Online Search Behavior Related to the COVID-19 Vaccine: An Infodemiology Study

Lawrence An, Daniel M Russell, Rada Mihalcea, Elizabeth Bacon, Scott Huffman, Ken Resnicow

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Lawrence An[1, 2] MD; Daniel M Russell[3] PhD; Rada Mihalcea[4] PhD; Elizabeth Bacon[1] MPH; Scott Huffman[3] PhD; Ken Resnicow[1, 5] PhD

[1]Center for Health Communications Research Rogel Cancer Center University of Michigan Ann Arbor US
[2]Division of General Medicine School of Medicine University of Michigan Ann Arbor US
[3]Google Mountain View US
[4]Computer Science and Engineering Division College of Engineering University of Michigan Ann Arbor US
[5]Department of Health Behavior & Health Education University of Michigan School of Public Health Ann Arbor US

Corresponding Author:
Lawrence An MD
Center for Health Communications Research
Rogel Cancer Center
University of Michigan
North Campus Research Complex, Building 16
2800 Plymouth Rd.
Ann Arbor
US

Abstract

Background: Vaccination against COVID-19 is an important public health strategy to address the ongoing pandemic. Examination of online search behavior related to the COVID-19 vaccine can provide insights into the public's awareness, concerns, and interest regarding COVID-19 vaccination.

Objective: The goal of this study is to describe online search behavior related to the COVID-19 during the beginning of public vaccination efforts in the US.

Methods: We examined Google Trends data from 1-1-2021 through 3-16-2021 to determine the relative search volume (RSV) for vaccine related searches. We also examined search query log data for COVID-19 vaccine-related searches and identified five categories of searches: 1) General or other information, 2) Vaccine availability, 3) Vaccine maker, 4) Vaccine side-effects and safety, and 5) Vaccine myths and conspiracy beliefs. We report on the proportion and trends for these different categories of vaccine-related searches.

Results: In the first quarter of 2021, the proportion of all online queries that were related to the COVID-19 vaccine increased from approximately 10% to nearly 50% of all COVID-19 related queries (P<.001). The proportion of COVID-19 vaccine queries that addressed vaccine availability increased from 36% to 44% (P =.05) including a particularly notable increase in the proportion of COVID-19 vaccine queries that included the name of a specific pharmacy (5% to 27%, P=.007). Queries related to vaccine side-effects or safety represented fewer than 5% of all searches and queries related to specific vaccine myths and conspiracy belief represented less than 1% of all COVID-19 vaccine-related searches throughout the study period.

Conclusions: This study demonstrates an increase in online search behavior related to the COVID-19 vaccine in early 2021 along with an increase in the proportion of these searches that were related to vaccine availability. These findings are consistent with an increase in public interest and intention to vaccinate during the initial phase of public COVID-19 vaccination efforts.

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Results:
In the first quarter of 2021, the proportion of all online queries that were related to the COVID-19 vaccine increased from approximately 10% to nearly 50% of all COVID-19 related queries (P<.001). A majority of COVID-19 vaccine queries addressed vaccine availability and there was a particularly notable increase in the proportion of queries that included the name of a specific pharmacy (6% to 27%, P=.01). Queries related to vaccine safety and side-effects (less than 5% of queries) or specific vaccine-related myths (less than 1% of queries) were uncommon and the relative frequency of both types of searches decreased during the study period.

Conclusions:
This study demonstrates an increase in online search behavior related to the COVID-19 vaccine in early 2021 along with an increase in the proportion of these searches that were related to vaccine availability at pharmacies. These findings are consistent with an increase in public interest and intention to vaccinate during the initial phase of public COVID-19 vaccination efforts.

Introduction

We are currently in the midst of a global pandemic caused by COVID-19. At all times, and particularly during a pandemic, it is critical for the public to have access to timely and accurate health information.[1-3] The internet is a major source of such health information.[4-7] Examination of online health-related search behavior can provide critical insight into the public's awareness and interest in specific health issues and their health concerns and information needs, health experiences, and health-related intentions and behaviors.[8-11]

Infodemiology is the scientific study of the "distribution and determinants of information in an electronic medium, specifically the internet, or in a population, with the ultimate aim to inform public health and health policy."[8] To date, there have been a number of infodemiologic studies of the COVID-19 pandemic. Many of these studies identified an association between general COVID-19-related or symptom-specific search trends and COVID-19 case incidence and death.[12-18] In several cases, search behavior appeared to be an effective predictor of disease trends. Several studies have examined the occurrence and spread of COVID-19-related misinformation which has been a public health challenge during the pandemic.[19-25] Another group of studies have examined search behavior to gain insights into public awareness, interest, attitudes, and behaviors related to COVID-19.[21, 26-28] Husain specifically found that countries that demonstrated a more rapid rise in public search interest regarding COVID-19 also tended to be more effective in their control of the pandemic.[27]

Vaccination against COVID-19 is a major public health strategy in the effort to end the pandemic. [29] As of the Spring of 2021, a number of effective COVID-19 vaccines are available that substantially reduce the risk of COVID-19 related illness, hospitalizations, and death.[30] Understanding public awareness and interest in the COVID-19 vaccines and willingness to vaccinate are critical to help guide vaccination efforts. Unfortunately, vaccine hesitancy is common and poses a major barrier to successful vaccination efforts.[31] Infodemiologic approaches can provide potentially important insights into the public's awareness, interests, concerns, and intentions related to the COVID-19 vaccine. Thus far, few infodemiological studies focused on the COVID-19 vaccine have been reported.[32, 33] To address this critical gap, we examine the relative search volume using Google Trends and also search query logs capturing online search behavior related to COVID-19 vaccines in the first quarter of 2021.

