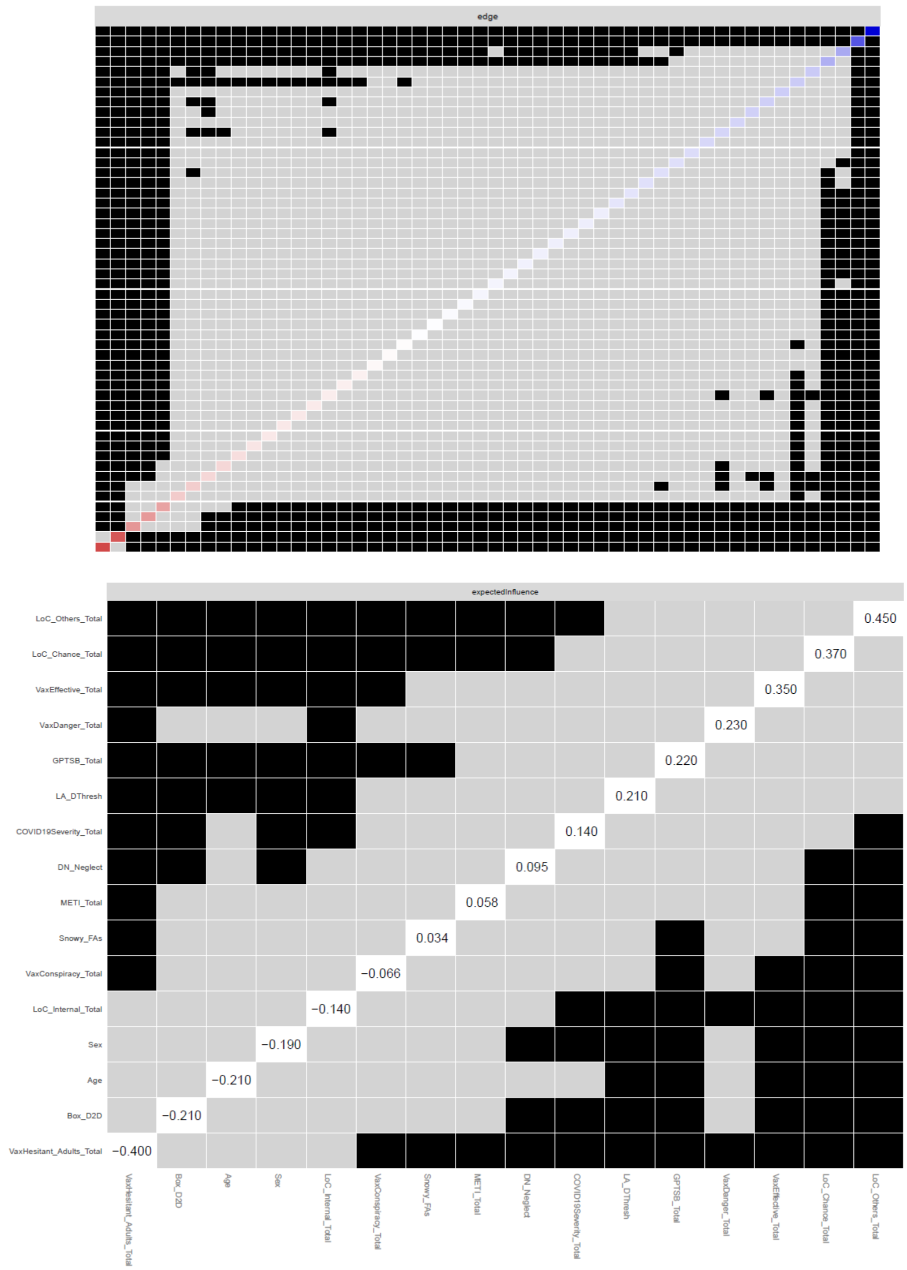

Figure S4. Bootstrapped difference tests (α = .05) between non-zero edge weights (top) or expected influences (bottom) in the estimated network. Black = parameters are significantly different for those edges. Grey = no significant difference. Each number in a white box represents the value of the tested parameter for that node. Darker colors on the diagonal of the edge-weight plot represent more positive (blue) or negative (red) edge weights.

In order to explore whether the pattern of partial correlations in the estimated network differed by biological sex, the estimated networks for male and female participants were compared using R's NetworkComparisonTest package 2.2.1. In an omnibus test, the networks for participants of different sexes did not differ, M = .09, *p* = .948, indicating that network visualized for all participants does not obscure sex differences in potential pathways leading to belief in SARS-CoV-2 vaccine conspiracy theories and reduced willingness to vaccinate.

Section S7. Results Regarding Participants' Intentions to Vaccinate their Children

Table S6.
Zero-order correlations

	Correlation with Child-focused Vaccine Intentions
Vaccine Intentions (Adults)	.82*
Perceived Vaccine Dangerousness	-.48*
Perceived Vaccine Effectiveness	.19^{+}
Perceived SARS-CoV-2 Severity	.27*
SARS-CoV-2 Vaccine Conspiracist Ideation	-.45*
Generalized Conspiracist Ideation	-.25*
Paranoia	.14
Epistemic Trust in Scientists	.40*
Locus of Control (Internal)	.04
Locus of Control (Chance)	.18
Locus of Control (Others)	.20^{+}
Draws to Decision (Box Task)	.02
Denominator Neglect	-.16
Illusory Pattern Perception (False Alarms)	.03
Decision Threshold (Painting Task)	.01

Note. All correlations are non-parametric (Spearman's rho), df=113. $^{+}$=p<.05, *=p<.01.

Structural equation models in the present study suggested that epistemic trust in scientists, as well as perceived severity of SARS-CoV-2 infection and perceived vaccine dangerousness (evidence was less conclusive regarding perceived vaccine effectiveness) mediate the relation between belief in SARS-CoV-2 vaccine-related conspiracy theories and adults' willingness to be vaccinated against SARS-CoV-2. To examine whether this result would hold for adults' willingness to vaccinate their children, we constructed a parallel mediation model with adults' willingness to their vaccinate children as the criterion variable, belief in SARS-CoV-2 vaccine conspiracy theories as an exogenous variable, and the remaining variables (epistemic trust in scientists, perceived vaccine effectiveness/dangerousness and perceived infection severity) as potential mediators.

