Prevailing Sentiment Analysis of COVID-19 Vaccine Tweets in the United States

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Abstract

This paper analyzes American sentiment and emotion towards the COVID-19 vaccines using two pre-trained RoBERTa models optimized for tweet analysis. We examined how Americans view the COVID-19 vaccines in general and, more specifically, the Moderna and Pfizer vaccines. Due to positive coverage from the press about the vaccine, we anticipated that most of the Tweets would be non-negative and display a strong sense of "optimism" and "joy." Our results confirmed this hypothesis, classifying the majority of Tweets as non-negative. The model output very similar sentiment classifications for both vaccines, suggesting little difference in U.S. sentiment towards each vaccine. Our first main conclusion is that COVID-19 vaccine sentiment is highly dependent on the type of vaccine. Our second main conclusion, which confirms our hypothesis, is that sentiment towards the COVID-19 vaccine is generally non-negative and mostly joyful.

1 Introduction

During the COVID-19 pandemic, individuals constantly used Twitter to express their feelings. This study examines how the sentiment of Tweets related to the COVID-19 vaccine in the United States has evolved throughout the pandemic. A central challenge the United States faces in overcoming the COVID-19 pandemic is reaching herd immunity which can be accelerated by vaccinations. Some vaccination hesitancy stems from misinformation on social media platforms like Twitter. We are most interested in quantifying U.S. sentiment and emotion of the COVID-19 vaccine so we can gain insight into citizens' mindsets towards the vaccine to better guide pandemic-related decision making.

We analyze U.S. sentiment towards the COVID-19 vaccine, both in general and specifically towards each of the Pfizer and Moderna vaccines. We are interested in looking closely at each type of vaccine because of the differences in how each causes side effects, was produced, and was tested, anticipating differences in how Americans view each type of vaccine. Due to the societally crippling nature of the pandemic, we expect that general sentiment regarding the vaccine was both positive and optimistic, particularly when the Modern and Pfizer vaccines were both first approved for use in December 2020.

Several papers have attempted to predict U.S. sentiment towards the COVID-19 vaccine. One recent study by researchers from the Edinburgh Napier University, University of Edinburgh, and Harvard University collaborated to perform a sentiment analysis study on 300,000 tweets and Facebook posts in both the UK and US about COVID-19 vaccines (Ali et al. 2021). This study did not limit their analysis to U.S. vaccines and American Tweets, but found the sentiment towards the vaccine overwhelmingly positive, even with specific negative events like AstraZeneca vaccine trial pause. A third study looked at vaccination hesitancy, not exclusively related to the COVID-19 vaccine (Abbas et al. 2017). The authors used a semantic network analysis to group their data into positive, negative, and neutral sentiments, but only analyzed 50 tweets. Still, the results of this paper showed a general hesitancy towards vaccines as around 50 percent of tweets were classified as negative. Our study examines a broader dataset with a more robust methodology to holistically analyze COVID-19 vaccine sentiments and emotions.

2 Methodology

We sourced our data from a Kaggle dataset of 69,718 Tweets from around the world about the COVID-19 vaccines (Preda n.d.). We pre-processed our dataset to 9,342 tweets from the United States, specifically related to the Moderna and Pfizer vaccines. The initial dataset abruptly cut off the text for Tweets that were longer than a specific character length. We used Twitter's API (tweepy library) to re-pull the original tweets so we

could access the full text from each Tweet. The Tweets range from December 13th, 2020 through April 23rd, 2021. We cleaned the tweet text by excluding the links and normalizing spacing.

We ran two pre-trained RoBERTa models optimized for tweet analysis (cardiffnlp/twitter-roberta-base, cardiffnlp/twitter-roberta-base-emotion n.d.). RoBERTa is a performance optimized version of the BERT transformer that mirrors the same multiple encoder to decoder structure. Two stage neural network approaches are common across many classification-deep learning use cases where the first learns what is important and pipes into the second which performs the desired classification. As described in "Attention Is All You Need," BERT, like other transformers, follows this general structure where the initial attention feature reads the entire text at once and learns the relationship between words in the training texts (Vaswani et al. 2017). To do this, BERT masks the classifications of a small subset of words during training and then measures the predictions against the ground truth. Then, it masks the second sentence in a subset of pairings and attempts to predict that sentence. The loss function is optimized to maximize the model's performance on these two tasks during training. RoBERTa follows a very similar architecture with a slightly different masking and tokenizing methodology. RoBERTa changes the pattern of masks dynamically and uses simpler sentence delimiters with the idea that this improves the model's generalizability (Liu et al. 2019). The foremost reason RoBERTa outperforms BERT, though, is because it is trained on roughly ten times the amount of data. This increase in data significantly improves performance, which is why we selected to use it for this project (Liu et al. 2019). The two specific models we used were RoBERTa models hosted on Hugging Face that were fine-tuned on a dataset of approximately 58 million tweets to perform sentiment analysis and emotion classification, respectively (Barbieri et al. 2020). The pre-trained sentiment analysis labels were positive, negative, and neutral while the pre-trained emotion classification labels were "anger", "joy", "optimism", and "sadness." In a benchmarking of the TweetEval dataset, the RoBERTa models that we used surpassed the RoBERTa base model, as well as other models such as SVM, FastText, and BLSTM, on all relevant tasks, making it a cost-effective, state-of-the-art approach to our problem.