Methods

The study reports on online search behavior using the Google search engine related to COVID-19 vaccines occurring in the first quarter of 2021. Google is the dominant search engine in the US accounting for approximately 89 percent of total search volume in the US as of January, 2021.[34] We focus on the time period from January 1, 2021 through March 16, 2021 that follows the US FDA's initial emergency use authorization for the Pfizer and Moderna COVID-19 vaccines and the start of public vaccination efforts.

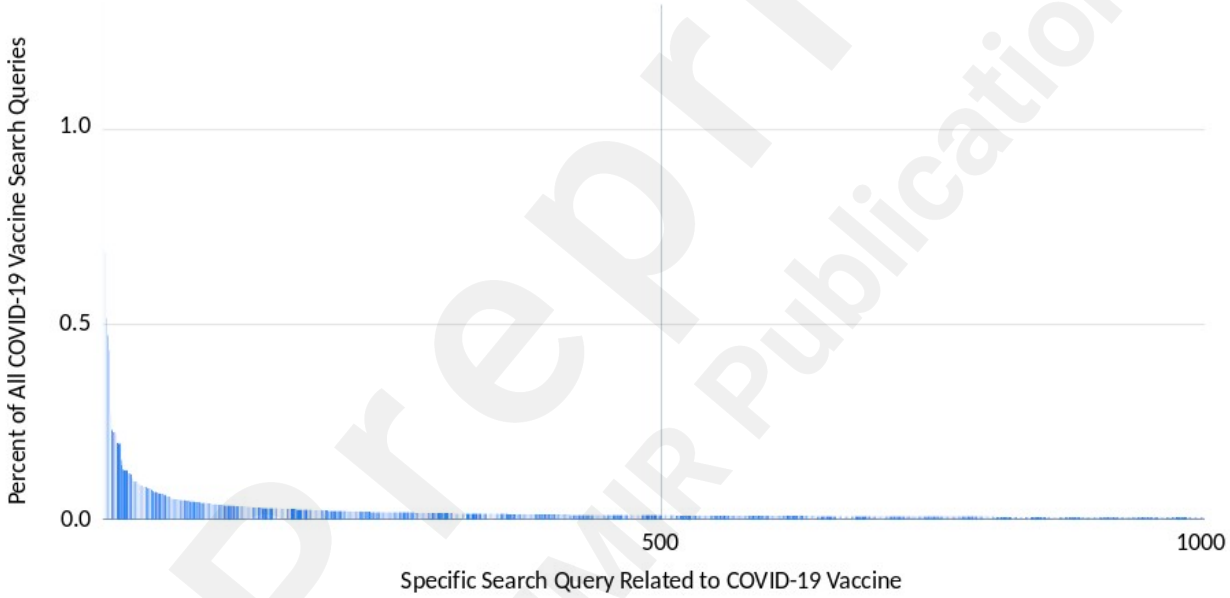
Data Sources

Google Trends. Google Trends provides open access to time series data related to Google search engine search volumes for specific terms.[35] Search query volume is normalized to a percentage scale (0 to 100) to provide a measure of relative search volume (RSV) with 100 corresponding to the peak in search volume in any given time frame for that specific topic. By searching simultaneously for multiple terms, one is able to compare the RSV for different terms. For this report, we focus on Google Trends data for COVID-19 vaccine-related searches in the US.

Search Query Logs. Search engine query logs record the specific language that users employ when

conducting online searches and can provide insight into users' information needs and interests and how these change over time.[36-38] To examine COVID-19 vaccine-related search behavior in greater detail, we compiled anonymized data from Google search query logs. That is, we examined a complete sample of English language queries conducted in the US between January 1, 2021 and March 16, 2021. We collected only queries that contain both the terms “COVID” and “vaccine.” This data set comprises over 45.4 million queries during the sample period. This data set shows that when people search for information about COVID-19 vaccines, they use a fairly limited number of common queries. For example, the top 150 most common queries related to the COVID-19 account for approximately half of all queries in the data set. The distribution of search queries by volume is shown in Figure 1. This figure shows that a small number of queries accounts for a large proportion of the overall query volume. This query volume distribution curve essentially becomes asymptotic after the top 1,000 most common queries. To create this search query log dataset, we collected the top 5,000 most common COVID-19 vaccine related search queries for each day during the study period.

Figure 1. Frequency Distribution of 1,000 Most Common Search Queries Related to “COVID-19 Vaccine”



Metrics

Metrics of interest for this study are based upon both Google Trends and the search query log data set. Specific Google Trend metrics are: 1) Comparison of the RSV for any COVID-19-related searches and for searches related to COVID-19 vaccine, 2) General RSV for the term “vaccine” going back to 2005, and 3) Comparison of RSV for specific vaccine myths and conspiracy beliefs identified in the search query logs.

Our main interest with the search query log data set is to examine the distribution and trends of different types of COVID-19 vaccine-related searches. We developed a COVID-19 vaccine search query classifier using the following steps.

