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Recommended Citation

AMCIS 2021 Proceedings

Artificial Intelligence and Semantic
Technologies for Intelligence Systems (SIG
ODIS)

Aug 9th, 12:00 AM

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Understanding the Public Sentiment and Discourse on COVID-19 Vaccine

Completed Research

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Abstract

The novel Coronavirus disease has negatively impacted human lives in various aspects leading to the global health crisis and economic fallout. The availability of vaccines in the U.S. is a relief. However, many people are not in favor of the COVID-19 vaccine. The study aimed to identify the emotions and themes of discourse related to the COVID-19 vaccine posted on Twitter. Sentiment analysis and topic modeling techniques were employed to discover the sentiment and prevalent themes. The findings suggest that overall, the public has positive opinions towards the vaccine. Those people that show positive opinions appreciate the efforts of leadership, medical experts and pharmaceutical companies in developing the COVID-19 vaccine. They are feeling hopeful and relieved as the vaccines are/will be available. There are also people that hold negative attitudes towards the vaccines because of disbelief in the government and concerns about the efficacy and adverse reactions caused by the vaccines.

Keywords

COVID-19 vaccine, sentiment analysis, topic modeling.

Introduction

Pandemics have been occurred from time to time throughout human history, causing millions of deaths and negatively affecting humanity economically and sociologically. The ongoing COVID-19 pandemic has caused devastating effects around the world as the virus is capable of human-to-human transmission through droplets generated while sneezing or coughing. The World Health Organization has declared the outbreak of COVID-19 as a global pandemic on March 11, 2020 (Cucinotta and Vanelli 2020). It has infected more than 27 million people and caused 499,017 deaths across the United States as of February 25th ("United States of America" 2020). The economic impact of the pandemic is unprecedented in its scale. It has created a demand shock, a supply shock, and a financial shock all at once (Kharas 2020).

While the immediate precautionary actions to contain the COVID-19 virus are social distancing, washing hands frequently, and wearing masks, vaccines have been believed to be crucial to controlling the virus in the long-term (World Health Organization 2020). According to WHO, it is paramount to ensure a sufficient percentage of the population gets vaccinated to break the chain of transmission of the coronavirus ("World Health Organization" 2020). The availability of vaccines in the U.S. from multiple organizations such as Pfizer and Moderna is a relief. However, people are divided on whether to take the vaccines. In a recent online survey conducted by (Malik et al. 2020), of the 672 U.S. participants surveyed, a majority of them (67%) would accept a COVID-19 vaccine if it is recommended for them. However, a significant percentage of the participants (33%) are not in favor of getting the COVID-19 vaccine. Another survey has found similar results ("Expectations for a COVID-19 Vaccine" 2020): while 49% of the 1056 surveyed participants say they plan to get vaccinated, 20% say they will not, and another 31% are not sure. Why do people show such disparity in COVID-19 vaccine acceptance? This is the research problem that motivates the current research. Researchers have identified various factors that have created the public's dilemma towards the

COVID-19 vaccine, including the novelty of the vaccine, unconventional route to the development of the vaccine, politicization of the vaccine, and efficacy of the vaccine based on polls and surveys (*KFF Health Tracking Poll,* 2020; Tyson et al. 2020). Nowadays, social media platforms have become the go-to datasets for us to understand popular perception about an issue. While polls such as (*KFF Health Tracking Poll 2020*) sampled the opinions of hundreds or thousands of participants, millions of people has flooded social media platforms such as Twitter and Facebook, sharing their views and emotions concerning the COVID-19 vaccine. This enormous and constantly growing data can be leveraged to provide insights into the public's opinions and sentiments about COVID-19 vaccines in real time, which can help us gain a broader understanding of people's view towards vaccines, quickly identify the major concerns, and promptly carry out appropriate efforts to increase confidence in the vaccine. This knowledge of the public's opinions and sentiments can be leveraged to create appropriate policies and strategies to educate about vaccine safety and to build trust and reliability towards health agencies and scientists (Chou and Budenz 2020).