This model was an excellent fit to the data: CFI = 1, RMSEA = 0, and SRMR = 0. Results (**Table S7**) suggested the presence of three mediation pathways. The first of these began with a direct relation between belief in SARS-CoV-2 conspiracy theories and the perception that vaccines, in general, are more dangerous, $\beta = 0.62$, $p < .001$, 95% CI = [.57 .67]. and continued with a relation between that perception and reduced willingness to vaccinate one's children, β =-0.33, *p* < .001, 95%CI = [-0.48 -0.18]. The resulting (negative) indirect pathway via perceptions of vaccine dangerousness was statistically significant, β = -0.21 [-0.36 -0.06]. The second mediation pathway supported by the data began with associations between belief in SARS-CoV-2 vaccine conspiracy theories and the perception that SARS-CoV-2 infection was less severe, β = -0.11, *p* = .006, 95%CI = [-0.19 -0.03], and between this perception and reduced willingness to vaccinate one's child, β = 0.19, *p* = .020, 95%CI = [0.03 0.35]. The resulting (negative) indirect pathway was marginally significant, β = -0.02 [-0.05 0.00]. The final mediation pathway supported by the data began with a direct relation between belief in SARS-CoV-2 vaccine conspiracy theories and the perception that vaccines were less effective, β = 0.12, *p* = .006, 95%CI = [0.03 0.21], and continued with a direct pathway from this perception to reduced willingness to vaccinate one's child, β = 0.17, *p* = .011, 95%CI = [0.04 0.30]. The resulting mediation pathway through perceived effectiveness of vaccines (β = 0.02 [0.01 0.03]) was statistically significant. The pathway through epistemic trust in scientists (β = -0.03 [-0.11 0.03]) was not supported by mediation testing.

Table S7.

Parallel Mediation Model Explaining the Relation Between Conspiracist Ideation and Willingness to Vaccinate Children

	Criterion	Predictor	Estimate [95% CI]	SE	|z|	*p*
Regressions						
(R^2 = .02)	Effectiveness	**Vax. Conspiracy**	**0.12 [0.02 0.22]**	**0.05**	**2.30**	**.022**
		Age	-0.01 [-0.13 0.11]	0.06	0.21	.837
		Sex	**0.11 [0.03 0.19]**	**0.04**	**2.59**	**.010**
(R^2 = .40)	Dangerousness	**Vax. Conspiracy**	**0.62 [0.57 0.67]**	**0.03**	**23.03**	**<.001**
		Age	0.07 [0.00 0.15]	0.04	1.89	.059
		Sex	0.00 [-0.07 0.06]	0.03	0.13	.901
(R^2 = .08)	Severity	**Vax. Conspiracy**	**-0.11 [-0.19 -0.03]**	**0.04**	**2.73**	**.006**
		Age	**0.19 [-0.28 -0.11]**	**0.04**	**4.55**	**<.001**
		Sex	**-0.21 [-0.29 -0.13]**	**0.04**	**5.17**	**<.001**
(R^2 = .19)	Epistemic Trust	**Vax. Conspiracy**	**-0.43 [-0.52 -0.35]**	**0.04**	**10.03**	**<.001**
		Age	-0.06 [-0.14 0.01]	0.04	1.67	.096
		Sex	0.04 [-0.11 0.04]	0.04	0.90	.367
(R^2 = .31)	Vax. Intentions	Vax. Conspiracy	-0.14 [-0.34 0.05]	0.10	1.45	.148

		Effectiveness	0.13 [-0.01 0.26]	0.07	1.83	.067
		Dangerousness	**-0.33 [-0.49 -0.17]**	**0.08**	**4.03**	**<.001**
		Severity	**0.19 [0.03 0.35]**	**0.08**	**2.26**	**.024**
		Epistemic Trust	0.08 [-0.10 0.25]	0.09	0.84	.399
		Age	0.01 [-0.23 0.21]	0.11	0.06	.949
		Sex	0.12 [-0.05 0.29]	0.09	1.43	.153
Intercepts						
	Effectiveness	**--**	**6.55 [5.98 7.11]**	**0.29**	**22.76**	**<.001**
	Dangerousness	**--**	**2.44 [2.14 2.73]**	**0.15**	**16.12**	**<.001**
	Severity	**--**	**4.91 [4.57 5.25]**	**0.18**	**27.96**	**<.001**
	Epistemic Trust	**--**	**7.95 [7.32 8.58]**	**0.32**	**24.76**	**<.001**
	Vax. Conspiracy	--	1.23 [1.23 1.23]	0.00	--	--
	Vax. Intentions	--	1.47 [-0.45 3.38]	0.98	1.50	.133
	Age	--	2.94 [2.94 2.94]	0.00	--	--
	Sex	--	1.06 [1.06 1.06]	0.00	--	--

Note. BOLD=significant. Coefficients for Sex denote effect of being male (vs. female). Vax. Conspiracy = belief in SARS-CoV-2 vaccine conspiracy theories.

This evidence for the mediation pathways through perceived dangerousness of vaccines and the perceived severity of SARS-CoV-2 infection is consistent with the mediation models examined for adults' willingness to vaccinate (reported in **SI Section S8**). However, the lack of an indirect pathway involving epistemic trust in scientists was specific to adults' willingness to vaccinate their children. Given that a significant pathway via epistemic trust in scientists was found for the mediation model based on the larger sample of individuals, but not for the mediation model based on the smaller sample (all adults in the study provided ratings of willingness to vaccinate, but only those with children provided ratings of willingness to vaccinate their child), it is quite possible that differences in statistical power drove the differing results. Consistent with this notion, simulation studies (Fritz & MacKinnon, 2003) suggest that over 300 individuals would likely have been required to reliably detect a mediated effect with component pathways the size of those for epistemic trust in scientists, which is considerably more than the 115 included in the model above. Alternatively, trust in scientists may have been a less relevant determinant of willingness to vaccinate children because, at the time of data collection, scientific data on the SARS-CoV-2 vaccine's safety and efficacy in children were not available. Regardless of the explanation for this discrepancy between the models for adults and children, the results from this mediation analysis are consistent with the notion that belief in SARS-CoV-2 conspiracy theories might impact adults' intentions to vaccinate their children via constructs from the Health Belief Model (perceived disease severity, perceived dangerousness of vaccines).

Results for network and causal discovery analyses involving adults' intentions to vaccinate their children are not depicted here because the 115 datapoints provided insufficient power to reliably detect causal relations between variables and is significantly below what simulation studies suggest would be optimal for a network analysis (Epskamp et al., 2018).

Future research should collect additional data from parents and examine how adults' willingness to vaccinate their children is related to conspiracist ideation and Health Belief Model constructs. Given the results of our causal discovery and psychometric network analyses in adults, this future work should test the hypothesis that parents' willingness to vaccinate their children against SARS-CoV-2 is causally influenced by perceived dangerousness of vaccines (in general) and perceived severity of SARS-CoV-2 infection, as well as the hypothesis that willingness to vaccinate one's child impacts belief in SARS-CoV-2 related conspiracy theories and epistemic trust in scientists. Future work may also consider whether the same pathways apply to adolescents' willingness to vaccinate themselves against SARS-CoV-2. Knowing more about the underpinnings of adolescents' willingness to vaccinate themselves would have practical implications given legal frameworks in several states that allow minors to assent to vaccination without parental permission.

