


Understanding coronavirus disease 2019 (COVID-19) vaccine hesitancy: Evidence from the community-driven knowledge site Quora

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Abstract

Objective: The present study aims to examine the threshold of coronavirus disease 2019 (COVID-19) vaccine hesitancy over time and public discourse around COVID-19 vaccination hesitancy.

Methods: We collected 3,952 questions and 66,820 answers regarding COVID-19 vaccination posted on the social question-and-answer website Quora between June 2020 and June 2021 and employed Word2Vec and Sentiment Analysis to analyze the data. To examine changes in the perceptions and hesitancy about the COVID-19 vaccine, we segmented the data into 25 bi-weekly sections.

Results: As positive sentiment about vaccination increased, the number of new vaccinations in the United States also increased until it reached a ceiling point. The vaccine hesitancy phase was identified by the decrease in positive sentiment from its highest peak. Words that occurred only when the positive answer rate peaked (e.g., safe, plan, best, able, help) helped explain factors associated with positive perceptions toward vaccines, and the words that occurred only when the negative answer rate peaked (e.g., early, variant, scientists, mutations, effectiveness) suggested factors associated with vaccine hesitancy. We also identified a period of vaccine resistance, where people who decided not to be vaccinated were unlikely to be vaccinated without further enforcement or incentive.

Conclusions: Findings suggest that vaccine hesitancy occurred because concerns about vaccine safety were high due to a perceived lack of scientific evidence and public trust in healthcare authorities has been seriously undermined. Considering that vaccine-related conspiracy theories and fake news prevailed in the absence of reliable information sources, restoring public trust in healthcare leaders will be critical for future vaccination efforts.

Keywords

COVID-19, vaccination, vaccine hesitancy, community-driven knowledge site, Quora, Word2Vec, sentiment analysis

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Introduction

Since its identification in December 2019, coronavirus disease-19 (COVID-19) has had a detrimental effect on various aspects of human lives all around the world. More than 6 million people have died of the disease, and the number of confirmed cases is more than 540 million as of June 2022.¹ The healthcare system has been overloaded,^{2,3} and many people have experienced financial hardship^{4,5} and depression.⁶

Thirteen COVID-19 vaccines have been developed,⁷ and some (i.e., those manufactured by Pfizer-BioNTech, Moderna, and Janssen) have been approved by the U.S.

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Food and Drug Administration (FDA) as safe and highly effective in preventing serious illness and death from severe acute respiratory syndrome coronavirus 2.⁸ Enough COVID-19 vaccine has been produced to provide adequate distribution in most developed countries. Although the COVID-19 vaccination rate has been gradually increasing globally,⁹ more than one-quarter of American adults (26.3%),¹⁰ and about one-fifth of people in France and Germany¹¹ report COVID-19 vaccine hesitancy. A cross-country comparison study revealed that slightly more than one-third of people in India, Bangladesh, Nigeria, and Sudan reported COVID-19 vaccine hesitancy.¹² Women,^{11,12} people with lower incomes and less education^{11–13} and individuals who identify as racial/ethnic minorities^{10,14,15} report higher COVID-19 vaccine hesitancy than their counterparts who are male, have higher incomes and education, and do not identify as racial/ethnic minorities. Additionally, those who mistrust the medical system and government, and have insufficient information are more likely to be hesitant about receiving the COVID-19 vaccine.^{16–19}

As such, most previous studies on COVID-19 vaccination have focused on explaining differences in vaccine hesitancy based on individual characteristics, including socioeconomic status, race/ethnicity, and perception of the medical system. However, it could also be helpful to compare public sentiment toward COVID-19 vaccination with the actual vaccination rate to better understand uptake of the COVID-19 vaccine. This knowledge could be used to help guide attempts to increase COVID-19 vaccination rates.

Social media can be an appropriate source for identifying the public's perceptions and attitudes about COVID-19 vaccines.^{20,21} Therefore, by analyzing big data from Quora, one of the most frequently used global social media platforms,²² we aimed to (a) discern the evolution of COVID-19 vaccine hesitancy over time and (b) examine discourse around COVID-19 vaccination hesitancy in terms of public attention.

Methods

The present study attempted to identify points in time at which public sentiment toward COVID-19 vaccine switched from more negative to more positive (or vice versa) and what kind of issues influenced those changes of public sentiment. We employed Word2Vec, a machine learning technique, and sentiment analysis (SA), an artificial intelligence technique for natural language processing (NLP), to analyze big data generated by online discourse among the public.

Data

We collected data from Quora, a community-driven question-and-answer (Q&A) website launched in 2010, which provides an excellent outlet for self-expression and

sharing “the wisdom of crowds”.²³ To compare user sentiments 6 months before and after the first COVID-19 vaccine became available on 11 December 2020, we collected all data regarding the COVID-19 vaccine posted between June 2020 and June 2021. We used the automated testing framework in Selenium WebDriver to crawl desired data²⁴ by using the query term “vaccine”. For the data crawled, we conducted pre-processing, where the data are split (referred to as tokenization) and organized into manageable units through lemmatization and lower-casing. Questions and answers that did not contain “COVID” or “COVID-19” were removed. After pre-processing, we collected a total of 3952 questions and 66,820 answers. To examine changes in Quora user perceptions and hesitancy about the COVID-19 vaccine, we segmented the data into 25 bi-weekly sections.

To compare trends in vaccine sentiment with COVID-19 vaccination uptake, we retrieved COVID-19 vaccination data from Our World in Data (<https://ourworldindata.org/>). Rates of COVID-19 vaccination, defined as people who received at least one COVID-19 vaccine dose in the United States and worldwide, were obtained for the dates of 11 December 2020, to 27 June 2021.

