Trust in science, risk perception, conspiratorial beliefs, and unrealistic optimism: a network approach to investigate the psychological underpinnings of COVID-19 vaccination intentions

Abstract

Using a network approach, we addressed in two studies interrelations among potential antecedents of vaccine intentions, related to both COVID-19 risk perception and epistemic beliefs (i.e., trust in science and conspiracy beliefs). In Study 1 and 2, we assessed in a US (N = 994) and in an international sample (*N* = 902) during spring and summer 2020.

The network analysis reveals a complex interplay of factors where trust in science, the closest predictor of vaccine intention, is associated to conspiracy beliefs and danger perception. Furthermore, we found evidence for unrealistic optimism, with participants perceiving the risk to get infected with COVID-19 as lower in comparison to the risk they attributed to other people. However, this bias was not associated with vaccine intention. Study 2 corroborated these results. The results call for a global change in the narrative which should highlight the epistemic authority of science in order to build a stronger trust in the scientific community. However, tackling trust in science needs a wider field of persuasion, that includes conspiracy beliefs and risk perception factors.

Keywords: COVID-19, optimism, pessimism, unrealistic optimism bias, risk perception, vaccination hesitancy, cognitive illusions, positive illusions, conspiracy, coronavirus, trust in science

In the current COVID-19 crisis, vaccines represent the key strategy to tackle the pandemics as it will prevent further spreading of the disease and therefore protect the collectivity. However, vaccine-compliance is required, and psychological research indicates that a substantial proportion of people is hesitant in getting vaccinated in general (de Figueiredo et al., 2016), and specifically against COVID-19 (Graffigna et al., 2020; Ikhlaq et al., 2020; Barello et al., 2020). To make the current vaccine strategy become successful, one needs to understand the factors that predict individuals' vaccine intentions to envisage the most effective communication strategy. In this paper, we test four key factors that may allow predicting people's decision to get a COVID-19 vaccine: people's risk perception, unrealistic optimism, trust in science, and belief in conspiracy. Moreover, we employed a network analytical approach, which allow us to assess the gestalt in which intention to get vaccinated is embedded, identifying the most distal and proximal underpinnings and their interconnections.

Risk Perception and Unrealistic optimism

Several health-specific behavioral theories, such as the Health Belief Model (Rosenstock, 1977), the Protection Motivation Theory (Rogers, 1975), and the Extended Parallel Process Model (Witte, 1992), predict that the anticipated likelihood and the perceived severity of health-specific harms (e.g., likelihood to get infected by COVID-19 and the danger of being infected by the virus), shape health-related intentions and behaviors. This prediction is well supported in the scientific literature, and several studies reported that these concepts are associated with health-promoting intentions and behaviors, including changing unhealthy habits, maintaining protective behaviors, and initiating protective actions (Dillard et al., 2012; Floyd et al., 2000; Brewer et al., 2007; Jones et al., 2015).

Furthermore, it is important to highlight that individuals' perception of risks usually does not match with objective risks. Research on unrealistic optimism has shown that most people expect negative events to be more likely for others than themselves, and vice versa for positive outcomes (Weinstein, 1980, 1983, 1984). Although unrealistic optimism helps people to cope with potentially threatening experiences (Taylor & Brown, 1988) and protects their wellbeing by holding fears in check (Hoorens, 1995; Klein & Weinstein, 1997), the flip side is that unrealistic optimism can be maladaptive in life-threatening situations as the shield from fears reduces the intention to engage in health promoting behaviors (Weinstein, 1983; Dillard et al., 2009). Currently, little is known about the role of unrealistic optimism in relation to attitudes toward COVID-19 vaccines although scholars have explicitly called for empirical research investigating this relation (Bottemanne et al., 2020).

Trust in Science

Usually, specialist knowledge and skills are required to understand how a vaccine is developed, and research data cannot be naively interpreted in respect to the safety and efficacy of vaccines. This complexity creates an imbalance of power between experts (e.g., healthcare professionals, scientists) and non-experts (patients). Vaccine decisions are therefore taken in a context where laypersons have to trust several actors who detain exclusive access to the available evidence. In other words, trusting vaccine experts means that individuals accept their vulnerable position and assume that someone else has the competence and the intention to take care of complex decisions, like the implementation of vaccine policies, the definition of vaccine dosage, and so forth. Scientists are particularly relevant in the context of COVID-19 vaccination, as they are in the first line of the development of vaccines, and assessment of vaccine safety both pre- and post-approval (Avorn & Kesselheim, 2020). Due to this reason, it is reasonable to assume that trust in science is the key building block of a positive attitude towards the process of vaccination.

Accordingly, past research suggests that trust is positively linked to vaccine intentions in different contexts (Larson et al., 2018; Marlow et al., 2007; Taylor-Clark et al., 2005; Van Der Weerd et al., 2011; Cooper et al., 2017; Dohle et al., 2020; Palamenghi et al., 2020).

Belief in Conspiracy

Conspiratorial beliefs are defined as beliefs about a number of actors who join together in secret agreement and try to achieve a hidden goal, which is perceived as unlawful or malevolent (Zonis & Joseph, 1994). According to previous research, conspiracy beliefs question scientists' legitimacy, and shift authority from experts (i.e., doctors, scientists) to non-experts (i.e., patients; Kata, 2012) and are negatively correlated with trust in general vaccination (Jolley & Douglas, 2014, 2017; Salvador Casara et al., 2019), and specifically with the intention to get vaccinated against COVID-19 (Bertin et al., 2020).

Network analysis approach

As reported, previous research already showed that risk perception, unrealistic optimism, trust in science and conspiracy beliefs predict play an important role in the current COVID-19 pandemic. However, to the best of our knowledge, these factors were usually tested independently and are not always used to predict vaccine intentions within an integrative model. To fill this gap and to test which of these factors contributes to vaccine intentions most strongly, we conducted two studies in which we applied network analyses. We propose that network analysis can serve as an innovative tool for unpacking the associations among drivers of COVID-19 vaccine intention and further our understanding of the attitudes toward vaccination as an interconnected belief system (Lange et al., 2020).

In our studies, nodes are the measured factors potentially relevant to vaccine intentions. Using an undirected network approach, we a) avoided to assume that these factors are independent of each other and b) are able to explore their interrelations.

In the contest of our studies, this allows exploring which factors are more strongly linked to vaccine intention and which nodes are more promising as a target for interventions and persuasion attempts (e.g., communication of vaccination policies) (Nudelman et al., 2019).

Present Research

Our major goal was to assess which of the most studied factors are strongest associated with COVID-19 vaccine intentions. Moreover, we wanted to enlarge the list of such factors investigating the so far neglected unrealistic optimism and to test whether this bias impact vaccine-related intentions. In particular, our second goal was to test whether unrealistic optimism (a) is present in the perception of the likelihood of being infected by COVID-19, (b) is present in the perceived likelihood of being already immune to the virus, and (c) predicts vaccine intentions.

In Study 1, using an undirected network model, we tested the strength of associations among the perceived likelihood of being infected with COVID-19, trust in science, conspiracy beliefs, and vaccine intention in a large U.S. sample. Moreover, we tested the presence of unrealistic optimism bias related to the likelihood of being infected and its predictive value on vaccination intention.

