

Demographic and Trend Analysis of COVID-19 Test Results of Boone County, Missouri

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Abstract

The COVID-19 pandemic has had a deep influence on American life. However, the burden of the COVID-19 pandemic has not been distributed equally among members of a population based on their demographic features. The purpose of this study was to investigate whether sex, age, race/ethnicity, and religion were associated with COVID-19 testing and positivity rates in Boone County, Missouri for 22 months period (March 2020 to December 2021) of the pandemic.

We analyzed the data using age distribution histograms with each demographic feature. We also computed two-way delta tables to highlight our study findings. These tables show that males with 0.012 delta percentage are significantly more likely to test COVID positive than females with -0.015 delta percentage. Black or African American “NONE” of 0.0072 delta percentage are significantly more likely to test COVID positive than White individuals of -0.0075 delta percentage. Our study results supported the hypothesis that males and minority races such as Black or African American and All-Other are more likely to test positive for COVID-19.

Additionally, we analyzed the data using the trend analysis graphs with each demographic feature across a collection of defined epochs of key events, such as vaccine release, delta variant, vaccine boosters, and omicron. Our study 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. Additionally, we explore interesting deviations between demographics within various epochs.

Chapter 1: Introduction

1.1 Problem Statement

The coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus (1,2). Since COVID-19 emerged in Wuhan, China in December 2019, it has rapidly spread worldwide. It was given pandemic status on March 11, 2020, (3,4).

By April 1, 2020, COVID-19, which is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), had infected more than 800,000 people and caused over 40,000 deaths in 205 countries and territories (4); and more recently it had infected more than 262 million people and taken more than 5.2 million lives worldwide (5). COVID-19 has deeply affected the United States, China, and Europe (3). The coronavirus pandemic has also caused enormous economic, public health, and social damages (6).

We should draw our attention that the risk factors of COVID-19 are still under investigation, but some demographic factors, such as age, gender, sex, race, marital status, and religion may play a vital role in increasing both the testing rates and positivity rates within a population. These rates could be significantly varying among different demographic features between the period before the release of the vaccine (before November 2020) and the period after the release of the vaccine (after November 2020).

In addition, the COVID-19 pandemic has affected major socio-economic and health disruptions all over the world (7). The persistence and emergence of COVID-19 in the United States after the death of more than half a million Americans has undoubtedly affected and altered American life (8).

Since COVID-19 is an airborne and infectious disease, it has been advertised by mainstream media and news channels as “a great equalizer” where social standing has no effect on vulnerability (8). However, data shows that vulnerability to COVID-19 is not identical across American society, but reflects stark racial differences (8).

For example, in the capital city of the United States, Washington D.C., African Americans represent approximately 46% of the population but make up 75% of COVID-19 deaths (8). We should note that COVID-19 has had a significant impact on ethnic minority and racial populations in the United States (9), but the role of economic inequities and geographic differences in these discrepancies have not been adequately studied (9). Previous studies have shown that non-white race, male sex, older age, and a preferred language other than English were associated with higher infection rates for COVID-19 (10). Among those infected, individual race, sex, and age were associated with increased likelihood of hospitalization (10).

Moreover, by November 2020, more than two hundred and fifty thousand people died and more than ten million had been infected with COVID-19 in the United States (11). However, by late November of 2020 many pharmaceutical companies announced that the results of the vaccine trials showed high efficacy for the majority of the trial individuals (11).

The coronavirus pandemic has caused a huge number of challenges to the global public health system as well as the global economy (12). The entire world was badly damaged in the early months of the pandemic (13–15). Additionally, it has deeply affected the United States, China, and Europe in several life sectors such as social, public health and economy (3).

It is worth mentioning that the economic crisis initiated by the COVID-19 pandemic was unprecedented in its scale (12). According to the U.S. Department of Labor, the unemployment rate reached 14.7% in April 2020, and the total value of exports of all the 50 states decreased by 29.8%, from \$414.95 billion in the second quarter of 2019 to \$291.47 billion in the second quarter of 2020 (12). It is also important to mention that the unemployment rate declined to 10.2% in July 2020 (12).

In the United States, the coronavirus 2019 (COVID-19) has excessively affected underserved groups, and ethnic/racial minorities, especially Native American, Latin American, and African American (16,17). Also, COVID-19 has had a significant impact on ethnic minorities and racial populations in the United States (9), but the role of economic inequities and geographic differences in these discrepancies have not been adequately studied (9). The stark differences emphasize economic, environmental, political, and social contexts that predate the pandemic (16,17).

In this study, we describe potential factors that contribute to the COVID-19 differences in Boone County, Missouri before and after the release of the vaccine from both social determinants and demographic feature perspectives. In June 2020, the Centers for Disease Control and Prevention (CDC) reported that 33.8%

of COVID-19 cases in the United States were Latin Americans, and 21.8% were African Americans (18). These groups comprise only 13% and 18% of the US population, respectively (16,17).

Previous studies have shown that non-white race, male sex, older age, and a preferred language other than English were associated with higher infection rates for COVID-19 (10). Among those infected, individual race, sex, and age were associated with an increased likelihood of hospitalization (10).

1.2 Contribution of the Thesis and Study Hypothesis

In our study, we analyzed the associations of COVID-19 testing and positivity rates with demographic features such as age, religion, race, and sex, for patients in Boone County, Missouri. We hypothesized that minority race/ethnicity, male sex, and any kind of religious faith are associated with higher COVID-19 positivity rates.

Therefore, our study analyzed the associations of COVID-19 testing and positivity rates with demographic features such as age, religion, race, and sex, for patients in Boone County, Missouri. We also hypothesized that the positivity rates will decrease after the vaccine release and after the vaccine boosters.

On the other hand, the positivity rates will increase during the delta and the omicron variants epochs. Our study analyzed the demographic features in many different periods from March 15, 2020, until December 2, 2021. Within these 22 months (March 2020 - December 2021), five study epochs affected the positivity rates for the individuals in Boone County, Missouri.

The first and second study epochs are the periods before and after the release of the vaccine (the vaccine got released in November 2020). The third study epoch is before and after the appearance of the delta variant (June 2021). The fourth study epoch is before and after the vaccine booster shot of the (September 2021). Finally, the fifth and last study epoch is before and after the appearance of the omicron variant (late November 2021).

In summary, we hypothesized that minority race/ethnicity, male sex, any kind of religious faith and older people have higher positivity rates before and after the vaccine release and before and after the vaccine boosters. Also, minority race/ethnicity, male sex, any kind of religious faith (Theist), and older people will have higher positivity rates during the delta and the omicron variants epochs.

Chapter 2: Methods

2.1 Dataset

2.1.1 Localized COVID-19 Test Data

Boone County, Missouri consists of 11 primary cities and towns: Columbia, Ashland, Centralia, Hallsville, Harrisburg, Sturgeon, Hartsburg, Rocheport, McBaine, Huntsdale, and Pierpont. Boone County is part of the Mid-Missouri geographic region within the Midwestern U.S. and is home to 180,463 residents (19).