Step 1. Identify search categories. Two study authors (DR, LA) performed independent manual review of a random sample of 1000 queries to identify common themes as well as unique terms associated with each category. The two authors met to review and resolve any discrepancies and reached complete agreement on both categories and associated terms. Based upon this review, we

identified the following categories of search queries: 1) Vaccine availability, 2) Vaccine maker or manufacturer, 3) Vaccine side-effects or safety, 4) Vaccine myth or conspiracy beliefs, and 5) General/Other vaccine-related searches. A definition of each of these categories of searches, associated search terms, and examples is shown in Table 1. Because pharmacies were a major channel for distribution of COVID-19 vaccines, we also created a sub-category of vaccine availability queries that asked about COVID-19 vaccines in relation to pharmacies (e.g. included the name of specific pharmacy chains).

Table 1. Types of COVID-19 Vaccine Related Search Queries

Category	Definition	Associated Terms	Examples of Specific Queries
Availability	Query that included a term or phrase identifying locations where or time when COVID-19 vaccines might be available	The names of US states, counties, or cities; names of organizations or specific locations that provide COVID-19 vaccines (e.g. pharmacies, hospitals or health systems, vaccination sites), when or where to get COVID-19 vaccines	"ny covid vaccine", "covid vaccine california", "florida covid vaccine", "covid vaccine near me", "where to get covid vaccine", "cvs covid vaccine", "covid vaccine rite-aid", "covid vaccine appointment", "when can I get covid vaccine"
Maker or Manufacturer	Query that included the name of a COVID-19 vaccine maker or manufacturer	Names of different COVID-19 vaccines, names of companies or organizations that developed or manufactured different vaccines	"pfizer vaccine", "moderna vaccine", johnson vaccine", "j&j vaccine"
Side-Effects or Safety	Query that included general or specific terms associated with side-effects or safety of COVID-19 vaccines	Side-effects, safety, specific vaccine-related worries and concerns	"covid vaccine side effects", "covid vaccine safety", "reaction to covid vaccine", "pregnant women covid vaccine", "covid vaccine blood clot", "problems with covid vaccine", "covid vaccine fever", "covid vaccine allergy"
Myths or Conspiracies	Query that included general or specific terms associated with COVID-19 vaccine myths or conspiracy beliefs	Specific myths or conspiracy beliefs	"covid vaccine infertility", "does covid vaccine change dna","covid vaccine microchip", "can I get covid from vaccine", "covid vaccine 5G"
General or Other	COVID-19 vaccine query that included no additional terms or terms not associated with any of the above categories	COVID-19 vaccine or vaccination or other topics other than identified above	"covid vaccine", "covid-19 vaccine", "coronavirus vaccine", "covid vaccine update", "covid vaccination rates"

Step 2. Identify terms associated with each search category. One study author (LA) then manually reviewed an additional random sample of 5,000 queries to identify any additional terms that might be associated with each search category. The results of this review were discussed with additional authors (DR, KR, RM) to create a final list of unique search query terms associated with each search category.

Step 3. Create and apply search query classifier. We created a rules-based classifier that assigned a query to one or more of the five categories based on the presence of a unique set of associated terms while accounting for common variations in spelling. Some search queries contained terms associated

with multiple categories and these queries were counted separately in each appropriate category. For example, a search for "Pfizer covid vaccine CVS" would be counted as a query related to vaccine availability (given presence of the name of a specific pharmacy) and also as a query related to vaccine maker (given presence of the name of a specific vaccine manufacturer).

Step 4. Evaluate performance of the search query classifier. This classifier was able to classify 90% of all queries in the entire COVID-19 vaccine search query log dataset. The remaining 10% of unclassified queries represented searches for additional vaccine-related information (e.g., "covid vaccination rates", or "how long does the covid vaccine last") and are labeled as “other” and included as part of the category of “general/other” searches. After application of the classifier, an additional random sample of 1,000 search queries with classifier result was reviewed separately by two authors (DR, LA) to assess the accuracy of the classifier. The two authors met to resolve any discrepancies in manual review and the results of this review were used to calculate the classifier's precision and recall for each of the search categories. The classifier performed well with precision of 99.8-100% and recall over 99.5% across all search query categories.

Analysis

Based upon the search query log data set, we employed linear regression to examine the time trends for the proportion of different types of COVID-19 vaccine-related searches over time. For each week during the study period, we calculated a proportion corresponding to each of our categories of interest. The proportions examined in these analyses correspond to the categories above. The proportion of COVID-19 vaccine-related searches in each of these categories serves as the dependent variable in separate linear regression models. In each of these models, time (i.e., week number since start of the study period) serves as the independent variable to examine the significance of trends over time.

Results

The relative search volumes for any COVID-19-related searches and for searches related to COVID-19 vaccines are shown in Figure 2. This figure shows a clear increase in the relative volume of COVID-19 vaccine-related searches over the study period.