Study 2 was aimed to replicate the findings obtained in Study 1: a) in a more culturally diverse sample involving several different countries, and b) during the time where COVID-19 had been already present for weeks/months. Besides corroborating the previously reported effects, we expanded the network by including the perception of COVID-19 danger and the perceived likelihood of being already immune to the virus. Moreover, we further explored the presence of the unrealistic optimism in both assessments of being at risk and of being already immune.

Study I

In Study 1, we assessed the network gestalt of four factors that may predict intentions to vaccinate against COVID-19: risk perception, unrealistic optimism bias, trust in science, and belief in conspiracy theories. We tested which of the above factors best explains individuals' willingness to get vaccinated against COVID-19.

Method

Participants

One thousand participants within the United States (515 women, 485 men; age ranging from 18 to 82, M = 45.33, SD = 15.95) were recruited for an online study via Prolific.com. Six participants (4 women, 2 men, M_{age} = 26.17, SD_{age} = 7.78) were excluded from the analyses due to lack of answers to the first question and/or a survey completion time below 10 seconds (which we treated as a proxy of lack of attention). The final sample consisted of 994 participants (511 women, 483 men, M_{age} = 45.45, SD_{age} = 15.92), ranging from 18 to 82. The data was collected from 05/07/2020 to 05/08/2020.

Questionnaire

Each question was displayed separately via Qualtrics. Respondents indicated their gender and age after answering the last survey question.

We asked participants to rate their agreement on 9-point rating scales (1 = d*efinitively no*; 9 = *definitely yes*) to assess their:

- *Vaccine intention (*"Are you going to take a shot once the COVID-19 vaccine is available on the market?")
- *Trust in science (*"In the coronavirus (COVID-19) case, can we rely on the results of research conducted by scientists?")

- *Conspiracy beliefs* ("I believe that some secret powers (e.g., countries, big corporations) are responsible for coronavirus/COVID-19?")
- *Perceived likelihood of self-infection* ("How likely is it that you will become infected with coronavirus (COVID-19)?")
- *Perceived likelihood of other-infection* ("How likely is it that your fellow countrymen will become infected with coronavirus (COVID-19)?").

In order to obtain a measure of the perceived likelihood of infection, we computed the mean of these two items.

In order to assess the unrealistic optimism bias, we computed the difference between estimating the likelihood of getting infected with the virus for "fellow countrymen" and "myself". Moreover, we created another variable by categorizing participants into three groups: pessimistic (negative indicator value), optimistic (positive indicator value), or neutral (indicator equal to 0).

Results

Unrealistic optimism: prevalence and impact on vaccine intentions

Respondents judged the likelihood of future coronavirus infection to be higher for their compatriots (M = 5.35, SD = 2.05), than for themselves (M = 4.29, SD = 1.89), $t(993)$ = 15.49, p <.001, d = .49.

Similar results were achieved using the categorical variable. A total of 57.7% (N = 574) of participants were optimists (i.e., they assessed it more likely that their compatriots would be infected than themselves), 26.5% (N = 263) were neutral, and 15.8% (N = 157) were pessimists, $\chi^2(2) = 283.55$; p < .001. In other words, the results show that most of our participants believed to be more protected from COVID-19 in comparison with others.

Unrealistic optimism bias was not associated to vaccine intention (Pearson r = -.03, p = .29).

Network analysis

In order to test which of the assessed factors best explains the intention to get vaccinated against COVID-19, an undirected network model was computed. The EBICglasso procedure (EBIC; Epskamp, 2016) was applied, using the software JASP (Love et al., 2019) in order to estimate the network model. The EBIC tuning parameter was set to 0.5. This procedure estimates networks based on partial correlations and it involves the GLASSO regularization technique (based on the true network structure and sample size) aiming to control spurious correlations (Epskamp, 2016; Friedman et al., 2008; Tibshirani, 1996) and shrinks small coefficients to zero (Costantini et al., 2015; Epskamp & Fried, 2018). As an outcome of this procedure, the network shows the regularized partial correlation among each pair of nodes after controlling the effect of the rest of the nodes in the network (Figure 1). Moreover, in order to check edge-weight accuracy, we estimated Network stability using the bootnet package (Epskamp et al., 2018). Specifically, we used a nonparametric bootstrap (with 1000 iterations) to estimate the 95% confidence interval of each edge. The results, as reported in Table 1, Figure 1, and Figure 2, showed that edge-weight accuracy was good for almost all associations. In fact, from the estimated relationships, only the association between the perceived likelihood of infection and trust in science included 0 within the 95% confidence interval, indicating that the link between these two variables was not robust.

Vaccine intention was positively associated with trust in science, and negatively associated with conspiracy beliefs. The perceived likelihood of infection was associated with trust in science, but it was not associated with conspiracy beliefs. However, the perceived likelihood of infection was associated with vaccine intention.

Table 1

Edge list with estimated weight, standard deviation, and confidence intervals.

Edge	sample	bootstrap mean	sd	CIlower	CIupper
Conspiracy beliefs—Perceived likelihood infection	0,00	0,00	0,01	-0,03	0,03
Trust in science—Conspiracy beliefs	-0,27	-0,26	0,03	-0,34	-0,20
Trust in science—Perceived likelihood infection	0,07	0,07	0,04	-0,01	0,15
Vaccine intention—Conspiracy beliefs	-0,12	-0,12	0,04	-0,19	-0,04
Vaccine intention—Perceived likelihood infection	0,13	0,13	0,03	0,07	0,20
Vaccine intention—Trust in science	0,60	0,60	0,03	0,55	0,66

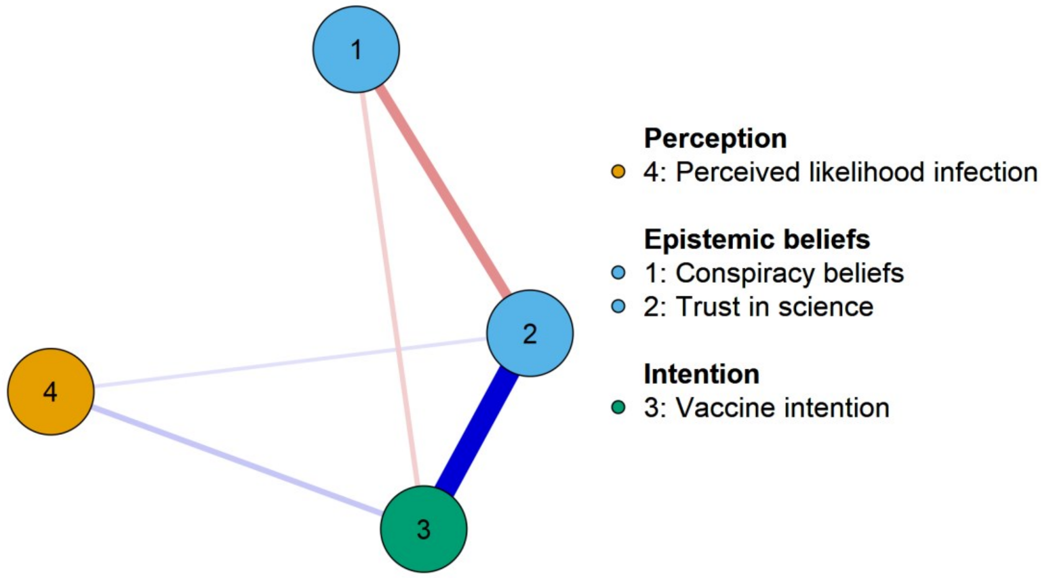

Figure 1. Empirical network model. Each node represents an attribute associated with the behavioral intention target. The edges represent the relationship among attributes. The thicker the edge is, the greater is the relationship between attributes.