Based on data from the 2019 U.S. Census Bureau, most of the Boone County population identify as non-Hispanic White (79%), followed by Black or African American 9%, with all other races/ethnicities making up the remaining 12%. The county has 93,841 females (52%) and 86,622 males (48%) (20). The percentage of the population that affiliates with any religion is 39.4%, and 60.6% of the Boone County population are not religious (21).

We used data from the Cerner Electronic Health Record (EHR) from the University of Missouri Hospital and Clinics in the Mid-Missouri area on individuals who were tested for COVID-19 between March 2020 and December 2021. The data includes the demographic information for 236,809 patients.

We combined the races and ethnicities of Other, Some-Other-Race, Unknown, Unable-to-Acquire, Refused or Declined, Hispanic, Asian, Native Hawaiian, and American Indian (i.e., all except “non-Hispanic White” and “non-Hispanic Black or

African American” into one category called “All Other”. We combined the following marital status categories: “Married” with “Life Partner”, and “Divorced” with “Separated”.

We combined all religious identifications in the population sample (Lutheran, Baptist, Catholic, Methodist, Latter Day Saints, Protestant, Amish, Episcopalian, Disciples of Christ, Presbyterian, Church of Christ, Pentecostal, Assembly of God, United Church of Christ, Nazarene, Community of Christ, Church of God, Christian Science, Salvation Army, Adventist, Mennonite, Yahweh, Mormon, Unitarian/Universalist, Jehovah's Witness, Islam, Bahai, Jewish, Hindu, Christian, Muslim, and Other) into one category called “Theist”, and combined “Atheist”, “Agnostic” and “Nothing in Particular” with “NONE” (22,23). For all these features (race/ethnicity, marital status, and religion), we combined all “Unknown” missing values, nan, or Null into one category called “Unanswered”. We only counted one positive test for each individual to avoid redundant data.

The positivity rate was calculated by taking the number of the unique individuals with one or more positive tests divided by the number of unique individuals in our testing data. The total number of tested individuals from Boone County was 74,769. The total number of individuals with positive tests was 14,637, and the total number of individuals without positive tests was 60,132. This gives a 19.6% positivity rate in the testing population. Based on state government reporting, the current number of positive cases in Boone County is 36,135 which gives 11.73% positivity rate of the county’s population (19).

Table 1 shows the three demographic features that were used in this study. The first demographic feature studied was sex. The number of females in Boone County is 93,841 (52%), and the number of males is 86,622 (48%). The number of females in the tested individuals was 41,354 (55.3%) and the number of males was 33,415 (44.7%). In the tested individuals that were positive for COVID, 7,890 (53.9%) were females and 6,747 (46.1%) were males.

The second demographic feature is the race/ethnicity. In Boone County there are 142,566 White people (79%), 16,242 Black or African American people (9%), and 21,655 people of all other races/ethnicities (12%). The testing population that identified as White made up 78.1%, Black or African Americans made up 12.8%, and all other races/ethnicities accounted for 9.1%. In Boone County, 69.9% of White people tested positive for COVID-19 compared to 77.83% of all tested individual. There were 11.5% of the Black or African Americans who tested positive compared to 13.74% in the tested individuals, and 18.5% out of all other races/ethnicities in Boone County tested positive compared to 8.42% in the tested individuals.

The third and last demographic feature is religion. In Boone County, 71,102 people (39.4%) affiliate with a religion (theist) and 109,361 people (60.6%) are not affiliated with any religion belief (NONE). Of the tested individuals, 28,644 (38.31%) were theist, 31,913 (42.68%) were "NONE", and 14,212 (19%) did not give an answer about their religion. Also, 38.7% of the theist individuals, 42.4% of the "NONE", and 18.9% of the unanswered individuals tested positive for COVID-19.

Table 1. Boone County, Missouri COVID-19 Demographic Statistics.

	Tested	COVID Positive	Population	Current Positive
Cohort Size: n (%)	74,769	14,637 (19.6%)	180,463	36,135 (11.73%)
Gender: n (%)				
Female	41,354 (55.3%)	7,890 (53.9%)	93,841 (52%)	19,400 (53.68%)
Male	33,415 (44.7%)	6,747 (46.1%)	86,622 (48%)	16,735 (46.32%)
Race: n (%)				
White	58,392 (78.1%)	11,392 (77.83%)	142,566 (79%)	25,259 (69.9%)
Black or African	9,598 (12.8%)	2,012 (13.74%)	16,242 (9%)	4,163 (11.5%)
All Other	6,779 (9.1%)	1,233 (8.42%)	21,655 (12%)	6,713 (18.5%)
Religion: n (%)				
Theist (With Religion)	28,644 (38.31%)	5,665 (38.7%)	71,102 (39.40%)	N/A
NONE (No Religion)	31,913 (42.68%)	6,207 (42.4%)	109,361 (60.60%)	N/A
Unanswered	14,212 (19%)	2,765 (18.9%)	0.00 (0%)	N/A

2.1.2 Boone County's COVID-19 Positivity Rates by Demographic

Features

Table 2. Terms definition and their acronyms used to construct the equations for calculating the positivity rates needed for the time-trend Figures 6, 7, 8 and 10.

Term Definitions					
PR	Positive Rate	W_{pr}	White Positive Rate	N_{pr}	"None" Positive Rate
TP	Total Positive	W_p	White Positive	N_p	"None" Positive
TT	Total Tested	W_{tt}	White Total Tested	N_{tt}	"None" 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

The positivity rate was calculated by taking the number of the total positive tests divided by the total number of tested individuals:

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

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.

Table 3 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.

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 were 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%) "NONE", 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 "NONE" 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.

Table 3. Boone County, Missouri COVID-19 demographic statistics for tested individuals, and positive cases before and after the vaccine release.

	Total Tested	COVID-19 Positive Cases	Positive Cases Before Vaccine Release	Positive Cases After Vaccine Release
Cohort Size: n (%)	148,328	15,903 (10.72%)	8,411	7,492
Gender: n (%)				
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: n (%)				
White	116,200 (78.33%)	12,261 (77.1%)	6,637 (78.9%)	5,624 (75.07%)
Black or African	19,981 (13.47%)	2,284 (14.36%)	1,097 (13.05%)	1,187 (15.84%)
All Other	12,147 (8.2%)	1,358 (8.54%)	677 (8.05%)	681 (9.09%)
Religion: n (%)				
Theist (With Religion)	60,900 (41.05%)	6,213 (39.07%)	3,364 (40%)	2,849 (38.03%)
NONE (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%)

2.2 Statistical Exploration

The descriptive statistics for the age of the tested individuals is 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 are calculated using the following formula:

$$df = (r - 1)(c - 1) \quad (2)$$

where r is the number of rows and c is the number of columns. A two sided alpha level of 0.05 was used to determine statistical significance in all hypothesis tests. In addition, the Chi-Square was calculated using R programming language following this equation:

