COVID-19 Misinformation, Believability, and Vaccine Acceptance Over 40 Countries

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This manuscript was compiled on December 15, 2020

The COVID-19 pandemic has been damaging to the lives of people all around the world. Accompanied by the pandemic is an *infodemic*, an abundant and uncontrolled spreading of potentially harmful misinformation. The infodemic may severely change the pandemic's course by interfering with public health interventions such as wearing masks, social distancing, and vaccination. In particular, the impact of the infodemic on vaccination is critical because it holds the key to reverting to pre-pandemic normalcy. This paper presents findings from a global survey on the prevalence of misinformation on the novel coronavirus and its association with vaccine acceptance. Based on responses gathered from over 18,400 individuals from 40 countries, we find a strong association between perceived believability of misinformation and vaccination hesitancy. This association is even more prominent for vaccination-related misinformation. Our findings seem to suggest that reactively fact-checking false claims is insufficient to combat the infodemic when individuals are susceptible to believing in it, highlighting the importance of proactive attitudes in delivering facts before rumors. We discuss how public information campaigns should raise public awareness of the coronavirus' risks and side effects.

COVID-19 | Coronavirus | Infodemic | Misinformation | Vaccination

In the contemporary world with social media, misinformation and disinformation can be rapidly disseminated to millions of people (1, 2). Studies suggest that harmful false information spreads more broadly than the truth online (3). Due to social media's global reach with a rapid amplification mechanism (4), information can quickly inundate the Internet and get reinforced, potentially creating an "infodemic" (5, 6). In the context of COVID-19, false information rapidly gained a strong foothold among the general population. A study reports that as high as 82% of the pandemic claims on social media are false (7), highlighting their severity.

The infodemic has led to harmful consequences around the world. An early example of its harms was an incident in South Korea (8), where a church administrator sprayed saltwater in worshippers' mouths under the belief that doing so could prevent the disease, resulting in a cluster of 43 patients. Misinformation about alcohol-based disinfecting measures led to hundreds of deaths and many more hospitalizations in Iran due to methanol poisoning (9). Similar incidents were reported in Turkey, Qatar, and India. There are also reports demonstrating that false information has triggered threats and violence against healthcare workers worldwide (10).

The absence of attested therapeutics or vaccines for COVID-19 has resulted in the mitigation strategies to be heavily reliant on behavioral measures, which sparked much controversy across the general population (e.g., see riots that followed lockdowns (11)). Effective communication of accurate information to the public is critical for the adoption of appropriate measures. Previous scholarly work has shown that communicating even the most basic health-related information to the public can be a daunting task (12, 13).

Previous work addressing misinformation in healthcare has found that false and misleading claims negatively influence people's attitudes towards vaccine acceptance — the central topic of this study. One study conducted in the Democratic Republic of the Congo during the Ebola epidemic found an adverse effect of false information on vaccine acceptance (14). The World Health Organization (WHO) has highlighted how misinformation has raised doubts on the effectiveness of human papillomavirus (HPV) vaccines (15). Furthermore, vaccine refusal has led to the measles' resurgence in the US, even after decades of containment (16).

Research has proven that vaccines do save lives (17). According to WHO, more than 17.1 million lives had been saved from measles due to widespread vaccination from 2000 to 2015, and vaccines still prevent 2 million deaths every year (18). In the absence of validated therapeutics for COVID-19, a vaccine is widely believed to be the only way out towards pre-pandemic normalcy (19). Nonetheless, an indirect and potentially more

Significance Statement

Coronavirus-related misinformation has proved to be harmful worldwide. Considering the significance of vaccination in the COVID-19 pandemic's control, the current study conducted a survey (N=18,407 from 40 countries) to analyze misinformation's spread and its association with vaccine acceptance. Our results show that various rumors disseminated globally while their fact checks seem to lag behind. Our findings confirm that misinformation, particularly those questioning vaccines, is associated with an increase in vaccine hesitancy. Although fact-checks seem to balance out the adverse effect of misinformation, its effect appears insufficient for those susceptible to believing in rumors. Our findings suggest that rather than solely relying on reactive debunking strategies, preemptive efforts to deliver facts before rumors are urgently required to mitigate misinformation' ill effects.

M.C. and C.C. conceptualized this research. K.S. and G.L. ran the survey and analyzed the data. All authors participated in the survey design and editing of the paper.

The authors declare no competing interest.