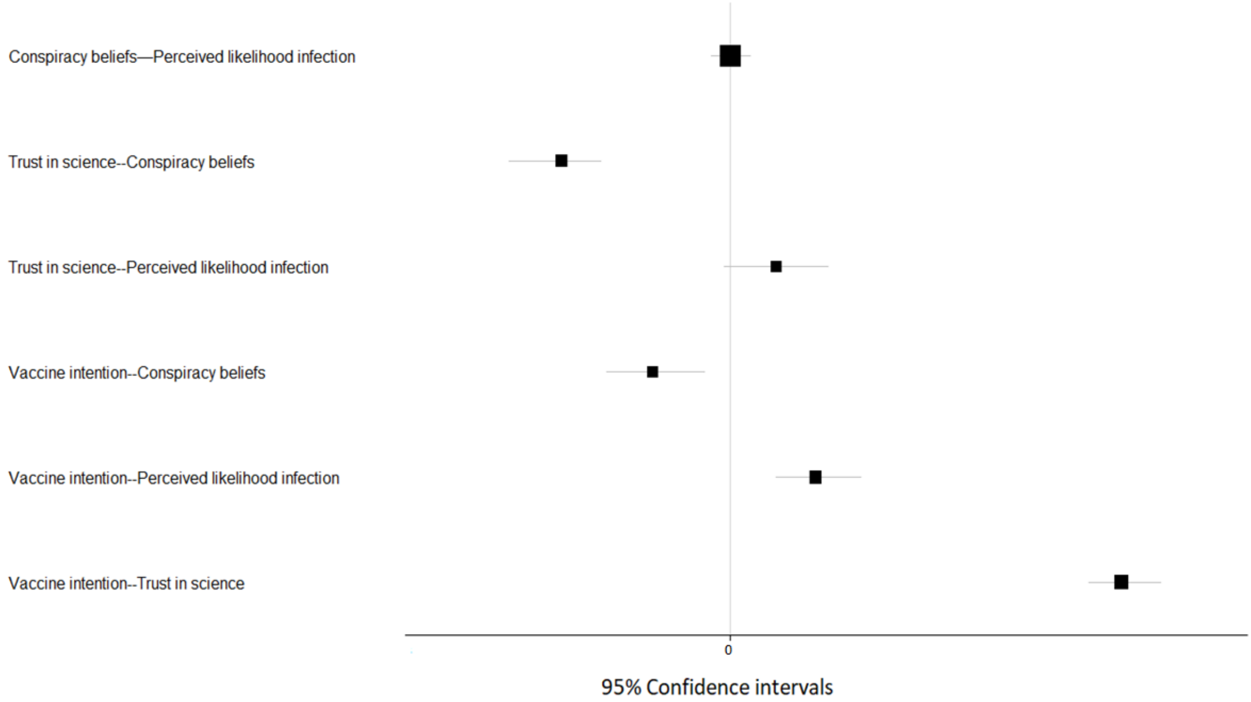

Figure 2. 95% confidence intervals of the bootstrapped edges.

Discussion

Study 1 provides initial insights on the degree to which different factors are associated with vaccine intentions. First, we found evidence for the existence of unrealistic optimism related to COVID-19. That is, people tend to believe that the likelihood to get infected with COVID-19 is higher for other people than for themselves. Second, network analyses demonstrate that vaccination intentions are positively related to trust in science as well as to the perceived likelihood of infections, and negatively related to conspiracy beliefs. The presence of the unrealistic optimism was not associated with the degree of vaccination intention. Trust in science was the closest predictor of vaccine intentions and was weakly positively associated with the perceived likelihood of infection. Given the association between trust in science and conspiracy beliefs, we may conclude that communication tackling both elements may be the most effective.

Study 2

In Study 1 the sample, even if high-powered, was limited to participants recruited from the U.S.A. In order to overcome this limit, in Study 2, we aimed to replicate the results obtained in Study 1 in a more diverse sample of several countries that had different experiences with COVID-19.

Despite a more diverse sample, we modified the method to some extent. First, we assessed perceived danger. In Study 1, we focused only on the perceived susceptibility to COVID-19. However, in the health-related decision-making literature (Brewer et al., 2007), also the perceived danger (severity) of disease represents a relevant driver for health-promoting behaviors.

Second, as an additional measure of unrealistic optimism, in Study 2, we expanded the investigation of participants' risk assessment to their social network by investigating perceived risks at three social distances: the self, a friend/neighbor and fellow countrymen.

Finally, as Study 2 was conducted while COVID-19 was already a pervasive reality, we measured participants' perceived belief of being immune against COVID-19. This new variable tackles two goals: First, we were interested to which degree the belief of being immune reduces vaccine intentions. Second, we aimed at studying whether the belief about one's immunity is based on an unrealistic optimism meaning that individuals' belief that they are more likely immune against COVID-19 than other individuals. Again, this assessment was evaluated at three social distances: the self, a friend/neighbor, and a fellow countryman.

Method

Participants

Participants were recruited via social media postings (with participants coming from Canada, France, Germany, India, Italy, New Zealand, Spain, Switzerland, and USA), via

Amazon's Mechanical Turk (participants from USA), and mailing lists of university students (participants from Poland, Italy, and Germany). Overall, we recruited 1016 participants (see supplementary materials for subsamples descriptive statistics). 114 were excluded from the analysis due to lack of answers (which we treated as a proxy of lack of attention) or a declaration of a positive COVID-19 test result. The final sample consisted of 902 participants (567 women, 328 men, 6 non-binary, 1 missing) with an age ranging from 18 to 76 (M = 34, SD = 11.68). The reason for collecting data across nations was to enhance generalizability and to ensure that conclusions were not limited to one particular socio-political circumstance. Nation level differences were not analyzed as the number of nations is too small to draw meaningful cross-national comparisons, and any such comparisons would be difficult or even problematic to interpret.

Measures

Participants answered to the same questions of Study 1 assessing Vaccine intention, Trust in science, Conspiracy beliefs, Perceived likelihood of self-infection, Perceived likelihood of other-infection. In addition, we also measured:

- *Perceived severity of the infection* ("How safe or dangerous is SARS-CoV-2/COVID-19 in your opinion?")
- *Perceived likelihood of friend-infection* How likely is it that your average friend, or your average neighbor, will become infected with coronavirus (SARS-CoV-2/COVID-19)?"
- *Perceived likelihood of self-immunity* ("How likely is it that you were infected with SARS-CoV-2/COVID-19 at some point in the past, and therefore you have developed immunity or resistance to coronavirus infection?")
- *Perceived likelihood of friend-immunity* ("How likely is that your average friend, your average neighbor was infected with SARS-CoV-2/COVID-19 at some point in the

past, and therefore s/he has developed immunity or resistance to coronavirus infection?")