The purpose of our study is to discover public views towards COVID-19 vaccines based on social media data. It aims to 1) understand the public's sentiments and emotions towards COVID-19 vaccines and the changes of the sentiments and emotions over time, and 2) identify the factors leading to positive opinions or negative ones towards COVID-19 vaccines. Relying on Twitter data, we employ text mining techniques including sentiment analysis and emotion detection to detect the public's sentiments and emotions and use topic modelling to discover prevalent themes of discussion on COVID-19 vaccines. Based on our literature search, we believe that our research is one of the first studies that use social media data to analyze COVID-19 vaccine acceptance. The findings of our research can potentially provide information for public health policymakers to develop targeted policies and messaging to improve vaccine acceptance.

Related Work

Several studies have utilized social media such as Twitter content as the source of input data to analyze the impact of the ongoing COVID-19 pandemic on public sentiments. For instance, the authors of (Barkur et al. 2020) have analyzed the impact of lockdown in India due to COVID-19 using sentiment analysis and text mining techniques. In (Samuel et al. 2020), the authors analyzed the dominant sentiment pertinent to reopening the economy for two different situations - an early opening and a delayed opening, and the consequences of each situation. Numerous studies have also employed text mining to explore the major themes among the public discourse on the Twitter platform. For example, in (Odlum et al. 2020), the authors conducted research to investigate health disparity for COVID-19 among African Americans from a publicly available corpus of tweets. In (Xue et al. 2020), a large number of tweets are used to explore the topics and psychological reactions during the early stage of COVID-19. The above-mentioned research studies contribute to the surveillance of public health in this unprecedented time of public health crisis.

To our knowledge, the current research is one of the first studies that use social media data to analyze the public's opinions towards COVID-19 vaccines. Various surveys and polls have been conducted to understand the public's sentiments on the COVID-19 vaccine. Our research expands the existing literature that mainly relies on surveys and polls to explore the discourse, sentiments, and emotions of the public towards COVID-19 vaccines. It is intended to provide useful insights extracted from social media for public health policymakers to plan strategically to increase public confidence in vaccines of novel viruses.

Methodology

Data Collection

The data for this study was mined from Twitter. Twitter provides a common platform for people from all walks of life to publish their opinions on any topic, thereby generating a massive amount of data. Using text mining and natural language processing to analyze the Twitter content and understand the public sentiment on infectious diseases is an active research area (Zarrad et al. 2014). We collected tweets for a time frame beginning from July 1st to January 28th. We stared data collection on July 1st, as Pfizer/BioNTech announced early positive data from phase 1 and 2 studies of their vaccine on that day ("Results of Pfizer COVID-19 MRNA Vaccine Phase 1/2 Study" 2020). The tweets were gathered using hashtags including #coronavirusvaccine, #covidvaccine, and #covid19vaccine. We collected only the tweets written in the English language, and we excluded re-tweets and replies. Our final dataset includes a total of 78075 tweets.

Data Analysis

The collected data was first exposed to preprocessing steps to ensure quality. We have used the Python programming language to preprocess the data. We first converted all the tweets to lowercase. We then removed common words, stop words, punctuation marks, numbers, URLs, special characters, public replies represented by @, and hashtag symbols represented by #. We also performed lemmatization on the resultant data. Lemmatization is the process of removing inflectional endings so that just the base or dictionary form of a word is remaining. Next, we conducted tokenization, splitting each tweet into smaller units called tokens (i.e., usually individual words). After data preprocessing, we obtained a text corpus for text mining that includes a large and structured set of texts, each representing a tweet.