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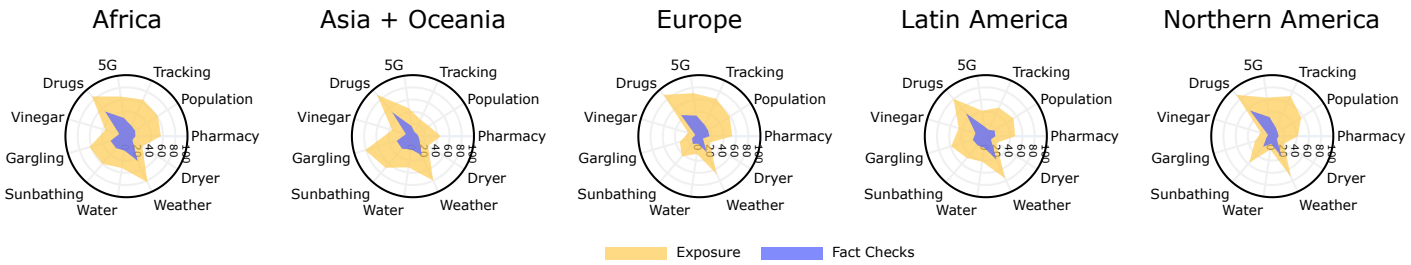

Fig. 1. Region-level exposure to misinformation (yellow) and fact-checks (blue). The plot indicates the percentage of participants who have seen each claim and its corresponding fact-check in a specific region covered by our study. The numbers are calculated after post-stratification weighting by the process of raking. The radial axis represents the percentages ranging from 0 to 100. In the angular axis, distinct claims representing similar notions, i.e., vaccination-related claims, are arranged together.

severe impact of misinformation seems to be deterring people from getting vaccinated. A national UK survey indicated that only 78% of the residents would agree to take a COVID-19 vaccine (20). This vaccination rate might not be enough to develop herd immunity (21).

More worryingly, the Internet's inability to discriminate between true and false information (22) likely allows unfounded eccentric opinions and disinformation regarding vaccination to spread widely online and possibly prevail online in the coming decades (23). These anti-vaccination movements are fueled by conspiracy theories (24), inability to differentiate between types of information (25), lack of trust in the healthcare systems, and corporations (26), past experiences with vaccination, and various other factors (12), undermining attempts for widespread vaccination.

Given the dire consequences of coronavirus misinformation, several studies have provided insights into various rumors' reach. One study has tracked both rumors and fact-checks on Twitter and examined the network shape through which both spread (27). Recent work has examined 5G conspiracy theories (28), discussed medication-related misinformation (29), and explored anti-vaccine information shared on social media (30). Other studies have also examined the association between exposure to social media, news media, and COVID misperceptions (31), as well as online health information-seeking behaviors of parents, which could affect their vaccination decisions for their children (32). Critically, Kim et al. (33) have highlighted the negative consequences of misinformation during a global pandemic. In light of the importance of widespread vaccination in containing the current pandemic, the current study builds upon these efforts and investigates the worldwide exposure to unproven claims and their impact on vaccine acceptance.

We quantified the extent to which the COVID-19 infodemic spread during the pandemic's early days through a global survey conducted across six continents. We tested whether exposure to false information, their respective fact-checks, and believability are associated with vaccine acceptance. Our findings show that exposure to false claims was nearly two times higher than the exposure to their fact-checks in every continent for all major claims studied (Fig. 1). We examined the impact of exposure to misinformation on attitudes towards rumor believability and vaccine acceptance, and we found a positive association between exposure and both believability and vaccination hesitancy. We find that those who perceive the pandemic as more threatening are more willing to accept a future vaccine, highlighting the importance of raising public awareness concerning the disease's risks. Our regression analysis suggests that exposure to fact-checks could nearly balance out the adverse effect of exposure to misinformation. This remedy, however, doesn't seem to be effective for individuals who report being susceptible to false information; to what extent participants found claims believable was much more strongly associated with vaccine hesitancy.

Results

Quantifying the Infodemic. Our study estimated the worldwide exposure to the COVID-19 infodemic with the following questions: i) have you seen or heard this information in the past month? ii) Have you ever seen an official source confirming or denying this claim? iii) How believable does this information seem to you?* These questions were repeated for 11 false or unproven claims that circulated widely at the time of the survey (see Materials and Methods). The claims covered a broad range of topics, including do-it-yourself (DIY) measures to deliberate disinformation.

We recruited survey respondents through social media, similar to prior studies in late demographic research (34, 35). Our survey was made available through the Facebook Advertisement Platform from June 18th until July 13th, 2020, in five different languages: English, Spanish, French, Portuguese, and Arabic. The recruitment procedure yielded 1,946,516 responses from 44,239 Facebook users located in 152 countries. After removing incomplete and duplicated responses, we also discarded data from countries with less than 30 respondents. The final dataset comprised of 805,816 responses from 18,314 users in 40 countries (see Fig. 2 for map and Table S1 for demographic distributions).

The radar charts in Fig. 1 show the exposure to misinformation and its respective fact-checks over a scale from 0 to 100%. Results are aggregated by world regions, after weighting by the population of the represented countries and regions (36). The COVID-19 infodemic disseminated massively. The Weather and Drugs rumors were the most widespread, reaching 70 to 95% of the respondents worldwide. However, the infodemic's reach varied by region for many other claims; for instance, Gargling reached a majority (60–80%) of respondents in Asia, Africa, and Latin America, whereas it only reached 30% of respondents in Europe and North America. The 5G claim was seen more widely in Africa, Europe, and North America. The rumors attracted a lot of attention online (37), and was often accompanied by vaccination-related misinformation (38).

* Instead of directly asking whether respondents believed in the rumors, we asked them whether they perceived them as believable to deal with possible social desirability biases. Otherwise, participants might have responded negatively to be seen more favorably.