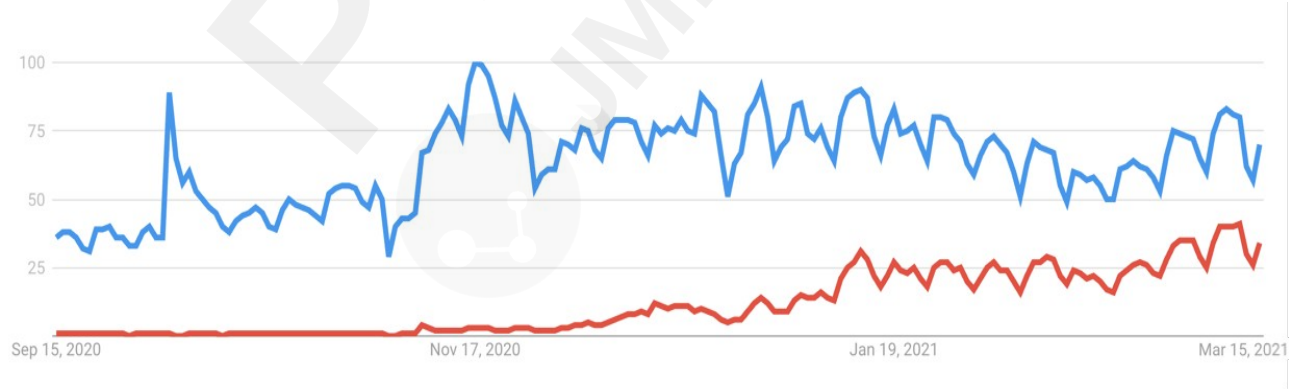


Figure 2: Relative Search Volume (RSV) for the terms “COVID” (Blue) and “COVID vaccine” (Red) from September 2020 through March 2021.

In the beginning of January 2021, approximately 10% of all COVID-19-related queries were about vaccines. By March 2021, nearly 50% of all COVID-19-related searches were vaccine-related. A linear regression was calculated to predict the fraction of queries about COVID-19 vaccines based on

daily change during the sample period. A significant linear regression model was found (df=103, R^2=0.76, beta coefficient for time=0.31, *P* 0<.001) indicating that the RSV for COVID-19 vaccine queries increased over the study period.

Figure 3 provides a broader historical context for the level of vaccine-related search interest. This figure shows the relative search volume for the term “vaccine” from January 2005 through the first quarter of 2021. The small peak in vaccine-related search volume occurring in October 2009 coincides with the H1N1 influenza epidemic.[39] The peak in vaccine-related searches in early 2021 is several-fold higher than this prior peak in 2009.

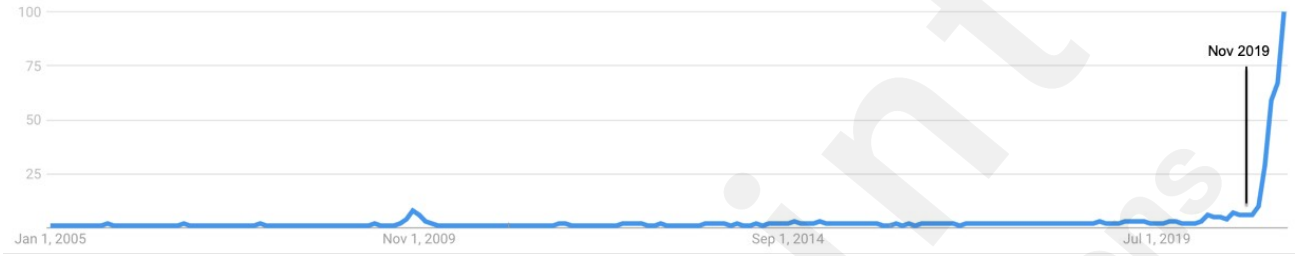


Figure 3: Relative Search Volume for the term “vaccine” from January 2005 through March 2021.

A breakdown of the proportion and trends for different types of COVID-19 vaccine-related queries based upon search query log data is shown in Figure 4a-4d. Trends for proportion of different categories of COVID-19 vaccine-related searches are described below.

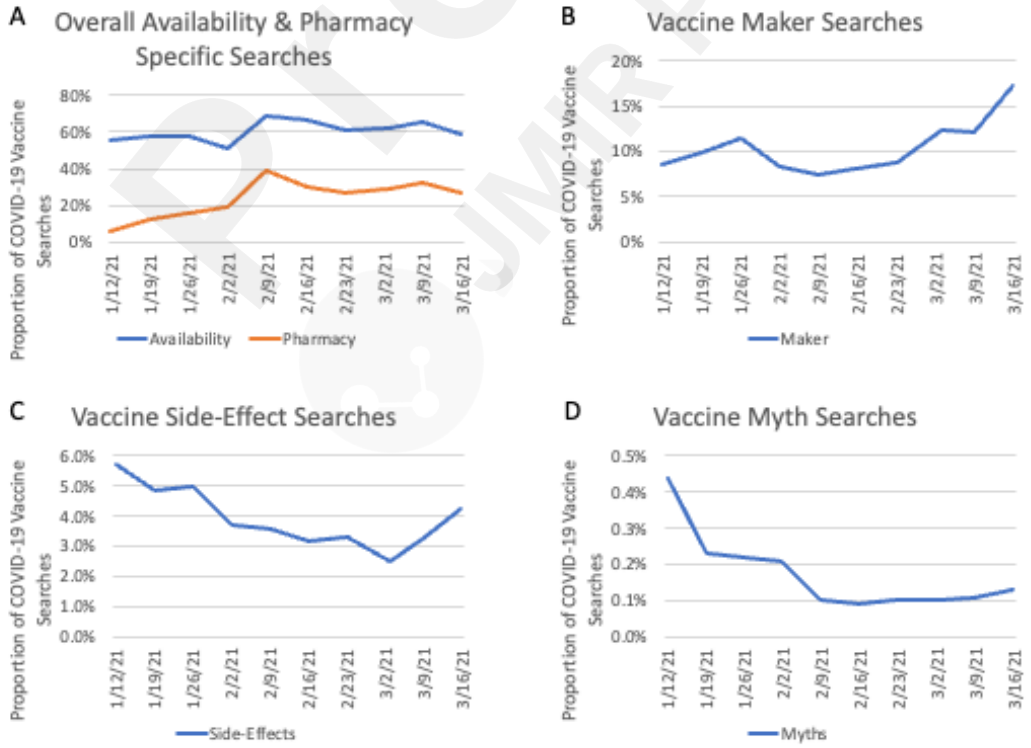


Figure 4: Trends for Different Categories of COVID-19 Vaccine Search Queries: Overall Availability and Pharmacy (a), Vaccine Maker (b), Side-Effects & Safety (c), Myths and