- *Perceived likelihood of other-immunity* ("How likely is it that your fellow countryman will become infected with coronavirus (COVID-19)?"

In order to obtain a measure of the general perceived likelihood of infection, we computed the mean between the three items of *Perceived likelihood of infection*. To compute a score for the unrealistic optimism, we computed the mean in estimating the likelihood of getting infected with the virus for "a fellow countryman" and "friend/neighbor and then subtracted this value from the score to the question of getting infected "myself".

In order to obtain a measure of a general immunity belief, we averaged the answers to all three questions. In order to assess the unrealistic optimism bias toward immunity, we computed the mean in estimating the immunity to the virus for another person and friend and then subtracted this value from the score of the answer to immunity for the self.

Results

Unrealistic optimism bias: prevalence and impact on vaccine intentions

Perceived susceptibility

In order to test the unrealistic optimism across different countries, we performed a mixed effects linear regression model with social distance (self vs. friend vs. fellow countryman) as fixed effect, and with participants and country as random effects on the intercepts. Social distance was nested within participants. Participants estimated that both a close friend (β = .37, *SE* = .06, $p < .001$) and a fellow countryman (β = .80, *SE* = .06, $p < .001$) were more likely to get infected in the future in comparison to themselves (intercept = 5.57, SE = .18; see Figure 3).

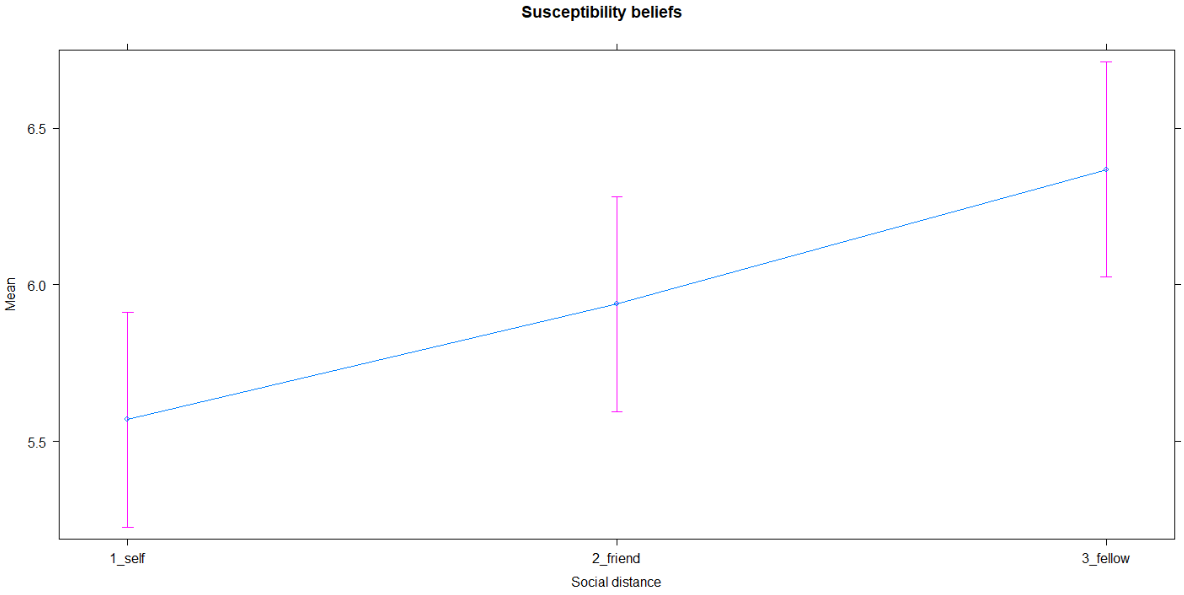

Figure 3. Susceptibility beliefs levels per social distance.

Similar results were achieved using the categorical variable, $\chi^2(2) = 171.51$; $p < .001$: A total of 51.4% ($N = 464$) of participants were optimists (i.e., they assessed it more likely that others would be infected than themselves) and 32.7% ($N = 295$) were neutral – that is, they estimated the likelihood of infection for themselves and others as equally high. 15.9% ($N = 143$) were pessimists, i.e. they assessed it as more likely that they themselves would be infected than their compatriots.

The association between unrealistic optimism related to perceived risk to COVID-19 and vaccine intention was not statistically significant (Pearsons $r = -.03$, $p = .24$)

Immunity Beliefs

In order to investigate the unrealistic optimism bias in terms of immunity beliefs, we performed a multilevel linear regression with social distance (self vs. friend vs. fellow countryman) as fixed effect, participants, and country random effects on the intercepts. Social distance was nested within participants. Participants estimated that both a close friend (β =

.28, *SE* = .06, $p < .001$) and a fellow countryman (β = .53, *SE* = .06, $p < .001$) were more likely to be immune to COVID-19 due to a past infection in comparison to themselves (intercept = 4.98, *SD* = 4.98; see Figure 4).

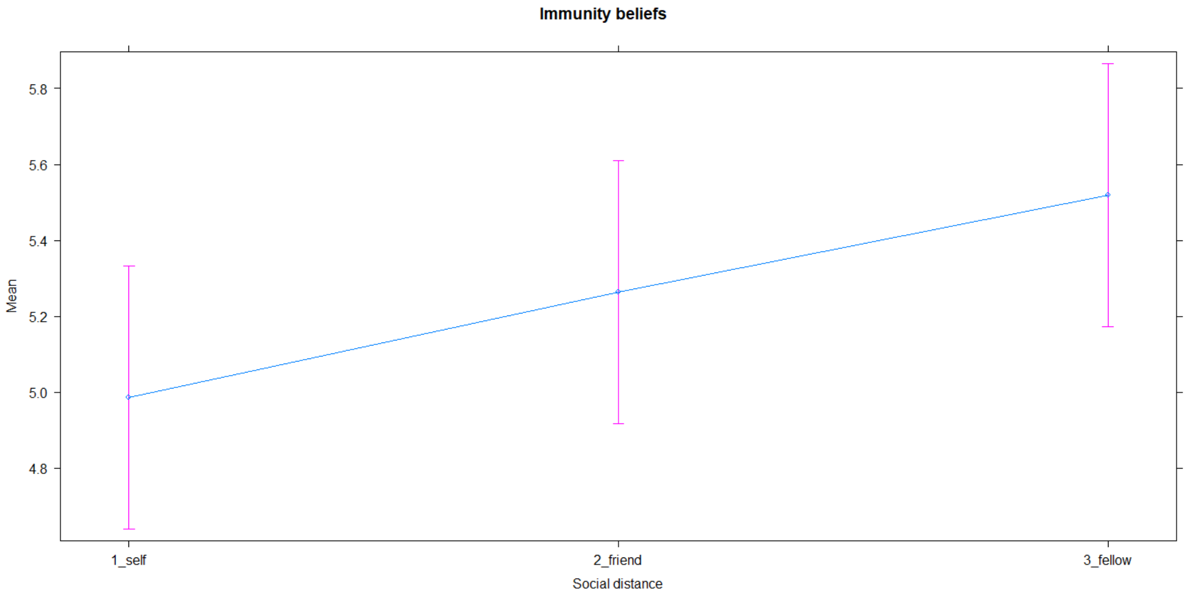

Figure 4. Immunity beliefs per social distance.