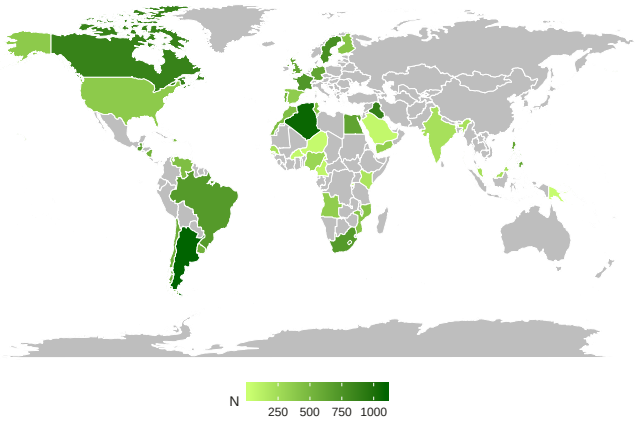

Fig. 2. Distribution of respondents across the world. The study obtained responses from 18,407 participants from 40 countries across the globe.

Moreover, respondents in these regions also largely report having seen vaccine conspiracy related claims, denoted as Tracking, Control, and Pharma (i.e., vaccines are being developed to implant microchips, as population control, or for pharmaceutical companies' profits, respectively). These claims were seen at a comparatively lower rate in Asia and Latin America.

Fact-checks of the 11 claims, represented as the inner polygons in Fig. 1, reached nearly half of respondents who had been exposed to the misinformation. Nevertheless, the claims with widespread reach were also most frequently fact-checked (Spearman's correlation over 40 countries is 0.65). For instance, Weather and Drugs are not only the two most seen but also the most widely fact-checked claims. Misinformation addressing DIY measures to prevent or kill the coronavirus, such as Dryer and Vinegar, are the least frequently debunked across most regions. We report the numerical values of Fig. 1 in Table S3.

Misinformation and Vaccine Acceptance. After quantifying public exposure to misinformation, we assessed the perceived believability of each rumor (termed *believability* hereafter) and its relationship to willingness to get vaccinated (termed *vaccine acceptance*). Our primary goal was to examine whether extensive exposure to misinformation increases rumor believability and whether such reinforcement further leads to vaccine hesitancy (i.e., a decrease in vaccine acceptance). At the end of the survey, respondents were also asked demographic questions (summarized in Table 1) and to what extent they perceived the novel coronavirus as a threat, which was measured via a threat scale introduced in (39) (termed *perceived threat*). The scales used for encoding responses are indicated in Table 1.

We analyzed the survey responses through three different regression models. The first model (Model 1) predicts average believability based on one's exposure to misinformation and its corresponding fact-checks. The next two models examine which specific aspects of infodemic are associated with changes in attitudes towards COVID-19 vaccination. For Model 2, we aggregate responses across all claims, while for Model 3, we cluster them into different groups: i) DIY measures, ii) temperature-related (termed Hot&Co), iii) vaccination conspiracies, and iv) 5G conspiracy. The rationale behind this grouping is to test the influence of distinct notions of misinformation and behavioral measures on vaccine acceptance. Finally, all the presented models control for demographic features and consider other survey responses as independent variables. We add two-way interaction terms between the degree of exposure to claims and fact-checks, as the two are likely to be correlated (i.e., popular claims are more likely to be fact-checked). Table 2 reports, for each model, the average marginal effects (M). The regression coefficients are reported in Tables S7 - S18 for fixed-, mixed-effects, elastic, and lasso models.

For Model 1, we find that exposure to misinformation is positively correlated with overall claim believability (M=0.098, 95% CI 0.093 – 0.103). A higher perceived threat concerning the pandemic is also associated with higher believability (M=0.114, 95% CI 0.095 – 0.133). Our findings indicate a weak effect of exposure to fact-checks in believability (M=–0.010, 95% CI -0.015 – -0.004).

Model 2 results, in which claims are not grouped, show that mere exposure to misinformation is not strongly associated with vaccination willingness (M=–0.004, 95% CI -0.007 – -0.001). However, the perceived believability of false information is associated with vaccine refusal (M=-0.128, 95% CI -0.137 – -0.119). Although statistically significant, the marginal effect size of overall past-vaccination history is negligibly small, while those who had received a non-mandatory vaccine in the past also report higher vaccine acceptance (M=0.184, 95% 0.170 – 0.199), as those who perceive the pandemic as more threatening (M=0.166, 95% CI 0.155 – 0.177).

Our final logistic regression model (Model 3), which groups related claims into distinct types, indicates that increased exposure to vaccine-related misinformation is directly associated with an increased level of vaccination hesitancy (M=-0.035, 95% CI -0.042 – 0.027). A more substantial association is seen for reported believability of false vaccination-related claims (M=-0.120, 95% CI -0.128 – -0.113). Our results also show that increased exposure to fact-checked vaccination-related information is correlated with increased vaccine acceptance (M=0.032, 95% CI 0.018 – 0.045).