Analysis

The analysis involved two major approaches. First, we used the Word2Vec model to find words semantically close to the keyword “vaccine” in the collected data using Python version 3.8.5. This model provides an efficient method for analyzing word associations and semantic meanings from a large amount of unstructured text.²⁵ To identify temporal changes in the patterns of words semantically similar to the keyword (i.e., vaccine), we adopted the skip-gram model for Word2Vec because it is useful to predict words that surround a keyword in diverse contexts.²⁵ Additionally, we employed negative sampling. Negative sampling has the advantage of understanding words in context, which creates annotations. Words that share a lot of contexts have similar annotations. That is, using negative sampling is effective in accurately representing the similarity between words.²⁶

Second, we used SA, which allows big data analysis of people's attitudes, opinions, and emotions toward events, individuals, or topics on social media.²⁷ Through SA, we measured people's perceptions and emotions regarding COVID-19 vaccine and vaccination from the big data provided by Quora. The transformer-based model is employed for SA as a state-of-the-art NLP methodology for classification and generation tasks.²⁸ The present study used BERT (Pre-training of Deep Bidirectional Transformers for Language Understanding). The model's performance can vary depending on the pre-trained data because embedding in vector spaces is sensitive to the trained data. Therefore, the pre-trained data should change along with the purpose

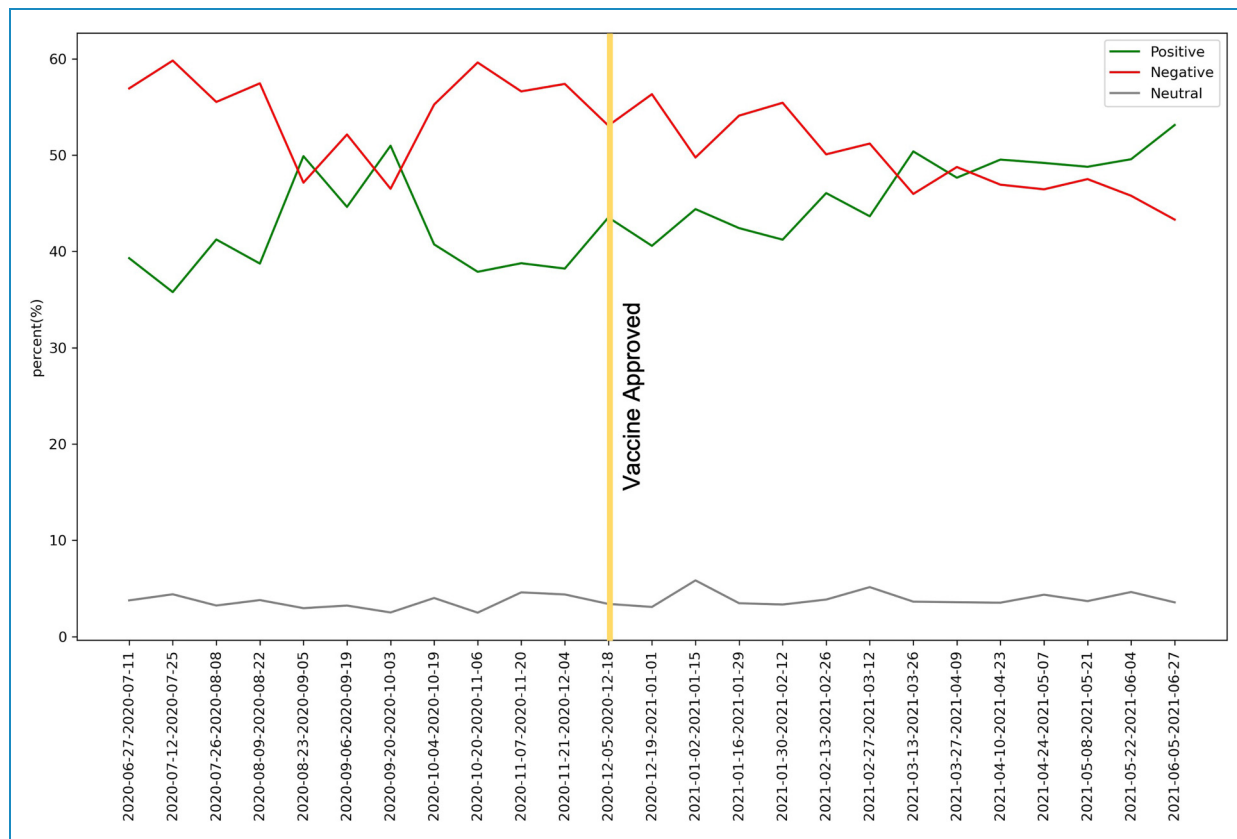


Figure 1. Prevalence of positive, negative, and neutral answers about coronavirus disease 2019 (COVID-19) vaccine (June 2020 to June 2021).

and area of research. Because our data are from Quora, a social Q&A platform, we needed to pre-train a model using social media-related data. Since “Bert-tweet” used Twitter data and outperformed several previous models,²⁹ we pre-trained our model with “Bert-tweet.”

Results

This section reports our findings as follows: (a) proportion of positive, negative, and neutral answers regarding COVID-19 vaccine questions posted on Quora before and after vaccine availability, (b) vaccine hesitancy and acceptance phases (i.e., peaks and troughs in positive sentiment toward COVID-19 vaccination) during the 1-year observation period and how these phases correspond with vaccine uptake, and (c) results from the sentiment analysis that identified words associated with the two phases of vaccine hesitancy and acceptance.

Figure 1 presents the positivity, negativity, and neutrality of the 66,820 answers to questions about the COVID-19 vaccine posted on Quora from June 2020 to June 2021. Before the availability of a COVID-19 vaccine (indicated by the vertical yellow line), the proportions of positive and negative answers fluctuated. However, after the

vaccine release, the overall rate of negative answers decreased, while the rate of positive answers increased. Rates of neutral answers remained stable throughout the period. Note that positive sentiment outweighed negative sentiment after 23 April 2021.