We ran each tweet through these RoBERTa models to get both the sentiment and emotion associated with each text. The model returns a probability of a tweet belonging to each label, which maps to the most probable classification.s

We also initially tested Open AI's GPT-3 davinci model for these tasks and our preliminary results indicated equivalent or higher performance on our initial subset, but running the GPT-3 model on our whole dataset was economically infeasible as it required six cents per token (an approximate cost of over two thousand dollars).

3 Results

Table 1 shows the sentiment analysis for the tweets related to the COVID-19 vaccine in general, the Pfizer vaccine, and the Moderna vaccine. The table gives the percentage of tweets that were classified as specific sentiments and the model's prediction confidence. For example, the model assigned tweets classified as positive an average 0.82 probability of being positive over negative or neutral. Our initial hypothesis is that Americans view the COVID-19 vaccine positively, and our model confirms this. Overall, American sentiment is non-negative towards the COVID-19 vaccine, as 41.34% of tweets are classified as positive and only 16.7% of tweets are labeled as negative. Additionally, there is little difference in how Americans view the Pfizer and Moderna vaccines, as 45.94% of tweets associated with Pfizer and 40.33% of Tweets related to Moderna were positive.

Table 2 highlights the classified emotions for the tweets, specifically for the emotions anger, joy, sadness, and optimism. Similar to the sentiment analysis from Table 1, the model classified most tweets positively, assigning the "joy" to 44.43% and "optimism" to 24.43%. Only 9.54% of Tweets were labelled "anger" while 21.60% of tweets were classified as "sad." This confirms our hypothesis that in general, Americans have an optimistic and joyful view on the COVID-19 vaccine. Overall, the model was confident in its predictions, particularly in assigning the "joy" label to tweets, giving these tweets a confidence of 0.75. This is also the case when looking specifically at the Moderna and Pfizer vaccines. Interestingly, for only tweets related to the Pfizer vaccine, 33.06% of tweets were classified as "joy" while for the Moderna vaccine, 47.12% were reported as "joy." Both Pfizer and Moderna have similar percentages of "sad" tweets; however, Pfizer has almost double the percentage of Tweets classified as "anger".

Figure 1 plots the percentage of Tweets that were labeled to a specific sentiment over seven-

day averages, starting from December 12, 2020 to April 23rd, 2021. We also include a vertical line to show the effect that the Johnson & Johnson vaccine being recalled and the AstraZeneca vaccine being recalled in Europe had on American sentiment towards the COVID-19 vaccine.

We observed that the error for negative sentiment is the lowest. We also discovered that positive sentiment decreases for most of December 2020, January 2021, and March 2021, though it increases at the beginning of each of these three months. We see the greatest increase in positive sentiment at the beginning of January 2021, which was soon after the COVID-19 vaccines were approved in the US. Overall, the positive sentiment ends up around the same percentage from the beginning of December 2020 to the end of April 2021. Throughout the duration of this period, either positive sentiment or neutral sentiment is always the highest, with positive being the highest for more total time. Oftentimes, we see that the error bars for neutral and positive sentiment overlap, indicating that there is not a significant difference between the percentage of neutral and positive sentiment for that time. Neutral sentiment seems to have the opposite trend as positive sentiment. On the other hand, negative sentiment increases greatly during December 2020 and decreases greatly starting about half way through April 2021 and directly after the J&J recall event, and fluctuates slightly between these two times. Interestingly, negative sentiment towards the COVID-19 vaccine declined after April 13th, when J&J recalled their vaccine, which differs from our initial hypothesis.