Aside from the vaccination-related claims, our results suggest that exposure, believability, and fact-checking of other types of misinformation are not strongly associated with vaccine acceptance (see Table 2). Additionally, following our initial model results, respondents who feel more threatened by the pandemic are more likely to get vaccinated (M=0.147, 95% CI 0.135 – 0.158). People with previous experience with non-mandatory vaccines also report higher vaccine acceptance (M=0.171, 95% CI 0.157 – 0.185), whereas general past-vaccination has no statistically significant effect. The relative marginal effects for Model 3 can be visualized in Fig. 3.

Discussion

The current study showed that misinformation spread was disproportionate across world regions by quantifying the infodemic's reach and perceptions. Why specific claims had a higher appeal to certain regions may need to be examined from cultural aspects. Moreover, we observe that some claims spread broadly, mostly within localized regions (e.g., Dryer). On the other hand, other (seemingly scientific) rumors were equally distributed across continents (e.g., Weather, which has not been completely debunked or confirmed (40, 41)).

This pattern is in line with the previous study that reported that false information related to COVID-19 was more likely to be tweeted than science-based information but was less

Table 1. Coding rules used for regression analysis of believability and vaccine acceptance.

Variable	Values	Usage
Age	0 – 5	Coded Values
Sex	0 & 1	Coded Values
Education	0 – 4	Coded Values
Financial	-2 – 2	Coded Values
Vaccine History	0 & 1	Factor
Perceived Threat	0 – 3	Mean
Exposure	0 & 1	Count
Fact-Checks	0 & 1	Count
Believability	-2 – 2	Mean
Vaccine Decision	0 & 1	Factor

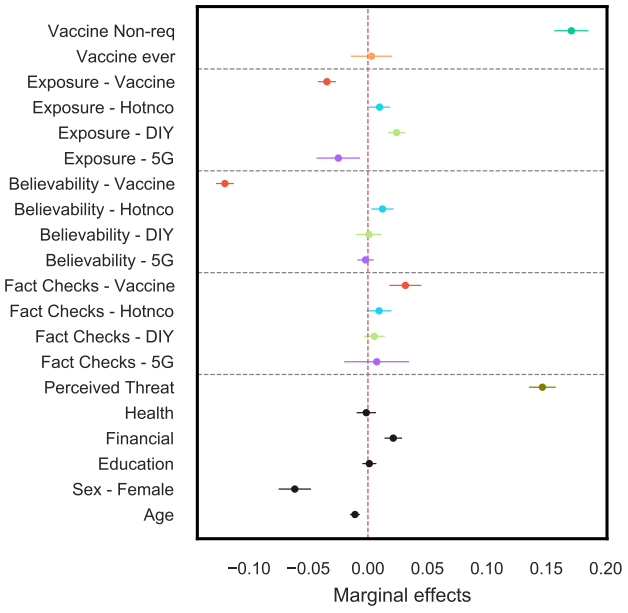

Fig. 3. Model 3's marginal effects of all predictors and their 95% confidence intervals. Variables are color-coded as per the groups. The horizontal dashed lines indicate *Expsoure*, *Believability* and *Fact Checks* for different groups.

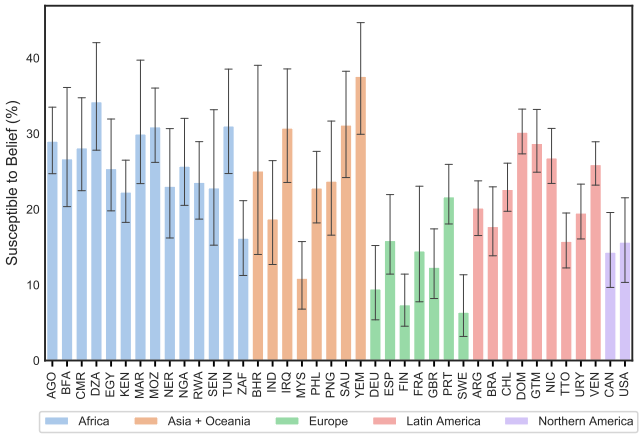

Fig. 4. Country-level reported believability grouped by world regions. Respondents from African countries seem to be most susceptible to believing in misinformation, while our results suggest that Europeans are overall the least vulnerable to it. The x-axis presents each country's ISO 3166-1 alpha-3 codes.

likely to be retweeted (42). Misinformation might get instant local attention, but it might not become widely disseminated if claims cannot be supported with apparently scientific elements.

In terms of believability, European Nordic countries seem to be the least susceptible to misinformation, while African countries might be the most permitting of rumors (Fig. 4). Previous work has investigated the differences in trust in health-related information from social media, revealing cultural differences between countries (43). For example, Asians had more trust in experience-based health information, online support groups, and social networks, while North Americans relied more on expertise-based health information. A possible cause for this finding is cultural differences, as Asian cultures emphasize Collectivistic practices by focusing on societal aspects. There is evidence that African countries also rely on similar Collectivistic cultures (44). With the rapid expansion of social media, combined with the low health literacy rate in Africa, false claims with experience-based health information related to COVID-19 on social media could have a detrimental impact (45).

