REVIEW ARTICLE

Epidemiological Analysis of Vaccination Strategies and Demographic Patterns In COVID-19 Cases in The Midwest Region of The United States

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ABSTRACT

Introduction: The study discusses the uneven impact of the COVID-19 pandemic across various demographic groups in the US, focusing on Boone County, Missouri. The aim is to identify any correlation between factors such as gender, age, ethnicity, and religious beliefs with COVID-19 infection rates over a span of 22 months (from March 15, 2020, to December 2, 2021).

Methods: The research methodology involves time trend analysis graphs for each demographic group, benchmarked against significant events like vaccine launches, the introduction of the delta variant, vaccine boosters, and the arrival of the omicron variant.

Results: Preliminary findings suggest that males and certain racial groups, including Black or African Americans and the "All-Other" category, exhibit higher COVID-19 positivity rates throughout these defined periods. The study also delves into unique patterns among demographic groups during various phases of the pandemic.

Conclusion: Our results supported the hypothesis that males and minority races such as Black or African Americans and All-Other are more likely to have a higher COVID-19 positivity rate across our defined epochs.

Keywords: COVID-19 Pandemic, infection rates, Demographic Patterns, Time Trend Analysis, Epidemiological Insights

INTRODUCTION

COVID-19, an infectious ailment triggered by the SARS-CoV-2 virus, originated in Wuhan, China, in December 2019.[1,2] It rapidly proliferated globally, gaining pandemic status by March 11, 2020.[1,3] Statistics from April 1, 2020, show that the virus affected over 800,000 individuals and resulted in over 40,000 fatalities across 205 countries.[4] By November 2020, the US alone reported over 250,000 deaths and over 10 million infections.[4,5] Pharmaceutical companies announced promising news regarding vaccine efficacy by late November 2020.[6,7]

The trials for the COVID-19 vaccines showcased impressive efficacy for a majority of the participants.[6,8] The pandemic has wreaked havoc on global public health systems and the economy.[9,10] Its early phase significantly impacted the entire world, with countries like the United States, China, and several in Europe facing disruptions across various sectors, including social, public health, and economic domains.[4,9,32]

While research on risk factors for COVID-19 is ongoing, certain demographic attributes, such as age, gender, ethnicity, marital status, and religious beliefs, might influence both testing and infection rates within communities.[9,11,12] These rates might differ based on demographic features in periods before and after the vaccine's release in November 2020.[13,14] The economic turmoil caused by the pandemic was unparalleled.[15,16] Data from the U.S. Department of Labor reveals that the unemployment rate surged to 14.7% in April 2020.[9,17] Additionally, the total export value across all 50 states fell by 29.8%, decreasing from $414.95 billion in Q2 2019 to $291.47 billion in Q2 2020.[9,15,18] However, there was a slight reprieve as unemployment rates dropped to 10.2% by July 2020.[9,15,32]

In the U.S., COVID-19 disproportionately affected marginalized communities, particularly racial and ethnic minorities like Native Americans, Latin Americans, and African Americans.[19,20] The virus's significant impact on these groups is evident, but the influence of economic disparities and regional differences on these variances hasn't been thoroughly examined.[20,21] Existing disparities in economic, environmental, political, and social contexts, which predate the pandemic, are accentuated by these stark contrasts.[19,22,23]

This research strives to identify and elaborate on potential elements that could explain the disparities in COVID-19 figures in Boone County, Missouri, both before and after the vaccine's rollout.[19,22] The perspective is twofold: social determinants and demographic features.[19,24,32] In June 2020, the Centers for Disease Control and Prevention (CDC) disclosed that 33.8% of the COVID-19 cases in the U.S. were Latin Americans and 21.8% were African Americans, even though these groups only constitute 13% and 18% of the U.S. population, respectively.[2,25,26]

Term Definitions:

Positive Rate (PR): The proportion of tested individuals who are found to be positive for COVID-19, calculated by dividing the number of positive cases by the total number of tests conducted and then multiplying by 100 to get a percentage.

White Positive Rate (Wpr): The proportion of individuals identified as 'White' who test positive for COVID-19. Determined by dividing the number of positive cases among the White population by the total number of tests conducted within that group, then multiplying by 100 to get a percentage.

Atheist Positive Rate (Apr): The proportion of individuals identified as 'Atheist' who test positive for COVID-19. Determined by dividing the number of positive cases among the Atheist population by the total number of tests conducted within that group, then multiplying by 100 to get a percentage.

Total Positive (TP): The absolute number of individuals who have tested positive for COVID-19, regardless of demographic categorization.

Past research has indicated that factors like non-white race, male gender, advanced age, and primary language other than English correlated with elevated COVID-19 infection rates.[21,25] Among the infected population, individual attributes such as race, gender, and age were linked to a higher probability of requiring hospitalization.[13,26] Thus, this study focuses on assessing the relationships between COVID-19 testing and positivity rates and demographic factors like age, religion, ethnicity, and gender in Boone County, Missouri.[15,25] The hypothesis is that positivity rates will likely diminish post-vaccine release and subsequent booster shots. Conversely, the introduction of the delta variant is expected to cause an upsurge in positivity rates.[17,31]

The study evaluates demographic characteristics over various timeframes, spanning from March 15, 2020, to December 2, 2021. During these 22 months, five distinct epochs influenced the positivity rates for Boone County residents:

First and Second Epochs: These cover periods before and after the vaccine rollout, which occurred in November 2020.

Third Epoch: This phase looks at the time before and after the emergence of the delta variant in June 2021.

Fourth Epoch: This pertains to the timeframe before and after the vaccine booster shot introduction in September 2021.

Fifth Epoch: The final epoch focuses on the period before and after the appearance of the omicron variant in late November 2021.

The hypothesis posits that groups such as minority races/ethnicities, males, individuals of any religious faith, and the elderly are likely to exhibit elevated positivity rates both before and after the vaccine's in-

troduction and subsequent booster shots. This trend is also expected to persist during the epochs marked by the delta and omicron variants.