Similar results were achieved using the categorical variable, $\chi^2(2) = 67.16$; $p < .001$, : A total of 43.8% (*N* = 395) of participants were pessimist (i.e., they assessed it more likely that others would be immune than themselves) and 34.6% (*N* = 312) were neutral – that is, they estimated the likelihood of immunity for themselves and others as equally high. 21.6% (*N* = 195) were optimist, i.e. they assessed it as more likely that they themselves would be immune than others.

The association between unrealistic optimism related to perceived immunity to COVID-19 and vaccine intention was not statistically significant (Pearsons $r = -.06$, $p = .07$).

Network analysis

In order to assess the best predictor of vaccine intention, an undirected network model was estimated using the same procedure of Study 1.

As reported in Table 2 and Figure 5 and Figure 6, the edge-weight accuracy was good for almost all associations. Importantly, the association between the perceived likelihood of infection and conspiracy beliefs, and the association between the perceived likelihood of infection and vaccine intention included 0 within the 95% confidence interval, meaning that the estimated associations between these variables was not robust. The results showed that vaccine intention is positively associated with trust in science and perceived danger of COVID-19, and negatively associated with conspiracy beliefs. No association was found between vaccine intention and immunity beliefs. Furthermore, trust in science was positively associated with both perceived likelihood and danger of infection, and it was negatively associated with conspiracy beliefs. Finally, immunity beliefs were positively associated with conspiracy beliefs and perceived likelihood of infection.

Table 2

Edge list with estimated weight, standard deviation, and confidence intervals.

Edge	sample	bootstrap mean	sd	CIlower	CIupper
Conspiracy beliefs--Trust in science	-0,26	-0,26	0,03	-0,32	-0,19
Conspiracy beliefs--Vaccine intention	-0,10	-0,09	0,05	-0,21	0,00
Immunity beliefs--Conspiracy beliefs	0,24	0,24	0,03	0,17	0,30
Immunity beliefs--Trust in science	0,00	0,00	0,01	-0,03	0,03
Immunity beliefs--Vaccine intention	0,00	-0,01	0,02	-0,04	0,04
Perceived danger infection--Conspiracy beliefs	-0,13	-0,13	0,04	-0,21	-0,05
Perceived danger infection--Immunity beliefs	0,00	0,00	0,02	-0,03	0,03
Perceived danger infection--Perceived likelihood infection	0,26	0,27	0,03	0,19	0,33

Perceived danger infection--Trust in science	0,14	0,14	0,04	0,06	0,22
Perceived danger infection--Vaccine intention	0,18	0,18	0,03	0,12	0,25
Perceived likelihood infection--Conspiracy beliefs	0,00	0,03	0,04	-0,09	0,09
Perceived likelihood infection--Immunity beliefs	0,39	0,39	0,03	0,33	0,45
Perceived likelihood infection--Trust in science	0,17	0,17	0,03	0,10	0,24
Perceived likelihood infection--Vaccine intention	0,09	0,08	0,05	-0,01	0,19
Trust in science--Vaccine intention	0,31	0,31	0,03	0,24	0,37

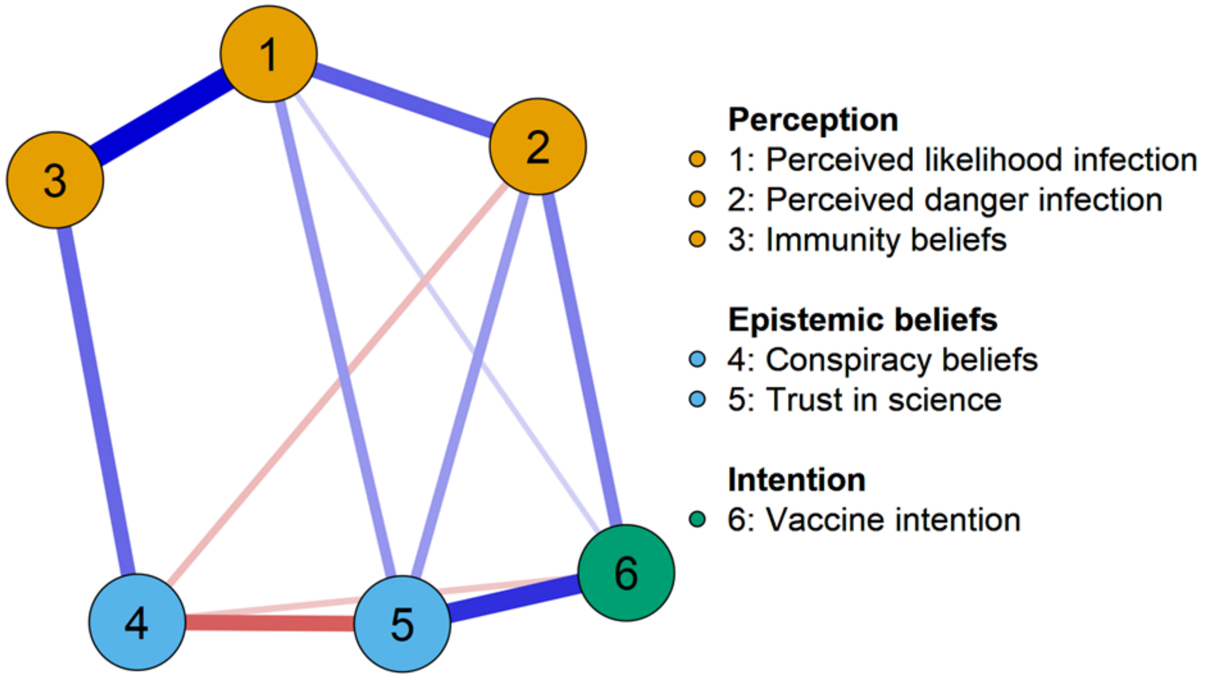

Figure 5. Empirical network model. Each node represents an attribute associated with the behavioral intention target. The edges represent the relationship among attributes. The thicker the edge is, the greater is the relationship between attributes.