Conspiracy Beliefs (d)

Vaccine Availability: During the study period, a majority of searches were classified as related to vaccine availability with the specific proportion each week ranging from 55% to 69% (Figure 4a). The high proportion of vaccine availability searches was consistent over the study period. Linear regression showed that the time trend for the proportion of queries related to vaccine availability during the study period was not significant (df=8, R^2=0.19, beta coefficient for time = 0.81, *P*=0.20).

During the study period, there was a substantial increase in the sub-category of searches related to pharmacies. The proportion of COVID-19 vaccine-related queries that include a specific pharmacy name. increased from 5.9% at the start of the study period up to 27.2% at the end of the study period (Figure 4a). Linear regression again shows the time trend for this change is positive and significant (df=8, R^2=0.56, beta coefficient for time = 2.51, *P*=0.01).

Vaccine makers: Over the same period, the proportion of vaccine manufacturer-related searches (e.g. Pfizer, Moderna, Jansen/Johnson & Johnson) averaged 10.4%. Linear regression shows that the time trend for the proportion of vaccine manufacturer-related searches during the study period was not significant (df=8, R^2=0.38, beta coefficient for time =0.61, *P*=0.06).

Side-effects/Safety: The proportion of searches related to side-effects or safety of COVID-19 vaccines was quite small and the proportion actually decreased slightly (from 5.7% to 4.2%) over the study period. Linear regression showed a negative time trend for the proportion of queries related to vaccine side-effects or safety during the study period (df=8, R^2=0.51, beta coefficient for time =-0.23, *P*=0.02).

Myths: During the study period, the overall proportion of COVID-19 vaccine-related queries that included mention of myths or conspiracies related to the COVID-19 vaccine was quite low. This proportion actually decreased slightly (from 0.4% to 0.1%) over the study period. Linear regression showed a negative time trend for the proportion of queries related to vaccine myths or conspiracy beliefs during the study period (df=8, R^2=0.58, beta coefficient for time =-0.01, *P*=0.01). Searches related to specific myths or conspiracy beliefs included searches related to the COVID-19 vaccine and: 1) infertility, 2) potential to cause change in DNA, 3) 5G and the vaccine, 4) microchips, and 5) getting COVID-19 from the vaccine. The Google Trends RSV for searches related to these specific myth and conspiracy topics is shown in Figure 5. This figure reveals that searches related to COVID-19 vaccine and “infertility” and “DNA” were the most common vaccine myth-related searches.

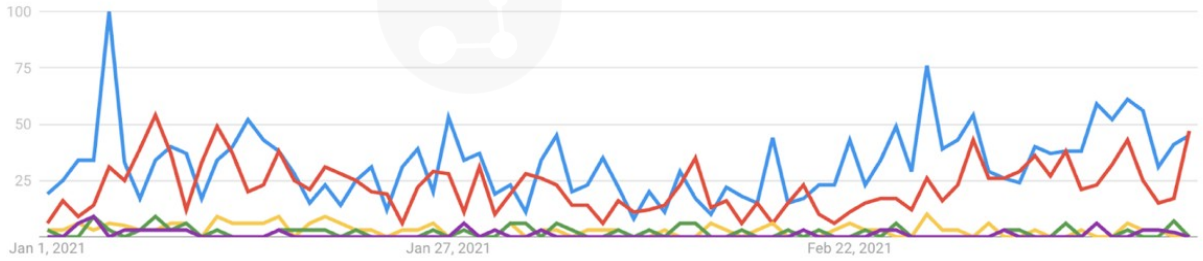


Figure 5: Google Trends Relative Search Volume for queries related to specific COVID-19 vaccine myths and conspiracy beliefs (red is vaccine + dna, blue is vaccine + fertility, green is vaccine + microchip, gold is vaccine + 5G, and purple is “COVID from vaccine”).

Discussion

This study reports on online search behavior related to the COVID-19 vaccine occurring in the US from during the first quarter of 2021. Over this time period, there was a clear increase in the volume of online searches for information about COVID-19 vaccines with a consistently high proportion of those searches related to the vaccine availability. Online search behavior is influenced strongly by external events and associated media coverage.[40, 41] Critical events that are likely drivers of the observed patterns in online search behavior include emergency use authorizations by the US FDA for three different vaccines (i.e., Pfizer on 12-11-20, Moderna on 12-18-20, Johnson & Johnson on 2-26-21) and the beginning of public vaccination efforts. During this time, online registration also happened to be one of the major means to obtain a vaccine appointment. A particularly notable rise in the proportion of COVID-19 vaccine searches that include the names of specific pharmacies is consistent with the US national strategy that featured pharmacies as vaccination sites.