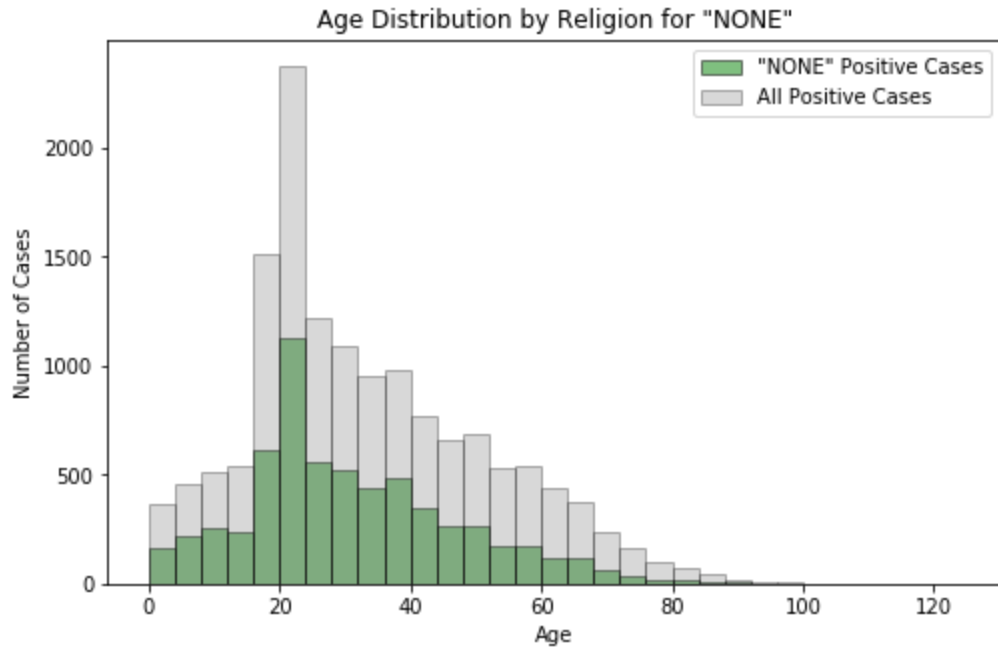
$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (3)$$

Where c is the degree of freedom, O_i is the observed value, and E_i is the expected value. χ^2 (degrees of freedom, N = sample size) = Chi-square statistic value, p = p value. 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.

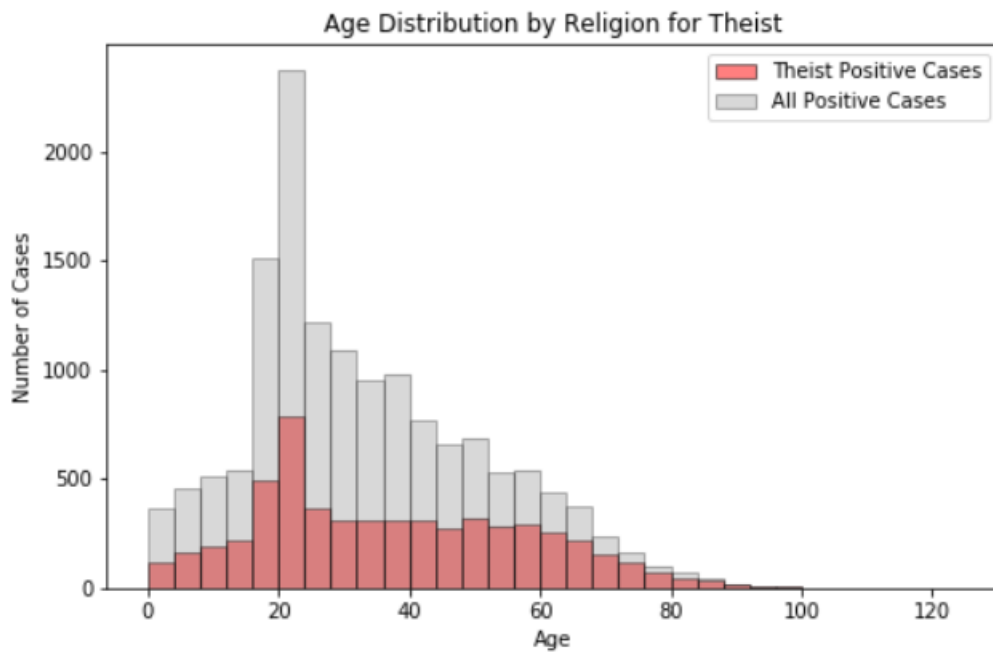
Second, a Chi-Square Test of Independence was performed to assess the relationship between COVID-19 and race. There was a significant relationship between the two variables, Chi-Square (2, 74769) = 20.18, p = .00004158. P-value is less than 0.05 which means that it is very significant.

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.

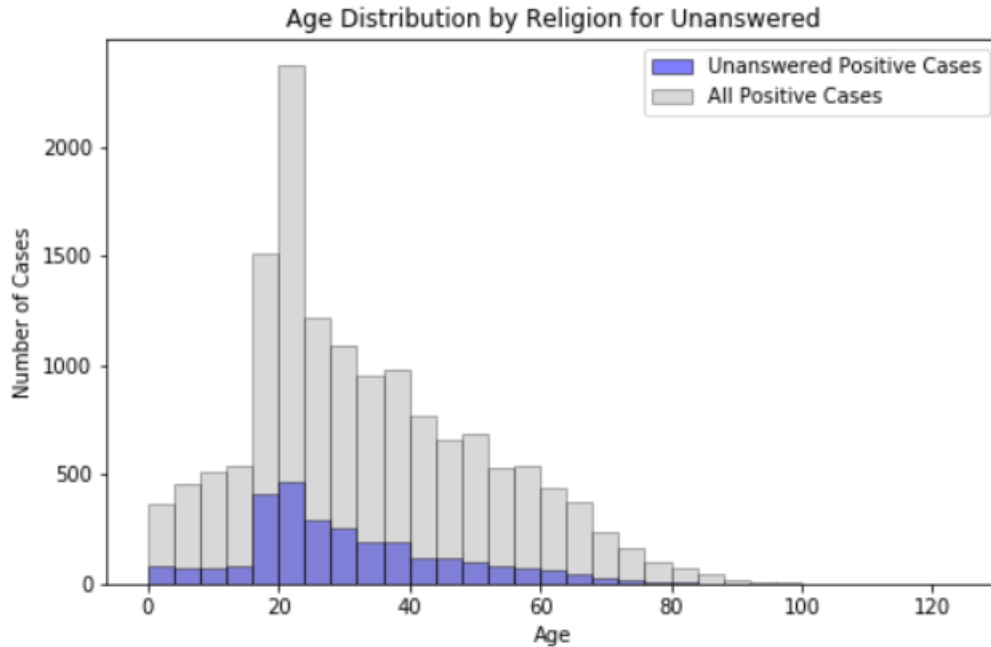
Figure 1 shows the histogram for the age distribution by religion for (a) "NONE", (b) theists and (c) unanswered. The "NONE" and unanswered histograms are skewed to the left towards the younger generation. There were more younger individuals of the "NONE" and unanswered who tested positive for COVID compared to older generation. On the other hand, the younger and older theist individuals had tested positive on same rate except for some of the younger (ages 16-24) individuals who tested positive for COVID at a higher rate.