Our findings indicate that increased exposure to misinformation is positively correlated with its perceived believability. This may be explained by complex contagion, i.e., affirmation from multiple sources can increase the adoption of an idea (46). Although a similar pattern could also play a role in disseminating accurate information, studies suggest that misinformation spreads faster than their fact-checks (3), and hence could dominate online networks in terms of contagion (23).

Although to a lesser degree than exposure to false information, our results suggest a negative association of exposure to fact-checked information with belief susceptibility. A higher perceived threat from COVID-19 is associated positively with believability, suggesting that people who are more anxious about the pandemic could be open to ingesting and accepting more unconfirmed coronavirus information. Conversely, those who perceive the novel coronavirus as more threatening also exhibit increased willingness to get vaccinated. Hence, our results suggest that this anxiety could also translate to people opting for a COVID-19 vaccine once it becomes available.

Our analysis also reveals that exposure to misinformation

Table 2. Summary of regression analysis. The table presents the average marginal effects of all main predictors across the three models proposed by the study and their corresponding 95% confidence intervals. The scale of the variables can be referred to in Table 1. Significance marked as $^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$. Regression coefficients are presented in SI Table S6 - S8.

Predictors	Average Believability (Model 1)	Vaccine Acceptance (Model 2)	Vaccine Acceptance Grouped (Model 3)
Control Variables			
Perceived Threat	$0.114^{***}(0.095 - 0.133)$	$0.166^{***}(0.155 - 0.177)$	$0.147^{***}(0.135 - 0.158)$
Past Vaccination	–	$-0.029^{**}(-0.046 - -0.012)$	$0.003(-0.014 - 0.020)$
Past Non-Mandatory Vaccination	–	$0.184^{***}(0.170 - 0.199)$	$0.171^{***}(0.157 - 0.185)$
Independent Variables			
Exposure	$0.098^{***}(0.093 - 0.103)$	$-0.004^{*}(-0.007 - -0.001)$	–
Believability	–	$-0.128^{***}(-0.137 - -0.119)$	–
Fact-Checks	$-0.010^{**}(-0.015 - -0.004)$	$0.016^{***}(0.012 - 0.019)$	–
5G Claims			
Exposure	–	–	$-0.025^{**}(-0.043 - -0.007)$
Believability	–	–	$-0.002(-0.009 - 0.005)$
Fact-Checks	–	–	$0.007(-0.02 - 0.035)$
DIY Claims			
Exposure	–	–	$0.024^{***}(0.017 - -0.031)$
Believability	–	–	$0.001(-0.010 - 0.012)$
Fact-Checks	–	–	$0.005(-0.004 - 0.014)$
Hot&Co Claims			
Exposure	–	–	$0.010^{*}(0.001 - 0.019)$
Believability	–	–	$0.012^{*}(0.003 - 0.022)$
Fact-Checks	–	–	$0.009(-0.001 - 0.020)$
Vaccination Claims			
Exposure	–	–	$-0.035^{***}(-0.042 - -0.027)$
Believability	–	–	$-0.120^{***}(-0.128 - -0.113)$
Fact-Checks	–	–	$0.032^{***}(0.018 - 0.045)$

influences vaccination decisions. Interestingly, false information's perceived believability is a much more decisive factor in vaccine acceptance compared to mere exposure. Susceptibility to believing in misinformation, and consequent belief in an unconfirmed piece of information, could have critical implications on public health behaviors. On the other hand, increased exposure to fact-checked information is associated with a more positive attitude towards the coronavirus vaccine. Although the adverse impact of perceived believability of misinformation in vaccine acceptance is more pronounced than that of fact-checked information, its positive effect highlights the importance of concerted efforts for disseminating accurate and debunking information to the public.

As the claims addressed in this study cover various aspects of the infodemic, we also studied whether different misinformation categories have varying effects on people's vaccination tendencies. Although increased exposure to vaccination-related false information and associated believability negatively affects vaccine acceptance, our results suggest marginally adverse or even positive effects for other types of misinformation (see Fig 3).

These conflicting and marginal results indicate that misinformation not directly addressing vaccination might not be associated with vaccine refusal. For instance, those who have been exposed to more DIY-related claims show higher rates of vaccine acceptance; people adhering to various behavioral measures for their safety might also feel more threatened about the coronavirus and thus may be more willing to accept a vaccine. Another hypothesis is that people who are interested in personal health and well-being, i.e., arguably more likely to have seen DIY rumors, are active followers of coronavirus-related information to protect themselves from the infection. The opposite effect was observed for the 5G rumor; people who have seen this conspiracy theory might also have been exposed to vaccination-related conspiracies (38) and hence show higher vaccine refusal rates.

Implications

Our results demonstrate how misinformation could lead to vaccination hesitancy. While the aggregate exposure to misinformation could affect people's attitudes towards vaccine acceptance, vaccine conspiracies exhibit the most considerable effect. Our finding could imply that combating vaccine-related misinformation should be a public priority until vaccines become publicly available. Already some research warns how anti-vaccine fronts could undermine widespread vaccination efforts and herd immunity (47). Evidence of the adverse effect shown in our research could back up the suggestions from other research.