When graphing the same plot as above but for emotion (Figure 2), we found that optimism steadily decreased from December 2020 until late March 2021, and dramatically increased at the end of March 2021. Conversely, sadness has steadily increased from December 2020 until late March 2021, and then dramatically decreased during April 2021 after the J&J recall event. Joy fluctuated throughout the time period, decreasing dramatically during the end of December 2021, steadily increasing from February 2021 to mid March 2021 and then decreasing again during April 2021. Anger has remained the most steady throughout the time period, increasing in December 2020, plateauing, and finally decreasing after the J&J recall event. Throughout this graph, we see that many of the error bars overlap with error bars of other emotions, indicating that there was not an extremely significant difference in the percentages of each emotion.

When graphing the percentage of positive sentiment for Moderna and Pfizer tweets, we found that there was a significant increase in positive sentiment for the Moderna vaccine from late December 2020 to mid-January 2021. Concurrently, there is a significant decrease in positive sentiment for the Pfizer vaccine. From February 2021 until late April 2021, there is less positive sentiment surrounding the Pfizer vaccine as compared to the Moderna vaccine.

Finally, we create a choropleth map for the percentage of positive sentiment by state for December 2020 - April 2021 (Figure 4). From this, we saw that South Dakota had the highest percentage of positive sentiment, followed by Kansas, Utah, and Mississippi. On the other hand, South Carolina, Arkansas, and Louisiana had the lowest percentages of positive sentiment. We also created a choropleth map for the percentage of optimistic emotion by state for December 2020 - January 2021 (Figure 5). In this map, we observed that Vermont and Idaho had the highest percentage of optimistic emotion, while North Dakota and Delaware had the lowest percentage of optimistic emotion.

4 Discussion

Our analysis confirms our hypothesis that American sentiment towards the COVID-19 vaccine is non-negative, as the majority of tweets were classified as positive or neutral, and there was almost always the highest percentage of joyful tweets. This concurs with our impression of press coverage of the COVID-19 vaccine: that the vaccine is society's only path in its return to normalcy. The results bolster this belief with high confidence, as the model labeled the majority of tweets as "optimistic" and "joyful," and only a small fraction of tweets were filled with "anger" and "sadness." There was also very little difference in both the sentiment and emotional analysis between the tweets specifically related to the Moderna vaccine and the Pfizer vaccines. This deviates from our initial belief that Americans could view each vaccine differently due to the differences in production, side effects, and ingredients. This suggests that Americans show no preference in how they view one vaccine versus the other.

As stated previously, neutral and positive sentiments actually increased while negative sentiment decreased starting exactly when the J&J vaccine was recalled on April 13th, 2021, as depicted in Figure 1. This is contrary to our

original hypothesis, in which we believed that a negative event surrounding one vaccine would create negative sentiment towards all of the vaccines. However, this result is understandable considering that our data does not contain any data regarding the J&J vaccine. Thus, in reality, a negative event surrounding one vaccine could have made the sentiment towards only that vaccine become more negative while, as we saw, the sentiment towards other vaccines like Modern and Pfizer became more positive. We also see that directly after the J&J vaccine was recalled, optimism greatly increased and joy, anger, and sadness all decreased. The optimism increasing and anger and sadness decreasing could be attributed to the previously mentioned reasoning that J&J was not included in our dataset, so optimism for the other vaccines increased. However, this seems contrary to the idea that joy decreased. One reason for this decrease in joy could be that joy is connected to overall vaccines and COVID-19 decreased due to the negative events surrounding J&J, while optimism is connected to specific vaccines. Further research could examine more closely the sudden change in sentiment and emotion after the J&J vaccine was recalled.

We confirm this idea that sentiment of vaccines is separated by vaccine type, contrary to our hypothesis. When examining the progression of positive sentiment for the Moderna and Pfizer vaccines, we find they seem to always progress in opposite manners. Furthermore, we believe that the Pfizer vaccine initially had more positive sentiment because Pfizer is a more well-known and larger company than Moderna.

We also examined how the AstraZeneca recall in Europe on March 11, 2021 affected sentiment and emotion. Right around this event, positive sentiment decreased while negative sentiment slightly increased. Additionally, joy and sadness decreased, while optimism and anger increased. These changes in these emotions seem to conflict--we would expect joy and optimism to be correlated and sadness and anger to be correlated--leading us to believe that this event did not have a strong impact on U.S. sentiment and emotion. This result is reasonable considering that the AstraZeneca vaccine is not used in the U.S.