Section S8. Additional Pre-registered Analyses

Comparison of the SARS-CoV-2 Vaccines made by Pfizer and Moderna

Participants in the present study were randomly assigned to make vaccine hesitancy ratings regarding the SARS-CoV-2 vaccine manufactured by either Pfizer or Moderna. Participants read the EUA fact sheet for one of these vaccines before indicating their willingness to vaccinate against SARS-CoV-2, and items of the instrument measuring willingness to vaccinate referenced either the Pfizer or Moderna vaccine. This was done to allow for exploratory analyses examining whether adults were generally more hesitant to receive one of these vaccines and whether the relations between conspiracist ideation or concerns about vaccine safety/effectiveness were more strongly associated with hesitancy to receive one of the vaccines.

To examine whether adults were more hesitant to receive the Pfizer or Moderna vaccine, willingness to vaccinate was compared using an independent-samples *t*-test. No evidence of a preference for the Pfizer (M=25.57, SD=9.10) or Moderna (M= 26.66, SD=8.82) vaccines was observed, $t(551)=1.44$, p=.152. To investigate whether conspiracist ideation or concerns about vaccine safety/effectiveness were more strongly related to willingness to receive a particular vaccine, multiple regression models were constructed to examine whether vaccine type interacted with any of these variables in predicting vaccine intentions. No evidence of any interaction effect was observed (all $t < 1.13$, all $p > .258$).

These results are broadly consistent with the notion that willingness to receive the Pfizer or Moderna vaccine is impacted similarly by the constructs of interest in the present study, and that participants are not differentially willing to receive one of the two vaccines. Accordingly, vaccine type is not controlled for in analyses conducted for the present study.

Mediators of the Relation Between Belief in SARS-CoV-2 Vaccine Conspiracy Theories and Willingness to Vaccinate

As mentioned in the main text, previous studies suggest that Health Belief Model constructs mediate the relation between belief in conspiracy theories and willingness to vaccinate. Similarly, previous studies suggest that (mis)trust mediates the relation between belief in conspiracy theories and engagement in preventative health behaviors. For example, observational studies have found that mistrust in governments mediates the relation between belief in SARS-CoV-2 conspiracy theories and reduced engagement in certain preventative behaviors (avoiding physical proximity to others during the pandemic; Bruder & Kunert, 2013). Results from experimental studies have been similar, suggesting that mistrust of healthcare providers mediates the relation between exposure to conspiracy theories and reduced willingness to engage in health-promoting behaviors, like visiting a doctor (Natoli & Marques, 2020). Taken together, these studies suggest that belief in conspiracy theories generally reduces trust in the organizations and individuals that encourage and administer preventative health measures, thereby impacting willingness to accept these measures. Consistent with this hypothesis, exposure to conspiracy theories reduces willingness to vaccinate in a manner mediated by reduced trust in authority figures (Jolley & Douglas, 2014).

Extrapolating from this literature, we hypothesized that the relation between belief in SARS-CoV-2 vaccine conspiracy theories and willingness to vaccinate against SARS-CoV-2 would not only be mediated by Health Belief Model constructs, but also by mistrust of professional groups (health care providers, scientists) and institutions (governments, the Food and Drug Administration) that have encouraged acceptance of SARS-CoV-2 vaccines. The present study focuses on the possible role of epistemic mistrust of scientists as experts. Epistemic mistrust of scientists may be a particularly important determinant of willingness to vaccinate against SARS-CoV-2 given that such vaccines are highly novel (increasing reliance on assurances from clinical trials of safety and effectiveness, as opposed to anecdotal information from others) and employ cutting-edge methods (injecting mRNA to generate protein antigens) that may not be well understood by the general public.

Accordingly, (and as pre-registered), we explored whether epistemic mistrust of scientists and Health Belief Model constructs independently mediated the relation between belief in conspiracy theories and willingness to vaccinate against SARS-CoV-2. In order to explore this issue, a parallel mediation model was constructed with belief in SARS-CoV-2 vaccine conspiracy theories as the exogenous variable, willingness to vaccinate against SARS-CoV-2 as the outcome variable, and several possible parallel mediators (perceived vaccine effectiveness, perceived vaccine dangerousness, perceived severity of SARS-CoV-2 infection, and epistemic trust in scientists).

This model was specified using *R's Lavaan* package, version *0.6.5* (Rosseel, 2019). MLR, a variant of the maximum likelihood approach that is robust to non-normality, was used to estimate parameters and associated standard errors. Full information maximum likelihood (FIML) was used to handle missing data (Enders and Bandalos, 2009). Model fits were examined using the following indices (and cutoffs): Comparative Fit Index (CFI; >.95), Root Mean Square Residual (RMSEA;<.06), Standardized Root Mean Square Residual (SRMR;<.08) (Hu and Bentler, 1999). Chi-square statistics were not considered because they tend to over-reject models in the presence of large sample sizes (Bentler and Bonett, 1980). Bias-corrected bootstrapped 95% confidence intervals with 1000 re-samples were generated for all parameters; intervals that did not contain zero were considered statistically significant. Indirect effects were deemed significant if Monte Carlo simulation (R's semTools package, version 0.5.2, monteCarloMed function; with 1,000,000 replications) produced confidence intervals that did not contain zero, as recommended by MacKinnon et al. (2002).

The lavaan syntax for this mediation model (**Table S8**) was as follows:

```
mod1 <- '
#path a
VaxEffective_Total ~ p*VaxConspiracy_Total + Age + Sex
VaxDanger_Total ~ q*VaxConspiracy_Total+ Age + Sex
COVID19Severity_Total ~ r*VaxConspiracy_Total+ Age + Sex
METI_Total ~ l*VaxConspiracy_Total+Age+Sex
#path b
VaxHesitant_Adults_Total ~
s*VaxConspiracy_Total+t*VaxEffective_Total+u*VaxDanger_Total + m*METI_Total +
v*COVID19Severity_Total+ Age + Sex

VaxEffective_Total ~~ VaxDanger_Total
VaxEffective_Total ~~ COVID19Severity_Total
VaxDanger_Total ~~ COVID19Severity_Total
METI_Total ~~ VaxDanger_Total
METI_Total ~~ COVID19Severity_Total
```

```
METI_Total ~~ VaxEffective_Total

#Indirect and Total Effects
IE1 := p*t
IE2 := q*u
IE3 := r*v
IE4 := l*m
TE1 := s + (p*t)
TE2 := s + (q*u)
TE3 := s + (r*v)
TE4 := s + (l*m)
'
```

The model above was an excellent fit to the data, CFI = 1, RMSEA = 0, and SRMR = 0. Results (**Table S8**; **Figure S5**) suggested the presence of multiple partial mediation pathways.