Our results are worrying in showing that the effect of fact-checks in fighting misinformation in the current pandemic might be overshadowed by susceptibility to believing in these false claims. Previous work has found that people resist fact-checks that go against their beliefs (48, 49). Therefore, the spread of correct information should not be reactive, in that it debunks misinformation out in the wild, but also proactive. Public campaigns that focus on correcting false claims should also preemptively share up-to-date and accurate information to the masses so that people are already sensitized to it before they are exposed to harmful misinformation.

Under a similar premise, in March 2020, we launched "Facts Before Rumors" (50), a public communication campaign to

combat COVID-19 misinformation by spreading fact-checked information from countries that suffered from false information to regions that were yet to be exposed to the same claims. Our campaign's hallmark is its proactiveness; instead of reactively sharing fact-checks as claims become popular, we aimed to preemptively suppress false rumors by translating and sharing accurate information that had been previously fact-checked in other regions into over 20 languages.

Finally, our findings show that those who feel more threatened about the disease are also more willing to accept future vaccines. This is in line with the Health Belief Model (51), which states that perceived susceptibility and severity are important factors influencing the public engagement with health-related behavior. Public policies and organizations should increase public awareness of the risks and side-effects of COVID-19 so that perceived susceptibility to, and severity of, the disease can influence vaccine acceptance. For instance, public figures have disseminated rumors that the coronavirus is not harmful to the youngest layers of society (52, 53), undermining the possible risks and unknown side-effects of the disease. These statements should be combated at its infancy before the public perception of the disease is swayed.

Governments could develop health policies to promote vaccination against the novel coronavirus based on this finding. For example, national campaigns that increase the awareness of risks, disease progress, and complications of COVID-19 might increase the perceived susceptibility and severity. Many of the anti-smoking public advertisements use similar strategies, e.g., by putting warning signs or pictures of cancerous lungs in cigarette packaging (54). Advertisement and public education to increase public susceptibility might increase the public acceptance of COVID-19 vaccines.

Conclusion

The current study indicates that misinformation, particularly to what extent people are open to believing in it, negatively influences their acceptance of the coronavirus vaccine. A more fine-grained analysis revealed how vaccination-related claims could contribute to vaccination hesitancy, while other false information does not seem to influence these decisions. Worryingly, our findings indicate that the positive effect of fact-checks on vaccine acceptance is less pronounced than the extent to which the population is susceptible to believing in misinformation.

Although we recruited our respondents through social media to cover a wide range of respondents from different world regions and adopted weighting methods to compensate for non-respondents, our results are not strictly representative of the world population. For instance, we have focused our efforts on economically undeveloped countries (e.g., in Africa), as previous work indicates that developing countries are more vulnerable to communicable diseases (55), and hence our respondents do not cover the majority of other countries. Similarly, although we maximized the reach of our survey by translating it into some of the most widely spoken languages, we did not cover Chinese, Indic, and Slavic languages.

Future work on the COVID-19 infodemic could extend the current study to understand what personal factors, e.g., cultural practices, mediate the effect of believability in vaccination acceptance. It will also be an important future study to examine how different sources of information, e.g., celebrities (56), health authorities (57), traditional media (58), can influence participants' views on misinformation and promote/hinder health decisions, as our work has not controlled for many factors which have been shown to influence health decisions. Controlling for other factors like political orientation could be a non-trivial task due to the unique characteristics of political systems around the world. Finally, it is important to consider a possible limitation concerning self-selection biases; participants who chose to take part in the study by clicking on its advertisement might have been particularly interested in the pandemic.

Our findings highlight the importance of proactive dissemination of accurate information during the pandemic. If misinformation is found to be believable, our results suggest that it might be hard to circumvent it through fact-checks. Therefore, public organizations should take the lead in disseminating correct information before false claims are spread to the general public. The extent to which people found the coronavirus to be threatening also played a significant role in their vaccination acceptance, suggesting that accurate information promulgating public awareness about the disease's risks and side effects is important for widespread vaccine acceptance.

Materials and Methods

Survey Design. Our survey gathered data on the prevalence of COVID-19 misinformation. For identifying popular false claims, we collected over 200 COVID-19 rumors from DXY.cn, a Chinese online community for physicians and healthcare professionals, on March 18, 2020. This site hosted a comprehensive list of Chinese social media rumors during the Chinese epidemic's infancy. After removing redundant content and lockdown-related claims, we investigated 30 pieces of misinformation addressing health-related behaviors. We combined these pieces into 11 distinct claims (e.g., combining the effect of multiple different rumors into a single claim). Corroborating these claims with fact-checked information from credible sources, including the World Health Organization (WHO) 's Mythbusters (59) and the International Fact-Checking Network (IFCN) 's #CoronaVirusFacts Alliance database (60), we arrived at the following list of 11 misinformation claims (and their respective groups for later analysis, e.g., in Model 3):

1. 5G (5G): 5G networks can contribute the spreading of the coronavirus.
2. Dryer (Hot&Co): Hot-air dryers can kill the coronavirus.
3. Gargling (DIY): Gargling with salt water can prevent coronavirus infection.
4. Drugs (DIY): Existing drugs for malaria and HIV can help treat COVID-19.
5. Pharma (Vaccination): Pharmaceutical companies are spreading COVID-19 so they can profit from its vaccine.
6. Population (Vaccination): The COVID-19 vaccines currently being developed are forms of population control.
7. Sunbath (Hot&Co): Standing in the sun can kill the coronavirus.
8. Tracking (Vaccination): The COVID-19 vaccine is being developed to implant people with tracking microchips.
9. Vinegar(DIY): Apple cider vinegar can kill the coronavirus in the throat.
10. Water (DIY): Drinking water every 15 minutes will prevent getting infected with the coronavirus.
11. Weather (Hot&Co): The coronavirus will only spread in cold, dry weather and does not survive in hot, humid weather.