Finally, vaccination rollout has varied throughout the country, most notably, when comparing southern and midwestern states to the rest of the country. As shown in the map in Figure 4, the percentage of Tweets that are labeled as positive is much lower than other parts of the United States. Aside from Mississippi and South Dakota, sentiment in these regions of the country is much more negative towards the COVID-19 vaccine than other areas of the country. Future analysis could further examine these regional differences and why they occur.

5 Conclusion

Our first main conclusion is that COVID-19 vaccine sentiment is highly dependent on the type of vaccine. We saw this with the sentiment towards the vaccines in our dataset which did not include J&J becoming positive directly after the J&J recall event. This indicates that sentiment towards COVID-19 vaccines are specific to the type of vaccine. We also saw this with the opposite trends of positive sentiment for the Pfizer and Moderna vaccine. This conclusion disproves our hypothesis that negative sentiment towards one type of vaccine would create negative sentiment towards the COVID-19 vaccine in general.

Our second main conclusion, which confirms our hypothesis, is that sentiment towards the COVID-19 vaccine is generally non-negative and mostly joyful. We propose that rather than spending time, effort, and money on advertising the need for the vaccine in order to create more positive sentiment and more joyful emotion, the government should focus on the rollout. However, the government should continue to provide information regarding the number of people who are receiving the vaccine and the low rates of COVID-19 in order to increase optimism regarding the COVID-19 vaccine.

In the future, we believe that it would be beneficial to look further into the differences in the sentiment and emotion around the country. Because we had small numbers of data in some of the states, our map of sentiment and emotion may not properly reflect the spread across the country. Additionally, it would be interesting to investigate why these differences occur. Thus, we suggest a study that uses a larger amount of data that is spread evenly across the various states and could possibly include the distribution of a survey indicating why people feel certain sentiments or emotions about the vaccine.

As stated earlier, we had originally wanted to use the OpenAI's GTP-3 model to analyze the sentiment and emotion, as this model typically performs better. With the correct funding, we believe the results of this model run with more data would be even more robust and informative.

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Appendix

Table 1: Percentages and Confidence Scores for Sentiment of the Vaccine in General, the Pfizer Vaccine, and the Moderna Vaccine for Dec 2020-April 2021

Sentiment for General Vaccine, Pfizer, and Moderna for December 2020–January 2021

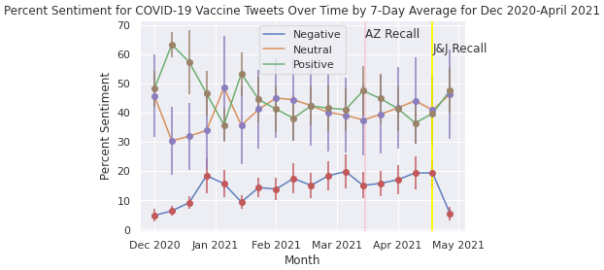
Sentiment	General	Pfizer	Moderna
Negative	16.711%(71.726% confidence)	15.902%(70.697% confidence)	16.378%(71.435% confidence)
Neutral	41.944%(67.075% confidence)	38.155%(66.316% confidence)	43.294%(66.124% confidence)
Positive	41.344%(81.683% confidence)	45.943%(82.042% confidence)	40.328%(81.489% confidence)

Table 2: Percentages and Confidence Scores for Emotion of the Vaccine in General, the Pfizer Vaccine, and the Moderna Vaccine for Dec 2020-April 2021

Emotion for General Vaccine, Pfizer, and Moderna for December 2020–January 2021

Emotion	General	Pfizer	Moderna
Anger	9.54%(72.895% confidence)	12.378%(73.528% confidence)	7.894%(72.192% confidence)
Joy	44.431%(74.49% confidence)	33.055%(72.981% confidence)	47.12%(75.083% confidence)
Optimism	24.429%(60.438% confidence)	33.472%(60.98% confidence)	22.876%(60.658% confidence)
Sadness	21.599%(70.142% confidence)	21.094%(65.02% confidence)	22.11%(71.087% confidence)

Figure 1: Percent Sentiment for COVID-19 Vaccine Tweets Over Time by 7-Day Average for Dec 2020-April 2021 (with error bars)



Percent Sentiment for COVID-19 Vaccine Tweets Over Time by 7-Day Average for Dec 2020-April 2021 (without error bars) *we decided to put the charts in both with and without error bars, as the error bar charts were cluttered

