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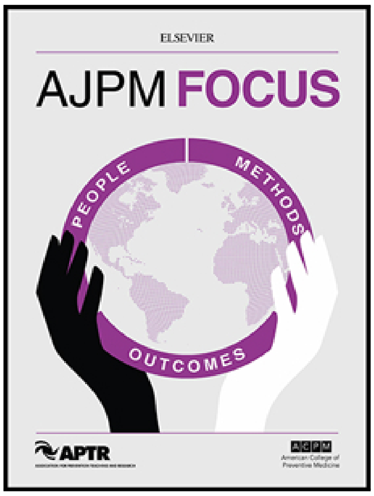


# Spatial and Temporal Trends in Travel for COVID-19 Vaccinations

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**Highlights**

- Disparities in distances people traveled for vaccinations by demographics exist.
- Males and White people traveled longer distances for vaccination appointments.
- Travel distances of over 10 miles for vaccination likely required motorized transportation.

**Spatial and Temporal Trends in Travel for COVID-19 Vaccinations**

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**ABSTRACT**

**Introduction:** Understanding spatial and temporal trends in travel for COVID-19 vaccinations by key demographic characteristics (i.e., gender, race, age) is important for ensuring equitable access to and increasing distribution efficiency of vaccines and other health services. The aim of this study is to examine trends in travel distance for COVID-19 vaccinations over the course of the vaccination rollout in North Carolina.

**Methods:** Data were collected using electronic medical records of individuals who had first- or single-dose COVID-19 vaccination appointments through UNC Health between December 15, 2020, and August 31, 2021 (N = 204,718). Travel distances to appointments were calculated using the Euclidean distance from individuals' home ZIP code centroids to clinic addresses. Descriptive statistics and multivariable regression models with individuals' home ZIP codes incorporated as fixed effects were used to examine differences in travel distances by gender, race, and age.

**Results:** Males and White individuals traveled significantly farther for vaccination appointments throughout the vaccination rollout. On average, females traveled 14. 4 miles, 3.5% shorter distances than males; Black individuals traveled 13.6 miles, 10.0% shorter distances than White individuals; and people aged 65 and older traveled 14.5 miles, 2.6% longer distances than younger people living in the same ZIP code.

**Conclusions:** Controlling for socioeconomic status and spatial proximity to vaccination clinics at the ZIP code level, males and White individuals traveled longer distances for vaccination appointments, demonstrating more ability to travel for vaccinations. Results indicate a need to consider differential ability to travel to vaccinations by key demographic characteristics in COVID-19 vaccination programs and future mass health service delivery efforts.

***Keywords:*** COVID-19 Vaccination, Travel Distance; Disparities; North Carolina

## INTRODUCTION

Historical and well-documented health disparities in the U.S. have been compounded by starkly disproportionate rates of COVID-19 morbidity and mortality among people of color.[1–3] COVID-19 vaccination rates have also varied by race; Black individuals have been less likely than their White counterparts to receive a vaccine throughout the vaccination rollout.[4] Though Black individuals have been found to live in closer proximity to COVID-19 testing and vaccination sites, less car access and other barriers may keep them from getting vaccinated at comparable rates to White individuals.[1,5–7] In addition to race, age and gender are known to influence COVID-19 risk as well as vaccination access and uptake.[8,9]

This study aims to examine spatial and temporal trends in travel for COVID-19 vaccination appointments among a sample of individuals in a large North Carolina health system between December 2020 and August 2021. Understanding patterns in travel for COVID-19 vaccinations over vaccination rollout phases, across space, and by key demographic characteristics (i.e., gender, race, age) is important for moving toward more equitable access to vaccines and other health services.



## MATERIAL AND METHODS

The Carolina Data Warehouse for Health (CDW-H), a central data repository containing clinical, research, and administrative data sourced from the UNC Health system, provided the data for this study. Data were collected using electronic medical records of individuals who had first- or single-dose COVID-19 vaccination appointments at UNC Health vaccine clinics between

December 15, 2020, and August 31, 2021. The UNC Health system operates about 113 unique clinics located across 36 ZIP codes, around 17% of all vaccination clinics. Individuals' home ZIP code, gender, race, and age were included in the data along with vaccination appointment location (clinic name and address) and date. The research study protocol was reviewed and approved by the Institutional Review Board at the University of North Carolina at Chapel Hill. The data does not record any socio-economic status (SES) measures, such as ethnicity, income, and car ownership at the individual level that may also influence the vaccination access. However, we incorporate home ZIP-code level fixed effects as proxy measures of SES at the neighborhood level to control for potential covariates associated with living in common neighborhoods, such as availability of vaccination clinics, proximity to vaccination clinics, social-economic characteristics. Multivariable regression models of the natural logarithm of travel distance ($\log D_{ij}$) assessed differences by gender, race, and age ($X_{ij}$) controlling for unobserved ZIP-code level factors ($Z_j$), including SES and spatial proximity to vaccination sites. For every one-unit changes in the independent variable, our dependent variable changes by (exp(β)-1)*100.

$$\log D_{ij} = \beta_0 X_{ij} + \beta_1 Z_j + \mu_{ij}$$

Travel distances to appointments were calculated using the Euclidean distance (in miles) from individuals' (i) home ZIP code (j) centroids to vaccination clinic addresses. Mean travel distances and distances representing the 5$^{th}$ and 95$^{th}$ percentiles were calculated by vaccine eligibility phase and individual demographics. Phases were determined by vaccination eligibility in North Carolina:

1. Phase 1: December 15, 2020–January 14, 2021; Health care workers treating and caring for COVID patients and long-term care facility staff and residents eligible for the vaccine.
2. Phase 2: January 15–March 1, 2021; Adults aged 65 years and older eligible.
3. Phase 3: March 2–April 6, 2021; Frontline essential workers eligible beginning March 2, and adults at high risk due to underlying conditions eligible beginning March 15.
4. Phase 4: April 7–August 31, 2021; Everyone aged 16 years and older eligible.

In our analysis, we excluded individuals aged under 16 and people living outside of North Carolina. We also excluded outliers who traveled in the 99$^{th}$ percentile of distances. This reduced the sample from 214,454 to 204,718 individuals for the descriptive statistics. The sample size for the regression models was 197,018 individuals after dropping observations missing demographic information and further excluding 270 ZIP codes with fewer than 10 observations.

**RESULTS**

204,718 individuals were included in the study sample, representing approximately 3.7% of the state's population aged 16-plus vaccinated against COVID-19 between December 2020 and August 2021.[10] 57.9% identified as male, 42.0% as female. 70.8% of individuals identified their race as White or Caucasian ("White"), 14.3% as Black or African American ("Black"), 5.5% as Asian ("Asian"), and 6.1% as another race ("Other"). 64.5% were aged 16–64 years; 35.5% were aged 65 years and older. Recent Census estimates suggest 70.6% of North Carolina residents identify as White, 22.2% as Black or African American, and 3.2% as Asian; 16.7% of North Carolina's population is aged 65 and older.[11]

Males and females traveled mean distances of 15.0 and 14.4 miles, respectively, for vaccination appointments (**Table 1**). Males consistently traveled farther than females throughout all phases of the vaccination rollout. White individuals had a longer mean travel distance (14.9 miles) than individuals of other races; Black individuals had the shortest mean travel distance (13.6 miles). Of note, males and White individuals who traveled in the 95$^{th}$ percentile, or top 5% of distances for vaccination appointments, traveled significantly longer distances—49.1 miles and 47.7 miles, respectively—than counterpart females and Black individuals, who respectively traveled 44.3 miles and 38.8 miles. People aged 25–44 had the longest mean travel distance (15.4 miles), and those aged 16–64 traveled longer mean distances than those aged 65 and older in Phases 2–4. Generally, mean travel distances were shorter for individuals living in ZIP codes that contained or were located near a vaccination clinic (**Figure 1**).

Models show significant variation in travel distances by gender, race, and age (**Table 2**). Females traveled 3.5% shorter distances, on average, than males living in the same home ZIP code with common socioeconomic status and spatial proximity to vaccination clinics. Black individuals traveled 10.0% shorter distances than White individuals. People aged 65 and older traveled 2.6% longer distances than younger people.

**DISCUSSION**

Results point to disparities in distances people traveled for COVID-19 vaccinations by key demographic characteristics. Males and White individuals traveled significantly longer distances for vaccination appointments throughout all phases of the vaccination rollout; females and Black individuals traveled significantly shorter distances. These gender and racial disparities persist even when controlling for individuals' home ZIP codes, which reflect their spatial proximity to vaccination clinics and SES at the ZIP code level. Accordingly, the longer travel distances of males and White individuals observed in this study do not reflect more spatial proximity to vaccination sites, but rather demonstrate greater ability to travel longer distances to access vaccination sites where appointments are available, perhaps due to more car access.

Though mean travel distances decreased over the course of the vaccination rollout, distances were still long enough (>10 miles) that travel for vaccination appointments likely required motorized transportation. Expanding vaccination sites and providing transportation for people that lack car access could promote more equitable vaccine distribution and uptake.

**Limitations**

This study has several limitations that should be addressed in future studies. First, this study was limited by the resolution of individuals' home location information, as trip origins were the same for all individuals with common home ZIP codes regardless of where they lived within a ZIP code. Second, data was collected for individuals vaccinated in one North Carolina health system (UNC Health); accessing and analyzing data for individuals vaccinated through other health systems and at more vaccination sites could allow for more generalizable results. Third, we do not measure the SES and vaccination hesitance at the individual level. Future studies to use self-administration survey with individual-level detailed data could offer more insights on the variation of vaccination access.

## CONCLUSION

Controlling for socioeconomic status and spatial proximity to vaccination clinics at the ZIP code level, males and White individuals traveled longer distances for COVID-19 vaccination appointments, evidencing more ability to travel for vaccinations. Results indicate a need to consider differential ability to travel to vaccinations by key demographic characteristics when planning and designing COVID-19 vaccination programs and future mass health service delivery efforts.

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This work was sponsored by a contract from the Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE), a Regional University Transportation Center sponsored by a grant from the US Department of Transportation's University Transportation Centers Program. We also acknowledge the assistance of the NC Translational and Clinical Sciences (NC TraCS) Institute for accessing the study data, which is supported by the National Center for Advancing Translational Sciences (NCATS), National Institutes of Health, through Grant Award Number UL1TR002489.

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**Table 1.** Mean travel distances and percentage of individuals vaccinated overall and by phase of the vaccination rollout broken down by individuals' gender, race, and age group. 5th and 95th percentile travel distances also presented overall. All distances reported in miles.

| | Overall | | | | | Phase 1 | | Phase 2 | | Phase 3 | | Phase 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | Mean (SD) | 5th | 95th | % | Mean (SD) | % | Mean (SD) | % | Mean (SD) | % | Mean (SD) |
| Gender[a] | | | | | | | | | | | | | |
| Male | 85,994 | 42.0 | 15.0 (15.5) | 2.4 | 49.1 | 10.3 | 14.0 (14.3) | 34.9 | 15.9 (16.0) | 35.5 | 16.1 (16.7) | 19.3 | 11.9(11.9) |
| Female | 118,610 | 57.9 | 14.4 (14.5) | 2.3 | 44.3 | 14.6 | 13.8 (12.8) | 40.0 | 15.2 (15.1) | 29.4 | 15.1 (15.8) | 15.9 | 11.8 (11.5) |
| | | | *** | | | | | | *** | | *** | | |
| Race[b] | | | | | | | | | | | | | |
| White | 144,746 | 70.7 | 14.9 (15.2) | 2.4 | 47.7 | 13.2 | 13.6 (13.1) | 41.8 | 15.4 (15.5) | 31.0 | 16.1(16.9) | 13.9 | 11.7 (11.3) |
| Black | 29,428 | 14.4 | 13.6 (13.0) | 1.8 | 38.8 | 7.8 | 14.4 (11.8) | 30.6 | 14.0 (13.4) | 35.1 | 13.8 (13.2) | 26.5 | 12.8 (12.7) |
| Asian | 11,386 | 5.6 | 13.8(15.5) | 1.5 | 49.1 | 9.3 | 12.8 (12.7) | 19.7 | 16.0 (17.1) | 45.5 | 15.7 (17.4) | 25.5 | 9.3 (9.6) |
| Other | 12,448 | 6.1 | 14.3 (14.4) | 1.9 | 43.5 | 9.6 | 13.9 (13.0) | 19.7 | 17.3 (17.1) | 37.0 | 14.4 (14.7) | 33.7 | 12.7 (12.7) |
| | | | *** | | | | ** | | *** | | *** | | *** |
| Age group | | | | | | | | | | | | | |
| 16-24 | 16,122 | 7.9 | 14.4(16.2) | 2.4 | 50.2 | 5.0 | 16.2 (17.8) | 9.7 | 17.5(19.9) | 41.1 | 16.6 (18.7) | 44.2 | 11.5(11.5) |
| 25-44 | 54,937 | 26.8 | 15.4(15.4) | 2.4 | 48.4 | 17.6 | 13.3 (12.0) | 18.1 | 16.3(16.0) | 41.0 | 17.5(17.7) | 23.3 | 12.4(12.0) |
| 45-64 | 60,950 | 29.8 | 14.2(14.2) | 2.3 | 41.0 | 12.9 | 13.5 (11.7) | 18.2 | 15.6 (15.1) | 48.2 | 15.0 (15.4) | 20.8 | 11.8 (11.6) |
| 65+ | 72,709 | 35.5 | 14.5(14.8) | 2.3 | 46.8 | 10.8 | 14.6 (15.5) | 75.6 | 15.2 (15.2) | 9.6 | 10.7 (10.4) | 4.0 | 10.3 (10.6) |
| | | | *** | | | | *** | | *** | | *** | | *** |

Notes: [a]114 missing for gender; [b]6,710 missing for race; T-test/ANOVA: *** P<0.001; ** p<0.01; * P<0.05

**Table 2.** Multivariable Model results with home ZIP-code level fixed effects.

| | Overall | | | Phase 1 | | | Phase 2 | | | Phase 3 | | | Phase 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Est. | Exp (Est.) | *P*-value | Est. | Exp (Est.) | *P*-value | Est. | Exp (Est.) | *P*-value | Est. | Exp (Est.) | *P*-value | Est. | Exp (Est.) | *P*-value |
| Gender (ref: Male) | | | | | | | | | | | | | | | |
| Female | -0.04 | 0.97 | <0.001 | -0.03 | 0.97 | <0.001 | -0.05 | 0.96 | <0.001 | -0.04 | 0.96 | <0.001 | -0.02 | 0.98 | <0.001 |
| Race (ref: White) | | | | | | | | | | | | | | | |
| Black | -0.10 | 0.90 | <0.001 | -0.03 | 0.97 | 0.041 | -0.09 | 0.91 | <0.001 | -0.13 | 0.88 | <0.001 | -0.03 | 0.97 | <0.001 |
| Asian | -0.03 | 0.97 | <0.001 | 0.04 | 1.04 | 0.027 | -0.01 | 0.99 | 0.573 | -0.03 | 0.97 | 0.002 | 0.00 | 1.00 | 0.801 |
| Other | -0.06 | 0.94 | <0.001 | 0.01 | 1.01 | 0.454 | 0.04 | 1.04 | 0.012 | -0.14 | 0.87 | <0.001 | 0.02 | 1.02 | 0.029 |
| Age group (ref: 22-45) | | | | | | | | | | | | | | | |
| 16-24 | -0.04 | 0.96 | <0.001 | 0.06 | 1.06 | 0.015 | 0.01 | 1.01 | 0.788 | -0.06 | 0.94 | <0.001 | 0.03 | 1.03 | 0.002 |
| 45-64 | -0.04 | 0.96 | <0.001 | -0.04 | 0.96 | <0.001 | -0.01 | 0.99 | 0.254 | -0.08 | 0.92 | <0.001 | -0.07 | 0.94 | <0.001 |
| 65+ | 0.03 | 1.03 | <0.001 | 0.13 | 1.14 | <0.001 | 0.04 | 1.04 | <0.001 | -0.21 | 0.81 | <0.001 | -0.17 | 0.84 | <0.001 |
| N of Home ZIPs[a] | 339 | | | 169 | | | 234 | | | 211 | | | 165 | | |
| N | 197,018 | | | 23,043 | | | 73,462 | | | 63,980 | | | 34,354 | | |
| Adjusted $R^2$ | 0.42 | | | 0.54 | | | 0.41 | | | 0.38 | | | 0.49 | | |

Note: [a]270 ZIP codes excluded with fewer than 10 observations

LIST OF FIGURES

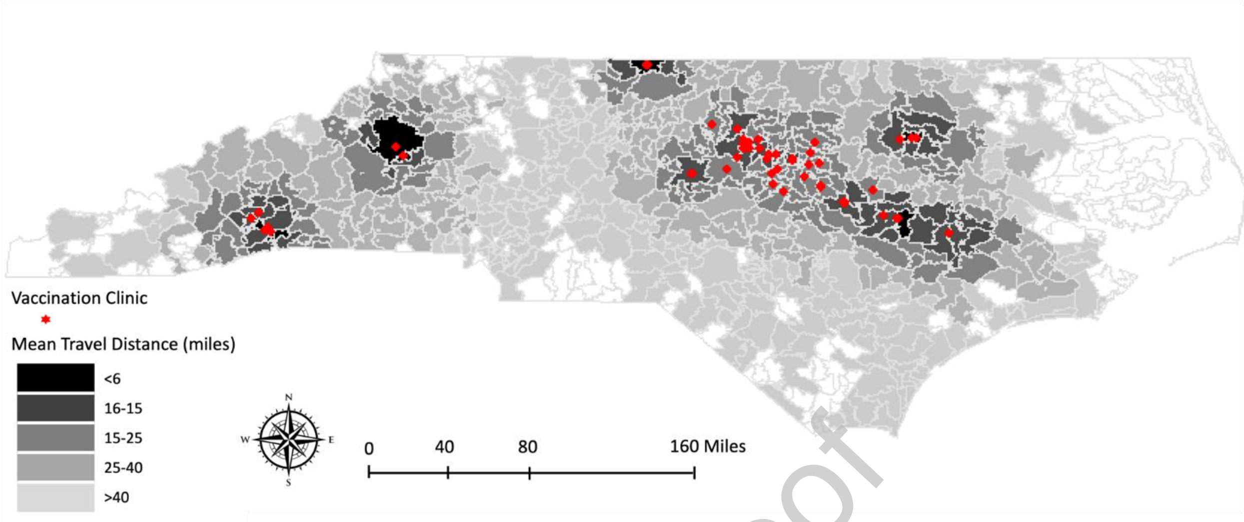


**Figure 1.** Mean travel distance for COVID-19 vaccinations by ZIP code.

Note: No data for 199 ZIP codes.



**Declaration of interests**

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

**Credit author statement**

**Abigail L. Cochran**: Conceptualization, Methodology, Writing- Original draft preparation; Writing-Revision. **Jueyu Wang:** Conceptualization, Methodology, Data curation, Writing-Revision. **Mary Wolfe**: Writing- Reviewing and Editing **Evan Iacobucci**: Writing- Reviewing and Editing **Emma Vinella-Brusher:** Writing- Reviewing and Editing; **Noreen C. McDonald:** Conceptualization, Methodology; Writing- Reviewing and Editing**;**