METHODOLOGY

Localized COVID-19 Test Data: Boone County, situated in Missouri, encompasses eleven primary towns and cities, including Columbia, Ashland, Sturgeon, Centralia, Hallsville, Hartsburg, Rocheport, Harrisburg, McCaine, Huntsdale, and Pierpont.[27] Boone County lies within the Mid-Missouri geographical region of the Midwestern U.S. As of the April 1, 2020, census, it houses 183,610 inhabitants.[28] The data for this study is sourced from the Cerner Electronic Health Record (EHR) from the University of Missouri Hospital and Clinics in the Mid-Missouri area. This dataset encompasses individuals tested for COVID-19 from March 2020 to December 2021, providing demographic details for 236,809 patients. The racial and ethnic classifications have been amalgamated into groups such as Other, Some-Other-Race, Unknown, Unable-to-Acquire, Refused or Declined, Hispanic, Asian, Native Hawaiian, and American Indian.

For the purpose of this study, certain racial and ethnic categories were merged. All categories, excluding "non-Hispanic White" and "non-Hispanic Black or African American" were grouped under the label "All Other." Similarly, marital statuses were combined, pairing "Married" with "Life Partner" and "Divorced" with "Separated."

When considering religious identification, numerous denominations, and faiths, ranging from Christian denominations like Baptist, Catholic, and Methodist to religions such as Islam, Hinduism, and Judaism, were all grouped under the label "Theist." Meanwhile, "None" and "Atheist" were combined. For all these attributes, including race/ethnicity, marital status, and religion, any "Unknown," missing values, or null entries were labeled as "Unanswered."

The positivity rate (PR) was calculated by taking the number of the total positive tests (TP) divided by the total number of tested individuals (TT):

$$PR = TP/TT \times 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

The total number of tested individuals from Boone County was 148,328. The total number of individuals with positive tests was 15,903, which gives a 10.72% positivity rate in the testing population.

Statistical Exploration: The descriptive statistics for the age of the tested individuals are as follows: mean of 34.42, standard deviation (std) of 20.48, minimum of 0, 25% percentile of 20, 50% percentile (median) of 31, 75% percentile of 49, and maximum of 104. To test our hypothesis, we first conducted a Chi-Square test to find any positive or negative association between COVID-19 results and sex, race, or religion. The degrees of freedom for the Chi-Square were calculated, and a two-sided alpha level of 0.05 was used to determine statistical significance in all hypothesis tests. First, a Chi-Square Test of Independence was performed to assess the relationship between COVID-19 and sex. There was a significant relationship between the two variables, Chi-Square (1, 74769) = 14.45, p = .0001436. P-value is less than 0.05 which means that it is very significant. Second, a Chi-Square Test of Independence was performed to assess the relationship between COVID-19 and race. There was a significant relationship between the two variables, Chi-Square (2, 74769) = 20.18, p = .00004158. P-value is less than 0.05 which means that it is very significant. Third and lastly, a Chi-Square Test of Independence was performed to assess the relationship between COVID-19 and religion. There was no significant relationship between the two variables, Chi-Square (2, 74769) = 1.19, p = .5512. P-value is bigger than 0.05 which means that it is not significant.

Table 1: Terms definition and their acronyms used to construct the equations for calculating the positivity rates needed for the time-trend Figures 6, 7, 8,10, and 11

Term Definitions					
PR	Positive Rate	W_{pr}	White Positive Rate	A_{pr}	Atheist Positive Rate
TP	Total Positive	W_p	White Positive	A_p	Atheist Positive
TT	Total Tested	W_{tt}	White Total Tested	A_{tt}	Atheist Total Tested
F_{pr}	Female Positive Rate	B_{pr}	Black Positive Rate	T_{pr}	Theist Positive Rate
F_p	Female Positive	B_p	Black Positive	T_p	Theist Positive
F_{tt}	Female Total Tested	B_{tt}	Black Total Tested	T_{tt}	Theist Total Tested
M_{pr}	Male Positive Rate	AO_{pr}	All Other Positive Rate	U_{pr}	Unanswered Positive Rate
M_p	Male Positive	AO_p	All Other Positive	U_p	Unanswered Positive
M_{tt}	Male Total Tested	AO_{tt}	All Other Total Tested	U_{tt}	Unanswered Total Tested

RESULTS

Table 2 shows the positive cases before the vaccine release and after the vaccine release for three demographic features. The **first demographic feature** studied before and after the vaccine release was sex. The total number of tested females in Boone County was 86,175 (58.1%), and the number of males was 62,153 (41.9%). The total number of females who tested positive was 8,595 (54.05%), 4,550 (54.1%) before the vaccine release, and 4,045 (54%) after the vaccine release. The total number of males who tested positive was 7,308 (45.95%), 3,861 (45.9%) before the vaccine release, and 3,447 (46%) after the vaccine release.

Table 2: Boone County, Missouri COVID-19 demographic statistics for tested individuals, and positive cases before and after the vaccine release

| Variables	Total Tested (%)	Positive Cases (%)	Positive Before Vaccine (%)	Positive After Vaccine (%)
Cohort Size:n (%)	148,328	15,903 (10.72)	8,411	7,492
Sex				
Female	86,175 (58.1)	8,595 (54.05)	4,550 (54.1)	4,045 (54)
Male	62,153 (41.9)	7,308 (45.95)	3,861(45.9)	3,447 (46)
Race/Ethnicity				
Non-Hispanic White	116,200 (78.33)	12,261 (77.1)	6,637 (78.9)	5,624 (75.07)
Black or African American	19,981 (13.47)	2,284 (14.36)	1,097 (13.05)	1,187 (15.84)
All Other Races	12,147 (8.2)	1,358 (8.54)	677 (8.05)	681 (9.09)
Religion				
Theist (With Religion)	60,900 (41.05)	6,213 (39.07)	3,364 (40)	2,849 (38.03)
Atheist (No Religion)	65,227 (43.98)	6,764 (42.53)	3,496 (41.56)	3,268 (43.62)
Unanswered	22,201 (14.97)	2,926 (18.4)	1,551 (18.44)	1,375 (18.35)
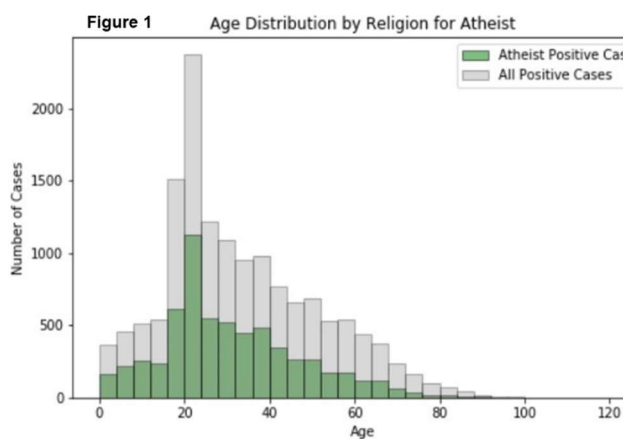
Figure 1: Histogram for the Age Distribution by Religion for Atheists showing that younger (ages 16-36) individuals were testing positive for COVID more than older individuals. The gray color shows all the positive cases in the tested population.