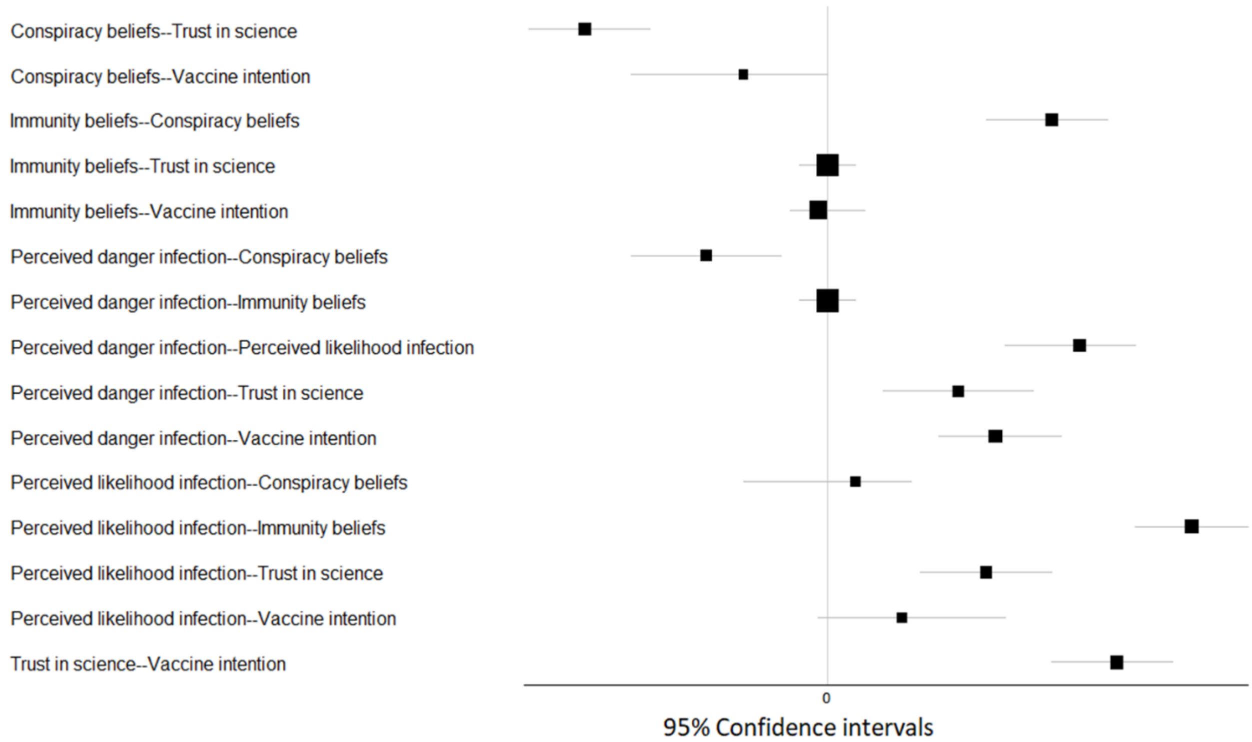

Figure 6. Bootstrapped Edges confidence intervals.

Discussion

Study 2 produced important insights about unrealistic optimism and potential drivers of vaccination intention. The unrealistic optimism found in Study 1 was here replicated, as respondents tended to estimate their likelihood of *future* coronavirus infection as lower than that of others. Moreover, going one step further than Study 1, our results indicate that this bias is present in relation to both referent groups. That is, participants judged their likelihood to get infected with COVID-19 as smaller than both the likelihood of friends and of fellow countryman. However, respondents tended to estimate their likelihood of *past* coronavirus infection (and the associated likelihood of present immunity to the virus) as being lower than that of others. This finding can be interpreted in different ways. On the one hand, one could interpret it as a pessimistic bias, because participants assigned the most desirable outcome (i.e., immunity to the virus) to others as compared to themselves. On the other hand, it can be interpreted as unrealistic optimism, because the question of being immune was coupled with the notion that immunity can only be achieved by being infected in the past. As unrealistically optimist participants perceive the likelihood of getting infected as very low, they might have concluded that they cannot be immune. As both explanations are plausible, this result calls for future investigations.

Furthermore, our network analyses replicated the pattern of Study 1 by demonstrating that trust in science is the variable with the stronger association with vaccine intention. Moreover, trust in science was linked to all the other variables except the perceived likelihood of immunity to COVID-19.

Additional analysis indicates that among the measured risk perception factors (perceived COVID infection likelihood, danger, and immunity) it is the perceived danger of COVID-19 the one more strongly related to vaccine intention, whereas, coherently with Study 1, the perceived likelihood was only weakly and unreliably linked to it. In addition, the perceived likelihood of immunity was not directly linked to vaccine intention.

General Discussion

The results of our studies showed that trust in science is most strongly associated with vaccine intention and is, therefore, a promising factor for communication campaigns aimed at promoting vaccination. Past research has shown that several factors need to be taken into consideration when communicating with the public. For example, communicating lack of scientific consensus can reduce perceived certainty and trustworthiness of presented findings (Gustafson & Rice, 2019) even when agreement between researchers is as high as 80% (Aklin & Urpelainen, 2014); (Chinn et al., 2018). Thus, one should be careful in communicating disagreement between experts when there is actually little or no disagreement. Another factor that should be considered is imprecise communication. Using words such as “estimated” or “around” before a point estimate may hamper trust in the scientific results (van der Bles et al., 2020). Thus, when communicating estimates of numbers, one should be more precise. Finally, trust in science increases when the replicability of a result is mentioned (Hendriks et al., 2020), (Wingen et al., 2020). Thus, the number of experiments providing support for vaccines and/or the number of studies reporting no side effects of the vaccines can be highlighted to gain trust in the public.

Besides trust in science, the perceived danger of the disease is associated with the intention to get vaccinated too. This suggests that when promoting vaccines in public speaking, one could highlight the danger of the pandemic for the society. This suggestion is in line with the "fear appeal" concept (Maloney et al., 2011), which refers to the role of fear in enhancing protective behaviors like vaccination. Based on this model, it is assumed that the threat generated by the fear of getting COVID-19 creates psychological stress and increases individuals' willingness to engage in health-promoting behaviors, such as getting vaccinated, for instance. The network approach used in our studies provides relevant insights that are not limited to the prediction of vaccine intention but further highlight the interplay among variables. Specifically, both in Study 1 and 2, conspiracy beliefs appeared weakly linked to vaccine intention but the network models revealed that conspiracy beliefs were negatively associated with both trust in science and perceived danger of COVID-19, two variables that have a strong connection with vaccine intention. Therefore, under a connectionist model of attitudes (Dalege et al., 2016), the final evaluative reaction toward an object is the result of the interplay of several interconnected elements. Because of cognitive consistency needs, it would be particularly hard to change the final attitude addressing only one of its related evaluative elements, especially when it is strongly related to other relevant evaluative reactions. Based on this perspective, trust in science is the closer attitude related to vaccine intention. However, it is plausible that tackling trust in science needs a wider field of persuasion, that includes conspiracy beliefs and risk perception factors. Promoting transparency and inoculating against conspiracy theories (Jolley & Douglas, 2017)may prevent people to distrust scientists and minimize the impact of COVID-19, in order to reach the final outcome of promoting vaccine intention. Similarly, the detected network allows to spot the interrelation among the components of COVID-19 risk perception. Even if perceived immunity and perceived susceptibility do not appear to have a direct predictive value on vaccine intention, still these evaluative reactions are linked, and therefore may influence the perceived danger of COVID-19. Their interconnections suggest that a social marketing campaign should take in account all the components of risk perception.