(a)



(b)

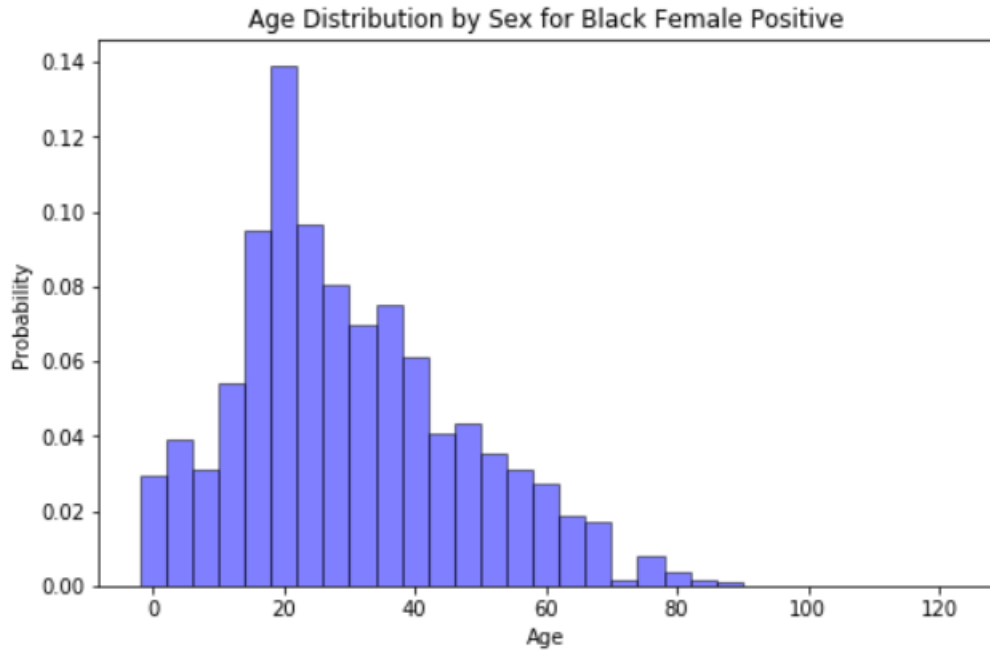


(c)

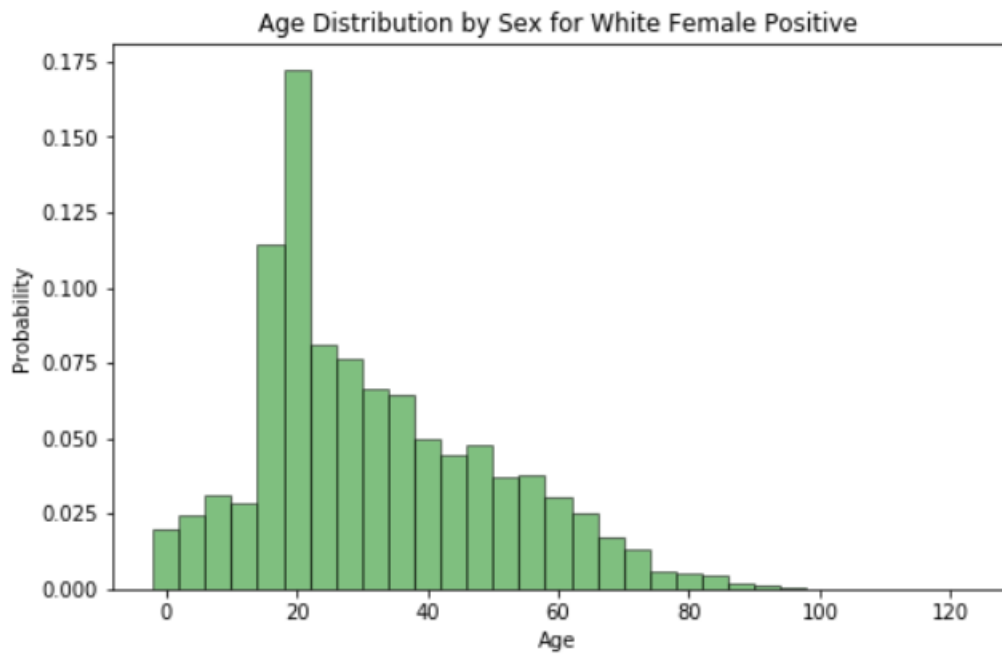
Figure 1. Histogram for the Age Distribution by Religion (a) for “None” showing that younger (ages 16-36) individuals were testing positive for COVID more than older individuals, (b) for Theists showing that younger (ages 16-24) were testing positive for COVID more than older individuals and (c) for Unanswered showing a slightly peak in the younger generation (ages 16-24). The gray color shows all the positive cases in the tested population.

Figure 2 probability mass function (PMF), i.e., histogram normalized to area 1.0, for the age distribution by sex (a) for Black or African American females showing that younger (ages 16-44) individuals were testing positive for COVID more than older individuals, (b) for White females showing that younger (ages 16-28) were testing positive for COVID more than older individuals.

Both histograms clearly show that Black or African American females are more likely to test COVID positive more than the White females. Black or African American females tend to test COVID positive at higher rate than the White females especially in the ages of 0-12 and between 32-44.



(a)



(b)

Figure 2. Histogram for the Age Distribution by Sex (a) for Black or African American females showing that younger (ages 16-44) individuals were testing positive for COVID more than older individuals, (b) for White females showing that younger (ages 16-28) were testing positive for COVID more than older individuals. Both histograms clearly show that Black or African American females are more likely to test COVID positive than the White females.

2.3 Time Trend Analysis Based on the Demographic Features

Table 4 clearly identifies the five study epochs during the COVID-19 pandemic over the 22 months 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 represent 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 represent the first recorded case of the delta variant in Boone County.

In addition, the “vaccine boosters” is 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 (November 20, 2021) in Figures 6, 7, 8, 10 and 11 represents the appearance of the omicron variant in Boone County.

Table 4. 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

Chapter 3: Results

3.1 Bivariant Analysis

Heatmaps were computed from two-way delta tables to highlight our study findings. The “red” color represents a higher possibility of testing positive for COVID (higher delta percentage values), and the “blue” color represents a lower possibility of testing positive for COVID (lower delta percentage values).

Numbers were computed by calculating the difference of the percentage as deltas between the individuals who tested positive and the entire tested individuals (positive tested minus all tested). Those tables were computed to study the association between the demographic features of sex, race/ethnicity, and religion for tested individuals and their positivity rates.

Figure 3 represents a two-way delta table for sex and race/ethnicity, showing a large disparity between White females versus White males, with males (red square, 0.012) significantly more likely to test COVID positive than their female (blue square, -0.015) counterparts.

On the other hand, Black or African American females are more likely to test positive for COVID comparing to Black or African American males. Also, the All-Other races/ethnicities males are more likely to test positive for COVID than All-Other races/ethnicities females.

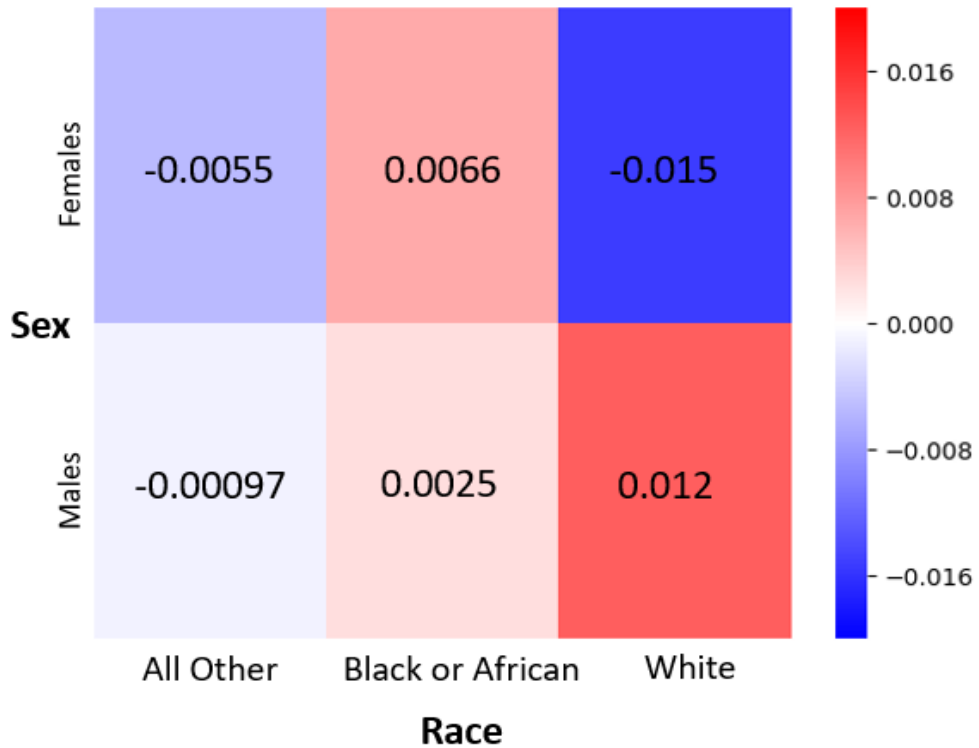


Figure 3. Two-way Delta Table for Sex and Race/Ethnicity, showing a large disparity between White females versus White males, with males significantly more likely to test COVID positive than their female counterparts.

Figure 4 represents a two-way delta table for sex and religion, showing that patients who affiliated with a religious belief (theist) and unanswered males (both red squares, 0.0067) were more likely to test COVID positive than their female (blue squares, -0.0027 and -0.0079, respectively) counterparts. In addition, the “NONE” females are less likely to test positive for COVID comparing to the “NONE” males. The unanswered females are the least likely to test positive for COVID, whereas unanswered and theist males are the most likely to test positive for COVID.

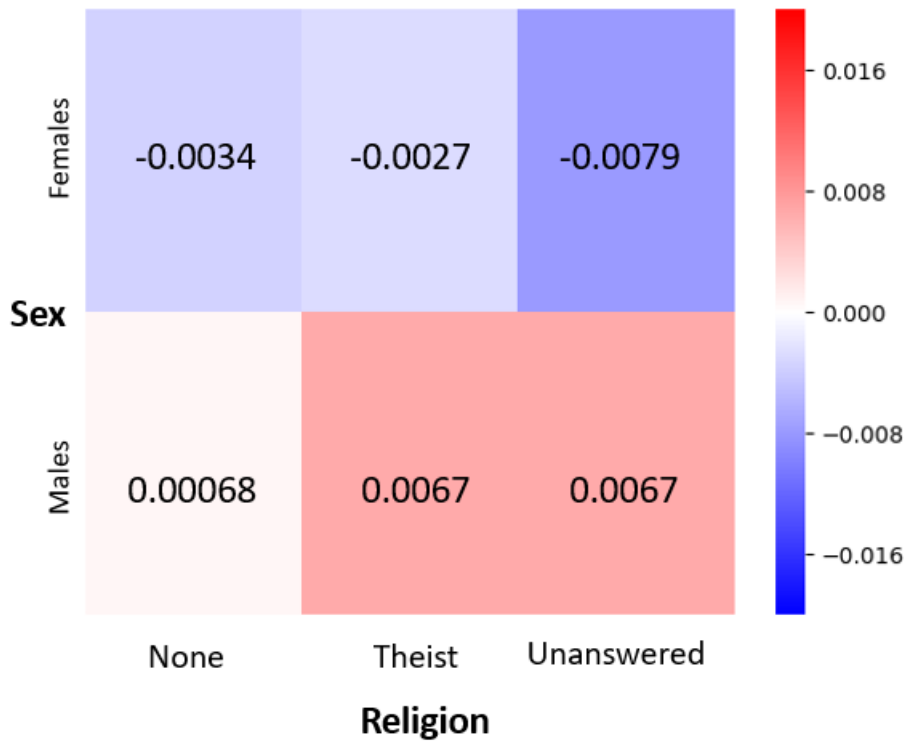


Figure 4. Two-way Delta Table for Sex and Religion, showing theist and unanswered males more likely to test COVID positive than their female counterparts.

Figure 5 represents a two-way delta table for religion and race, showing a large disparity between White “NONE” versus Black or African American “NONE”, with Black or African American “NONE” (red square, 0.0072) significantly more likely to test COVID positive than their White (blue square, -0.0075) counterparts. Also, Black, or African American theists are more likely to test positive for COVID compared to White theists, but the White unanswered are more likely to test positive than the Black or African American unanswered. Additionally, it clearly shows that “NONE” of All-Other race/ethnicity (light blue square, -0.0024) were more likely to test COVID positive than to White, “NONE” (dark blue square, -

0.0075). Also, Black, or African American “NONE” (red square, 0.0072) were more likely to test COVID positive than White “NONE” (dark blue square, -0.0075).

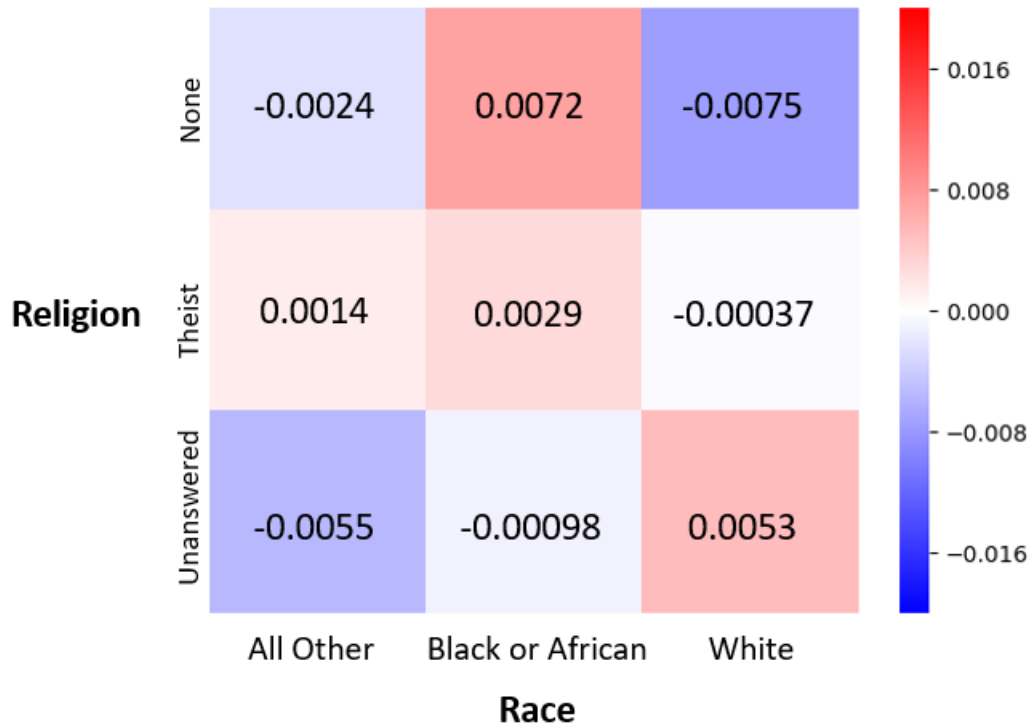


Figure 5. Two-way Delta Table for Religion and Race, showing a large disparity between White “NONE” versus Black or African American “NONE”, with Black or African American “NONE” significantly more likely to test COVID positive than their White counterparts.

3.2 Time trend analysis for all the tested individuals

Figure 6 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 scatter-plot smoothing (LOESS) to smooth out daily fluctuations in positive cases. It is worth mentioning that the positivity rate was calculated using equation 1.

From Figure 6 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 (24). Figure 6 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.

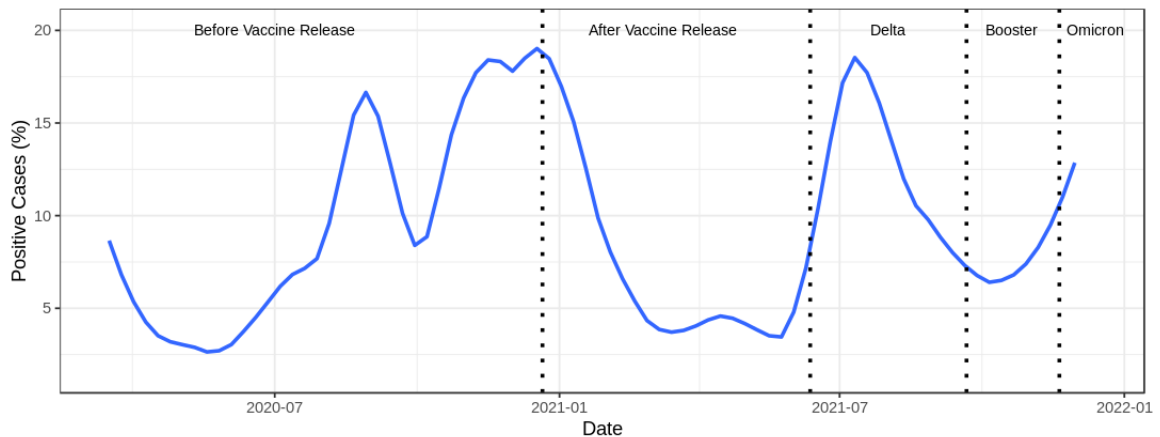


Figure 6. Trend analysis for COVID-19 positivity rate for the tested individuals in Boone County, Missouri from March 15, 2020, until December 2, 2021. The graph is divided into five major study epochs: before and after vaccine release, appearance of delta variant, vaccine boosters, and the appearance of the omicron variant.

3.3 Time trend analysis for the tested individuals by sex

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

$$F_{pr} = F_p/F_{tt} \times 100 \quad (4)$$

$$M_{pr} = M_p/M_{tt} \times 100 \quad (5)$$

In addition, we conducted LOESS to smooth out the daily fluctuations in positive cases for both males and females. In Figure 7 we can notice a major decrease in the positivity rate in late December 2020 and early January 2021 for both males and females after the release of the vaccine. It is worth mentioning that females only had a higher COVID-19 positivity rate than males in the mid epoch of after the vaccine release around mid-April 2021. The positivity rates for both sexes started to increase again in June 2021 due to the appearance of the delta variant. Males had a higher positivity rate for COVID-19 than females during the delta variant crisis.

Figure 7 also shows a significant decrease in the positivity rate for both sexes in September 2021 due to the vaccine boosters. Females faced lower COVID-19 positivity rate than males during the vaccines booster. Finally, the positivity rate of COVID-19 started to increase again in late November 2021 because of the first recorded case of the omicron variant, where males seemed to have higher positivity rate than females during this epoch. The results in Figure 7 supported our hypothesis that the male sex is associated with higher COVID-19 positivity rate

before and after vaccine release, delta variant, vaccine boosters, and omicron variant.

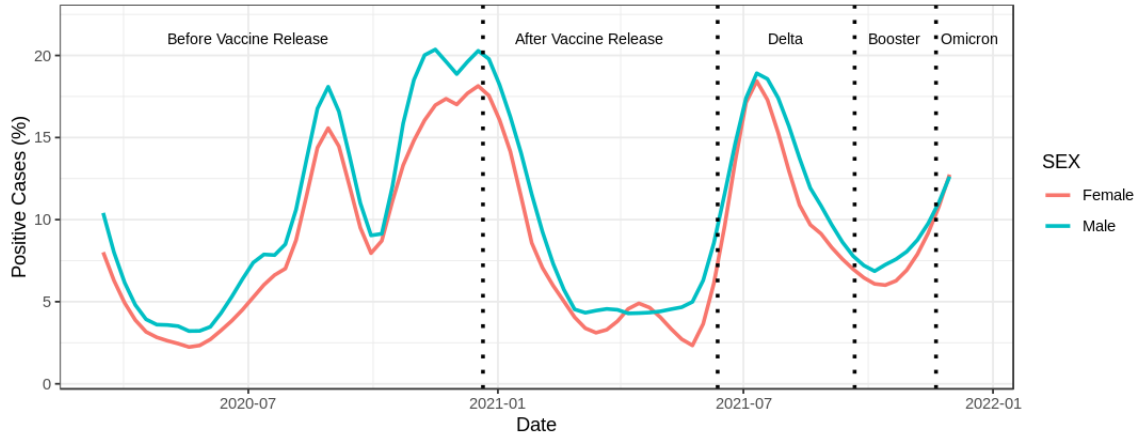


Figure 7. Trend analysis for the COVID-19 positivity rate by sex for the tested individuals in Boone County. It shows a disparity between males and females, with males associated with higher COVID-19 positivity rates than their female counterparts during all epochs. Females only had a higher COVID-19 positivity rate than males in the middle of the After Vaccine Release epoch around mid-April 2021.

3.4 Time trend analysis for the tested individuals by race/ethnicity

Figure 8 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:

$$W_{pr} = W_p / W_{tt} \times 100 \quad (6)$$

$$B_{pr} = B_p / B_{tt} \times 100 \quad (7)$$

$$AO_{pr} = (AO_p) / (AO_{tt}) \times 100 \quad (8)$$

We utilized LOESS to smooth out the daily fluctuations in positive cases for the three races/ethnicities (White, Black or African Americans, and All Other). Figure 8 clearly shows a major decrease in the COVID-19 positivity rate in late December 2020 and early January 2021 for the three races/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 Other 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 the All Other had a minimum of 0, first quartile of 16.52, median of 20, mean of 21.94, third quartile of 27.78 and maximum of 55.56. Black or African American 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.

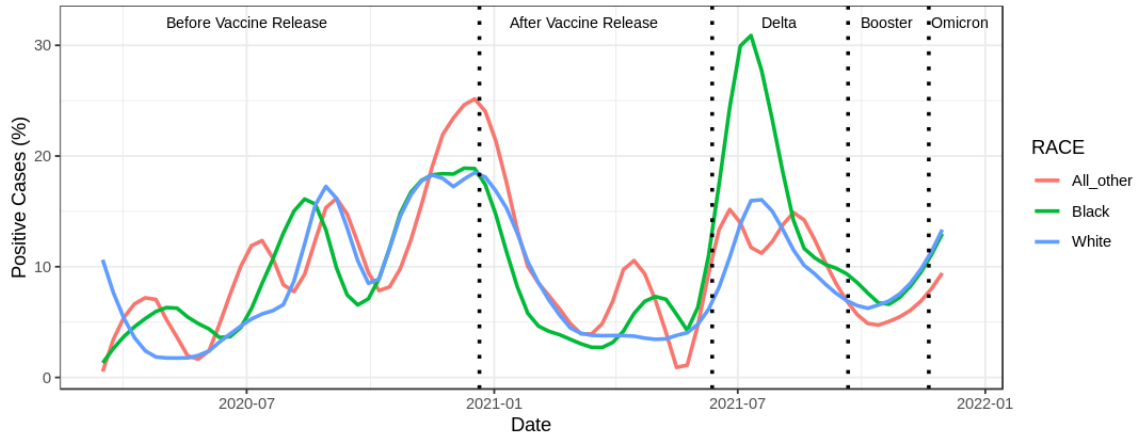


Figure 8. Trend analysis for the COVID-19 positivity rates by race for the tested individuals in Boone County. The All Other had a higher positivity rate on December 22, 2020, than White and Black or African American individuals. In Mid July 2021, Black or African Americans had a much higher COVID-19 positivity rate compared to White and All Other individuals.

The COVID-19 positivity rate for the three races/ethnicities started to increase again in June 2021 due to the appearance of the delta variant. Black or African American 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 shows 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 9 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 9 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 particular period. Black or African Americans had a huge increase in the COVID-19 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 maximum of 68.18.

During the delta epoch, All Other had a very low COVID-19 positivity rate than Black or African American 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 8 also shows a significant decrease in the positivity rates for the three races/ethnicities in September 2021 due to the booster (third vaccine shot) roll-out. Additionally, White individuals and All Other Race faced lower positivity rate 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 races/ethnicities. The results in Figure 8 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.

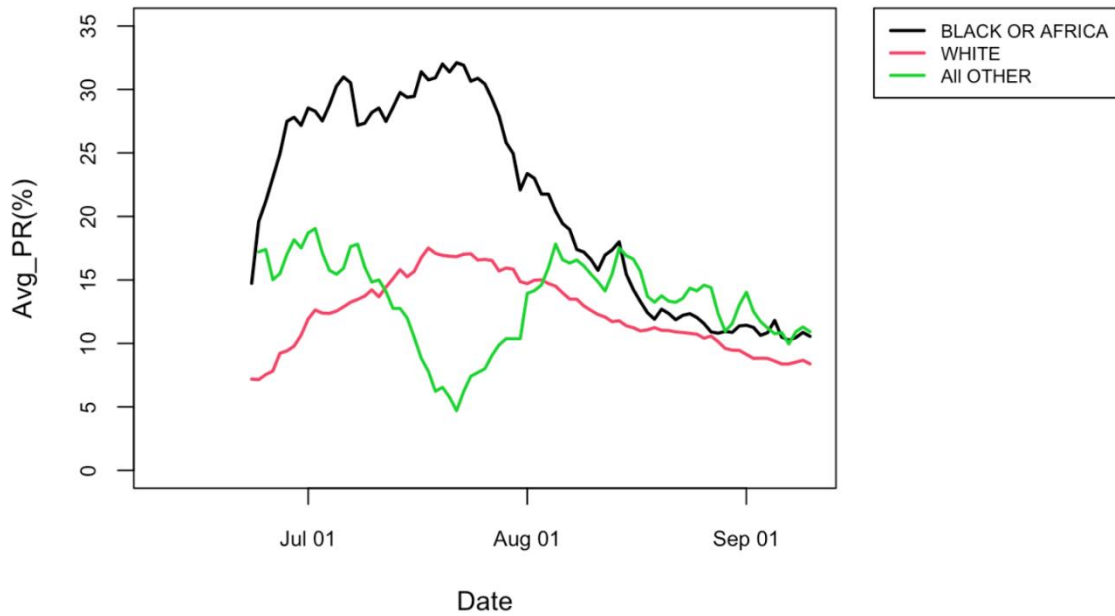


Figure 9. Delta Epoch focus on 14-day moving average by race between the period of June 10, 2021, and September 10, 2021. It shows significantly higher COVID-19 positivity rate for Black or African Americans than All Other.

3.5 Time trend analysis for the tested individuals by religion

Figure 10 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 the below equations:

$$N_{pr} = N_p / N_{tt} \times 100 \quad (9)$$

$$T_{pr} = T_p / T_{tt} \times 100 \quad (10)$$

$$U_{pr} = U_p / U_{tt} \times 100 \quad (11)$$

We used LOESS to smooth out the daily fluctuations in positive cases for the three religions (Theist, "NONE", 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 rate than "NONE" 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.