Figure 2: Histogram for the Age Distribution by Religion for Theists showing that younger (ages 16-24) were testing positive for COVID more than older individuals. The gray color shows all the positive cases in the tested population.

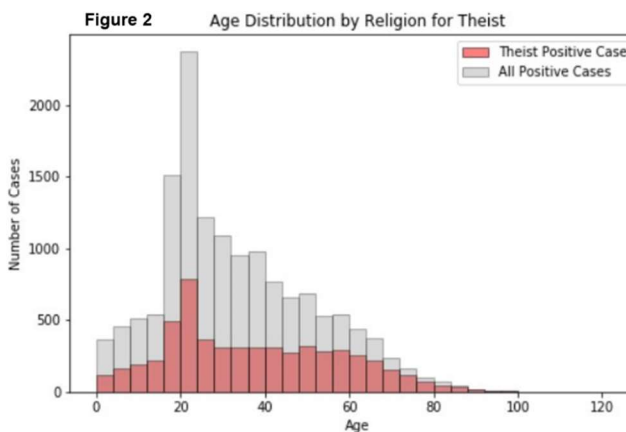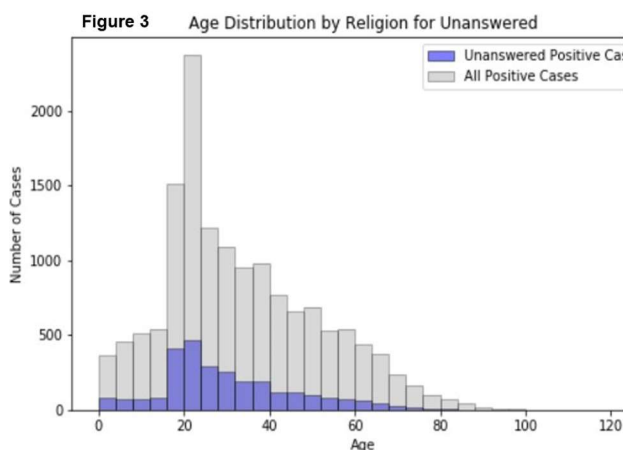Figure 3: Histogram for the Age Distribution by Religion for Unanswered showing a slight peak in the younger generation (ages 16-24). The gray color shows all the positive cases in the tested population.

The **second demographic feature** studied before and after the vaccine release was race/ethnicity. The total number of tested White individuals was 116,200 (78.33%), 19,981 (13.47%) Black or African Americans, and 12,147 (8.2%) were All Other Races. The total number of White individuals who tested positive was 12,261 (77.1%), 6,637 (78.9%) before the vaccine release, and 5,624 (75.07%) after the vaccine release. The total number of Black or African Americans who tested positive was 2,284 (14.36%), 1,097 (13.05%) before the vaccine release, and 1,187 (15.84%) after the vaccine release. The total number of All Other Race individuals who tested positive was 1,358 (8.54%), 677 (8.05%) before the vaccine release, and 681 (9.09%) after the vaccine release.

The third demographic feature studied before and after the vaccine release was religion. The total number of tested theist individuals was 60,900 (41.05%), 65,227 (43.98%) atheist, and 22,201 (14.97%) was unanswered. The total number of theist individuals who tested positive was 6,213 (39.07%), 3,364 (40%) before the vaccine release, and 2,849 (38.03%) after the vaccine release. The total number of atheists who tested positive was 6,764 (42.53%), 3,496 (41.56%) before the vaccine release, and 3,268 (43.62%) after the vaccine release. The total number of unanswered individuals who tested positive was 2,926 (18.4%), 1,551 (18.44%) before the vaccine release, and 1,375 (18.35%) after the vaccine release.

Trend Analysis Based on the Demographic Facets:

Table 3 identifies the five study epochs during the COVID-19 pandemic over the 22-month period (March 15, 2020 - December 2, 2021). The "before vaccine release" is the period between March 15, 2020, and December 21, 2020. The "after-vaccine release" is the period between December 22, 2020, and June 12, 2021. It is important to note that the first dotted line (December 22, 2020) in Figures 6, 7, 8, 10, and 11 represents the beginning of the vaccine roll-out in Boone County. The "delta variant" is the period between June 13, 2021, and September 20, 2021. The second dotted line (June 13, 2021) in Figures 6, 7, 8, 10, and 11 represents the first recorded case of the delta variant in Boone County. In addition, the "vaccine boosters" are the period between September 21, 2021, and November 19, 2021. The third dotted line (September 21, 2021) in Figures 6, 7, 8, 10, and 11 represents the beginning of the vaccine boosters in Boone County. Lastly, the "omicron variant" epoch is the period between November 20, 2021, and December 2, 2021. The fourth dotted line (Nov 20, 2021) in Figures 6, 7, 8, 10, and 11 represents the appearance of the omicron variant in Boone County.

Trend analysis for all the tested individuals: Figure 4 shows the time trend for COVID-19 positivity rate for all the individuals in Boone County, Missouri from March 15, 2020, until December 2, 2021. To compare the positivity rate in five different periods within two years, trend analysis was conducted using locally estimated scatterplot smoothing (LOESS) to smooth out daily fluctuations in positive cases. It is worth mentioning that the positivity rate was calculated using Equation 1.