Limitations and future directions

Despite these implications, it is important to highlight some limitations of our studies. Even if the network analysis provided interesting insights about vaccine intention's drivers and their interrelation, it is important to note the correlation design of our studies do not allow deriving at causal inferences. Nevertheless, by using two highly powered samples and by replicating our key findings, we were able to provide robust evidence of relevant associations. Thus, based on the correlational character of our studies, the results can be seen as a promising starting point for future experimental studies and intervention pilots.

The exploration of risk perceptions allowed us to detect the presence of unrealistic optimism bias related to the susceptibility (due to future infections) and immunity to COVID-19. In Study 1 and Study 2, we found that people have an unrealistic optimism bias as they perceived the risk to get infected with COVID-19 as lower than for others. Nevertheless, the results in Study 2 on the belief of immunity could potentially be interpreted as a pessimistic bias, because participants believed that they are less likely immune than others. However, as the question about immunity belief was linked to the premise that one was already infected with COVID-19, this result should be interpreted with caution. Future research could assess the belief of being immune separately from the belief of being already infected to disentangle these two constructs and to measure the unrealistic optimism immunity bias more precisely.

Conclusion

Vaccines against COVID-19 will most likely be the fundamental force that ends the COVID-19 pandemic. However, the discovery of safe and effective vaccines is only one (although important) part of the fight against the pandemic. As a substantial number of people is hesitant against vaccines, understanding the psychological factors associated with vaccine compliance is another important element. In two studies, we demonstrated that individuals' risk perception of the virus plays an important role on the intention to get vaccinated, and it is the building of trust in science that represent the most promising driver of vaccine intentions. Communication campaigns promoting COVID-19 vaccines, and vaccines in general, may implement this finding to reach a large number of people and thereby herd immunity.

Declaration of interest statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Author Contributions

Conceptualization, Dolinski D., Genschow O., Kulesza W., Salvador Casara B. G., Suitner C.; methodology, Genschow O., Kulesza W., Salvador Casara B. G., Suitner C.; formal analysis, Salvador Casara B. G.; investigation, Genschow O., Kulesza W., Martinez-Conde S., Salvador Casara B. G., Suitner C.; resources, Genschow O., Kulesza W., Muniak P.; data curation, Muniak P., Martinez-Conde S.; writing—original draft preparation, Salvador Casara B. G.; writing—review and editing, Dolinski D., Genschow O., Martinez-Conde S., Salvador Casara B. G., Suitner C.; visualization, Salvador Casara B. G.; supervision, Suitner C., Kulesza W.; project administration, Kulesza W., Muniak P.; funding acquisition, Dolinski D., Kulesza W., Muniak P. All authors have read and agreed to the published version of the manuscript.”.

Aklin, M., & Urpelainen, J. (2014). Perceptions of scientific dissent undermine public support for environmental policy. *Environmental Science and Policy*. https://doi.org/10.1016/j.envsci.2013.10.006

Avorn, J., & Kesselheim, A. (2020). Regulatory Decision-making on COVID-19 Vaccines during a Public Health Emergency. In *JAMA - Journal of the American Medical Association*. https://doi.org/10.1001/jama.2020.17101

Barello, S., Nania, T., Dellafiore, F., Graffigna, G., & Caruso, R. (2020). 'Vaccine hesitancy' among university students in Italy during the COVID-19 pandemic. *European Journal of Epidemiology*. https://doi.org/10.1007/s10654-020-00670-z

Bertin, P., Nera, K., & Delouvée, S. (2020). Conspiracy Beliefs, Rejection of Vaccination, and Support for hydroxychloroquine: A Conceptual Replication-Extension in the COVID-19 Pandemic Context. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2020.565128

Bottemanne, H., Morlaàs, O., Fossati, P., & Schmidt, L. (2020). Does the Coronavirus Epidemic Take Advantage of Human Optimism Bias? *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2020.02001

Brewer, N. T., Chapman, G. B., Gibbons, F. X., Gerrard, M., McCaul, K. D., & Weinstein, N. D. (2007). Meta-analysis of the relationship between risk perception and health behavior: The example of vaccination. *Health Psychology*. https://doi.org/10.1037/0278-6133.26.2.136

Chinn, S., Lane, D. S., & Hart, P. S. (2018). In consensus we trust? Persuasive effects of scientific consensus communication. *Public Understanding of Science*. https://doi.org/10.1177/0963662518791094

Cooper, D. L., Hernandez, N. D., Rollins, L., Akintobi, T. H., & McAllister, C. (2017). HPV vaccine awareness and the association of trust in cancer information from physicians among males. *Vaccine*. https://doi.org/10.1016/j.vaccine.2017.03.083

Costantini, G., Epskamp, S., Borsboom, D., Perugini, M., Mõttus, R., Waldorp, L. J., & Cramer, A. O. J. (2015). State of the aRt personality research: A tutorial on network analysis of personality data in R. *Journal of Research in Personality*. https://doi.org/10.1016/j.jrp.2014.07.003

Dalege, J., Borsboom, D., Van Harreveld, F., Van den Berg, H., Conner, M., & Van der Maas, H. L. J. (2016). Toward a formalized account of attitudes: The Causal Attitude Network (CAN) Model. *Psychological Review*. https://doi.org/10.1037/a0039802

de Figueiredo, A., Johnston, I. G., Smith, D. M. D., Agarwal, S., Larson, H. J., & Jones, N. S. (2016). Forecasted trends in vaccination coverage and correlations with socioeconomic factors: a global time-series analysis over 30 years. *The Lancet Global Health*. https://doi.org/10.1016/S2214-109X(16)30167-X

Dillard, A. J., Ferrer, R. A., Ubel, P. A., & Fagerlin, A. (2012). Risk perception measures' associations with behavior intentions, affect, and cognition following colon cancer screening messages. *Health Psychology*. https://doi.org/10.1037/a0024787

Dillard, A. J., Midboe, A. M., & Klein, W. M. P. (2009). The dark side of optimism: Unrealistic optimism about problems with alcohol predicts subsequent negative event experiences. *Personality and Social Psychology Bulletin*. https://doi.org/10.1177/0146167209343124

Dohle, S., Wingen, T., & Schreiber, M. (2020). Acceptance and adoption of protective measures during the COVID-19 pandemic: The role of trust in politics and trust in science. *Social Psychological Bulletin*. https://doi.org/10.32872/spb.4315

Epskamp, S. (2016). Regularized Gaussian Psychological Networks: Brief Report on the Performance of Extended BIC Model Selection. *ArXiv*.