Figure 2 depicts trends in positive sentiment toward COVID-19 vaccination over the same 1-year period and how such trends related to COVID-19 vaccination rates both in the United States and globally. Positive percent represents the rate of positive sentiment expressed in Quora answers as a percentage. The US new vaccination rate indicates the number of new COVID-19 vaccinations administered every two weeks (per million Americans). The US vaccination rate depicts the cumulative total US vaccination rate as a percentage. The world new vaccination rate indicates the number of new COVID-19 vaccinations administered every 2 weeks (per million people worldwide). Plotting these rates overtime highlights several peaks and troughs in vaccine sentiment that directly correspond with the rate of new COVID-19 vaccination in the United States. As seen in Figure 2, there were four positive peak points, which indicate an increase in the public’s positive perception of the vaccine, and four troughs, which indicate a decrease in the public’s positive perception of the

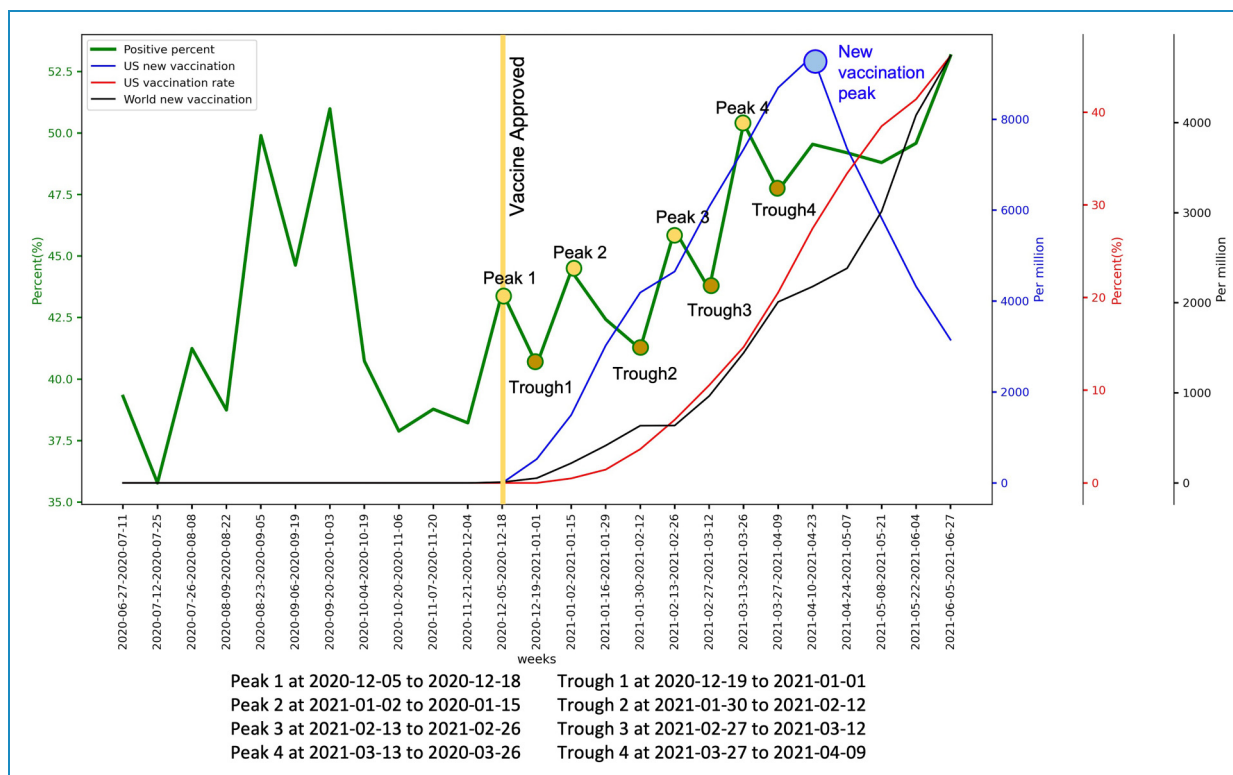


Figure 2. Trends of positive sentiment and coronavirus disease 2019 (COVID-19) vaccination rates (June 2020 to June 2021).

vaccine, before the new US COVID-19 vaccination rate reached its initial ceiling point.

Additionally, we were able to demarcate a vaccine hesitancy phase and a vaccine resistance phase in the United States. The vaccine hesitancy phase ran from 11 December 2020, to 23 April 2021, and can be identified by the decrease in positive sentiment from its highest peak. Once reaching the peak in new vaccinations, this trend is referred to as vaccine resistance rather than vaccine hesitancy, because those who have not been vaccinated by the ceiling point likely reflect those who have decided not to be vaccinated and are unlikely to be vaccinated without further enforcement or incentive. The vaccine resistance phase began once reaching the ceiling point of new US vaccinations on April 24, 2021 (i.e., the point at which the number of new vaccinations per million stopped increasing). Note that the ceiling point of new COVID-19 vaccinations occurred when 27.46% of the US population had been vaccinated. Interestingly, the hesitancy threshold, the point at which positive sentiment outweighed negative sentiment (23 April 2021), preceded the ceiling point of new vaccination (9397.9 per million). In other words, as positive sentiment about vaccination increased, the number of new vaccinations also increased until it reached the ceiling point.

Table 1 presents the results of the Word2Vec analysis. These are the top 15 semantically close words with “vaccine” only at the peaks or troughs of positive

answers. In other words, the present study has excluded words that appeared in both peaks and troughs. The rank of words is determined by cosine similarity, which represents semantic closeness to the word “vaccine”.

The top 15 most semantically close words with “vaccine” (e.g., safe, plan, able, choice, death, new) that occurred only when the positive answer rate peaked are presented in column one of Table 1. Representative “quotes” (that have been paraphrased due to copyright protection) that clarify how these 15 individual words were used in context are provided in Table 2.

These comments expressing positive sentiment dispel distrust of the vaccines and argue that vaccination is safe, without serious side effects, helpful, and the best choice to defeat COVID-19. They emphasize that, if the vaccination process is successful and herd immunity is achieved, COVID-related deaths can be greatly reduced, and people can return to normal daily life. In contrast, the top 15 most semantically close words with “vaccine” (e.g., early, variant, scientists, booster, cost, information, evidence) that occurred only during the troughs are presented in column two of Table 1. Representative “quotes” (paraphrased due to copyright protection) that clarify how these 15 individual words were used in the context provided in Table 3.

These comments expressing negative sentiment highlight the confusion and concerns caused by less reliable and early data on COVID-19 vaccination. Some comments

Table 1. Top 15 semantically close words with “vaccine” in peaks and troughs of positive answers.

	Peaks of positive answers	Troughs of positive answers
1	Safe	Early
2	Plan	Variant
3	State	Scientists
4	Choice	Booster
5	Best	Cost
6	Death	Mutations
7	New	Second
8	Able	Type
9	Canada	Information
10	Majority	Issue
11	Force	Research
12	Nations	Evidence
13	Clear	Trump
14	USA	News
15	Help	Effectiveness

revealed their information needs, acknowledgment of fake news, and recognition of the need to stop the spread of fake news. They also shed light on doubts about whether vaccination can defeat the variants, distrust of vaccine experts, concerns about the side effects of vaccination, and the negative consequences of former President Trump’s COVID-19 vaccine policy.

Discussion

The present study attempts to identify what influenced COVID-19 vaccine hesitancy and acceptance by analyzing public sentiment toward COVID-19 vaccination on social media.

By analyzing 66,820 answers to questions about the COVID-19 vaccine asked between June 2020 and June 2021 on Quora, we have found that positive sentiments increased, and negative sentiments decreased after the availability of COVID-19 vaccination. As public opinion toward vaccination grew more positive, the number of people (per million) who were newly vaccinated increased as well until the ceiling was reached. The fall in positive

sentiment from its high point marks the start of the vaccination hesitancy phase. Continued negative sentiments found in discourse about the COVID-19 vaccine even after the vaccine was widely available suggest that additional support or policy by governments is needed to promote continued uptake of COVID-19 vaccination.

Compared with previous studies of social media data that dealt with short texts in microblogs such as Twitter, we were able to observe more specific and detailed public perceptions regarding vaccination by analyzing long arguments and discourse data on Quora. Positive sentiment adjectives such as safe, best, able, plan, and clear indicate that people who accepted the vaccines’ safety desired to improve their daily lives through immunization. However, the words associated with negative sentiments (e.g., variant, mutations) imply that one of the main concerns contributing to vaccine hesitancy is the lack of efficacy against variants. Further, the ceiling point of new COVID-19 vaccinations, which was 27.46% of the US population, offers practical insights for increasing the vaccination rate. The ceiling point indicates that the number of people willing to be vaccinated voluntarily has been reached and suggests that governments should use new strategies, such as that financial reward programs,³⁰ conditional cash transfer³¹ or the conditional cash lottery program,^{32,33} to increase the vaccination rate, rather than just recommending that people get vaccinated as previous studies. Prior research has demonstrated that the COVID-19 vaccination incentive programs are especially beneficial for racial/ethnic minorities or those with lower levels of education, who are more likely to exhibit vaccine hesitancy.^{10,14,15,30,31}

We observed the public’s perceptions and attitudes about the COVID-19 vaccine and vaccination as they were shared in a social Q&A community and documented changes in those perceptions and attitudes. Analyzing the discourse around vaccine hesitancy could help to identify the public’s major concerns about vaccination. The division between positive and negative sentiments is largely based on vaccine safety and effectiveness. Positive sentiment increased when people were optimistic about the safety of the vaccines, COVID-related mortality was lowered, other nations approved the vaccines, and no apparent causal relationship could be drawn between vaccination and serious health problems. Conversely, negative sentiment reflected a belief that reliable data on the safety of vaccines were lacking, doubts about the effectiveness of vaccines, particularly with respect to new variants, an unwillingness to trust healthcare authorities or experts to provide credible guidelines for vaccines, and skepticism due to negative results (e.g., increased side effects during the second vaccination, vaccination rate that did not reach herd immunity).

Unlike previous studies,³⁴ our analysis excluded words that appeared in both peaks and troughs. We extracted semantically close words to the keyword, COVID-19

Table 2. Example “quotes” containing words observed at peaks of positive answers.

Keyword	Example quotes
Safe	<p>... It is a safe vaccine. Anti-vaxxers are doing everything they can to inflate claims that it is unsafe, but it has been used on over 200,000 people with no significant adverse effects. ...</p> <p>... so that I can travel again. It’s free (or nearly so), near-perfectly safe for those without allergies, adequately researched, highly effective (amazingly so), widely available (or soon will be), and developed in record time during a terrifying pandemic. ...</p>
Plan	<p>... Vaccinated people, on the other hand, can start making plans for 2021 and look forward to resuming aspects of the old normal as more people get vaccinated...</p> <p>... They can also be created and manufactured very quickly. It took Moderna six weeks to create one medicine, and the production can be ramped up to where they plan on producing over a billion doses next year ...</p>
State	<p>... By the time we have vaccinated about 20% of the population, we will have likely eliminated about 80% of the deaths and serious illnesses, which will make a significant difference. To return to normalcy, we would need to achieve herd immunity, which is a state in which the virus cannot spread and, as a result, sporadic outbreaks will fade on their own... It requires two doses, and not everyone follows the recommended protocols for virus containment, with or without the vaccine. We will be in a state of pandemic for AT LEAST another 6 months, although those who get vaccinated will be able to resume something closer to normal IF they continue to mask up, maintain ALL social distancing protocols, and wash their hands frequently...</p>
Choice	<p>... Given the choice dying from a vaccine with very treatable side effects (where were the doctors?) or COVID-19 with difficult symptoms—pneumonia, hyper coagulopathy, poor tissue perfusion, and subsequent acidosis—what would you prefer your elderly and frail relative do? ...</p> <p>... Also, vaccines are distributed according to the government’s wishes, and there is no choice, so why risk your life waiting for the one you mistakenly believe is the best? All vaccines on the western market have been approved by independent regulators. Over 2,000,0000 people have received the vaccine, with approximately 11 or 12 experiencing anaphylactic reactions and only one permanently disfigured. So I have faith in them all...</p>
Best	<p>... Having had the vaccine your body knows the best course of action to take. ...</p> <p>... The best vaccines provide 95% protection, while others provide 90% or lower percentages of protection. Using 95% protection as an example, 5% of those who receive the vaccine may become infected with the virus. 95% protection is significantly better than the flu vaccine currently available, so yes, the COVID-19 vaccine provides significantly better protection than not having the vaccine...</p>
Death	<p>... The vaccine protects against disease, and thus death from COVID-19. It almost certainly reduces transmission because it slows disease progression....</p> <p>... In the United States, the risk of death from COVID-19 is $0.17/0.0015 = 113$, compared to the risk of death from the vaccine. COVID-19 is more than a hundred times more likely to kill you than the vaccine...</p>
New	<p>...If this is the case, the mRNA vaccines can be quickly updated to include the new strain.</p> <p>Understanding COVID-19 vaccine nanotechnology Lipid nanoparticles are an essential component of the new Pfizer/ BioNTech and Moderna mRNA COVID-19 vaccines, effectively protecting and transporting the mRNA to the correct location in cells...</p>
Able	<p>... Personally, I would advise everyone to get the vaccine as soon as they’re able to, although it’s ultimately your decision...</p> <p>... The vaccine will ease restrictions. Moving forward, we will continue to be able to reduce COVID-19 to a completely manageable illness...</p>
Canada	<p>...The United States has some chaos and disparities in numbers that should have been resolved sooner. That issue does not exist in Canada, where provinces are primarily responsible for health...</p> <p>There are numerous vaccines. The Pfizer and Moderna vaccines approved in the United States and Canada contain no viruses, making COVID-19 transmission impossible...</p>
Majority	<p>...My reasons, which reflect my personal views, range from trial data showing that the vaccine is safe for the vast majority of</p>

(continued)

Table 2. Continued.

Keyword	Example quotes
	trial volunteers... ... I believe that the vast majority of health-care workers will receive the COVID-19 vaccine...
Force	...As long as they have proof of vaccination, and they follow the national or local regulations which might be in force in the places they visit, such as social distancing and the wearing of masks where required, I have no objections... ... A separate additive (an adjuvant) is used in a modern vaccine to force an immune response...
Nations	...Many countries that do not have their own vaccines can use vaccines developed in India, China, Russia, the United Kingdom, the United States, and other countries. They benefit from having a vaccine that has been approved for use in other nations . And with many of those new vaccines, we now have more experience... ... Many developed nations have agreed to supply vaccines to less developed nations ...
Clear	...The reason for this is that people are affected by widespread skepticism and misinformation, so they mistakenly believe all of this. It is obvious that there is no clear cut causality to the vaccine that has so far been proven... ... There are standard reactions to the vaccine that are similar to any vaccine and clear up within a few days. However, they are regarded as mild...
USA	...It wasn't overproduction. It was suitable production for USA citizens. They (unused vaccines) should be sent to third-world countries to do their best to prevent strains, variants, and mutations from evolving and biting us all in the butt... ... The key difference is that vaccines approved by the FDA in the USA have been tested according to strict protocols, including the use of placebos, and allowed a committee of experts, peers of the scientists who developed the vaccines, to review the test results to ensure the vaccines are safe and effective...
Help	... Vaccination helps you to fight Coronavirus more effectively than someone who has not been vaccinated... ... Vaccines are one of the great modern triumphs of public health. They have helped to increase human life expectancy by several decades and are one of the most effective tools for disease prevention...

COVID-19: coronavirus disease 2019; FDA: Food and Drug Administration.

vaccine or vaccination that appeared only in peaks and those that occurred only in troughs. The words only in peaks helped explain the factors that are associated with positive perceptions and attitudes toward vaccines, and the words that appeared only in troughs suggested the factors are associated with vaccine hesitancy. The factors that influence positive perceptions or attitudes have practical implications for vaccination promotion. Likewise, addressing the specific concerns driving negative perceptions could be an effective way to deal with vaccine hesitancy. For example, the use of words such as “variant” and “mutation” implies that the public is skeptical about booster shots not only because people fear variants, but also because they doubt the efficacy of the vaccines against variants. Furthermore, vaccine hesitancy occurred because uncertainty about vaccine safety was high due to a perceived lack of scientific evidence or data. Above all, as indicated in previous studies^{35,36} and this study, public trust in healthcare authorities and experts, such as the World Health Organization (WHO) and scientists, has been seriously undermined by the COVID-19 pandemic. The WHO's erroneous instructions on wearing masks and issues over its political neutrality during the fight over the epicenter of the pandemic have brought about international disappointment and damaged its authority,³⁷ which left

people in a state of panic about who to trust. Considering that vaccine-related conspiracy theories and fake news prevailed in the absence of reliable information sources, future policy efforts should be aimed at reducing the spread of misinformation about COVID-19 vaccination and limiting anti-vaccine public advertising.³⁸ It will also be important to restore public trust in authorities, health care professionals, and the healthcare system.^{39–42} To further build and maintain positive public perception of COVID-19 vaccines, it is important for governments and healthcare authorities to provide continuously updated, evidence-based information through popular social and traditional media sources. Such an approach should also help reduce people's reliance on unverified information, which can cause confusion and anxiety about vaccines and vaccination. Given that vaccine safety is of utmost concern to the public, providing up-to-date safety information will facilitate effective health communication. Additionally, rather than reporting the daily number of confirmed cases and deaths caused by the coronavirus, the media should focus on timely updates on the number of confirmed cases, severe cases, and deaths according to vaccination status. It may also be useful to provide information about how to alleviate the side effects of the COVID-19

Table 3. Example “quotes” containing words observed at troughs of positive answers.

Keyword	Example quotes
Early	<p>... However, nobody knows the best honest answer to your question yet. It is far too early to provide a scientific answer to your question. Because the clinical trials were relatively short, the data are not yet conclusive...</p> <p>... The issue right now is that those people may not have received their second shot yet, or they may have become infected before being vaccinated. It's too early to get any reliable data; in a year, we won't even have enough data to know if they worked ...</p>
Variant	<p>... This is why, despite vaccinating 97 million people, vaccination is plagued by shortages, a lack of evidence against new variants for which bridge trials are underway, and a scarcity of vaccine makers willing to join Covax, a global vaccine alliance...</p> <p>... With new variants on the way, huge logistical and manufacturing capacity issues, a rampant, clearly out of control virus, and an obviously incompetent government that has, by far, completely messed up in every single aspect of dealing with this pandemic...</p>
Scientists	<p>...People should think for themselves and weigh the evidence. I used to believe the scientists, but they've waffled too much for me to trust them anymore. Would I do it again knowing what I know now? You bet your bottom dollar I would...</p> <p>... Do you know what it is? It's the result of hard work by a group of scientists no one will ever meet who created something that will prevent more people from receiving the Darwin award...</p>
Booster	<p>... Their logic is that this is equivalent to receiving an initial dose of the vaccine, so when vaccine supplies are limited, using the vaccine as if it were a second booster shot helps to stretch the vaccine supply...</p> <p>... There is also the question of whether new variants emerge that reduce the effectiveness of the vaccination program and may necessitate booster shots of some kind. Another issue is whether or not people continue to use proper restraint measures after being vaccinated ...</p>
Cost	<p>... While this benefits poorer countries because the rich cannot buy up the stocks, it has likely slowed the overall global vaccination effort and will cost lives ...</p> <p>... Did they purchase enough vaccine? No, Trump refused to order sooner, and the delay cost us MONTHS and lives. Trump was a failure because HE DID NOT CARE...</p>
Mutation	<p>...Each new infection provides another opportunity for viral mutation, and if the virus mutates to the point where vaccines no longer recognize it, it could become a cat and mouse game between variants versus vaccine boosters/modifications...</p> <p>... The question is whether we can cover all potentially dangerous mutations of this virus with a small number of vaccines, or whether it will be a never-ending battle between virus and vaccines for the rest of our lives...</p>
Second	<p>... Because some facilities are saving some for second doses, which have already begun, and there have been distribution issues due to a lack of coordination between the states and federal controls, some doses aren't arriving on time...</p> <p>... My arm was sore after the first and second Pfizer vaccines, just like it is after a Tetanus shot...</p>
Type	<p>... This strand of mRNA takes control and reprograms the cell to construct and produce more Y protein spikes. This type of technology is being seriously considered for changing a person's DNA in a selfless manner, saving people's health, repairing damage within the body, and so on...</p> <p>... There are some vulnerable people who are unable to receive the shot. They could be allergic to some part of the vaccine or how it was prepared, or they may have the type of immune deficiency where the shot would not confer immunity since it requires an immune response to do so...</p>
Information	<p>...vaccines have a success rate of about 95%, but the Chinese did not release the data. Instead, they shipped their vaccines to Brazil, where they conducted a study and found it to be 52% effective, so you draw your own conclusions! I don't have enough information to make that determination...</p> <p>... The entire issue of COVID-19 and the vaccine has become so politicized that it takes time and sifting through various sources of information for the average person to arrive at a reasonable understanding...</p>
Issue	<p>...Because some vaccines have had issues for various reasons, having a pool of potential candidates means that if one</p>

(continued)

Table 3. Continued.

Keyword	Example quotes
	vaccine needs to be withdrawn, others can be substituted... ... There is one issue with Astra Zeneca: it was designed and manufactured for COVID-19. Meanwhile, a new [virus] has emerged. Because there have been so many cases, every infected body, even asymptomatic, has been and continues to be a laboratory for virus mutations...
Research	...According to research data Trusted Source submitted to the FDA, 7% of people aged 18 to 55 who received the first dose of the Pfizer vaccine reported fever, compared to 31% who reported fever after the second dose... ... There have been no deaths directly linked to any of the approved COVID-19 vaccines. Do us all a favor and stop spreading misinformation. Instead, conduct your own research . You could have answered the question yourself in the time it took you to write it...
Evidence	...The virus affects far fewer than one percent of children. They are investigating the problem of passing on the virus if you have been vaccinated, which appears to be based on little evidence While the vaccine may not be any more dangerous, there is substantial evidence that it is dangerous in and of itself. Consider this statistic: in the last 4 months, the COVID-19 vaccine has killed more people than any other vaccine in the last 15 years in the United States alone...
Trump	...Last year, the US government was less enthusiastic about vaccines than it is now. Trump's secret vaccination is one example. He could have served as an example to others... ... COVID-19 and perceived mismanagement are arguably the reasons Trump is no longer President of the United States. During the crisis, many government departments were also changed...
News	...It is the only way to reestablish trust in the vaccine and her leadership and begin to improve Germany's dismal record. 85% of the 1.5 million doses available in Germany are unopened. Why? Nobody wants the doses, so they go unused. Why? Because of fake news and scaremongering by immature politicians who care only about saving their own skin... ... It could be just this, and the prospect of other restrictions being imposed would be the ideal tool to motivate people to get the vaccine; after all, with all of the fake news , half-truths, and pseudo-science that anti-vaxxers preach...
Effectiveness	... Although several vaccines for the new coronavirus are in late-stage trials, they will not be able to answer all questions about a vaccine's effectiveness , particularly whether it can prevent serious illness or death from COVID-19... ... However, there are some concerns about the variants (it appears that the vaccine effectiveness drops to as low as 60% with some virus strains). Furthermore, it appears that even if you've had the vaccine, you can still spread COVID-19 ...

COVID-19: coronavirus disease 2019; FDA: Food and Drug Administration.

vaccinations. That type of communication could help the public make better decisions about vaccination.

The current study has several limitations that provide useful opportunities for future research. First, despite the fact that slightly more than one-third of Americans use Quora,⁴³ we were unable to determine whether the Q&A included in this study came from users in the United States. Second, we were unable to identify Quora user characteristics such as age or chronic illness status. Research has shown that people with chronic ailments are more vulnerable to COVID-19 than others, which could affect their receptivity to vaccination.⁴⁴ Also, younger people tend to have higher COVID-19 vaccine hesitancy than older people,^{45,46} thus future research should investigate whether perceptions of the vaccines differ by age. Third, as previously mentioned, Quora is one of the most frequently used social Q&A websites, but such websites generally have a young user base.⁴⁷ The perceptions of Quora

users might, thus, overrepresent the attitudes of younger people toward COVID-19 vaccines. Finally, we used "vaccine" as a keyword to retrieve the relevant questions. Although we attempted to collect as many questions about the COVID-19 vaccine as possible, our sample is not necessarily complete.

Conclusion

The current findings have important implications for future communication interventions aimed at promoting COVID-19 vaccine uptake. Before the ceiling point, the new vaccination rate per million continued to increase despite ups and downs in positive sentiments; after the ceiling point, new vaccination decreased drastically despite the increase in positive sentiment, indicating the presence of a vaccine-resistant population. Vaccine resistance must be mitigated to increase the COVID-19

vaccination rate and achieve herd immunity. Thus, one direction for future study is to identify the characteristics and major concerns of those who have not been vaccinated and provide tailored information to counter vaccine hesitancy and resistance.

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References

- World Health Organization (WHO). WHO coronavirus (COVID-19) Dashboard. <https://covid19.who.int/> [accessed 2022-6-28].
- Colbourn T. COVID-19: Extending or relaxing distancing control measures. *Lancet Public Health* 2020; 5: e236–e237.
- Reddavid C, Costa G, Valvo R, et al. Transcatheter aortic valve implantation during COVID-19 pandemic: An optimized model to relieve healthcare system overload. *Int J Cardiol* 2022; 352: 190–194.
- Galloway DP, Mathis MS, Wilkinson LT, et al. Effect of the COVID-19 pandemic on pediatric intestinal failure healthcare delivery. *J Parenter Enter Nutr* 2021; 45: 50–56.
- Shreffler J, Petrey J and Huecker M. The impact of COVID-19 on healthcare worker wellness: a scoping review. *West J Emerg Med* 2020; 21: 1059.
- Ettman CK, Abdalla SM, Cohen GH, et al. Prevalence of depression symptoms in US adults before and during the COVID-19 pandemic. *JAMA Netw Open* 2020; 3: e2019686.
- Li Q and Lu H. Latest updates on COVID-19 vaccines. *Biosci Trends* 2020; 14: 463–466.
- Christie A, Brooks JT, Hicks LA, et al. and COVID C, Team R. Guidance for implementing COVID-19 prevention strategies in the context of varying community transmission levels and vaccination coverage. *MMWR* 2021; 70: 1044.
- Our World in Data. Coronavirus(COVID-19) Vaccinations. 2021. https://ourworldindata.org/covid-vaccinations?country=OWID_WRL.
- Khubchandani J and Macias Y. COVID-19 vaccination hesitancy in Hispanics and African-Americans: a review and recommendations for practice. *Brain Behav Immun* 2021; 15: 100277.
- Steinert JI, Sternberg H, Prince H, et al. COVID-19 vaccine hesitancy in eight European countries: Prevalence, determinants, and heterogeneity. *Sci Adv* 2022; 8: eabm9825.
- Harapan H, Anwar S, Yufika A, et al. Vaccine hesitancy among communities in ten countries in Asia, Africa, and South America during the COVID-19 pandemic. *Pathog Glo. Health* 2022; 24: 1–8.
- Fisher KA, Bloomstone SJ, Walder J, et al. Attitudes toward a potential SARS-CoV-2 vaccine: a survey of US adults. *Ann Intern Med* 2020; 173: 964–973.
- Momplaisir FM, Kuter BJ, Ghadimi F, et al. Racial/ethnic differences in COVID-19 vaccine hesitancy among health care workers in 2 large academic hospitals. *JAMA Netw Open* 2021; 4: e2121931.
- Willis DE, Andersen JA, Bryant-Moore K, et al. COVID-19 vaccine hesitancy: race/ethnicity, trust, and fear. *Clin Transl Sci* 2021; 14: 2200–2207.
- Bogart LM, Ojikutu BO, Tyagi K, et al. COVID-19 related medical mistrust, health impacts, and potential vaccine hesitancy among Black Americans living with HIV. *J Acquir Immune Defic Syndr* 2021; 86: 200.
- Malik AA, McFadden SM, Elharake J, et al. Determinants of COVID-19 vaccine acceptance in the US. *EClinicalMedicine* 2020; 26: 100495.
- Turhan Z, Dilcen HY and Dolu İ. The mediating role of health literacy on the relationship between health care system distrust and vaccine hesitancy during COVID-19 pandemic. *Curr Psychol* 2021; 22: 1–0.
- Hwang SJ, Gil JA and Choi S. Vaccination acceptance for COVID-19: implications of trust in government. *Korea J Population Stud* 2021; 44: 95–120.
- Jennings W, Stoker G, Bunting H, et al. Lack of trust, conspiracy beliefs, and social media use predict COVID-19 vaccine hesitancy. *Vaccines (Basel)* 2021; 9: 593.
- Liu S, Li J and Liu J. Leveraging transfer learning to analyze opinions, attitudes, and behavioral intentions toward COVID-19 vaccines: social media content and temporal analysis. *J Med Internet Res* 2021; 23: e30251.
- George J, Gautam D, Kesarwani V, et al. What Does the Public Want to Know About The COVID-19 Pandemic? A Systematic Analysis of Questions Asked in The Internet. medRxiv. 1 January 2020.
- Surowiecki J. The wisdom of crowds. *Anchor*; 2005 Aug 16.
- Kumar A and Saxena S. Data driven testing framework using selenium WebDriver. *Int J Comput Appl* 2015; 118: 18–23.
- Mikolov T, Sutskever I, Chen K, et al. Distributed representations of words and phrases and their compositionality. *Adv Neural Inf Process Syst* 2013; 26: 1–9.
- Goldberg Y and Levy O. word2vec Explained: deriving Mikolov, et al.'s negative-sampling word-embedding method. arXiv preprint arXiv:1402.3722. 2014 Feb 15.
- Medhat W, Hassan A and Korashy H. Sentiment analysis algorithms and applications: a survey. *Ain Shamas Eng J* 2014; 5: 1093–1113.
- Pérez JM, Giudici JC and Luque F. Pysentimiento: A python toolkit for sentiment analysis and socialnlp tasks. arXiv preprint arXiv:2106.09462. 2021 Jun 17.