Table 3: The five study epochs during the COVID-19 pandemic and their time periods

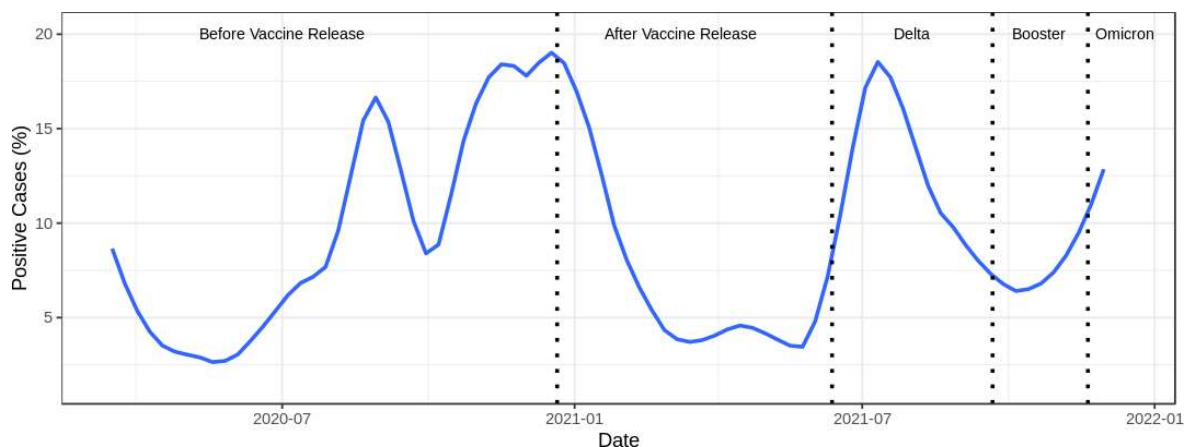| Study Epochs	Time Period
Before Vaccine Release	March 15, 2020 - December 21, 2020
After Vaccine Release	December 22, 2020 - June 12, 2021
Delta Variant	June 13, 2021 - September 20, 2021
Booster Shot Roll-Out	September 21, 2021 - November 19, 2021
Omicron Variant	November 20, 2021 - December 2, 2021

Figure 4: Trend analysis for COVID-19 positivity rate for the tested individuals in Boone County, Missouri from March 15, 2020, until December 2, 2021. The graph is divided into five major study epochs: before and after vaccine release, the appearance of the delta variant, vaccine boosters, and the appearance of the omicron variant.
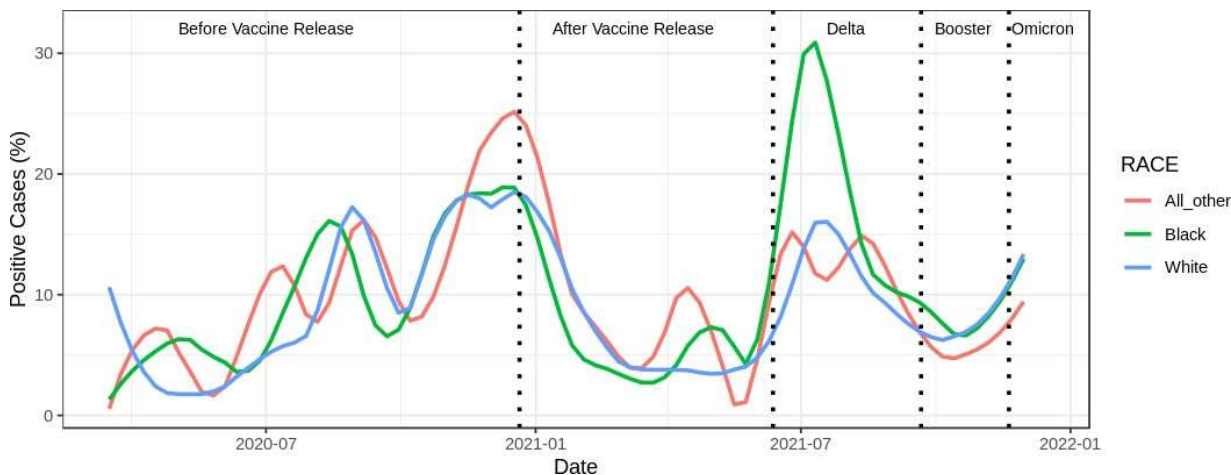
Figure 5: Trend analysis for the COVID-19 positivity rates by race for the tested in Boone County
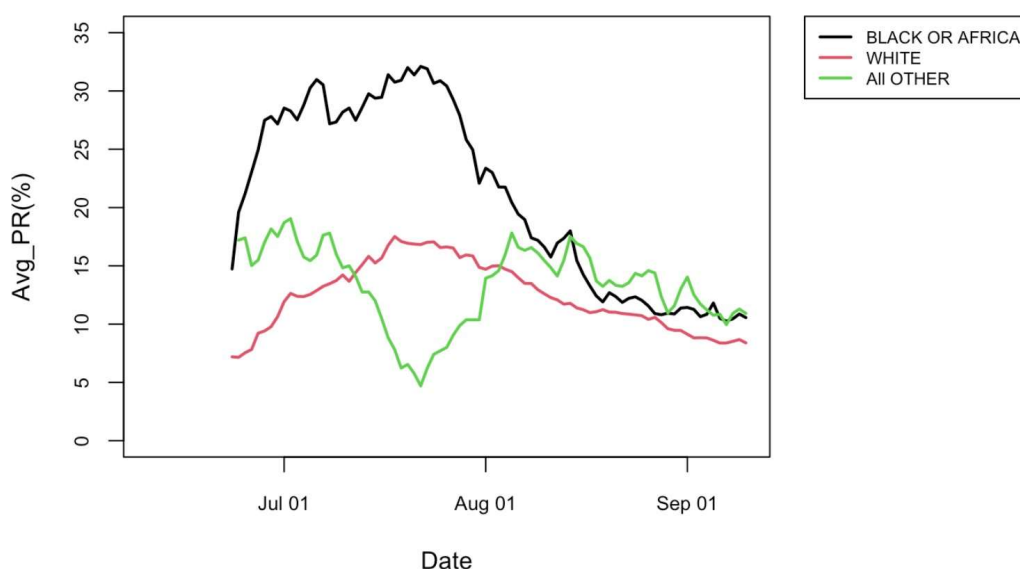

Figure 6: Delta Epoch focuses on a 14-day moving average by race between the period of June 10, 2021, and September 10, 2021. It shows a significantly higher COVID-19 positivity rate for Black or African Americans than All Other.