Our survey and claims were translated into English, French, Spanish, Portuguese, and Arabic. For French and Spanish, we first used Google Translate to obtain crude translations and then used the Prolific crowdsourcing platform (61) to recruit native speakers from these languages (minimum 18 each) to refine the translations. Recruited participants attended a short survey in which they were asked to refine the provided translations. This procedure was repeated three times for each language in an iterative manner. For Portuguese and Arabic, the translations were done entirely by volunteering native speakers from the second author's institution.

This study had been approved by the Institutional Review Board at the corresponding author's institution (KAIST IRB-20-229). Participants were presented with the following text before taking part in the study:

> Thank you for your interest in this survey. This survey will present you with some information regarding COVID-19 that has been shared on social media. We would like to know what you think about them. We are not looking for the correct answers, but your opinion on the matter. Please, read all the information provided in this survey carefully.
>
> The purpose of this research is to understand how people perceive information regarding COVID-19. This experiment is composed of an online survey that takes about 10 minutes to complete. The information we collect will be used only for research purposes and will be kept in secure computer files indefinitely. No names or other identifying information will be used in any publications or presentations that may result from this study. Your responses may be shared with other researchers; all information, however, will be anonymized and allow no inference on any particular individual.
>
> Results will be published only as aggregate statistics, allowing no inference on any particular individual. Your participation is voluntary and you may withdraw from the study at any time without any penalty. Your responses will be analyzed regardless of how many questions you have completed.
>
> Clicking next indicates that you have understood the information and consent to your participation.

After agreeing to the research terms, participants were asked their current residence country and their level of worry regarding the pandemic using a 5-pt Likert Scale. We do not utilize the participants' responses to the latter question for our analysis as responses were highly correlated with their perceived threat. The following questions were presented in random order to the survey participants for each of the claims:

1. *Exposure*: Have you seen or heard this information in the last month? (Answer: Yes, Partly, No, I don't remember)
2. *Fact-Checks*: Have you ever seen an official source confirming or denying the claim above? (Answer: Yes, No, I don't remember)
3. *Believability*: How believable does the information above seem to you? (Answer: Not believable at all, Not really believable, I am not sure, Somewhat believable, Very believable)
4. *Benefit*: To what extent would your community benefit from seeing a fact-checking result of the claim above? (Answer: Not at all, A little, Moderately, A lot)

After answering the infodemic-related questions presented above for each of the 11 claims addressed in this study, we presented a questionnaire to measure the coronavirus pandemic's perceived threat by the survey participants. Due to our study's cross-country nature, we solely employ the "Realistic Threat" scale proposed by (39). A higher value in this scale indicates that one feels more threatened by the disease vis-à-vis those who score lower.

The survey also asked which preventive measures participants had taken or are currently taking regarding the virus from the following list: Cough/sneezing etiquette, social distancing, quarantines, avoiding travel, self-medication, specific drinks to prevent the disease, sunbathing, head shaving, gargling with specific products, and using hot-air dryers to kill the coronavirus. To understand the effect of misinformation on people's willingness to get vaccinated against the coronavirus, we also ask the following vaccination-related questions.

1. If a vaccine against COVID-19 were available right now, would you get yourself and your family vaccinated? (Answer: Yes, No, I don't know)
2. Have you ever been vaccinated? (Answer: Yes, No, I don't know)
3. Have you ever received a non-mandatory vaccine (e.g., flu shots, H1N1)? (Answer: Yes, No, I don't know)

Finally, we ask demographic questions, such as age and sex, and participants' perceived health and financial status compared to their overall national level.

Data Collection. We conducted a large-scale online survey using the Facebook Advertising Platform from June 18 to July 13, 2020. The survey was designed in the SurveyMonkey platform, and the link to the survey was made available via advertisements on Facebook. As of March 2020, Facebook had 2.60 billion monthly active users and 1.73 billion daily active users (62), making it the largest social media platform. Some recent publications (34, 35) have explored Facebook's usage as a survey platform and noted its advantages of a deep and broad reach, rapid data collection, granular targeting, and cost-effectiveness. The Facebook Advertising Platform allows targeting based on age, location, spoken language, and interests. The concerns sample biases can be dealt with the adequate application of post-stratification weighting techniques, although studies such as (63) show that the demographic distributions of Facebook users tend to not differ hugely from census distributions.