To address the research objectives discussed previously, we performed two types of text mining tasks. First, we focused on deriving the public emotions and sentiments using the Sentiment Analysis technique. Sentiment analysis is a widely used NLP technique to extract subjective information about emotions, attitudes, and opinions written by the public in regards to various events, products, etc. (Liu 2012). We employed the National Research Council (NRC) Sentiment Lexicon developed by Saif Mohammad (Mohammad and Turney 2013) to classify the tweets into not just positive vs. negative, but also eight different emotion categories including "anger", "anticipation", "disgust", "fear", "joy", "sadness", "surprise", and "trust". The NRC lexicon includes a separate sentiment lexicon for negated words called the Negated Context Lexicon that allow it to take negation into account and capture the sentiment of words in negated contexts (Kiritchenko et al. 2014). We used the package "syuzhet" that implements the NRC Sentiment Lexicon in the R programming language to perform the sentiment analysis and emotion detection, which returned a data frame, in which each row represents a tweet in our dataset. This data frame contains eight emotion columns, each represents an emotion (e.g., "joy" or "anger"), and two sentiment columns "Positive" and "Negative", representing the positive or negative sentiment (Naldi 2019). Given a tweet, the "syuzhet" package counts the number of words related to each emotion and each sentiment. Based on the outputs of the package, we computed the emotion scores for each tweet in our dataset. For instance, if a tweet contains just words associated with one emotion "joy", we assign the "joy" score of 1 to this tweet. If a tweet has multiple words related to different emotions, we assign different emotion scores to this tweet and make sure the sum of the scores is 1. For instance, if a tweet has three words related to emotions, and two of them are associated with "joy" and one with "anger", we assign this tweet a "joy" score of 2/3, an "anger" score of 1/3, and 0 to the other emotions. We also assigned sentiment scores to each tweet in a similar fashion. If a tweet contains just words related to positive sentiment, we assign the "positive" score of 1 to it. If a tweet contains three sentiment words, two of them are positive and one negative, we assign a "positive" score of 2/3 and a "negative" score of 1/3 to this tweet.

We then used topic modeling, a statistical and unsupervised Machine learning method, to extract the topics of discussion by Twitter users regarding COVID-19 vaccines and based on the topics, identified the factors that impact people's attitudes towards vaccines. The topic modeling method can efficiently detect latent topics within a large text corpus, i.e., groups of documents are classified into coherent themes without manual interference. The Latent Dirichlet Allocation (LDA) (Blei 2003) algorithm is used to perform topic modeling. LDA is an unsupervised clustering method to find similar groups of texts. It assumes that each document can be described as a variety of topics, and each topic can be described as a mixture of words. For this study, we used the Python's Gensim package to conduct LDA.

Results

Sentiment Analysis

Sentiment analysis provided us with rich findings by clearly identifying negative and positive sentiments on COVID-19 vaccination. Figure 1 shows the results of the sentiment analysis. The sum of the "positive" scores of the tweets (please see the previous section about our methods for computing the "positive" or "negative scores" for each tweet). Among all the tweets that contain sentiment words, 70.6% of the tweets contained positive sentiments, 29.3% contained negative sentiments, and only a very small percentage of them (around 0.1%) contained both positive and negative sentiments. Hence, we believe that the overall public attitudes towards COVID-19 vaccination were positive. Figure 2 depicts the change of the public sentiments over the seven months. During the initial period in July, August, and September 2020, positive sentiments increased gradually with the development of vaccines. During this period, both