The All Other had a higher positivity rate on December 22, 2020 than White and Black or African American individuals. In mid-July 2021, Black or African Americans had a much higher COVID-19 positivity rate compared to White and All Other individuals.

Trend analysis for the tested individuals by ethnicity: Figure 5 shows the time trend for COVID-19 positivity rate by race/ethnicity from March 15, 2020, to December 2, 2021. To construct this time trend analysis graph, we calculated the COVID-19 positivity rate using the following equations.

$$W_{pr} = W_p/W_{tt} \times 100 \text{..} (2)$$

$$B_{pr} = B_p/B_{tt} \times 100 \text{..} (3)$$

$$AO_{pr} = AO_p/AO_{tt} \times 100 \text{..} (4)$$

We utilized LOESS (a regression and smoothing method)[22] to smooth out the daily fluctuations in positive cases for the three ethnicities (White, Black or African Americans, and All Other).

Time trend analysis for the tested individuals by religion: Figure 7 shows the time trend for COVID-19 positivity rate by religion from March 15, 2020, to December 2, 2021. To construct this time trend analysis graph, we calculated the COVID-19 positivity rate using equations.

$$A_{pr} = A_p/A_{tt} \times 100 \text{..} (5)$$

$$T_{pr} = T_p/T_{tt} \times 100 \text{..} (6)$$

$$U_{pr} = U_p/U_{tt} \times 100 \text{..} (7)$$

We used LOESS to smooth out the daily fluctuations in positive cases for the three religions (Theist, Atheist, and Unanswered). There was a significant change within the three religions between July 05, 2020, and January 10, 2021. The Unanswered individuals showed two major peaks with higher COVID-19 positivity rates than Atheist and Theist with a minimum of 0, first quartile of 8.33, median of 18.11, mean of 18.11, third quartile of 24.67, and maximum of 100.
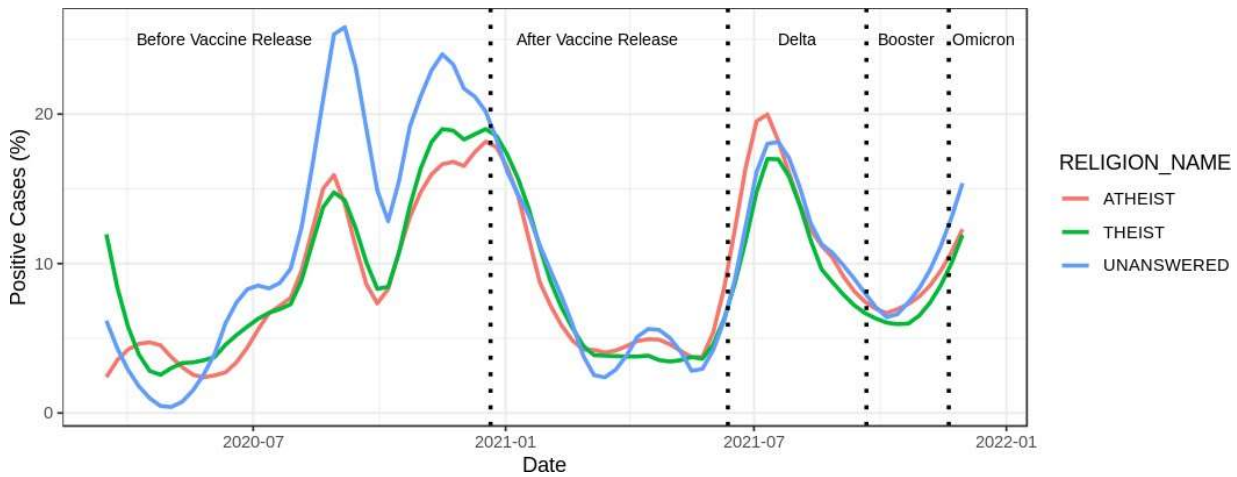
Figure 7: Trend analysis for COVID-19 positivity rate by religion for the tested individuals in Boone County.
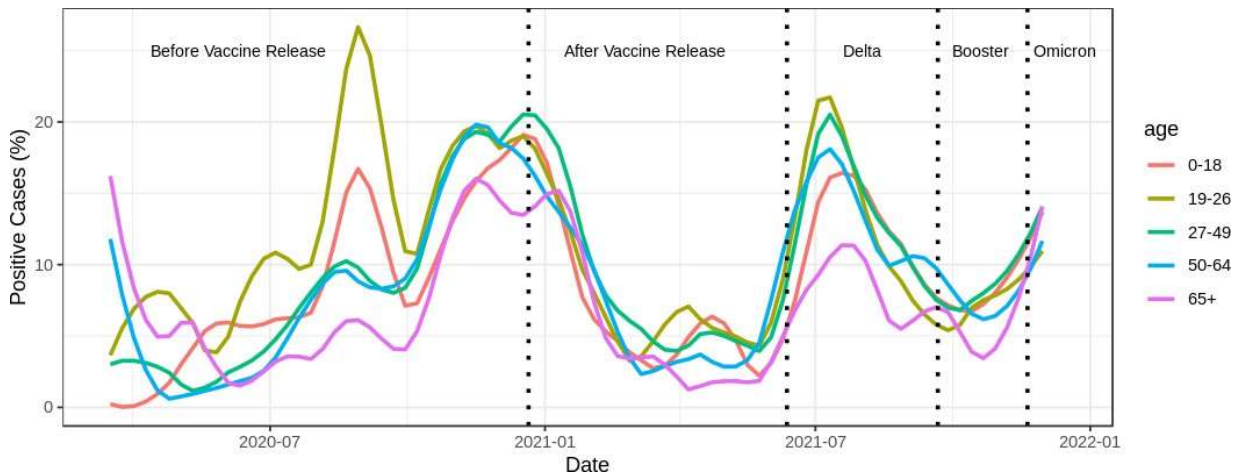
Figure 8: Trend analysis for COVID-19 positivity rate by age in Boone County

Atheists and theists had a very similar trend during this period. Theist had a COVID-19 positivity rate at a minimum of 0, a first quartile of 8.29, a median of 13.51, a mean of 13.65, a third quartile of 18.42, and a maximum of 34. The Atheist individuals had a COVID-19 positivity rate at a minimum of 2.77, a first quartile of 8.33, a median of 12.59, a mean of 12.99, a third quartile of 17.02, and a maximum of 30.66. The graph shows a significant increase in the COVID-19 positivity rate for the Unanswered individuals in September and November 2020 compared to Theist and Atheist individuals. Also, Atheist individuals showed a slightly higher COVID-19 positivity rate in early July 2021 than Theist and Unanswered individuals.

Trend analysis for tested individuals by age: Figure 8 shows the time trend for the tested individuals by age brackets, as proposed by the Centers for Disease Control and Prevention (CDC)[30], from March 15, 2020, to December 2, 2021. To construct this time trend analysis graph, we calculated the COVID-19 positivity rate using Equation 1. We used LOESS to smooth out the daily fluctuations in positive cases for all the age brackets (0-18, 19-26, 27-49, 50-64, and 65+). It important to mention that those age brackets are the same used by the Centers for Disease Control and Prevention (CDC).[30]

DISCUSSION

As COVID-19 is an ongoing source of threat, there will definitely be a continuous need for research studies and analyses to understand its behavior and to monitor the demographic and equitable distribution of life-saving resources for fighting the virus.

Table 2 is the demographic statistics to compare the population of Boone County with the tested individuals based on their demographic facets. The results of the comparison showed that the tested individuals are a very accurate sample to be compared to Boone County's population. The percentages of sex, race/ethnicity, and religion are very similar. We should note that the 19.6% positivity rate of the tested individuals is higher than Boone County's positivity 11.73% rate. The reason is that we were only counting one positive test result for each unique individual and discarding the negative test results. Boone County has a lower Black or African American percentage (9% vs. 12.8%) and positivity rate (11.5% vs. 13.74%) than the tested individuals.

Figures 1, 2, and 3 show the histogram for the age distribution by religion for atheists, theists, and unanswered. The atheist and unanswered histograms

are skewed to the left towards the younger generation. There were more younger individuals of the atheists and unanswered who tested positive for COVID compared to the older generation. On the other hand, the younger and older theist individuals had tested positive at the same rate except for some of the younger (ages 16-24) individuals who tested positive for COVID at a higher rate.

In Figure 7 we can notice a significant decrease in the number of COVID-19 positivity rates in late December 2020 and early January 2021 for the three religions after the release of the vaccine. The decrease is almost similar throughout the three religions with a slight favor for the "Unanswered." It is also important to note that Unanswered had a higher COVID-19 positivity rate before the vaccine release period than Theist and Atheist. The COVID-19 positivity rate for the three religions began to increase again in June 2021 due to the appearance of the delta variant. The three religions faced a very similar amount of increase in the COVID-19 positivity rate during the delta variant crisis with a slight favor to Atheist followed by Unanswered and then Theist.

Figure 8 shows a large disparity in September 2020 between "19-26" and the other age groups with "19-26" having a higher COVID-19 positivity rate compared to the other groups. It clearly shows a decrease in the number of COVID-19 positivity rates in late December 2020 and early January 2021 for all the age groups after the release of the vaccine. The decrease is identical throughout all the age brackets with "65+" having a slightly lower positivity rate. While the "27-49", "50-64" and "65+" had much lower COVID-19 positivity rate in this period. The COVID-19 positivity rate for all age groups began to increase again in June 2021 due to the appearance of the delta variant. The three age groups (19-26, 27-49, and 50-64) faced a very similar amount of increase in the COVID-19 positivity rate during the delta variant crisis. The age group "0-18" had a slightly lower positivity rate than the previous three age groups. However, the "65+" age group had a significantly lower positivity rate during this period.

Figure 8 shows a decrease in the positivity rates for all the age groups in September 2021 after the vaccine boosters. Additionally, all the age groups faced almost the same level of lower positivity rate during the roll-out of the booster shot except the "65+" age group which had a very low positivity rate than the other groups during the delta epoch. Two months later, the positivity rate for all age groups started to increase again in late November 2021 because of the first recorded case of the omicron variant. Finally, older individuals in the age bracket of "65+" have a lower COVID-19 positivity rate before and after the vaccine release, during the delta and omicron variants crisis, as well as before and after the booster shot compared to younger individuals.

The percentage of All-Other race/ethnicity individuals in Boone County (12%) and their positivity rate (18.5%) are higher than in the tested individuals (9.1% and 8.42% respectively). This indicates that more Blacks or African Americans individuals tested for COVID-19 than all other race/ethnicity individuals. Table 2 shows that the percentage of people with no religious affiliation is much higher in Boone County's population (60.6%) than in the tested individuals (42.68%), but the difference is approximately the same as the 19% of the tested individuals who did not give an answer about their religion (unanswered).

The results of the histograms and the trend analysis graphs support our hypothesis that males are more likely to test positive for COVID-19 than females. The same contrast applies to theists of all other ethnicities versus White theists, and Black or African American theists versus White theists. These significant findings support our hypothesis that minority races/ethnicities (Black or African Americans and All-Other individuals) were more associated with higher COVID-19 positivity rates than White individuals. Finally, there is not enough evidence to support the hypothesis that patients who affiliate with any religious belief (theist) are more likely to test positive for COVID-19 compared to atheist patients.

From Figure 4 we can notice a substantial decrease in the COVID-19 positivity rates in late December 2020 and early January 2021. This decrease is due to the vaccine release in Boone County during that period. However, the COVID-19 positivity rate levels started to increase again in June 2021 due to the appearance of the delta variant. The first recorded delta variant case was in mid-June 2020.[29] Figure 4 also shows a significant decrease in the COVID-19 positivity rates in the tested population of Boone County around September 2021 due to the vaccine boosters. Lastly, COVID-19 positivity rates started to increase again in late November 2021 because of the first recorded case of the omicron variant in Boone County.

Figure 5 clearly shows a major decrease in the COVID-19 positivity rate in late December 2020 and early January 2021 for the three ethnicities after the release of the vaccine. The All Other continue to have a higher COVID-19 positivity rate than White individuals and Black or African Americans after the vaccine release. Before the vaccine release, Black or African Americans and All Others had a higher COVID-19 positivity rate than White individuals. The period between November 10, 2020, and January 15, 2021, had a significant change for the three races. The All Other showed a very high peak compared to White and Black or African Americans. During this period, All Other had a minimum of 0, a first quartile of 16.52, a median of 20, a mean of 21.94, a third quartile of 27.78, and a maximum of 55.56. Black or African Americans had a much lower peak (COVID-19 positivity rate) with a minimum of 0, first quartile of 12.5, median of 17.65, mean of 16.72, third quartile of 20.81, and maximum of 40. The White individuals had a minimum of 6.67, first quartile of 14.77, median

of 16.67, mean of 17.204, third quartile of 19.72, and maximum of 25.83.

The COVID-19 positivity rate for the three ethnicities started to increase again in June 2021 due to the appearance of the delta variant. Black or African Americans faced a drastic increase in the COVID-19 positivity rate during the delta variant epoch compared to White and All Other individuals, especially between June 10, 2021, and October 11, 2021. We should also note that there are no data anomalies or spikes, but the COVID-19 positivity level is just significantly higher. The Black or African Americans show the highest local maximum (highest peak) in mid-July 2021. On the other hand, All Other shows the lowest local minimum during the delta epoch. Figure 5 shows the significant change for Black or African American compared to All Other over 14 days moving average during the delta epoch (between June 2021 and September 2021). Figure 6 shows a more detailed view of the delta epoch. Black or African Americans had a much higher COVID-19 positivity average rate especially in late July 2021, whereas All Other had a much lower average positivity rate for that period. Black or African Americans had a huge increase in the COVID-19. The positivity rate compared with White and All Other with a minimum of 0, first quartile of 7.25, median of 13.56, mean of 16.84, third quartile of 23.90, and a maximum of 68.18. During the delta epoch, All Other had a very low COVID-19 positivity rate than Black or African Americans with a minimum of 0, first quartile of 3.03, median of 10, mean of 11.6, third quartile of 16.67, and a maximum of 50. The White individuals had the lowest COVID-19 positivity rate during this period with a minimum of 0, first quartile of 7.35, median of 10, mean of 10.56, third quartile of 12.88, and maximum of 28.85.

Figure 5 also shows a significant decrease in the positivity rates for the three ethnicities in September 2021 due to the booster (third vaccine shot) roll-out. Additionally, White individuals and All Other Race faced lower positivity rates than Black or African Americans during the vaccine boosters. Finally, the positivity rate for COVID-19 started to increase again in late November 2021 because of the first recorded case of the omicron variant. All Other Race seemed to have a lower positivity rate than the other two ethnicities. The results in Figure 5 supported our hypothesis that minority race/ethnicity is associated with higher COVID-19 positivity rates before and after vaccine release, delta variant, booster shot, and omicron variant.

Figure 7 shows a significant decrease in the positivity rates for the three religions in September 2021 due to the booster shot (third vaccine shot) roll-out. Additionally, the three religious beliefs faced almost the same level of lower positivity rate during the vaccine boosters. In addition, finally, the positivity rate for COVID-19 started to increase again in late November 2021 because of the first recorded case of the omicron variant. The three of them started to in-

crease in the same manner with a slight favor to the Unanswered.

Finally, there is not enough evidence to support the hypothesis that individuals who affiliate with any religious belief (Theist) are more likely to have a higher COVID-19 positivity rate before and after the vaccine release, during delta and omicron variants crisis and before and after the booster shot compared to the Atheist and Unanswered individuals.

Figure 8 shows a significant deviation between the age groups in the period between July 25, 2020, and October 10, 2020, before the vaccine release epoch. The age group "19-26" had a much higher COVID-19 positivity rate before the vaccine release period followed by the "0-18" age group. Also, the "19-26" age group shows a significant increase in COVID-19 positivity rate with a minimum of 0, first quartile of 10, median of 15.79, mean of 17.53, third quartile of 23.74, and a maximum of 50. While "0-18" age group shows a lower COVID-19 positivity rate than the "19-26" age group but higher than the other age groups with a minimum of 0, first quartile of 5.4, median of 9.85, mean of 11.29, third quartile of 15.43, and maximum of 40. In contrast, the "65+" age group shows the lowest positivity rate in this period with a minimum of 0, first quartile of 0, median of 2.99, mean of 4.99, third quartile of 8.08, and maximum of 40.

Despite the promising results, there are several limitations in our study. First, the tests are known to have the possibility of false positives and false negatives. Second, we do not have information about the individuals who did not test in Boone County or tested at some other clinics and facilities other than the University of Missouri hospital and clinics. Third, we do not have information about the vaccine boosters, as well as the first delta and omicron recorded cases dates at other hospitals, facilities, clinics, and vendors other than the University of Missouri hospital and clinics. Fourth, the "none" in the religion was represented at a high percentage in the tested data that could be errors entered by nurses, or patients who refused to say their religious beliefs. Fifth and lastly, we do not have vaccination status information for the study.

Our findings support the hypotheses that males and minority races are more likely to have a higher COVID-19 positivity rate during the vaccine period, delta, and omicron variants, as well as the vaccine boosters' period in Boone County, Missouri. However, more resources should be allocated to the most vulnerable sex, race/ethnicity, and religion to address the COVID-19 pandemic in an equitable manner. Therefore, our team is conducting additional studies that will include geospatial analysis based on the zip code addresses and census tracts of the tested individuals in Boone County, Missouri to study and define the associations and other features that could be related to the testing, positivity, and death rates for COVID-19.

CONCLUSION

From a demographic perspective, our study shows that males are more likely to test positive for COVID-19 and they are more likely to test positive than females. In addition, males have higher positivity rates than females in our tested population. It also shows that minority races such as Black or African Americans, and all other races are more likely to test positive for COVID than majority races such as White. There was no evidence that religion was associated with the positivity rate in our study population.

REFERENCES

1. Liang D, Shi L, Zhao J, Liu P, Sarnat JA, Gao S, et al. Urban air pollution may enhance COVID-19 case-fatality and mortality rates in the United States. The Innovation. 2020;1(3):100047.

2. Khan S, Dahu BM, Scott GJ, et al. A Spatio-temporal Study of Changes in Air Quality from Pre-COVID Era to Post-COVID Era in Chicago, USA. Aerosol and Air Quality Research. 2022; 22 (8):220053.

3. Tirupathi R, Muradova V, Shekhar R, Salim SA, Al-Tawfiq JA, Palabindala V. COVID-19 disparity among racial and ethnic minorities in the US: a cross sectional analysis. Travel medicine and infectious disease. 2020; 38:101904.

4. Kobia F, Gitaka J. COVID-19: Are Africa's diagnostic challenges blunting response effectiveness? AAS open research. 2020;3.

5. Wu X, Nethery RC, Sabath M, Braun D, Dominici F. Air pollution and COVID-19 mortality in the United States: Strengths and limitations of an ecological regression analysis. Science advances. 2020;6(45): eabd4049.

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

7. Abuelgasim E, Saw LJ, Shirke M, Zeinah M, Harky A. COVID-19: Unique public health issues facing Black, Asian and minority ethnic communities. Current Problems in Cardiology. 2020;45(8):100621.

8. Bilal U, Tabb LP, Barber S, Diez Roux AV. Spatial inequities in COVID-19 testing, positivity, confirmed cases, and mortality in 3 US cities: an ecological study. Annals of internal medicine. 2021;174(7):936-44.

9. Chen J, Zhang P. Clustering US States by Time Series of COVID-19 New Case Counts in the Early Months with Non-Negative Matrix Factorization. Journal of Data Science. 2022;20(1):79-94.

10. Bagchi B, Chatterjee S, Ghosh R, Dandapat D. Impact of COVID-19 on global economy. In: Coronavirus Outbreak and the Great Lockdown. Springer; 2020. p. 15-26.

11. Zohner YE, Morris JS. COVID-TRACK: world and USA SARS-COV-2 testing and COVID-19 tracking. BioData Mining. 2021;14(1):1-15.

12. Hu T, Yue H, Wang C, She B, Ye X, Liu R, et al. Racial segregation, testing site access, and COVID-19 incidence rate in Massachusetts, USA. Int J Environ Res Public Health. 2020;17(24):9528.

13. Dahu BM, Khan S, Li WS, Shu X, Woldu H, Popescu M, et al. Demographic and Time Trend Analysis of COVID- 19 Test Results of Boone County, Missouri. AMIA Summits on Translational Science Proceedings. 2023; 2023:91.

14. Atalan A. Is the lockdown important to prevent the COVID-19 pandemic? Effects on psychology, environment, and economy-perspective. Ann Med Surg. 2020; 56: 38-42.

15. Dahu BM, Aburayya A, Shameem B, Shwedeh F, Alawadhi M, Aljasmi S, et al. The Impact of COVID-19 Lockdowns on Air Quality: A Systematic Review Study. Southeastern European Journal of Public Health. 2023.

16. Boserup B, McKenney M, Elkbuli A. Disproportionate impact of COVID-19 pandemic on racial and ethnic minorities. The American Surgeon. 2020;86(12):1615-22.

17. Dahu BM, Alaboud K, Nowbuth AA, Puckett HM, Scott GJ, Sheets LR. The Role of Remote Sensing and Geospatial Analysis for Understanding COVID-19 Population Severity: A Systematic Review. International Journal of Environmental Research and Public Health. 2023;20(5):4298.

18. Egede LE, Walker RJ. Structural racism, social risk factors, and Covid-19—a dangerous convergence for Black Americans. New England Journal of Medicine. 2020;383(12): e77.

19. Tai DBG, Shah A, Doubeni CA, Sia IG, Wieland ML. The disproportionate impact of COVID-19 on racial and ethnic minorities in the United States. Clin Infect Dis. 2021; 72 (4):703-6.

20. Cao Y, Dahu BM, Scott GJ. A geographic computational visual feature database for natural and anthropogenic phenomena analysis from multi-resolution remote sensing imagery. In: Proceedings of the 9th ACM SIGSPATIAL International Workshop on Analytics for Big Geospatial Data; 2020. p. 1-10.

21. Lewis NM, Friedrichs M, Wagstaff S, Sage K, LaCross N, Bui D, et al. Disparities in COVID-19 incidence, hospitalizations, and testing, by area-level deprivation—Utah, March 3–July 9, 2020. Morb Mortal Wkly Rep. 2020;69(38): 1369.

22. Bambra C, Riordan R, Ford J, Matthews F. The COVID-19 pandemic and health inequalities. J Epidemiol Community Health. 2020;74(11):964-8.

23. Strully KW, Harrison TM, Pardo TA, Carleo-Evangelist J. Strategies to address COVID-19 vaccine hesitancy and mitigate health disparities in minority populations. Frontiers in Public Health. 2021; 9:645268.

24. Louis-Jean J, Cenat K, Njoku CV, Angelo J, Sanon D. Coronavirus (COVID-19) and racial disparities: a perspective analysis. J Racial Ethn Health Disparities. 2020;7(6):1039-45.

25. Cromer SJ, Lakhani CM, Wexler DJ, Burnett-Bowie SAM, Udler M, Patel CJ. Geospatial analysis of individual and community-level socioeconomic factors impacting SARS-CoV-2 prevalence and outcomes. Medrxiv. 2020.

26. CDC Coronavirus; Accessed on 2022-02-22. https://www.cdc.gov/.

27. Facts By City. Accessed 2022-01-17. https://www.factsbycity.com/popular-religions/Boone-county- MO/statistics.html.

28. Como Coronavirus. Accessed 2022-01-17. https://www.como.gov/coronavirus/.

29. Barone E. How the Delta variant overtook Missouri. Time; 2021. Available from: https://time.com/6085454/delta-variant/.

30. CDC Covid Data tracker. Centers for Disease Control and Prevention. Available from: https://covid.cdc.gov/ covid-data-tracker/#vaccination-demographics-trends.

31. Taryam M, Alawadhi D, Al Marzouqi A, Aburayya A, Al-baqa'een A, Alfarsi A, Makki I, Rahmani N, Aljasmi M, Mubarak S, Salloum SA. The impact of the covid-19 pandemic on the mental health status of healthcare providers in the primary health care sector in Dubai. Linguistica Antverpiensia. 2021 Jun 24;21(2):2995-3015.

32. Alaboud K, Toubal IE, Dahu BM, Daken AA, Salman AA, Alaji N, Hamadeh W, Aburayya A. The Quality Application of Deep Learning in Clinical Outcome Predictions Using Electronic Health Record Data: A Systematic Review. South Eastern European Journal of Public Health. 2023 Oct 30:09-23.