To obtain a large and more representative sample of every country, we designed independent Facebook campaigns for the target countries. Each campaign was further divided into four advertisements sets by age groups (18-24, 25-44, 45-64, and 65+ years). The English survey was run from June 18 to June 25, the Portuguese, Spanish and French surveys were conducted from June 22 to June 28, while the Arabic survey was run from July 7 to July 13.

To control for demographic factors, we ensure a minimum sample of 100 responses from each country. For countries with less than 30 complete responses from the initial round, the survey was rerun from July 7 to July 13. Since the respondents were recruited through the Facebook Advertising Platform, they did not receive any financial benefit from participating in the survey. Therefore, participation is voluntary, and respondents could choose to withdraw from the survey at any time.

Sample and Weighting. We obtained 1,946,516 responses (N=44,239) from Facebook users who have seen and clicked on our advertisement. We discarded incomplete responses and participants with duplicated IP addresses. Due to our weighted analysis, which requires each participant to report their sex, age, and country of residence, we discarded responses from participants who chose not to reveal their sex. We allowed participants to report their sex as "other." To control for countries where we did not reach enough people during our data collection process. To weigh responses successfully, we solely kept participants from those countries with at least 30 complete responses. Our final dataset consisted of 805,816 complete responses (N=18,314) from 40 countries. Our sample covers all continents and contains a median of 464 respondents per country. Demographic information regarding all participants is presented in SI Table S1.

Recruiting participants through the Facebook Advertising Platform allowed us to reach a larger and more representative pool of respondents than otherwise possible through crowdsourcing platforms. Nevertheless, Facebook users are still not demographically representative of countries' populations. For instance, although previous work has found a high correlation between the US Census and Facebook users, the latter was composed of younger and more educated people (63). Therefore, we applied raking as a weighting

method to adjust responses for making more demographically representative estimates of the infodemic's reach within countries and regions.

Raking is a process that uses marginal distributions of demographic variables to fit weights to each joint demographic group iteratively (36). The respondents' sample count is weighted to conform to a demographic variable (e.g., sex, age). This process is repeated iteratively between distributions until convergence. We apply this algorithm to calculate two different weights: country-level and continent-level weights.

The country-level weights are calculated through raking by utilizing each country's marginal sex and age distributions. Similarly, the continent-level weights are calculated considering the countries' marginal demographic distributions and the contribution of a country's population to its regions, i.e., the percentage of a region's citizens living in a specific country. Throughout the paper, we use the country-level weights for analysis when addressing the infodemic within and between countries; conversely, continent-level weights are used when discussing results within and between continents.

Models. This work presents three different regression models, all of which consider reported demographics features and the respondents' mean perceived threat as control variables. Demographic features in this study are reported age group, sex, education, health, and financial status. Except for sex and vaccination history-related dummies, all variables are treated as continuous or counts. Independent variables correspond to exposure to misinformation, and the respective fact-check counts for Model 1, and additionally, average believability for models 2 and 3. We add interaction terms for vaccination history (as history for a non-mandatory vaccine implies past vaccination) as well for exposure to claims and their respective fact-checks (to be exposed to a fact-checked also implies that one has been exposed to the claim, even if only at the time of debunking).

Model 1 is a linear regression predicting the average reported believability of false claims. It is of the form Eq. (1)

$$Y \sim \alpha + \sum_i \beta_i.C_i + \sum_g \beta_g.I_g + \sum_k \beta_k.T_k \qquad [1]$$

where Y is the mean believability, α is the intercept term, and β_i, β_g, β_k are coefficients for control variables C_i, independent variables I_g, and interaction terms T_k respectively.

Model 2 and 3 are logistic regression models predicting the dichotomized responses to the COVID-19 vaccine acceptance question (with the third option "I don't know" treated as a negative response). In order to segregate and identify the association of different categories of claims on the vaccination acceptance, we divide the claims into four groups in Model 3: DIY, Hot&Co, vaccination conspiracies, and the 5G-related claim. For Model 3, the independent variables are distinct exposure and fact-check counts and the mean believability of the segregated groups, whereas, for Model 2, we aggregate these variables across all claims. Also, we utilize respondents' vaccine history as another control variable alongside the respondent's perceived threat. Model 2 and 3 are of the form Eq. (2)

$$\log \frac{P}{1-P} \sim \alpha + \sum_i \beta_i.C_i + \sum_{c,g} \beta_{cg}.I_{cg} + \sum_h \beta_h.V_h + \sum_k \beta_k.T_k \qquad [2]$$

where P is vaccine acceptance, α is the intercept term, β_i, β_{cg}, β_h, β_k are coefficients for control variables C_i, independent variables I_{cg} (representing question categories c and variable g), vaccination history V_h, and interactions terms T_k (as explained above), respectively. We also run the same models with country-level random effects, with lasso and elastic regularization and present the results in the Tables S7 - S18.

ACKNOWLEDGMENTS.

G.L., K.S., and M.C. are supported by the Institute for Basic Science in South Korea (IBS-R029-C2). M.C is also supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF- 2017R1E1A1A01076400). Y.Y.A. is supported by the Defense Advanced Research Projects Agency (DARPA), contract W911NF-17-C-0094. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright annotation thereon. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of DARPA or the U.S. Government.

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