Epskamp, S., Borsboom, D., & Fried, E. I. (2018). Estimating psychological networks and their accuracy: A tutorial paper. *Behavior Research Methods*. https://doi.org/10.3758/s13428-017-0862-1

Epskamp, S., & Fried, E. I. (2018). A tutorial on regularized partial correlation networks. *Psychological Methods*. https://doi.org/10.1037/met0000167

Floyd, D. L., Prentice-Dunn, S., & Rogers, R. W. (2000). A meta-analysis of research on protection motivation theory. *Journal of Applied Social Psychology*. https://doi.org/10.1111/j.1559-1816.2000.tb02323.x

Friedman, J., Hastie, T., & Tibshirani, R. (2008). Sparse inverse covariance estimation with the graphical lasso. *Biostatistics*. https://doi.org/10.1093/biostatistics/kxm045

Graffigna, G., Palamenghi, L., Barello, S., & Stefania, B. (2020). "Cultivating" acceptance of a COVID-19 vaccination program: Lessons from Italy. In *Vaccine*. https://doi.org/10.1016/j.vaccine.2020.10.025

Gustafson, A., & Rice, R. E. (2019). The Effects of Uncertainty Frames in Three Science Communication Topics. *Science Communication*. https://doi.org/10.1177/1075547019870811

Hendriks, F., Kienhues, D., & Bromme, R. (2020). Replication crisis = trust crisis? The effect of successful vs failed replications on laypeople's trust in researchers and research. *Public Understanding of Science*. https://doi.org/10.1177/0963662520902383

Hoorens, V. (1995). Self-Favoring Biases, Self-Presentation, and the Self-Other Asymmetry in Social Comparison. *Journal of Personality*. https://doi.org/10.1111/j.1467-6494.1995.tb00317.x

Ikhlaq, A., Bint-E-riaz, H., Bashir, I., & Ijaz, F. (2020). Awareness and attitude of undergraduate medical students towards 2019-novel corona virus. *Pakistan Journal of Medical Sciences*. https://doi.org/10.12669/pjms.36.COVID19-S4.2636

Jolley, D., & Douglas, K. M. (2014). The effects of anti-vaccine conspiracy theories on vaccination intentions. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0089177

Jolley, D., & Douglas, K. M. (2017). Prevention is better than cure: Addressing anti-vaccine conspiracy theories. *Journal of Applied Social Psychology*, *47*(8), 459–469. https://doi.org/10.1111/jasp.12453

Jones, C. L., Jensen, J. D., Scherr, C. L., Brown, N. R., Christy, K., & Weaver, J. (2015). The Health Belief Model as an Explanatory Framework in Communication Research: Exploring Parallel, Serial, and Moderated Mediation. *Health Communication*. https://doi.org/10.1080/10410236.2013.873363

Kata, A. (2012). Anti-vaccine activists, Web 2.0, and the postmodern paradigm - An overview of tactics and tropes used online by the anti-vaccination movement. *Vaccine*. https://doi.org/10.1016/j.vaccine.2011.11.112

Klein, W. M. P., & Weinstein, N. D. (1997). Social Comparison and Unrealistic Optimism about Personal Risk. In *Health, coping, and well-being: Perspectives from social comparison theory*.

Lange, J., Dalege, J., Borsboom, D., van Kleef, G. A., & Fischer, A. H. (2020). Toward an Integrative Psychometric Model of Emotions. *Perspectives on Psychological Science*. https://doi.org/10.1177/1745691619895057

Larson, H. J., Clarke, R. M., Jarrett, C., Eckersberger, E., Levine, Z., Schulz, W. S., & Paterson, P. (2018). Measuring trust in vaccination: A systematic review. In *Human Vaccines and Immunotherapeutics*. https://doi.org/10.1080/21645515.2018.1459252

Love, J., Selker, R., Marsman, M., Jamil, T., Dropmann, D., Verhagen, J., Ly, A., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Wild, A., Knight, P., Rouder, J. N., Morey, R. D., & Wagenmakers, E. J. (2019). JASP: Graphical statistical software for common statistical designs. *Journal of Statistical Software*. https://doi.org/10.18637/jss.v088.i02

Maloney, E. K., Lapinski, M. K., & Witte, K. (2011). Fear appeals and persuasion: A review

and update of the extended parallel process model. *Social and Personality Psychology Compass*. https://doi.org/10.1111/j.1751-9004.2011.00341.x
Marlow, L. A. V., Waller, J., & Wardle, J. (2007). Trust and experience as predictors of HPV vaccine acceptance. *Human Vaccines*. https://doi.org/10.4161/hv.3.5.4310
Nudelman, G., Kalish, Y., & Shiloh, S. (2019). The centrality of health behaviours: A network analytic approach. *British Journal of Health Psychology*. https://doi.org/10.1111/bjhp.12350
Palamenghi, L., Barello, S., Boccia, S., & Graffigna, G. (2020). Mistrust in biomedical research and vaccine hesitancy: the forefront challenge in the battle against COVID-19 in Italy. *European Journal of Epidemiology*. https://doi.org/10.1007/s10654-020-00675-8
Rogers, R. W. (1975). A Protection Motivation Theory of Fear Appeals and Attitude Change1. *The Journal of Psychology*. https://doi.org/10.1080/00223980.1975.9915803
Rosenstock, I. M. (1977). The Health Belief Model and Preventive Health Behavior. *Health Education & Behavior*. https://doi.org/10.1177/109019817400200405
Salvador Casara, B. G., Suitner, C., & Bettinsoli, M. L. (2019). Viral suspicions: Vaccine hesitancy in the web 2.0. *Journal of Experimental Psychology: Applied*, *25*(3), 354–371. https://doi.org/10.1037/xap0000211
Taylor-Clark, K., Blendon, R. J., Zaslavsky, A., & Benson, J. (2005). Confidence in crisis? Understanding trust in government and public attitudes toward mandatory state health powers. *Biosecurity and Bioterrorism*. https://doi.org/10.1089/bsp.2005.3.138
Taylor, S. E., & Brown, J. D. (1988). Illusion and Well-Being: A Social Psychological Perspective on Mental Health. *Psychological Bulletin*. https://doi.org/10.1037/0033-2909.103.2.193
Tibshirani, R. (1996). Regression Shrinkage and Selection Via the Lasso. *Journal of the Royal Statistical Society: Series B (Methodological)*. https://doi.org/10.1111/j.2517-6161.1996.tb02080.x
van der Bles, A. M., van der Linden, S., Freeman, A. L. J., & Spiegelhalter, D. J. (2020). The effects of communicating uncertainty on public trust in facts and numbers. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1913678117
Van Der Weerd, W., Timmermans, D. R. M., Beaujean, D. J. M. A., Oudhoff, J., & Van Steenbergen, J. E. (2011). Monitoring the level of government trust, risk perception and intention of the general public to adopt protective measures during the influenza A (H1N1) pandemic in the Netherlands. *BMC Public Health*. https://doi.org/10.1186/1471-2458-11-575
Weinstein, N. D. (1980). Unrealistic optimism about future life events. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/0022-3514.39.5.806
Weinstein, N. D. (1983). Reducing unrealistic optimism about illness susceptibility. *Health Psychology*. https://doi.org/10.1037/0278-6133.2.1.11
Wingen, T., Berkessel, J. B., & Englich, B. (2020). No Replication, No Trust? How Low Replicability Influences Trust in Psychology. *Social Psychological and Personality Science*. https://doi.org/10.1177/1948550619877412
Witte, K. (1992). Putting the fear back into fear appeals: The extended parallel process model. *Communication Monographs*. https://doi.org/10.1080/03637759209376276
Zonis, M., & Joseph, C. M. (1994). Conspiracy Thinking in the Middle East. *Political Psychology*. https://doi.org/10.2307/3791566