Results indicated a direct path leading from belief in SARS-CoV-2 conspiracy theories to the perception that vaccines in general were more dangerous, β=0.62, *p*<.001, 95% CI=[0.57 0.67], and a second direct path leading from this perception to reduced willingness to vaccinate, β=-0.37, *p*<.001, 95% CI=[-0.44 -0.30]. When these direct effects were considered jointly, the resulting indirect effect through perceived dangerousness of vaccines was statistically significant, β=-0.23, 95% CI=[-0.29 -0.17]. There was also a direct path leading from belief in conspiracy theories to the perception that SARS-CoV-2 infection was less severe, β=-0.11, *p*<.001, 95% CI=[-0.19 -0.03], and from this perception to greater willingness to vaccinate, β=0.15, *p*<.001, 95% CI=[0.09 0.22]. The resulting indirect effect through perceived severity of SARS-CoV-2 infection was also significant, β=-0.02, 95% CI=[-0.03 -0.01]. Additionally, there was a direct path from belief in conspiracy theories to the perception that vaccines, in general, were more effective, β=0.12, *p*=.008, 95% CI=[0.03 0.21], and from this perception to increased willingness to vaccinate, β=0.15, *p*<.001, 95% CI=[0.09 0.21]. When these direct effects were considered jointly, the resulting indirect effect of belief in conspiracy theories on willingness to vaccinate was significant, β=0.02, 95% CI=[0.02 0.01]. Finally, there was a direct path from belief in SARS-CoV-2 vaccine conspiracy theories to reduced epistemic trust in scientists, β=-0.43, *p*<.001, 95% CI=[-0.52 -0.35], and a second direct path from epistemic trust to increased willingness to vaccinate, β=0.10, *p*=.002, 95% CI=[0.04 0.16]. When these direct effects were considered jointly, the resulting indirect effect of belief in conspiracy theories on willingness to vaccinate through epistemic trust in scientists was statistically significant, β=-0.04, 95% CI=[-0.07 -0.02]. These results, which are summarized in **Table S8** and **Figure S5**, were extremely similar to those obtained when the pathway through epistemic trust in scientists was excluded (both analyses were pre-registered): the sole qualitative difference was that the indirect pathway through perceived effectiveness was not significant (despite both component effects being significant) in the simpler model.

Table S8.

Parallel Mediation Model of the relation between Conspiracist Ideation and Vaccine Intentions

	Criterion	Predictor	Estimate [95% CI]	SE	|z|	*p*
Regressions						
(R^2 = .02)	Effectiveness	**Vax. Conspiracy**	**0.12 [0.03 0.21]**	**0.05**	**2.64**	**.008**
		Age	-0.01 [-0.11 0.09]	0.05	0.25	.806
		Sex	**0.11 [0.03 0.19]**	**0.04**	**2.59**	**.010**
(R^2 = .40)	Dangerousness	**Vax. Conspiracy**	**0.62 [0.57 0.67]**	**0.03**	**23.08**	**<.001**
		Age	**0.07 [0.00 0.14]**	**0.04**	**1.98**	**.048**
		Sex	0.00 [-0.07 0.06]	0.03	0.13	.901
(R^2 = .08)	Severity	**Vax. Conspiracy**	**-0.11 [-0.19 -0.03]**	**0.04**	**2.73**	**<.001**
		Age	**-0.20 [-0.28 -0.11]**	**0.04**	**4.78**	**<.001**
		Sex	**-0.21 [-0.29 -0.13]**	**0.04**	**5.20**	**<.001**
(R^2 = .19)	Epistemic Trust	**Vax. Conspiracy**	**-0.43 [-0.52 -0.35]**	**0.04**	**10.04**	**<.001**
		Age	-0.06 [-0.14 0.01]	0.04	1.63	.104
		Sex	-0.04 [-0.11 0.04]	0.04	0.92	.358
(R^2 = .57)	Vax. Intentions	**Vax. Conspiracy**	**-0.37 [-0.45 -0.29]**	**0.04**	**9.19**	**<.001**
		Effectiveness	**0.15 [0.09 0.21]**	**0.03**	**4.57**	**<.001**
		Dangerousness	**-0.37 [-0.44 -0.30]**	**0.04**	**10.06**	**<.001**
		Severity	**0.15 [0.09 0.22]**	**0.03**	**4.54**	**<.001**
		Epistemic Trust	**0.10 [0.04 0.17]**	**0.03**	**3.18**	**.002**
		Age	**-0.06 [-0.12 0.00]**	**0.03**	**1.97**	**.048**
		Sex	0.04 [-0.02 0.10]	0.03	1.23	.219
Intercepts						
	Effectiveness	**--**	**6.55 [5.99 7.11]**	**0.29**	**22.81**	**<.001**
	Dangerousness	**--**	**2.44 [2.14 2.73]**	**0.15**	**16.15**	**<.001**
	Severity	**--**	**4.91 [4.57 5.25]**	**0.18**	**28.00**	**<.001**
	Epistemic Trust	**--**	**7.95 [7.32 8.58]**	**0.32**	**24.76**	**<.001**
	Vax. Conspiracy	--	1.23 [1.23 1.23]	0.00	--	--
	Vax. Intentions	**--**	**2.44 [1.72 3.16]**	**0.37**	**6.66**	**<.001**
	Age	--	2.94 [2.94 2.94]	0.00	--	--
	Sex	--	1.06 [1.06 1.06]	0.00	--	--

Note. BOLD=significant. The model described in this table is visualized below. Coefficients for Sex denote effect of being male (vs. female). Vax. Conspiracy = belief in SARS-CoV-2 vaccine conspiracy theories.

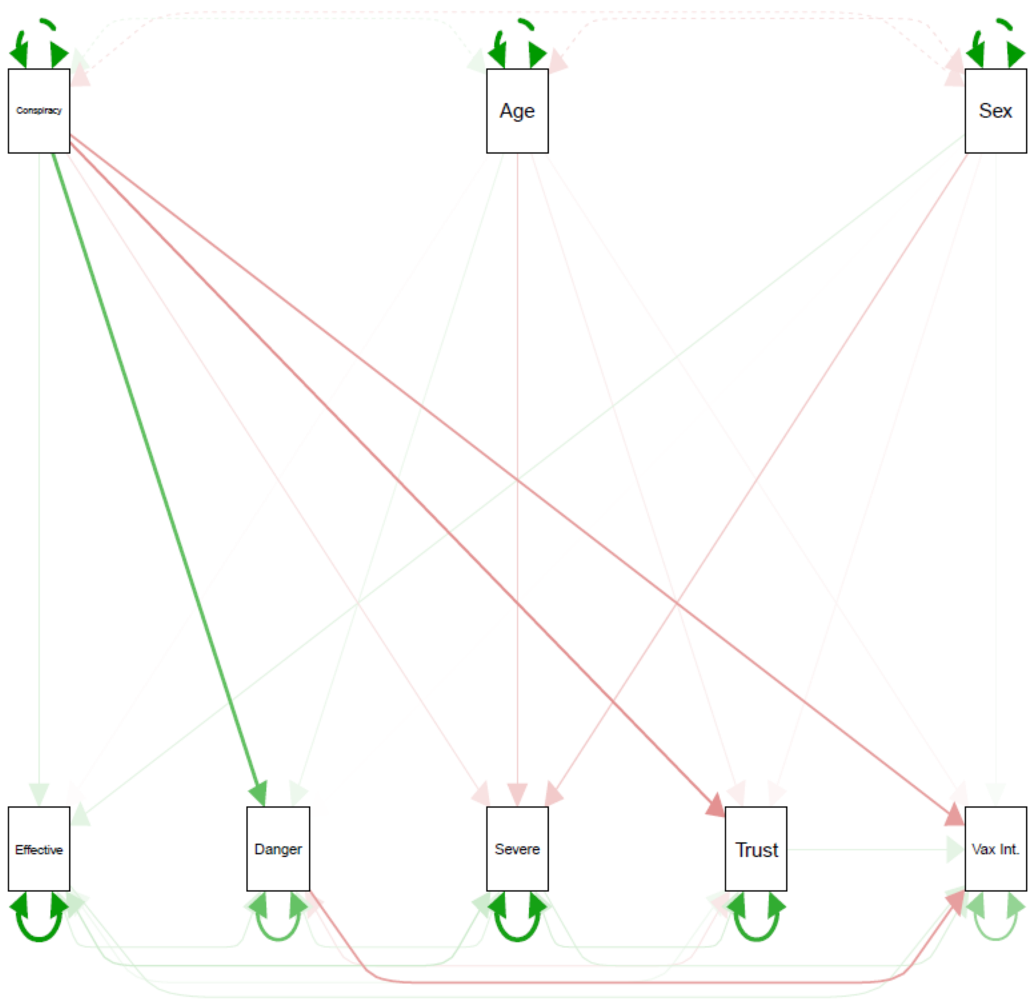

Figure S5. Visualization of the parallel mediation model depicted in **Table S8** (see that table for path coefficients). Red = negative relation; Green = positive relation. Vax. Int. = SARS-CoV-2 vaccine intentions. Conspiracy = Belief in SARS-CoV-2 vaccine conspiracy theories.

These results were broadly consistent with our hypothesis that belief in conspiracy theories might encourage epistemic mistrust in scientists, increase perceptions of vaccine dangerousness, and reduce perceptions of vaccine effectiveness and SARS-CoV-2 infection severity, and that these effects might discourage SARS-CoV-2 vaccination. However, this suggestion is not supported by the causal discovery analysis detailed in the main text, which indicated that perceived severity of SARS-CoV-2 infection, perceived dangerousness of vaccines, and vaccine intentions were causally upstream of belief in SARS-CoV-2 conspiracy theories. With this in mind, future research should repeat these mediation analyses in longitudinal datasets, which might provide more accurate estimates of causal pathways that unfold over time (Maxwell et al., 2011). Future research could build upon the analysis of trust in the present study by examining whether mistrust of individual scientists, rather than mistrust of scientists as a group, impacts belief in SARS-CoV-2 conspiracy theories and willingness to vaccinate. Trust in individual scientists, such as Dr. Antony Fauci in the USA, who served as prominent official information sources during the SARS-CoV-2 pandemic, might be the more important variable in these pathways given that these individuals were targets of conspiracy theories and personally encouraged vaccination.

Do Epistemic Mistrust and Reasoning Biases Interact in Predicting Conspiracist Ideation?

According to the recent socio-epistemic model of conspiracist ideation, belief in conspiracy theories results when individuals begin to mistrust information authorities, and therefore begin to search for alternatives to official accounts. Gathering and synthesis of information gained from this search may be influenced by reasoning biases, leading some individuals to endorse conspiracy theories they are exposed to during their search (Pierre, 2020). Following this account, the greatest chance of endorsing conspiracy theories should occur when individuals experience epistemic mistrust of information authorities and are biased reasoners. Individuals who do not mistrust information authorities may not feel compelled to search for alternatives to official accounts and are therefore less likely to be exposed to sufficient evidence for conspiracy theories to endorse them. Even if they mistrust official authorities, individuals who are less biased reasoners may be less susceptible to any misinformation they encounter (see: Bronstein et al., 2019) in their search that supports conspiracy theories. These less biased reasoners may also gather and integrate information in a manner more likely to favor (correct) official accounts. Accordingly, one might expect individuals who are both mistrusting of official accounts (encouraging the search for alternatives) and biased (leaving them vulnerable to misinformation and suboptimal evidence gathering and integration) to be most at risk of believing conspiracy theories.

If this account is correct, epistemic mistrust and reasoning biases should interact in predicting conspiracist ideation. One reasoning bias that may be particularly relevant is the tendency to gather less data prior to decision making (the “jumping to conclusions” bias). Individuals with this bias may terminate their search for alternative accounts after gathering only a limited amount of evidence, leaving these individuals vulnerable to situations where (by chance or because of biases in their search process) they primarily gather evidence favoring conspiracy theories, and fail to gather sufficient evidence to disabuse them of these theories. Accordingly, (as pre-registered) a multiple regression model was constructed to examine whether epistemic mistrust of scientists interacted with a bias toward less data gathering in predicting conspiracist ideation.

Table S9.

Do data gathering and mistrust interact in predicting SARS-CoV-2 vaccine conspiracist ideation?

Predictor	Estimate [95% CI]	SE	*t*	*p*
Data Gathering	-0.83 [-2.52 0.86]	0.86	<1	.333
Epistemic Trust	**-0.47 [-0.64 -0.30]**	**0.09**	**5.38**	**<.001**
Age	0.03 [-0.05 0.09]	0.04	<1	.614
Sex	**-2.28 [-3.95 -0.61]**	**0.85**	**2.69**	**.007**
Gathering:Trust	0.01 [-0.01 0.03]	0.01	<1	.522

Note. Bold = significant. The overall model was significant $F(5,548) = 28.36$, $p < .001$, adjusted $R^2 = .21$. Sex is coded as the effect of being male (vs. female).

As depicted in **Table S9** above, there was no significant interaction between data gathering tendencies and epistemic mistrust in predicting belief in SARS-CoV-2 vaccine conspiracy theories (or conspiracy theories in general [not shown]). Assuming that the aforementioned socio-epistemic model of belief in conspiracy theories is correct, one possible reason for the absence of the expected interaction is that the Box Task, which is relatively new, does not measure data gathering in a manner that generalizes to the relevant real-world situations (such as gathering data on the internet about possible alternatives to official accounts of important events). Consistent with this possibility, the Box Task has generated results that are inconsistent with other data gathering tasks, such as the Beads Task (Ephraums et al., 2017). In light of this possible explanation, future research should examine whether the Box Task and the Beads Task (and, indeed, other data gathering tasks used in the laboratory, such as the Lakes Task) predict real-world data gathering behaviors across a range of situations relevant to the false beliefs (such as conspiracy theories) of interest. If they do so, then the present results would more strongly call into question the socio-epistemic model of conspiracist ideation.