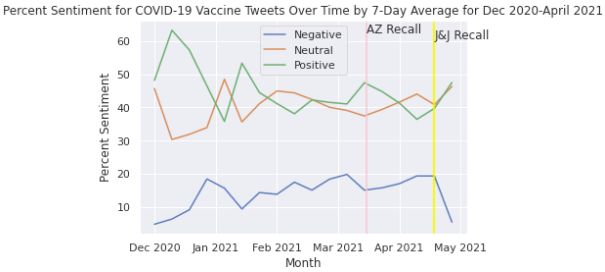
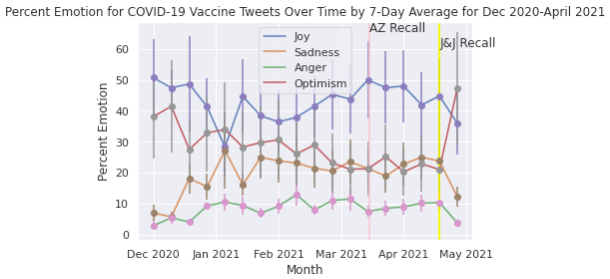


Figure 2: Percent Emotion for COVID-19 Vaccine Tweets Over Time by 7-Day Average for Dec 2020-April 2021 (with error bars)



Percent Emotion for COVID-19 Vaccine Tweets Over Time by 7-Day Average for Dec 2020-April 2021 (without error bars) *we decided to put the charts in both with and without error bars, as the error bar charts were sometimes cluttered

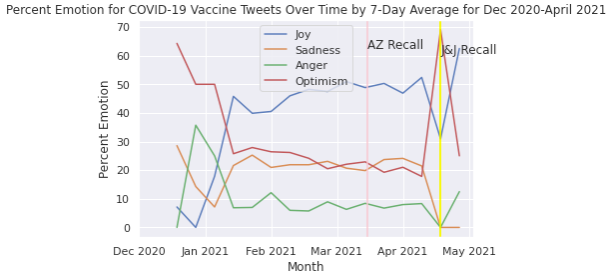
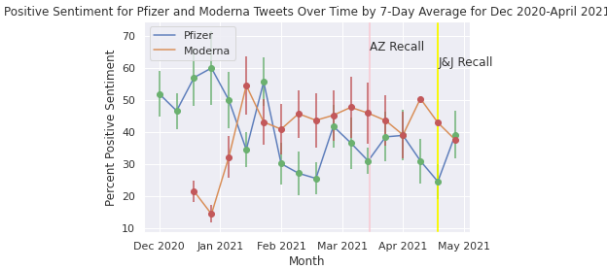


Figure 3: Percent Positive Sentiment for Pfizer versus Moderna COVID-19 Vaccine Tweets Over Time by 7-Day Average for Dec 2020-April 2021 (with error bars) *the Moderna line is cut off in the beginning because there were no positive tweets during this time period**:**



Percent Positive Sentiment for Pfizer versus Moderna COVID-19 Vaccine Tweets Over Time by 7-Day Average for Dec 2020-April 2021 (without error bars):

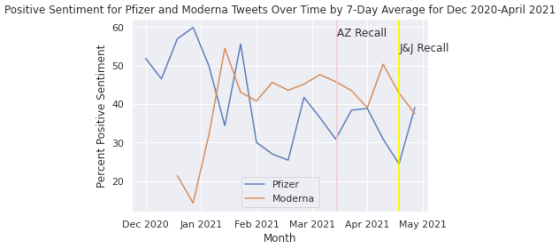


Figure 4: U.S. Map for the Percentage of Positive Sentiment Towards the COVID-19 Vaccine by State for Dec 2020-April 2021

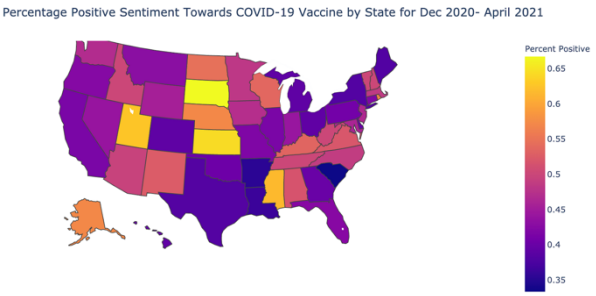


Figure 5: U.S. Map for the Percentage of Optimistic Emotion Towards the COVID-19 Vaccine by State for Dec2020-April 2021: