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1. Introduction

At over thirty-one million cases and over half a million deaths, the novel coronavirus (COVID-19) pandemic is having devastating impacts on health and well-being across the United States [1]. In response to the pandemic, there was a pharmaceutical race to develop efficacious vaccines for COVID-19 with multiple vaccines being granted Emergency Use Authorization (EUA) at the end of 2020 [2]. While the first vaccines were being developed, concurrently in the media, there was discourse occurring on the feasibility of mass distribution [3]. However, what was absent from these dialogues was thoughtful commentary on vaccine sentiments particularly in historically underserved communities. Even with an uptick in these types of conversations during vaccine rollout, we still do not have a comprehensive understanding of where negative vaccine sentiments are concentrated and what sentiments are driving hesitancy.

The existence of negative vaccine sentiments, people’s negative feelings, beliefs, attitudes, and opinions about vaccination [4,5], is not a new phenomenon, and vaccine hesitancy has existed for over a century. But fueled by misinformation and distrust of the government [6], negative vaccine sentiments have been surging over the past decade [7]. Communities that are more likely to be distrustful of vaccines include the poor, less educated, and communities of color [8,9]. These groups have increased exposure to infectious diseases, such as COVID-19 (e.g., due to being disproportionately represented among front line workers) but also have reasons to be suspicious considering their experiences of medical abuse and neglect. Although the “Tuskegee Study of Untreated Syphilis in the Negro Male,” is treated as a historical case study in ethics, the consequences, such as medical distrust in southern communities, are still present [10]. Coupled with limited access, insufficient infrastructure, rurality, and poverty, it is unsurprising that the southern United States holds sub-optimal levels of elective vaccination (e.g., influenza, HPV, etc.) [8,11], including COVID-19 vaccination [12,13].

Social media and online forums with real-time monitoring can inform public health efforts aimed at promoting vaccine confidence and reducing negative sentiments by offering insight into current perceptions [14]. Considering the broad usage of Twitter, and that many social interactions have moved online during the period of “stay at home” orders, we analyzed Twitter posts (tweets) related to the novel coronavirus vaccine to better understand the scope of negative vaccine sentiments across the country. We conducted state-level analysis on negative COVID-19 vaccine tweets to assess if such trends of negative opinions may be present across multiple states. We test two hypotheses that are informed from prior vaccine research: 1) the southern United States will have more tweets expressing negative sentiments toward
COVID-19 vaccination compared to non-southern states, and 2) higher-income states will witness lower prevalence of these negative tweets as compared to lower-income states.

2. Methods

2.1. Data

Twitter is an online social media platform where users share short (maximum 280 characters) messages called tweets. Twitter has 152 million daily users and more than 500 million daily new posts. The United States has the largest national number of Twitter users, estimated at ~47 million [15]. Using the Sysomos software, on May 1, 2020, we extracted one week’s (April 5 to April 11, 2020) worth of English language tweets from the United States, containing the phrases “COVID-19”, “coronavirus” or “SARS-CoV-2”, and referring to vaccine. This produced a sample of 208,973 tweets. We selected this study period to capture a public response to the event where Bill Gates went on TV and talked about a potential COVID vaccine in early April 2020. Search terms to identify the topic of vaccine were “vaccination,” “vaccine,” and “vaccinate.”

2.2. Defining geographic regions

The United States South is home to eight states, namely Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas [16]. Populations in these states are more likely to be culturally conservative, reside in rural settings, and have insufficient access to healthcare [17]. Other states were assigned to geographic regions as defined by the United States Census Bureau: Northeast, Midwest, and West [18].

2.3. Standardizing rates of tweets

To account for state population size, we calculated the prevalence of negative COVID-19 vaccine tweets per 10,000 population. We adopted state-level population size from the 2019 United States Census Bureau estimates.

2.4. State level income

We identified higher-income states as those with per capita income that was above the national median (2019) and lower-income states as those below the national median.

2.5. Statistical analyses

We performed t-tests to examine whether the number, prevalence, and percentage of negative COVID-19 vaccine tweets were different in the southern United States as compared with other geographic regions, and if there were statistically significant differences in these metrics between higher-income and lower-income states. We used Stata 16 (StataCorp LLC, College Station, TX) to analyze our data and Python to plot our state-level gradient heat map.

2.6. Statement

The University of Alabama at Birmingham Institutional Review Board deemed this study as non-human subjects research and therefore exempt (IRB-#300005071).

### Table 1

Tweets expressing negative COVID-19 vaccine sentiments by geographic region and state.

| State       | Number of Tweets | Prevalence per 10,000 Population | Percentage (%) |
|-------------|------------------|----------------------------------|----------------|
| Northeast   |                  |                                  |                |
| Connecticut | 96               | 0.27                             | 6.40           |
| Maine       | 56               | 0.42                             | 8.13           |
| Massachusetts | 163           | 0.24                             | 4.04           |
| New Hampshire | 38              | 0.28                             | 7.00           |
| New Jersey  | 200              | 0.23                             | 5.22           |
| New York    | 593              | 0.30                             | 4.48           |
| Pennsylvania | 376             | 0.29                             | 5.87           |
| Rhode Island | 38              | 0.36                             | 7.88           |
| Vermont     | 11               | 0.18                             | 3.83           |
| Average     | 174              | 0.28                             | 5.87           |
| Midwest     |                  |                                  |                |
| Illinois    | 273              | 0.22                             | 5.10           |
| Indiana     | 216              | 0.32                             | 9.24           |
| Iowa        | 64               | 0.20                             | 6.50           |
| Kansas      | 71               | 0.24                             | 7.64           |
| Michigan    | 372              | 0.37                             | 7.27           |
| Minnesota   | 167              | 0.30                             | 6.79           |
| Missouri    | 205              | 0.33                             | 7.23           |
| Nebraska    | 57               | 0.29                             | 7.38           |
| North Dakota | 13              | 0.17                             | 6.28           |
| Ohio        | 373              | 0.32                             | 7.59           |
| South Dakota | 24              | 0.27                             | 8.82           |
| Wisconsin   | 179              | 0.31                             | 9.32           |
| Average     | 168              | 0.28                             | 7.52           |
| South       |                  |                                  |                |
| Alabama     | 200              | 0.41                             | 9.04           |
| Arkansas    | 104              | 0.34                             | 10.45          |
| Delaware    | 19               | 0.20                             | 5.74           |
| Florida     | 1156             | 0.54                             | 7.85           |
| Georgia     | 359              | 0.34                             | 6.94           |
| Kentucky    | 146              | 0.33                             | 7.27           |
| Louisiana   | 151              | 0.32                             | 7.74           |
| Maryland    | 137              | 0.23                             | 5.40           |
| Mississippi | 102              | 0.34                             | 10.03          |
| North Carolina | 379            | 0.36                             | 7.59           |
| Oklahoma    | 160              | 0.40                             | 9.03           |
| South Carolina | 209            | 0.41                             | 8.47           |
| Tennessee   | 373              | 0.55                             | 9.31           |
| Texas       | 1555             | 0.54                             | 8.46           |
| Virginia    | 208              | 0.24                             | 6.01           |
| West Virginia | 56              | 0.31                             | 7.60           |
| Average     | 332              | 0.37                             | 7.93           |
| West        |                  |                                  |                |
| Alaska      | 41               | 0.56                             | 6.89           |
| Arizona     | 313              | 0.49                             | 7.68           |
| California  | 1133             | 0.25                             | 4.99           |
| Colorado    | 218              | 0.18                             | 6.42           |
| Hawaii      | 42               | 0.30                             | 7.69           |
| Idaho       | 66               | 0.37                             | 7.48           |
| Montana     | 61               | 0.57                             | 8.51           |
| Nevada      | 177              | 0.57                             | 7.42           |
| New Mexico  | 50               | 0.24                             | 6.31           |
| Oregon      | 169              | 0.40                             | 6.61           |
| Utah        | 50               | 0.16                             | 6.02           |
| Washington  | 202              | 0.27                             | 4.38           |
| Wyoming     | 51               | 0.88                             | 9.92           |
| Average     | 201              | 0.42                             | 6.99           |

Notes.

a Prevalence of negative vaccine tweets per 10,000 population was calculated using the following formula: .

b Percentage of all vaccine related tweets that expressed negative sentiments toward COVID-19 vaccines.
3. Results

Of our full sample (N = 208,973), 81.47 % (n = 170,268) tweets were associated with a user account that reported state location and were therefore included in the regional analysis; 7.08 % (n = 14,794) of vaccine related tweets expressed negative sentiments toward the COVID-19 vaccine.

In Table 1, we present the number and percentage of negative vaccine tweets, segmented by region and state. For each geographic region, we report state-level data as well as the average values across the region. We found wide variability across states. For example, in our sample, Utah had a prevalence of 0.16 negative tweet per 10,000 people while Wyoming had a prevalence of 0.88 tweet. Vermont had the lowest percentage of vaccine tweets expressing negative opinions (3.83 %) while Arkansas had the highest at 10.45 %. The five states with the highest percentage of vaccine tweets containing negative sentiments were Arkansas (10.45 %), Mississippi (10.03 %), Wyoming (9.92 %), Wisconsin (9.32 %), and Tennessee (9.31 %). When examining tweets by region, we found that while the Northeast, Midwest, and West had approximately 200 negative tweets per state, Twitter users residing in the South posted notably more, averaging about 332 (66 % more) negative COVID-19 vaccine tweets per southern state.

A few examples of negative COVID-19 vaccine tweets are:

Isn’t it unbelievable that so quickly there’s a vaccine for #coronavirus & testing for it???? What a #Hoax What a Joke! Flu season is over... #WakeUpAmerica #Truth.

Beware!!!! They are setting the stage to force vaccinations.

It is all about the NOW and the money for Gate and Fauci on the ‘new vaccine!’

![Fig. 1. Heat map of state-by-state prevalence of negative COVID-19 vaccine tweets on Twitter.](Image)

| Region       | Number of Negative Vaccine Tweets\(^a\) | Prevalence per 10,000 Population\(^b\) | Percentage\(^c\) (%) |
|--------------|-----------------------------------------|----------------------------------------|----------------------|
| Deep South\(^d\) | 514 (539)                               | 0.41 (0.09)                            | 8.26 (0.97)          |
| Other States | 176 (199)                                | 0.33 (0.14)                            | 7.00 (1.58)          |
| **p-value**  | 0.003***                                 | 0.150                                  | 0.040***             |
| Per Capita Income (2019 USD)\(^e\) |                                |                                        |                      |
| High-Income\(^f\)  | 181 (238)                                | 0.31 (0.14)                            | 6.41 (1.56)          |
| Low-Income    | 280 (349)                                | 0.38 (0.11)                            | 8.00 (1.10)          |
| **p-value**  | 0.040**                                  |                                        | <0.001***            |

Notes.
\(^a\) Number of negative vaccine tweets posted between April 4th and April 11th, 2020.
\(^b\) Prevalence of negative vaccine tweets per 10,000 population was calculated using the following formula: .
\(^c\) Percentage of all vaccine related tweets that expressed negative sentiments.
\(^d\) States in the Deep South include Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas.
\(^e\) Data from the United States Bureau of Economic Analysis.
\(^f\) High-income states are 25 states with per capita income higher than the national median; low-income states are those with per capita income lower than the national median.
States with the highest prevalence of negative vaccine tweets were Wyoming (0.88), Nevada (0.57), Montana (0.57), Alaska (0.56), and Tennessee (0.55). The five states with lowest prevalence of these tweets were Utah (0.16), North Dakota (0.17), Vermont (0.18), Delaware (0.20), and Iowa (0.20). Fig. 1 is a heatmap illustrating the state-by-state prevalence of negative vaccine tweets per 10,000 population.

In Table 2, we present data that indicates the southern region had significantly more negative vaccine tweets (p < 0.001) as well as a higher percentage of these negative tweets (p = 0.04), compared with the rest of the United States. Higher-income states had lower prevalence of vaccine tweets expressing negative opinions (p = 0.04) and lower percentage of these tweets (p < 0.001) compared to lower-income states.

5. Conclusions

Our findings illustrate that not only do negative sentiments toward COVID-19 vaccines exist, but also that there is geographic variability in the pervasiveness of this opinion. Southern states and states with lower income were associated with higher prevalence of negative COVID-19 vaccine sentiments. This is of concern, since these states are already underserved and hold some of the lowest rates of elective vaccination in the nation. Finding culturally acceptable methods to promote vaccine confidence may improve population health in these states.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Research reported in this publication was supported by the University of Alabama at Birmingham School of Public Health Back of the Envelope Award for RS.

Appendix

Search terms for COVID-19: “COVID19”, “coronavirus”, “COVID-19”, and “SARS-CoV-2”.

Search terms for vaccine: “vaccine”, “vaccine”, and “vaccination”.

Search terms to identify anti-vaccine sentiments: “NewWorld-OrderVirus”, “NewWorldOrder”, “NWO”, “SayNoToBillGates”, “NeVax”, “AttackBillGates”, “propoganda”, “plandemics”, “microchip”, “GatesVirus”, “forcedvaccination”, “WakeUpAmerica”, “VaccinesKILL”, “RightToChoose”, “MyBodyMyChoice”, “LeanTheRisk”, “JustAsking”, “VaccinesCauseAutism”, “VaccinesCauseNIDs”, “VaccinesUncovered”, “VaccineTruth”, “CDCWhistleBlower”, “HearThisWell”, “HHS42suits”.

References

[1] Centers for Disease Control and Prevention (CDC). Cases in the U.S. 2020. Available from: https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/cases-in-us.html (accessed April 20, 2021).

[2] Creech CB, Walker SC, Samuels RJ. SARS-CoV-2 vaccines. JAMA 2021;325(13):1318–20.

[3] Cullen S. Oxford University is partnering with a vaccine manufacturer, trial results expected in June. 2020. Available from: https://www.cnn.com/2020/04/30/uk/oxford-coronavirus-vaccine-trial-astazeneca-gbr-intl/index.html (accessed April 20, 2021).

[4] Salathé M, Kandelwal S, Meyers LA. Assessing vaccination sentiments with online social media: implications for infectious disease dynamics and control. PLOS Comput Biol 2011;7(10).

[5] Longo DL, Larson HJ, Gakdou E, Murray CJL. The vaccine-hesitant moment. NEJM 2022;387(1):58–65.

[6] Budhwani H, Sun R. Creating COVID-19 stigma by referencing the novel coronavirus as the “Chinese virus” on Twitter: quantitative analysis of social media data. J Med Internet Res 2020;22(5):e19301.

[7] Hoffman BL, Felter EM, Chu K-H, Shensa A, Herrmann C, Wolynn T, et al. It’s not all about autism: the emerging landscape of anti-vaccination sentiment on Facebook. Vaccine 2019;37(16):2216–23.

[8] Freimuth VS, Jamison AM, An J, Hancock GR, Quinn SC. Determinants of trust in the flu vaccine for African Americans and whites. Soc Sci Med 2017;193:70–9.

[9] Painter JE, Viana De OMS, Jimenez L, Avila AA, Sutter CJ, Sutter R. Vaccine-related attitudes and decision-making among uninsured, Latin American immigrant mothers of adolescent daughters: a qualitative study. Hum Vaccin Immunother 2019;15(1):121–33.

[10] Jamison AM, Quinn SC, Freimuth VS. “You don’t trust a government vaccine”: narratives of institutional trust and influenza vaccination among African American and white adults. Soc Sci Med 2019;221:87–94.

[11] Bhuiyan AR, Kabir N, Mitra AK, Ogungbe O, Payton M. Disparities in Hepatitis B vaccine coverage by race/ethnicity: the National Health and
Grumbach K, Judson T, Desai M, et al. Association of race/ethnicity with likeliness of COVID-19 vaccine uptake among health workers and the general population in the San Francisco Bay area. JAMA Intern Med 2022;182(1):90–3.

Khubchandani J, Sharma S, Price JH, Wiblishauser MJ, Sharma M, Webb FJ. COVID-19 vaccination hesitancy in the United States: a rapid national assessment. J Community Health 2021;46(2):270–7.

Meyer SB, Violette R, Aggarwal R, Simeoni M, MacDougall H, Waite N. Vaccine hesitancy and Web 2.0: exploring how attitudes and beliefs about influenza vaccination are exchanged in online threaded user comments. Vaccine 2019;37(13):1769–74.

Chua A, Chen X. Rumor retransmission on Twitter: message characteristics, user characteristics and retransmission outcomes. J Digit Inf Manag 2020;18:21–32.

Reif S, Salety D, McAllaster C, Wilson E, Whetten K. State of HIV in the US Deep South. J Community Health 2017;42(5):844–53.

Pac J, Carfinkel I, Kaushal N, Nam J, Nolan L, Waldfogel J, et al. Reducing poverty among children: evidence from state policy simulations. Child Youth Serv Rev 2020;115.

Galewít P. In Alabama, South Carolina and Louisiana, CVS vaccine appointments go unfilled. Kaiser Health News. 2021. Available from: https://khn.org/news/article/cvs-vaccine-supply-exceeds-demand-alabama-south-carolina-louisiana-available-appointments/ (accessed April 20, 2021).

Thanawala S. Deep South falls behind in coronavirus vaccine drive. The Associated Press; 2021. Available from: https://apnews.com/article/alabama-mississippi-georgia-coronavirus-pandemic-south-carolina-9edf9cdee1e19a8d3a5152eb5a5b887 (accessed April 20, 2021).

Hooper MW, Nápoles AM, Pérez-Stable EJ. COVID-19 and racial/ethnic disparities. JAMA 2020;323(24):2466–7.

Phadke VK, Bednarczyk RA, Salmon DA, Omer SB. Association between vaccine refusal and vaccine-preventable diseases in the United States: a review of measles and pertussis. JAMA 2016;315(11):1149–58.