The Association Between Data Gathering Behavior and Automatic vs. Controlled Processing

The tendency toward gathering less data has been linked to a variety of false beliefs, including belief in conspiracy theories (Pytlik et al., 2020) and delusions (fixed, false, and idiosyncratic beliefs) in individuals with schizophrenia (Ward & Garety, 2017). Research examining the relation between this tendency and false beliefs has used several tasks, including the Beads Task (Steffen Moritz et al., 2007), the Lakes Task (Speechley et al., 2010), and the Box Task (Steffen Moritz, Göritz, et al., 2017). Recently, attention has been called to the fact that the nature of the association between data gathering and false beliefs (delusions) differs across these tasks: while a positive association between data gathering and false beliefs has been observed using the Box Task (Steffen Moritz et al., 2020), a negative association between these variables has been observed using the Beads/Lakes Tasks (Steffen Moritz & Woodward, 2005; Woodward et al., 2009).

Researchers directly comparing these tasks (Ephraums et al., 2017) have suggested that the aforementioned pattern of conflicting results may be due to the fact that these tasks tap into different cognitive processes. Determining whether or not this is true has important implications: if the tasks do, in fact, tap into the same cognitive processes, but yield differing patterns of data gathering in delusion-prone individuals, this would suggest that any data gathering deficits in these individuals are highly situation specific, and would therefore call accounts suggesting that these deficits are capable of generating highly idiosyncratic false beliefs (such as delusions) into question.

Accordingly (as pre-registered), we planned to compare the relation between automatic and controlled processing and data gathering in our study, which employed the Box Task, with that observed in a previous study using the Lakes Task (Sanchez & Dunning, 2020). The previous study subjected data from a denominator neglect task to a process-dissociation scheme to obtain metrics of automatic and controlled processing. We used the same denominator neglect task in the present study, and closely followed the process dissociation scheme that the previous study used to derive metrics of controlled and automatic processing. The process of deriving these metrics began by separating the problems of the denominator neglect task into conflict problems (in which the urn with the higher number of winning beads was not the best gamble, because there were also a higher number of losing beads in that urn) and non-conflict problems (in which the urn with the higher number of winning beads was also the best gamble). Controlled processing was then calculated as the difference between the probability that participants would select the correct urn (the one with the highest chance of winning) on non-conflict problems and the probability that they would select the incorrect urn on conflict problems. Automatic processing was then calculated as probability that participants would give an incorrect response to conflict problems divided by one minus the metric of controlled processing.

At zero-order, we found that controlled and automatic processing were correlated with one another, rho(552) = -.39, $p < .001$, and that increased data gathering correlated with less controlled processing (rho(552) = -.20, $p <.001$), but did not correlate with automatic processing (rho(552) = .08, $p = .074$). When these metrics of controlled and automatic processing were entered into a multiple regression model (**Table S10**) along with age and sex, controlled processing continued to predict data gathering above and beyond the effect of automatic processing. However, the sign of the association changed: more controlled processing was associated with more data gathering.

Table S10.

Relation between Data Gathering Behavior and Controlled and Automatic Processing

Predictor	Estimate [95% CI]	SE	*t*	*p*
Automatic	-0.08 [-0.81 0.65]	0.37	<1	.828
Controlled	**1.84 [1.13 2.56]**	**0.36**	**5.08**	**<.001**
Age	0.00 [-0.02 0.03]	0.01	<1	.794
Sex	**-0.85 [-1.44 -0.26]**	**0.30**	**2.83**	**.004**

Note. Bold = significant. Sex is coded as the effect of being male (vs. female). $F(4,549) = 7.81$, $p < .001$, adjusted $R^2 = 0.05$.

In summary, these results suggest that controlled processing (on the denominator neglect task) is associated with more data gathering/less jumping to conclusions on the Box Task (when statistically controlling for variation in automatic processing). These results accord with previous research using the Lakes Task (Sanchez & Dunning, 2020), which also found that controlled processing (on the same denominator neglect task) was associated with more data gathering/less jumping to conclusions (when controlling for automatic processing).

Taken together, these findings provide initial evidence against the idea that the conflict between the positive association between data gathering and false beliefs observed using the Box Task (Steffen Moritz et al., 2020) and the negative association between these variables observed using the Beads/Lakes Tasks (ex: Speechley et al., 2010) can be accounted for by the fact that these tasks tap into different cognitive processes. Future research should continue to examine whether the association between data gathering and false beliefs differs across the two tasks (in the present study, reduced data gathering on the Box Task was associated with paranoia, which is more consistent with the results of the Beads Task) and whether they differ in their associations with basic cognitive processes. If the tasks tap into similar processes, but yield opposing relations between data gathering and delusion-proneness, this pattern of results would suggest that any deficit in these individuals' data gathering behavior is specific to particular situations. This would impugn theoretical accounts suggesting that a (generalized) bias toward less data gathering/jumping to conclusions predisposes individuals to delusions (and, potentially, other false beliefs as well): it is highly unlikely that a bias toward gathering less data that is extremely situation-specific could result in false beliefs, such as delusions, that are so highly idiosyncratic as to conflict with what almost everyone else in the person's peer groups believes.

Links Between Liberal Acceptance, Illusory Pattern Perception, and Conspiracist Ideation

Liberal acceptance (lowered decision thresholds) has been linked to multiple epistemically suspect beliefs, including anomalistic beliefs (Prike et al., 2018) and delusion-like forms of paranoia (Steffen Moritz et al., 2012). Traditionally, the liberal acceptance construct also includes increased endorsement of more absurd response options (which is thought to result from attenuated evidence gathering due to lowered decision thresholds), which have been linked to conspiracist ideation in past research (Georgiou et al., 2021). Taken together, these studies led us to hypothesize that liberal acceptance (lowered decision thresholds) would be associated with conspiracist ideation in the present study. However, this was not the case: at zero order, decision thresholds were not significantly associated with SARS-CoV-2 vaccine conspiracy theories rho(552) = .07, $p = .117$., and higher, not lower, decision thresholds were associated with generalized conspiracist ideation, rho(552) = .15, $p < .001$.

Liberal acceptance has also been linked to illusory pattern perception. For instance, these variables covary in the context of delusions (see: Brennan & Hemsley, 1984; Moritz et al., 2017). Thus, one might hypothesize that liberal acceptance is a cause of illusory pattern perception. Such a hypothesis would be broadly consistent with the notion that liberal acceptance increases confidence in incorrect responses (like endorsement of non-existent patterns) by curtailing data gathering (Steffen Moritz & Woodward, 2006). If liberal acceptance caused illusory pattern perception, this should result in an indirect pathway to belief in conspiracy theories, as experimental studies suggest that illusory pattern perception causes this belief (van Prooijen et al., 2018; Whitson & Galinsky, 2008). Thus, we had hypothesized that our causal discovery analyses would reveal evidence of this pathway. No evidence of a causal relation between SARS-CoV-2 related conspiracist ideation and illusory pattern perception was revealed by the causal discovery analyses in the main text (nor was there any when generalized conspiracist ideation was substituted for SARS-CoV-2 conspiracy beliefs). In our partial correlation network, which offers a more relaxed approach to identifying possible causal relations, illusory pattern perception was related to belief in conspiracy theories, as expected, but was unrelated to liberal acceptance. In structural equation models, liberal acceptance was unrelated to illusory pattern perception, and there was no indirect effect of liberal acceptance on conspiracist ideation. Thus, this hypothesis was not supported.

Liberal Acceptance, Controlled Processing, Data Gathering, and Conspiracist Ideation

Theoretical models of the interrelations between reasoning biases suggest that liberal acceptance causes less analytic (conscious, effortful) reasoning, which in turn causes reduced data gathering (Bronstein, Pennycook, Joormann, et al., 2019). Theoretical models also suggest that less analytic reasoning maintains conspiracist ideation (van Prooijen et al., 2020). Taken together, this literature suggests that liberal acceptance causes less analytic reasoning, which then causes both conspiracist ideation and jumping to conclusions, which would account for the correlation between the latter two variables that has been observed in past research (Pytlik et al., 2020; Sanchez & Dunning, 2020). Accordingly, we hypothesized that causal discovery analyses would suggest that liberal acceptance was as a likely cause of less analytic reasoning (as proxied by a metric of controlled processing derived from a denominator neglect task) and that less analytic reasoning (using the same proxy) was a likely cause of both belief in conspiracy theories and jumping to conclusions. To test this hypothesis, we repeated the causal discovery analysis in the main text after substituting the metric of denominator neglect for a metric of controlled processing derived from the same task. No evidence of a causal relation between liberal acceptance and less analytic reasoning was revealed, nor was there any evidence of a causal relation between less analytic reasoning and belief in conspiracy theories. Moreover, the analysis suggested that reduced data gathering was a possible cause of less analytic reasoning (though, the analysis also suggested that this relation may be confounded by an unmeasured latent variable). Thus, the aforementioned hypothesis was not supported. Given that a proxy measure of analytic reasoning (controlled processing on the denominator neglect task) was used in the present study, these results should be interpreted with caution. Future research should repeat these analyses with a proper metric of analytic reasoning, such as the cognitive reflection test.

Liberal Acceptance and Confidence Gaps

Liberal acceptance is thought to cause smaller confidence gaps [overconfidence in errors and relative lack of confidence in correct responses] because it reduces the chances of finding evidence for and against one's beliefs (see: Moritz, Woodward, Jelinek, & Klinge, 2008). The present study examines the possibility that liberal acceptance reduces confidence gap size in the context of an illusory pattern perception task. This choice of context was informed by research indicating that confidence gap size in pattern perception tasks correlates with individual differences in paranoia (Moritz et al., 2014), which are associated with liberal acceptance (Moritz, Van Quaquebeke, & Lincoln, 2012). This relationship suggests that individual differences in confidence gaps on pattern perception tasks are meaningful (i.e., not simply random noise), and implies they may result from individual differences in decision thresholds (liberal acceptance). To examine this possibility, we repeated the causal discovery analyses in the main text after substituting the metric of illusory pattern perception for a metric of confidence gaps derived from the same task. No evidence of a causal relation between liberal acceptance and confidence gaps was observed, in contrast to our hypothesis.

Paranoia and Conspiracist Ideation

Paranoia has been repeatedly associated with belief in conspiracy theories (Darwin et al., 2011; Freeman et al., 2020). However, the mechanisms underlying this association remain unclear. Paranoia may be associated with conspiracist ideation because both are markers of a general tendency towards mistrust (see: Freeman et al., 2020) and/or because both share underlying causes, such as liberal acceptance and other forms of biased reasoning. The causal discovery analysis reported in the main text does not support the notion that this association is due to shared underlying reasoning biases. Instead, belief in conspiracy theories (both generalized and specific to SARS-CoV-2) was related to paranoia via the belief that vaccines were dangerous. Extrapolating from this, paranoia and belief in conspiracy theories may be related to one another primarily because paranoia encourages a “dangerous-world” view that, in turn, encourages conspiracist ideation.

Causal Discovery and Network Analysis: Results for Generalized Conspiracist Ideation

Previous studies have indicated that the causes and consequences of conspiracy theories may differ according to their content (Oleksy et al., 2021). Readers may therefore wonder how the results of our network and causal discovery analyses compare for generalized conspiracist ideation and SARS-CoV-2 related ideation. To address this, the graphs depicting results concerning generalized conspiracist ideation are included below. These graphs were generated using the same method as the corresponding analysis in the main text (save that generalized conspiracist ideation replaced SARS-CoV-2 specific ideation). As one can see, the results were extremely similar regardless of which type of conspiracy theories were considered.

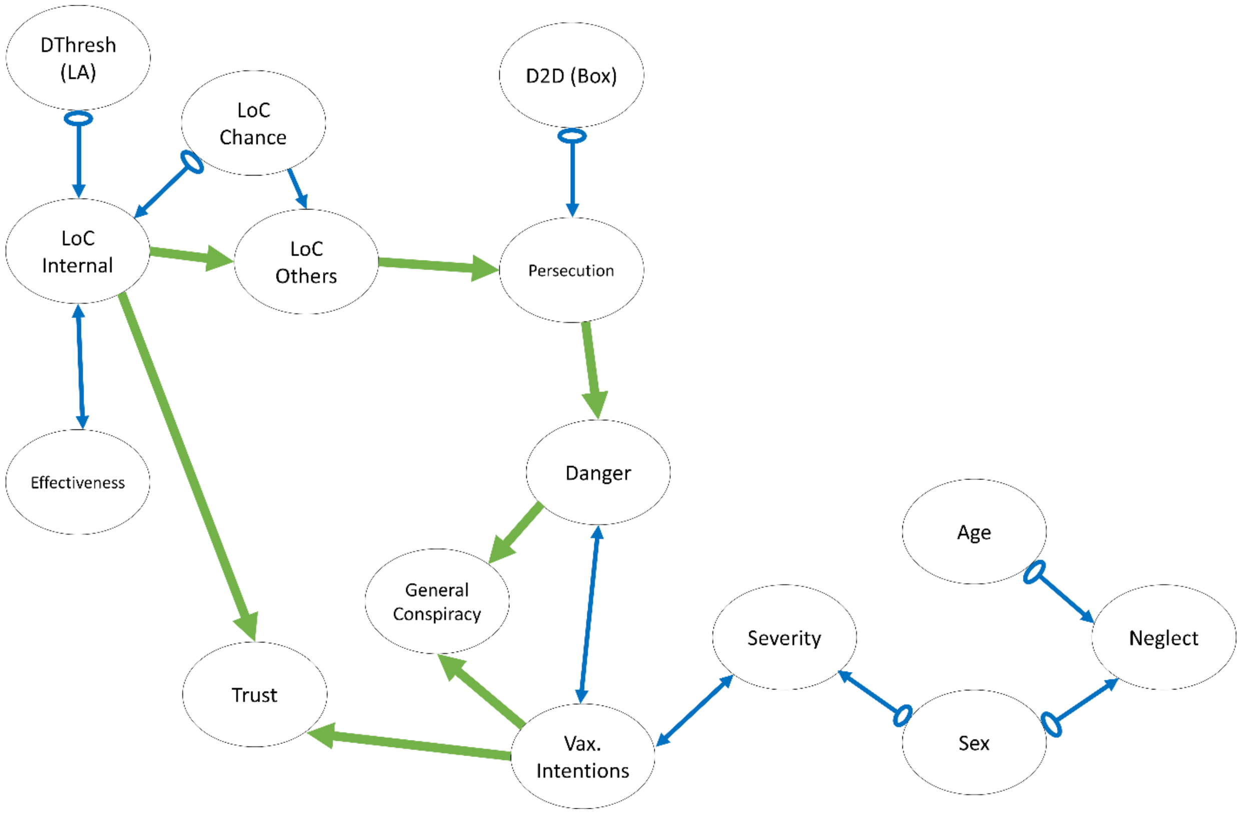

Figure S6. Directed Acyclic Graph suggested by the Greedy Fast Causal Inference (GFCI) causal discovery algorithm. See **Table 1** (main text) for a description of possible edge types. Variables are not depicted if GFCI could not determine a potential causal relation between them and another variable included in the analysis. Refer to **Figure S8** for information about the valence (positive/negative) and relative strength of potential causal effects depicted here. This graph differs from that in the main text in that it includes generalized (rather than SARS-CoV-2 related) conspiracist ideation.

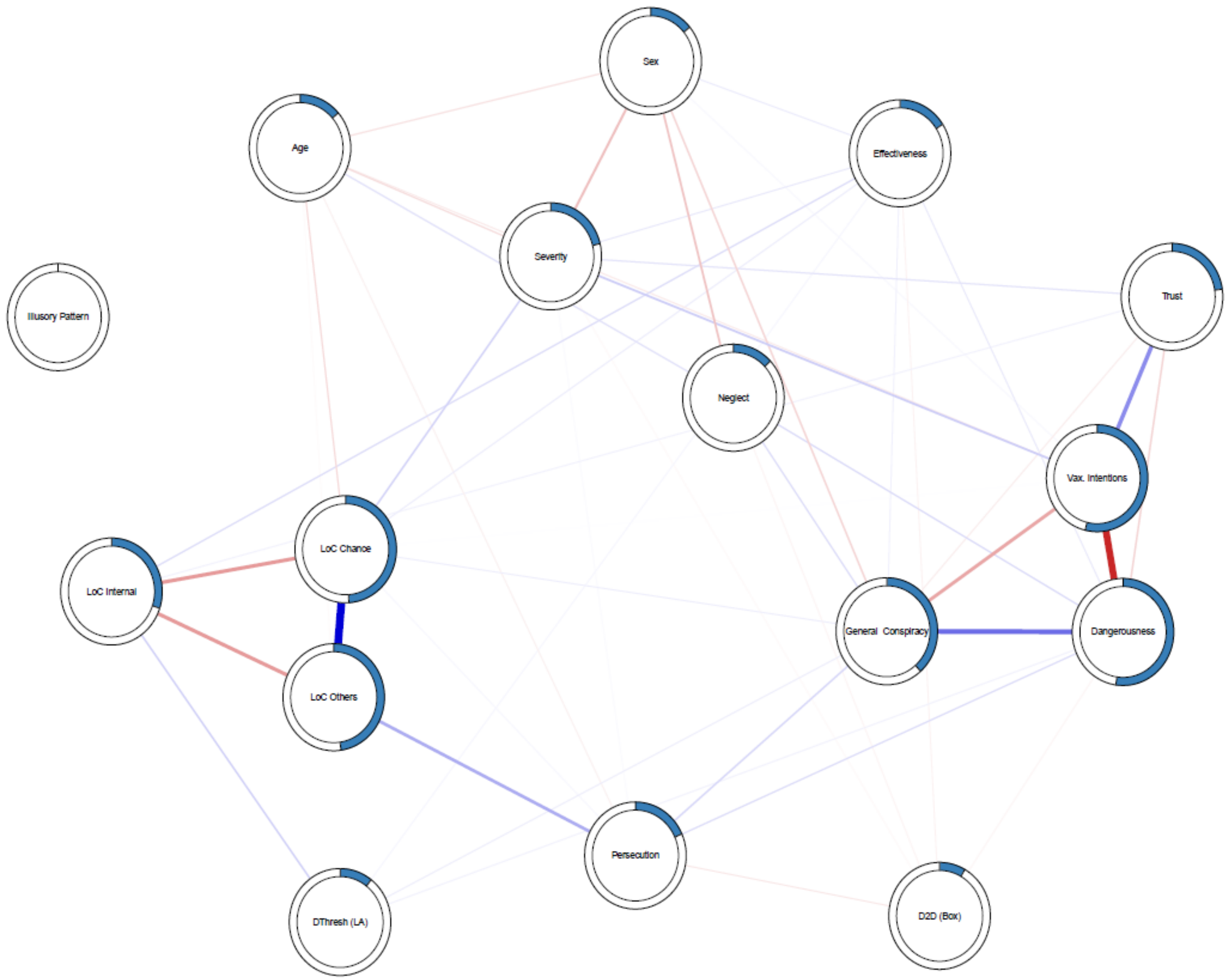

Figure S7. Regularized partial correlation network. Annulus surrounding each node denotes predictability (more filled=more predictable). Red = negative association. Blue = positive association. Neglect = Denominator Neglect. Trust = Epistemic Trust in Scientists. Vax. = Vaccine. LoC = Locus of Control. D2D = Draws to Decision. DThresh = Decision Threshold. Sex is coded as the effect of being male (vs. female). This network differs from that in the main text in that it includes generalized (rather than SARS-CoV-2 related) conspiracist ideation.

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