We interpret these patterns of online search behavior related to COVID-19 vaccines, particularly the rise in pharmacy-related searches, as a sign of increased population readiness and intentions to vaccinate during the study period. This interpretation is consistent with findings of national tracking surveys in the US that demonstrate a similar increase in intentions to vaccinate over the period of the study. Specifically, the Kaiser Family Foundation COVID-19 tracking survey shows that the proportion of US adults that either had been vaccinated or would want to get vaccinated as soon as possible increased from under 40% to over 60% during the time period covered by this study.[42] The increase in online searches related to COVID-19 vaccines is also consistent with national survey findings that reported an increase in the proportion of US adults reported they had “enough information about when or where to get the vaccine” also over the same period of time.[42]

It is interesting to consider how to interpret our findings regarding online search behavior related to information about COVID-19 vaccine side-effects and safety. National surveys conducted during the time period of the study show that among the majority of adults who had not yet been vaccinated a substantial proportion were concerned about the long-term effects of the COVID-19 vaccine (68%), the potential for serious side-effects from the COVID-19 (59%), or that the vaccines may not be safe (55%).[43] Given the prevalence of these concerns about COVID-19 vaccine side-effects and safety, the relatively low proportion and decreasing time trend for vaccine-related searches that addressed these topics is somewhat surprising. The low proportion of side-effect or safety related COVID-19 vaccine searches could be due to a relatively low rate of active information seeking (about vaccine side-effects or safety) among those who are hesitant to get the vaccine or active online searching for vaccine appointments among those individuals highly motivated to obtain the vaccine or some combination of these factors. In such a situation (where some segments of the population are highly motivated to search actively for information while others are not), the relative frequency of searches related to different topics does not appear to provide a good representation of the level of public concern or interest in these same topics.

Our findings regarding the frequency of online searches related to COVID-19 vaccine myths or conspiracy theories can be interpreted in a similar fashion. Belief, or at least uncertainty, regarding COVID-19 vaccine myths is unfortunately common. During the same time period as this study, national surveys show that 34% of adults in the US who had not been vaccinated either believed or were unsure about one or more common COVID-19 vaccine-related myths.[43] Yet at the same time we found less than 1% of online searches related to COVID-19 vaccines addressed these topics and that this proportion actually decreased over the study period. These findings suggest that many individuals who either believe or are unsure about COVID-19 vaccine myths are not actively seeking additional information online to help clarify their understanding. While making inferences regarding the population prevalence of a particular COVID-19 vaccine myth may be difficult based upon

analysis of search behavior, it is possible that relative search volume might be useful in helping to assess which particular myths are more or less common. For example, the results for our RSV comparison for specific vaccine myths, direct evaluation of online COVID-19 vaccine misinformation, and national population surveys all identify concerns about infertility related to the COVID-19 vaccine as among the most common.[33, 43]

There are several limitations to consider interpreting the results of this study. First, it is important to acknowledge these findings are based upon analysis of search behavior in the US and are likely to be influenced by specific vaccine approvals and distribution plans in this country. Future work is needed to determine how COVID-19-related vaccine search behavior might differ in different countries. Second, these results apply only to search queries conducted using the Google search engine. While Google is the dominant search engine in the US, future work is needed to understand how search behavior described here is similar or different for other search engines or on other platforms. For example, social media has been identified as a major source of exposure to COVID-19 related misinformation. Our finding of relatively low rates of active searching for COVID-19 vaccine myths and conspiracy beliefs might or might not apply to search behavior within social media platforms. Third, it is important to acknowledge the subjective nature of our approach to identifying and defining search themes and categories. Other teams could have certainly chosen to identify or define search categories (or sub-categories) in other ways. Fourth and relatedly, we also acknowledge that there is uncertainty regarding our interpretation of the observed patterns in search behavior as representing an increase in interest or intention to obtain the COVID-19 vaccine. While we believe the major finding of a large increase specifically in pharmacy-related COVID-19 vaccine queries strongly suggests active searching for the vaccine, future work that directly assesses users' information needs (e.g. near-time or real-time surveys) would be needed to confirm this interpretation. Finally, it is important to note that the results presented here are based upon aggregate search volume measured at the population level. We therefore are not able to determine the degree to which changing patterns in online search behavior are due to changes in the number of individuals performing a specific search or due to an increase in the number of searches performed by specific individuals or some combination of these factors.

Despite these limitations, the findings presented here provide important information about the use of an infodemiologic approach to assess COVID-19 vaccine-related interest and intentions. During the study period, online search behavior related to COVID-19 vaccines suggest a possible historic high in public interest in vaccines. Furthermore, the specific type of vaccine related searches (e.g., increased searches related to specific pharmacies and decreased searches related to vaccine side-effects) is consistent with reduced vaccine hesitancy and greater intention to vaccinate. The relatively low occurrence of some types of searches (e.g., COVID-19 vaccine myths and conspiracy beliefs) suggests that many individuals who lack or are uncertain about critical vaccine-related information are not engaged in active online search to address their information needs. Encouraging more active information-seeking, along with critical appraisal of online health information, could be an important strategy to combat misinformation about COVID-19 vaccines and increase vaccine confidence and intention to vaccinate in the general population.

Ethics Review

This was reviewed by the University of Michigan Institutional Review Board and judged to be exempt based upon its use of open-access and anonymized aggregate data.

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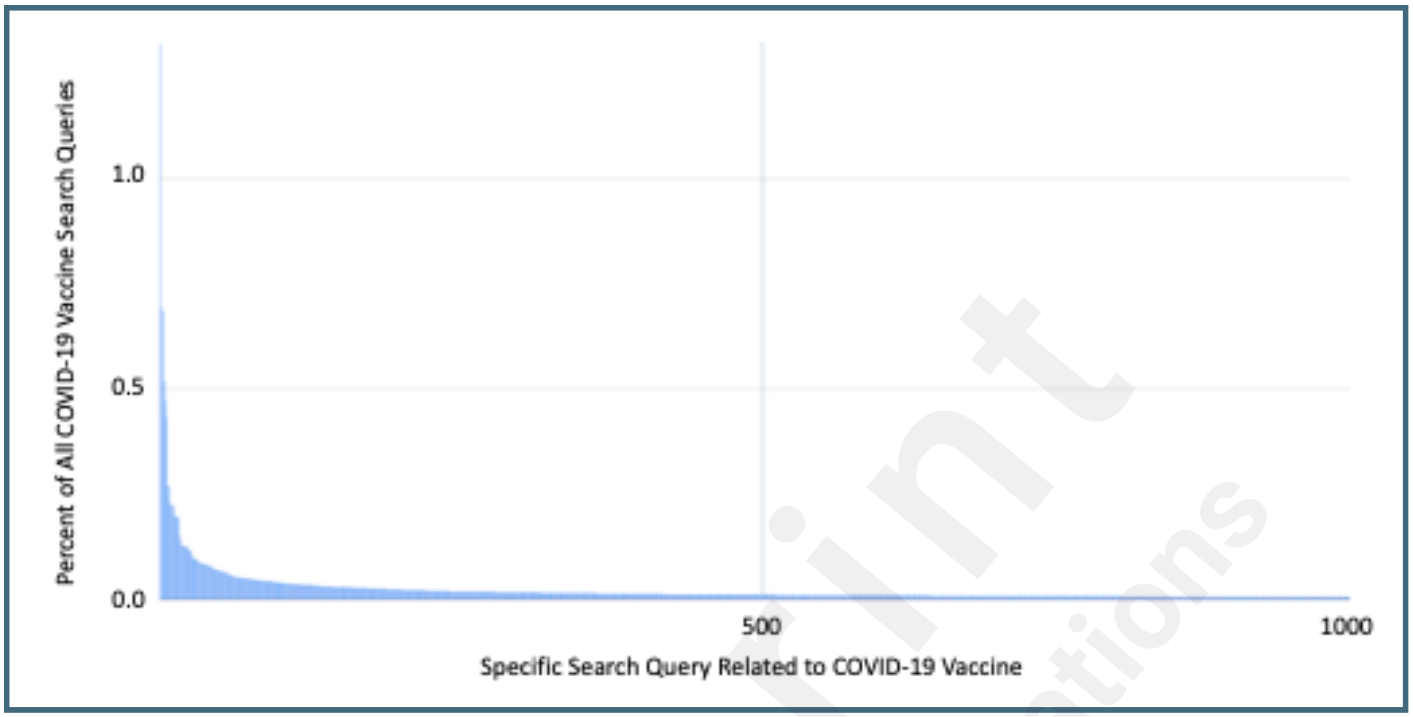
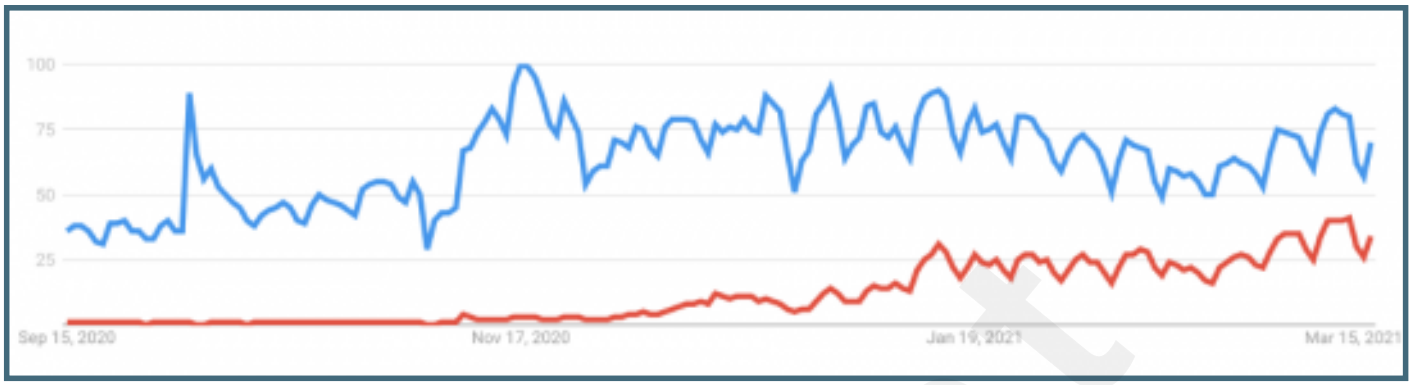
Supplementary Files