Pfizer/BioNTech's and Moderna's vaccines entered phase 3 of clinical trials on humans, and both declared promising initial results. Nonetheless, the positive sentiment decreased during October and November while the negative sentiment increased. During this period, a high number of COVID-19 positive cases were reported. The coronavirus-related death toll was over 250,000 - ("United States Coronavius" 2020) on November 13th, 2020. In December, the U.S. Food and Drug Administration (FDA) approved the first emergency use of vaccine developed by Pfizer/BioNTech (Commissioner 2020), which caused the increase in positive sentiments while lowering the negative sentiments.
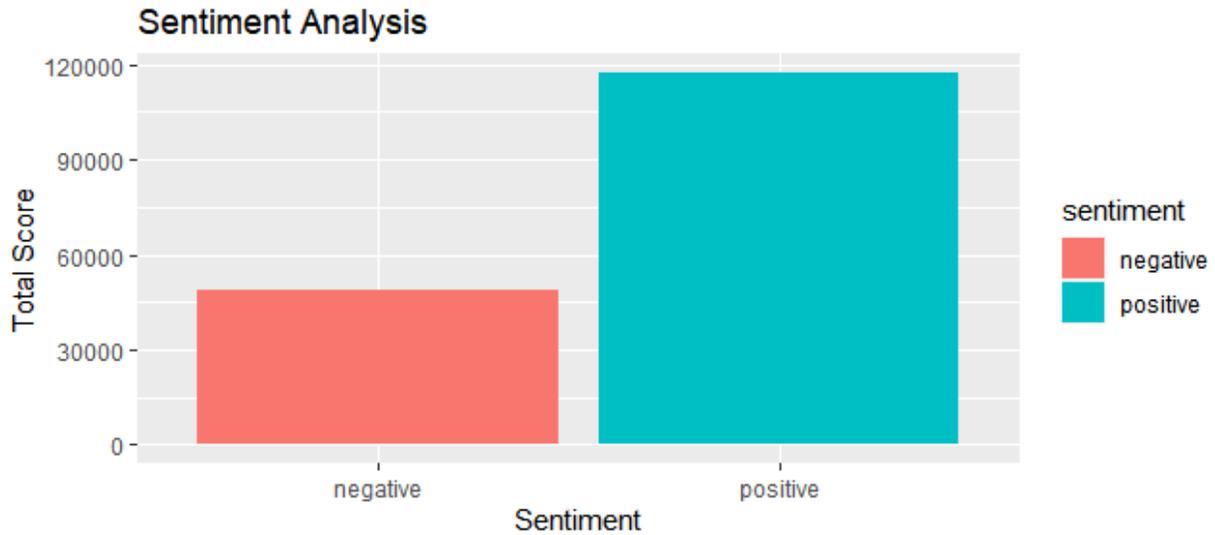

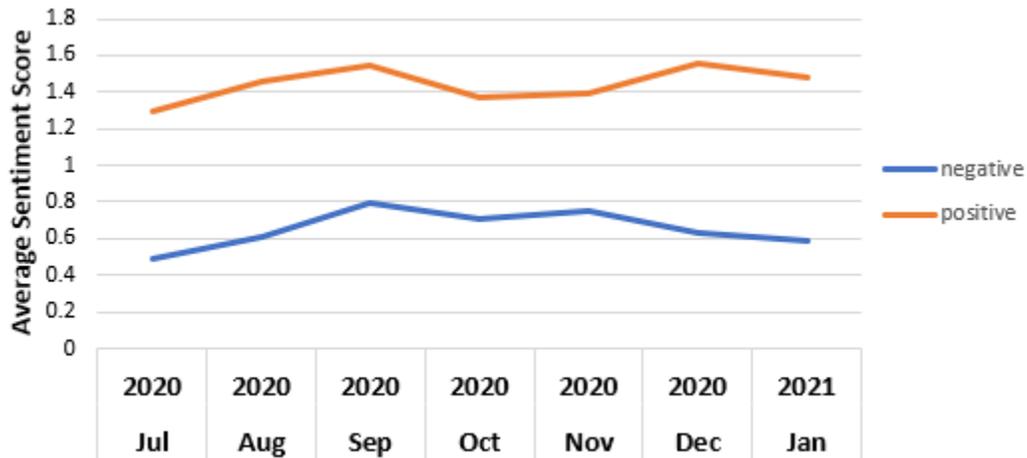**Figure 1. Sentiment Analysis of Tweets related to COVID-19 Vaccination.**

Figure 2. Change of Sentiment over seven months.