29. Nguyen DQ, Vu T and Nguyen AT. BERTweet: A pre-trained language model for English Tweets. arXiv preprint arXiv:2005.10200. 2020 May 20.
 30. Klüver H, Hartmann F, Humphreys M, et al. Incentives can spur COVID-19 vaccination uptake. *Proc Natl Acad Sci USA* 2021; 118: e2109543118.
 31. Kusuma D, Thabrany H, Hidayat B, et al. New evidence on the impact of large-scale conditional cash transfers on child vaccination rates: the case of a clustered-randomized trial in Indonesia. *World Dev* 2017; 98: 497–505.
 32. Acharya B and Dhakal C. Implementation of state vaccine incentive lottery programs and uptake of COVID-19 vaccinations in the United States. *JAMA Netw Open* 2021; 4: e2138238-.
 33. Barber A and West J. Conditional cash lotteries increase COVID-19 vaccination rates. *J Health Econ* 2022; 81: 102578.
 34. Monselise M, Chang CH, Ferreira G, et al. Topics and sentiments of public concerns regarding COVID-19 vaccines: social media trend analysis. *J Med Internet Res* 2021; 23: e30765.
 35. Conger K. How misinformation, medical mistrust fuel vaccine hesitancy. *Stanford*. 2021. <https://med.stanford.edu/news/all-news/2021/09/infodemic-covid-19.html>.
 36. Verger P and Dubé E. Restoring confidence in vaccines in the COVID-19 era. *Expert Rev Vaccines* 2020; 19: 991–993.
 37. Buranyi S. The WHO v coronavirus: why it can't handle the pandemic. *The Guardian* 2020 Apr 10; 10: 2020. <https://www.theguardian.com/news/2020/apr/10/world-health-organization-who-v-coronavirus-why-it-cant-handle-pandemic>
 38. Dubé E and MacDonald NE. COVID-19 vaccine hesitancy. *Nat Rev Nephrol* 2022; 18: 409–410.
 39. Rutten LJ, Zhu X, Leppin AL, et al. Evidence-based strategies for clinical organizations to address COVID-19 vaccine hesitancy. *Mayo Clin Proc* 2021; 96: 699–707.
 40. Joshi A, Kaur M, Kaur R, et al. Predictors of COVID-19 vaccine acceptance, intention, and hesitancy: a scoping review. *Front Public Health* 2021; 9: 1–20.
 41. Razai MS, Osama T, McKechnie DG, et al. COVID-19 vaccine hesitancy among ethnic minority groups. *Br Med J* 2021; 372: n153.
 42. Strully KW, Harrison TM, Pardo TA, et al. Strategies to address COVID-19 vaccine hesitancy and mitigate health disparities in minority populations. *Front Public Health* 2021; 9: 645268.
 43. Foundation. 21 Quora Statistics Marketers Need to Know for 2022. <https://foundationinc.co/lab/quora-statistics/>.
 44. Daly M and Robinson E. Willingness to vaccinate against COVID-19 in the US: representative longitudinal evidence from April to October 2020. *Am J Prev Med* 2021; 60: 766–773.
 45. Robertson E, Reeve KS, Niedzwiedz CL, et al. Predictors of COVID-19 vaccine hesitancy in the UK household longitudinal study. *Brain Behav Immun* 2021; 94: 41–50.
 46. Shih SF, Wagner AL, Masters NB, et al. Vaccine hesitancy and rejection of a vaccine for the novel coronavirus in the United States. *Front Immunol* 2021; 12: 558270.
 47. Jiang H, Qiang M, Zhang D, et al. Climate change communication in an online Q&A community: a case study of Quora. *Sustainability* 2018; 10: 1509.
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