"NONE" and Theist have a very similar trend during this period. Theist had a COVID-19 positivity rate at a minimum of 0, first quartile of 8.29, median of 13.51, mean of 13.65, third quartile of 18.42, and a maximum of 34. The "NONE" individuals had a COVID-19 positivity rate at a minimum of 2.77, first quartile of 8.33, median of 12.59, mean of 12.99, third quartile of 17.02 and a maximum of 30.66.

In Figure 10 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 "NONE".

The number of 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 "NONE" followed by Unanswered and then Theist.

Figure 10 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 the 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 omicron variant.

The three of them started to increase 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 “NONE” and Unanswered individuals.

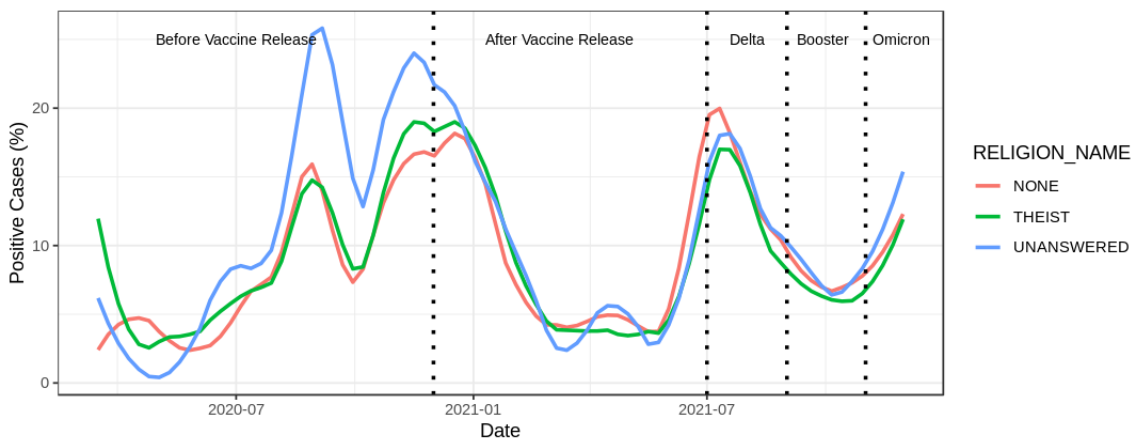


Figure 10. Trend analysis for COVID-19 positivity rate by religion for the tested individuals in Boone County. The graph shows a significant increase in the COVID-19 positivity rate for the Unanswered individuals in September and November 2020 compared to Theist and “NONE” individuals. Also, “NONE” individuals show a slightly higher COVID-19 positivity rate in early July 2021 than Theist and Unanswered individuals.

3.6 Time trend analysis for tested individuals by age

Figure 11 shows the time trend for the tested individuals by age brackets, as proposed by the Centers for Disease Control and Prevention (CDC) (18), 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+).

Figure 11 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 for 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 maximum of 50. While “0-18” age group shows a lower COVID-19 positivity rate than “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.

It clearly shows a significant 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 significant lower positivity rate during this period. Figure 11 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 delta and omicron variants crisis as well as before and after the booster shot compared to younger individuals.

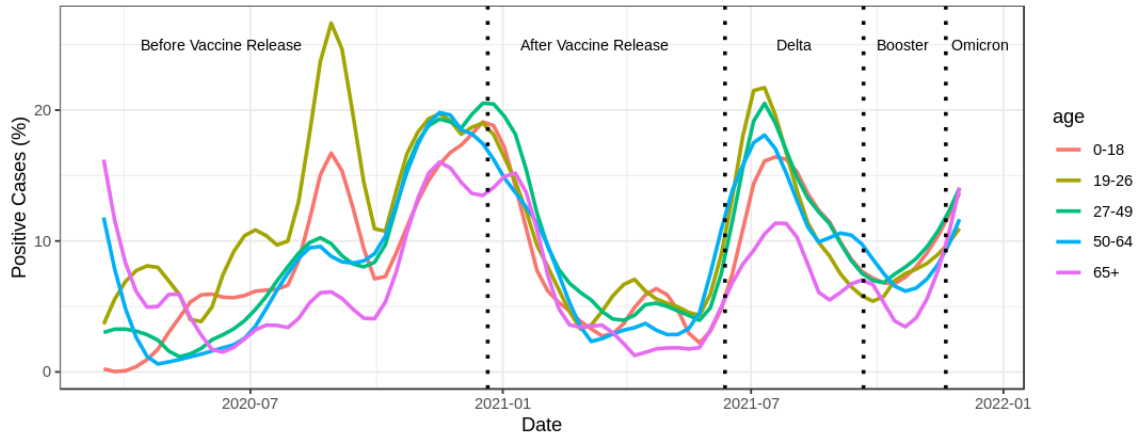


Figure 11. Trend analysis for COVID-19 positivity rate by age in Boone County, showing a large disparity in September 2020 between “19-26” and the other age groups with “19-26” having a significantly higher COVID-19 positivity rate compared to the other groups.

Chapter 4: Discussion and Limitations

4.1 Study Discussion

Table 1 is the demographic statistics to compare the population of Boone County with the tested individuals. 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 the sex, race/ethnicity and religion are very similar. We should note that the 19.6% positivity rate of the tested individuals is higher than the Boone County's positivity 11.73% rate. The reason is that we were only counting one positive test results for each unique individual and discarding the negative test results.

Boone County has a lower Black or African American percentages (9% vs. 12.8%) and positivity rate (11.5% vs. 13.74%) than the tested 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 than All-Other race/ethnicity individuals.

Table 1 shows that the percentage of people with no religion affiliation are 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 two-way delta tables 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 races/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 the “NONE” patients.

4.2 Study Limitations

There are several limitations in our study. First of all, the tests have known to have the possibility of false positives and false negatives. Second, we do not have the 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 the information about the vaccine, 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 a vaccination status information for study.

Chapter 5: Conclusion and Future Work

5.1 Conclusion

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. 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 American, and All-Other races are more likely to test positive for COVID than majority race such as White.

There was no evidence that religion was associated with the positivity rate in our study population. 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.

5.2 Future Work

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.

Additionally, our main future research objective is to use of artificial intelligence (AI) and remote sensing to identify features in satellite images that are associated with population and public health. Under **Dr. Grant Scott's** supervision and by leveraging the wealth, knowledge, and abilities of expertise in geospatial epidemiology at the University of Missouri and by collaborating with **Dr. Lincoln Sheets** and his lab team at the school of medicine and public health, we will be able to develop two test cases for this new technology to demonstrate its usefulness in predicting vector-borne, communicable, and non-communicable diseases. Lastly, our future work will focus on pursuing the following aims:

Aim 1: To design and train deep convolutional neural networks (DCNNs) to identify geospatial and visual characteristics in remote sensing and satellite imaging data.

Aim 2: To apply our methods and techniques developed for communicable diseases (e.g., COVID-19) to non-communicable diseases (e.g., obesity), and vector-borne diseases (e.g., malaria) to research disease rates in other geographic regions such as the middle east and Africa.

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