Emotion Analysis

Figure 3 represents the emotions of the tweets analyzed using the NRC lexicon. Through this analysis, we identified that 24% of the tweets show the emotion "trust", and 19% "anticipation". This indicates that much of the public believes in healthcare experts and is eagerly anticipating the vaccines. 12% of the tweets display "joy" as many mainly because of the positive results from vaccine clinical trials. There are, however, also a significant percentage of the tweets that show negative emotions. 13% of tweets display "fear", and 11% of tweets expressed "sadness", mainly due to the rapidly growing death toll and the economic fallout. We also

found that a relatively small portion of tweets (8%) show "anger", mainly from individuals that oppose the COVID-19 vaccination.
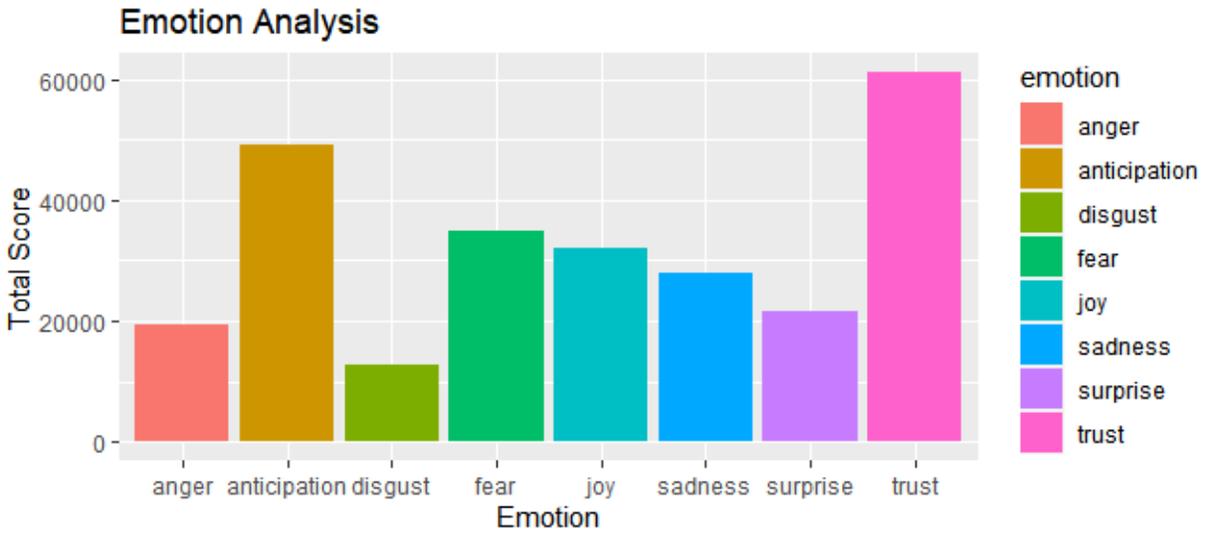

Figure 3. Emotion Analysis using the emotions from National Research Council sentiment lexicon.

Figure 4 represents the change observed in emotions from July 2020 to January 2021. Overall, the number of tweets associated with "trust" has been increasing during the time period. We see a clear spike in September as Johnson & Johnson started its phase 3 trials, and Moderna and Pfizer revealed information of how they will evaluate their vaccines in an attempt to gain trust, but a dip in November 2020. Similar fluctuations have also been observed with the average score of "anticipation" and "joy". The average score of "fear" (computed by averaging the "fear" scores of all the tweets. Please see the previous section for our method for computing the emotion scores for each tweet.) increased in August, September and then again in November 2020, but it has gone down since that as the high reported *efficacy of the vaccines* from Pfizer/BioNTech and Moderna have provided more reassurance. During September 2020, the average score of sadness recorded was the highest (0.41). It underwent slight decrease in October 2020 and then has been steady ever since.
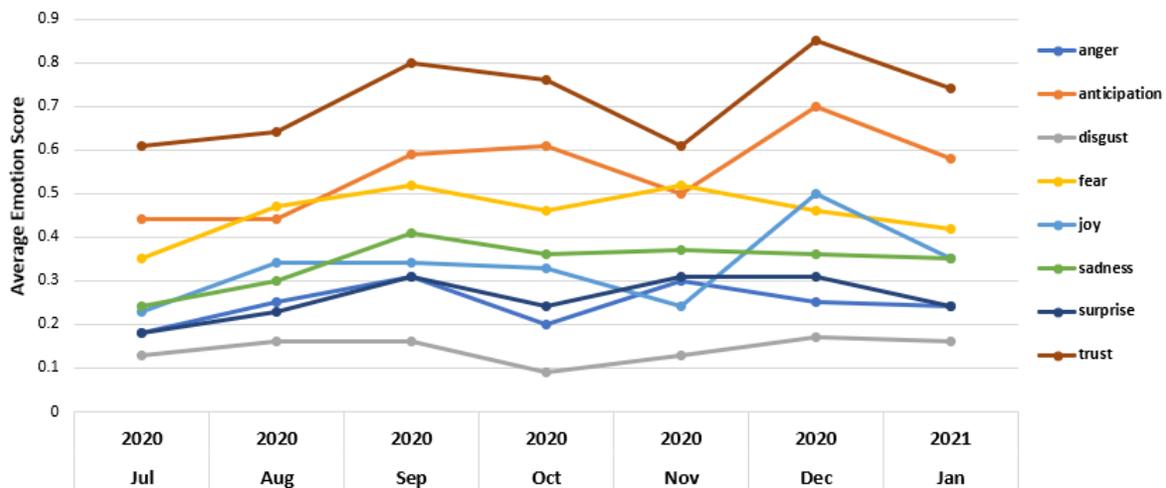

Figure 4. Change of emotions over the seven months.

Topic Modelling

We used topic modeling to extract themes or topics of discussion from the tweets. More specifically, we divided our text corpus into two datasets based on the sentiment analysis results. One dataset includes tweets with positive sentiments, and the other tweets with negative sentiments. We removed tweets that contains both positive and negative sentiments, which accounts for only 01.1% of data. We then applied the Latent Dirichlet Allocation (LDA) method for topic modeling to each of the two datasets. This enabled us to discover topics of discussion from people that showed positive towards the vaccines as well as those that showed negative attitude. When applying LDA, we were required to provide *k*, the optimal number of topics. We derived k by computing the topic coherence scores for different numbers of topics from 3 to 15 with 5-fold cross-validation. A topic coherence score is a score assigned by calculating the degree of semantic similarity between the words in the topics. We then selected the optimal number of topics that generated the highest coherence score, which in our case is six for the dataset containing tweets with positive sentiments and four for that with negative tweets.

Table 1 describes the six topics associated with the tweets with positive sentiments and the top 10 most common words in each topic. Topic 1 is related to the positive outlook of the public towards the leaders who are working to rapidly develop the COVID-19 vaccine. Topic 2 can be attributed to public feeling grateful as volunteers receive vaccine and appreciating the efforts of healthcare workers. Examples of such keywords include 'grateful', 'amazing', and 'volunteer'. The keywords such as 'community', 'pharmacy', and 'supply' in topic 3 are relate to pharmacies coming together to supply the vaccine to the community. The words in topic 4 focus on achieving herd immunity through the distribution of the vaccine. The keywords include 'herd', 'immunity', 'safe', and 'distribution'. The top words in topic 5 seem to capture the hope and relief of nursing homes over vaccine that have been catering the COVID-19 patients, topic 6 deals with the public's love and support towards the workers who are vulnerable to COVID-19 urge to protect them by distributing the vaccine first to them. The factors leading to positive sentiments towards the vaccine are role of leadership, safety and efficacy of the vaccines, and efforts of medical experts and healthcare organizations. This is consistent with findings from the existing polls (Funk et al. 2020).

No.	Top 10 common words	Topic
Topic 1	'0.068*"feel"+0.044*"great"+0.044*"leadership"+0.039 *"covid"+0.038*"faster"+0.018*"fall"+0.017*"thankful"+ 0.016*"excite"+0.015*"experiment"+0.013*"centralized	Public's thankfulness on leadership to expedite vaccine development.
Topic 2	'0.049*"grateful" + 0.018*"mask" + 0.016*"health" + 0.016*"amazing"+0.015*"experience"+0.014*"vaccinated "+0.013*"administer"+0.013*"volunteer"+0.012*"link" + 0.011*"effort"'	Public grateful for administering the COVID-19 vaccine to volunteers.
Topic 3	'0.165*"dose" + 0.050*"community" + 0.029*"pharmacy" +0.023*"pandemic"+0.020*"live"+0.018*"supply"+0.01 7*"healthcare"+0.015*"proud"+0.015*"together"+0.014* "believe"'	Appreciating the role of pharmacies in supplying the COVID-19 doses to the community.
Topic 4	'0.039*"immunity"+0.031*"herd"+0.030*"spring"+0.02 8*"arm"+0.024*"safe"+0.022*"milestone"+0.021*"scien ce"+0.018*"distribution"+0.018*"staff"+0.016*"appoint ment"'	Public feeling safe due to herd immunity that could be brought by vaccine by the spring season.
Topic 5	'0.056*"life"+0.037*"care"+0.033*"nurse"+0.029*"hom e"+0.028*"patient"+0.021*"major"+0.017*"relief"+0.016 *"hope" + 0.015*"washingtonian" + 0.014*"happy"'	Nursing homes providing care to COVID-19 patients feel relieved due to the vaccine.
Topic 6	'0.086*"protect"+0.048*"distribute"+0.034*"love"+0.02 6*"vulnerable" + 0.023*"worker" + 0.022*"reach" + 0.018*"summer"+ 0.016*"healthy" + 0.015*"centralized" + 0.015*"decisive"'	Protecting the vulnerable workers by providing vaccines first to them.

Table 1. The developing topics in positive tweets related to the COVID-19 vaccine

For the negative sentiment tweets, 4 topics were identified as described in Table 2. The example keywords in topic 1 include 'government', 'failure', and 'blame'. Topic 1 can be related to the public's opinion towards the government's failure to protect the vulnerable. The second topic refers to the deaths of people with underlying health issues due to the novel virus specifically, people of older age and people with smoking habits. Topic 3 deals with the adverse reactions caused by the COVID-19 vaccine who has various allergies such as peanuts. Lastly, topic 4 attributes to the concerns regarding the safety, distribution of the vaccine, and ill faith in the health experts. The factors leading to negative sentiments include concerns about efficacy and side effects from the vaccine and politicization of the vaccine. These factors are in line with findings from the previous surveys and polls ("KFF Health Tracking Poll – September 2020" 2020; Tyson et al. 2020).

No.	Top 10 common words	Topic
Topic 1	'0.026*"government" + 0.020*"failure" + 0.019*"high" + 0.014*"blame" + 0.014*"fail" + 0.012*"allow" + 0.012*"vulnerable" + 0.012*"governor" + 0.012*"live" + 0.011*"scam"'	Blaming the government for scams and failure to protect the vulnerable.
Topic 2	'0.041*"death" + 0.029*"die" + 0.019*"old" + 0.018*"system" + 0.018*"less" + 0.018*"arm" + 0.015*"cigarette" + 0.013*"health" + 0.012*"wake" + 0.011*"eat"'	Deaths caused due to COVID-19 of old people, people who smoke a cigarette and who have health issues.
Topic 3	'0.033*"covid" + 0.029*"reaction" + 0.027*"allergic" + 0.020*"risk" + 0.017*"peanut" + 0.015*"rollout" + 0.013*"mask" + 0.013*"setting" + 0.013*"congregate" + 0.012*"mean"'	Adverse reaction to the COVID-19 vaccine for people allergic to peanuts.
Topic 4	'0.034*"dose" + 0.020*"distribution" + 0.018*"lie" + 0.018*"safe" + 0.016*"million" + 0.014*"protect" + 0.012*"dangerous" + 0.011*"care" + 0.011*"frustrating" + 0.010*"doctor"'	Concerns regarding the safety and distribution of the vaccine.

Table 2. The developing topics in negative tweets related to the COVID-19 vaccine.

Discussion

This research explores the public's opinions towards COVID-19 vaccines based on Twitter data collected from July 1st, 2020 to January 28th, 2021. It quickly provides an overall picture of the public's emotions and discourse towards the vaccines, which has the potential to advance health informatics and surveillance to guide public health decisions and interventions. We address the limits of similar studies based on surveys and polls by enabling real-time and rapid analysis of Big Data from social media platforms.

The results of the sentiment analysis and opinion mining reflect that overall, the public have a positive attributes and outlooks about COVID-19 vaccines. A majority of them expressed positive emotions of trust and anticipation, indicating confidence in health experts and the vaccines. People expressed joy when promising results from the clinical trials were reported. As COVID-19 has caused negative impacts on various aspects of human life, many hoped for a vaccine to bring an end to their misery. However, there are also a significant number of people who are not positive towards COVID-19 vaccines. The users felt fearful due to the adverse symptoms related to the vaccines. Negative sentiments such as sadness and anger were triggered among people because of increase in the number of infected people and deaths and the politicization of vaccines. Most of the people were surprised by the novelty and expeditious speed the vaccines were being developed. We also investigated how the emotions and sentiments changed over time. The public has shown a gradual increase in positive sentiments and emotions towards vaccines, and the reported high efficacy and the FDA's approval of the emergency use of the Pfizer/BioNtech's and Moderna's vaccines caused spikes in positive emotions such as trust, joy, and anticipation.

We then employed topic modeling, a machine learning technique, to extract topics of discussions related to the COVID-19 vaccine from the positive tweets vs. the negative tweets. We found that those people that

expressed positive opinions towards vaccines appreciate the coordinated efforts of leadership, medical experts, companies and pharmacies in developing the COVID-19 vaccine. They feel relieved as the vaccine are/will be available. On the other hand, many people expressed negative opinions mainly because of their disbelief in the government, doubts about the efficacy of the vaccines, and also concerns about adverse reactions.

These findings from this study can be employed to help public health officials make informed decisions related to COVID-19 vaccines. The negative attitudes toward the vaccines often arise from doubts about the efficacy of the vaccines and worries about adverse reactions. Based on this knowledge, public healthcare officials can develop appropriate educational programs on vaccine effectiveness and safety to facilitate confidence in the vaccines. It is also necessary for governments to provide psychological help during this strenuous time of the pandemic, as many people showed the emotion of sadness and anger. Methodologically, our study indicates that public health officials can leverage social media platforms to monitor people's opinions and opinion changes in real-time and quickly respond to people's concerns.

Conclusion

With sentiment analysis and topic modeling approach, we identified the overall public sentiment and common topics of discussion related to the COVID-19 vaccine using data from Twitter. The findings of this study depict the crucial role of IT and social media in understanding the public outlook towards the COVID-19 vaccine. Social media can be effectively used to track the sentiment and emotions of the public in real-time. By identifying the factors leading to positive and negative sentiment, appropriate actions can be taken by the administration to increase the vaccine uptake. Our study has a few limitations. Tweets written only in English from the U.S. were extracted. This focuses the analysis only on a group of people and does not represent the entire world population. The future research work will include data representing a larger sample of the population.

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