Figures

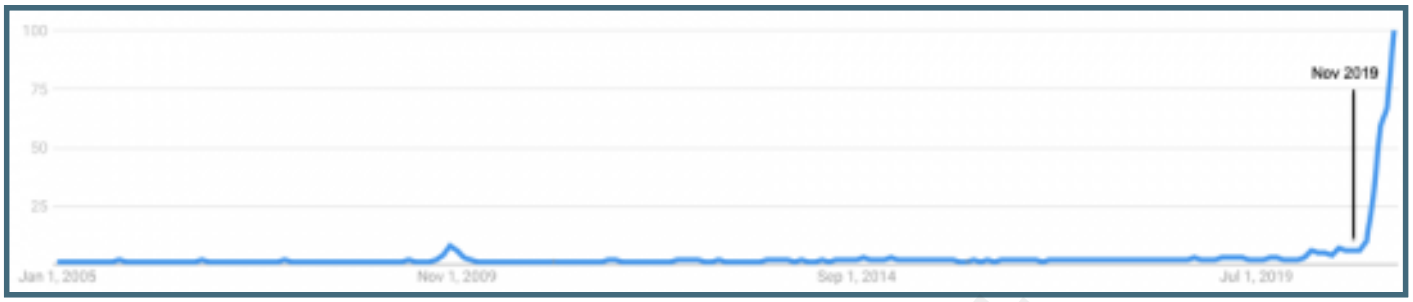
Frequency distribution of 1,000 most common search queries related to "COVID-19 vaccine".



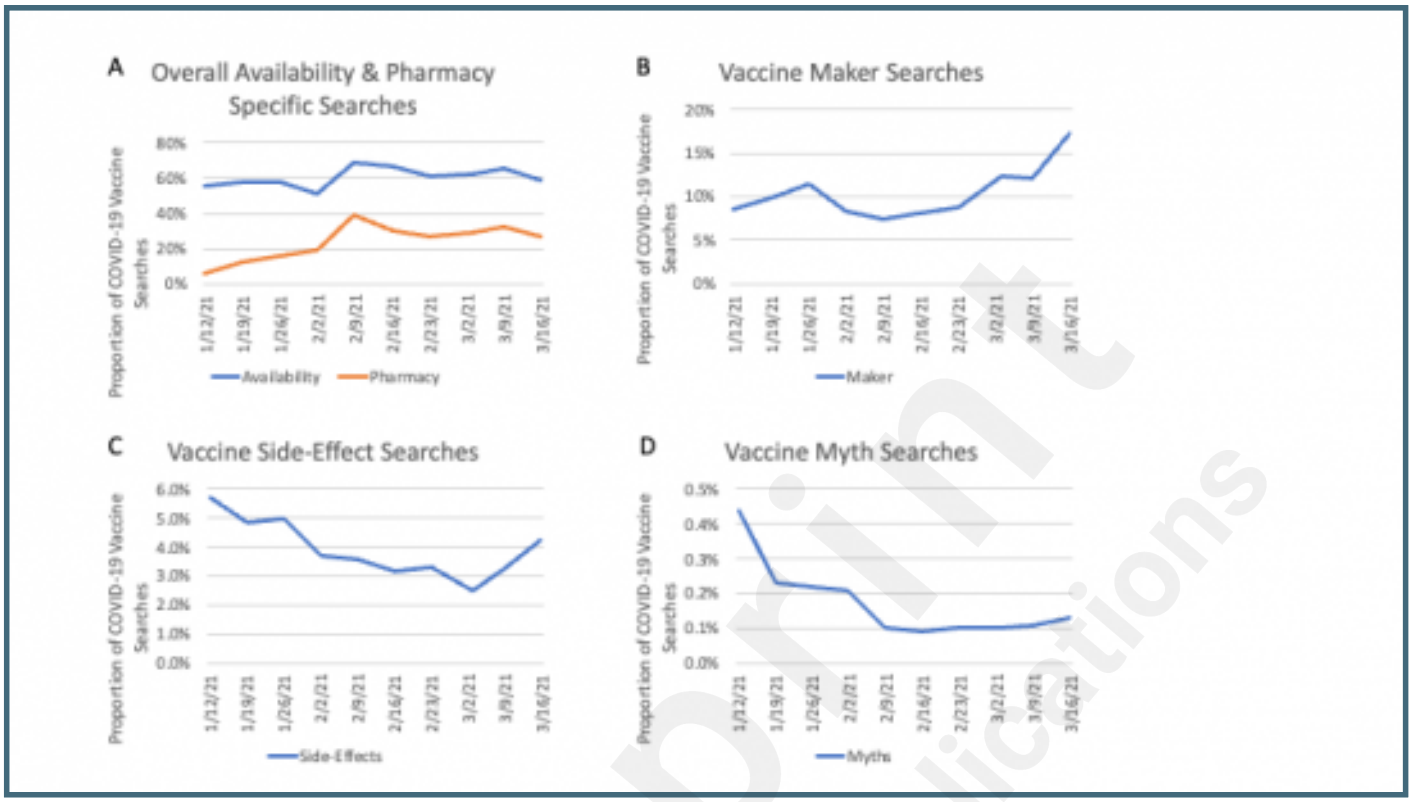
Relative Search Volume (RSV) for the terms “COVID” (Blue) and “COVID vaccine” (Red) from September 2020 through March 2021.



Relative Search Volume for the term “vaccine” from January 2005 through March 2021.



Trends for Different Categories of COVID-19 Vaccine Search Queries: Overall Availability and Pharmacy (a), Vaccine Maker (b), Side-Effects & Safety (c), Myths and Conspiracy Beliefs (d).



Google Trends Relative Search Volume for queries related to specific COVID-19 vaccine myths and conspiracy beliefs (red is vaccine + DNA, blue is vaccine + fertility, green is vaccine + microchip, gold is vaccine + 5G, and purple is “COVID from vaccine”).