Preventive Medicine Reports 54 (2025) 103091

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Short communication

Spatial inequities in COVID-19 vaccination in Philadelphia by race and income

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ARTICLE INFO

Keywords:
COVID-19
Vaccination
Income
Race-ethnicity
Health inequities

ABSTRACT

Objective: Vaccination is a key intervention to prevent severe COVID-19, but in the early months of vaccination availability in the United States, there were wide spatial inequities in vaccination by neighboorod racial-ethnic composition and socioeconomic status. To explore whether and how these inequities persisted, we examined the association between neighborhood-level income and racial-ethnic composition and COVID-19 vaccination coverage in Philadelphia, and described trends in inequities in 2021 and 2022.

Methods: Using vaccination data for 46 Philadelphia neighborhoods (zip codes), from the Philadelphia Department of Public Health, we estimated vaccination coverage on April 18th, September 26th, and November 21st of 2021, as well as April 3rd, June 26th, and August 7th of 2022. We estimated and compared average vaccination coverage by neighborhood-level income and racial-ethnic composition. We explored inequities in coverage by estimating absolute and relative differences in vaccination by date.

Results: COVID-19 vaccination coverage varied substantially by neighborhood-level income and racial-ethnic composition. On all dates, rates were higher in high income and non-Hispanic White neighborhoods compared to medium-income, low-income, mixed, and non-Hispanic Black neighborhoods. The absolute and relative differences in vaccination between neighborhoods narrowed over time but persisted through August 2022.

Conclusions: This study provides evidence for the importance of policies that target low-income and non-Hispanic Black neighborhoods during pandemics, including during vaccination rollout, as they have experienced a disproportionate infection, hospitalization, and mortality burden due to COVID-19 and experienced lower vaccination rates.

1. Introduction

By March 2023, the novel coronavirus SARS-CoV-2 that causes COVID-19 had led to over 100 million cases, nearly 450,000 hospitalizations, and at least 1.1 million deaths in the United States (*COVID-NET Laboratory-Confirmed COVID-19-Associated Hospitalizations*, 2023; Johns Hopkins University of Medicine Coronavirus Resource Center, 2023). The impact of the COVID-19 pandemic in the US has been inequitable, with inequities in incidence, mortality, and hospitalizations by race-ethnicity, socioeconomic status (SES), and geographic location (Mackey et al., 2021). For example, in the first six months of the pandemic, neighborhoods in Chicago, New York City, and Philadelphia with higher social vulnerability (e.g., lower income and more racially and ethnically minoritized populations) experienced higher confirmed cases and mortality than neighborhoods with lower social vulnerability (Bilal et al., 2021). Factors driving inequities include differential exposure due to occupational and housing conditions, and differences in access to testing and treatment (Barber et al., 2020; Bilal et al., 2021).

While effective at reducing COVID-19 hospitalization and death, there are inequities in vaccination by race-ethnicity, SES, and geographic location (Bilal et al., 2022; Brown et al., 2021; Rich et al., 2022; Sacarny and Daw, 2021). For example, among 16 large U.S. cities, including Philadelphia, COVID-19 vaccination through September of 2021 was 16 % lower in neighborhoods with the highest social

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https://doi.org/10.1016/j.pmedr.2025.103091
Received 17 December 2024; Received in revised form 24 April 2025; Accepted 25 April 2025
Available online 26 April 2025

vulnerability compared to the lowest (Bilal et al., 2022). Such inequities are influenced by systemic and structural racism, which leads to differential access to resources (e.g., transportation, paid sick leave), and unequitable vaccination opportunities (Bailey et al., 2017).

Though prior research found an association between COVID-19 vaccination rates, race-ethnicity, and SES across the US in the early months of vaccine availability, to our knowledge, it is not yet known whether these inequities persisted as the pandemic and vaccine rollout progressed. We describe trends in COVID-19 vaccination inequities by neighborhood-level income and racial-ethnic composition from the beginning of vaccine rollout, April 2021, through August 2022 in Philadelphia, located in Pennsylvania, US, a city which has documented inequities in both COVID-19 outcomes and vaccinations (Bilal et al., 2022; Bilal et al., 2021).

2. Methods

2.1. Data sources

We included all 46 major zip-code tabulation areas (ZCTAs) in Philadelphia. We used publicly available data from the Philadelphia Department of Public Health (PDPH) to estimate COVID-19 vaccination coverage on five dates in which eligibility opened or changed: April 18, 2021 (full eligibility aged 16+), September 26, 2021 (booster aged 65+ and comorbidities aged 18+), November 21, 2021 (booster aged 18+), April 3, 2022 (second booster aged 50+ and immunocompromised), June 26, 2022 (booster aged 6 months+), and August 7, 2022 (last date of reported data) (Philadelphia Department of Public Health, 2023). To capture sociodemographic characteristics, we used publicly available neighborhood-level data from the 2015–2019 American Community Survery (ACS) (U.S. Census Bureau, 2022). This research was exempt from ethical compliance because it used only publicly available, de-identified data.

2.2. Measures

Our outcome was full COVID-19 vaccination coverage, defined as the percentage of the population in a neighborhood that had received two Pfizer or Moderna or one Janssen/Johnson & Johnson vaccine dose.

We classified median household income into terciles of low ($20,353–$41,105), medium ($44,006–$57,735), and high ($60,970–$107,388). Based on Philadelphia's racial-ethnic composition in 2015–2019, we classified neighborhoods: 60 % or more non-Hispanic White (NHW), 60 % or more non-Hispanic Black (NHB), and Mixed (no majority).

2.3. Statistical analysis

To explore differences in mean vaccination rates by neighborhood income and race-ethnicity, we ran analysis of variance tests at each date. We explored inequities by estimating absolute and relative differences in vaccination rates between neighborhoods categorized by income or race by date. All analyses were conducted using R version 4.2.1.

3. Results

The average median household income across all 46 ZCTAs was $52,866, and most neighborhoods were mixed race-ethnicity (39 %), followed by NHW (33 %) and NHB (28 %). Between April and September 2021, the average neighborhood vaccination rate nearly doubled (29 % to 53 %), increased to 64 % by April 2022, and leveled off to 65 % by August 2022.

Fig. 1 displays average vaccination coverage by date and by neighborhood-level income and racial-ethnic composition. Coverage grew over time in all groups, as rates more than doubled from April 18th, 2021 to August 7th, 2022 among NHB, mixed, low- and medium-income neighborhoods and nearly doubled in NHW and high-income neighborhoods. At each date, we found statistically significant

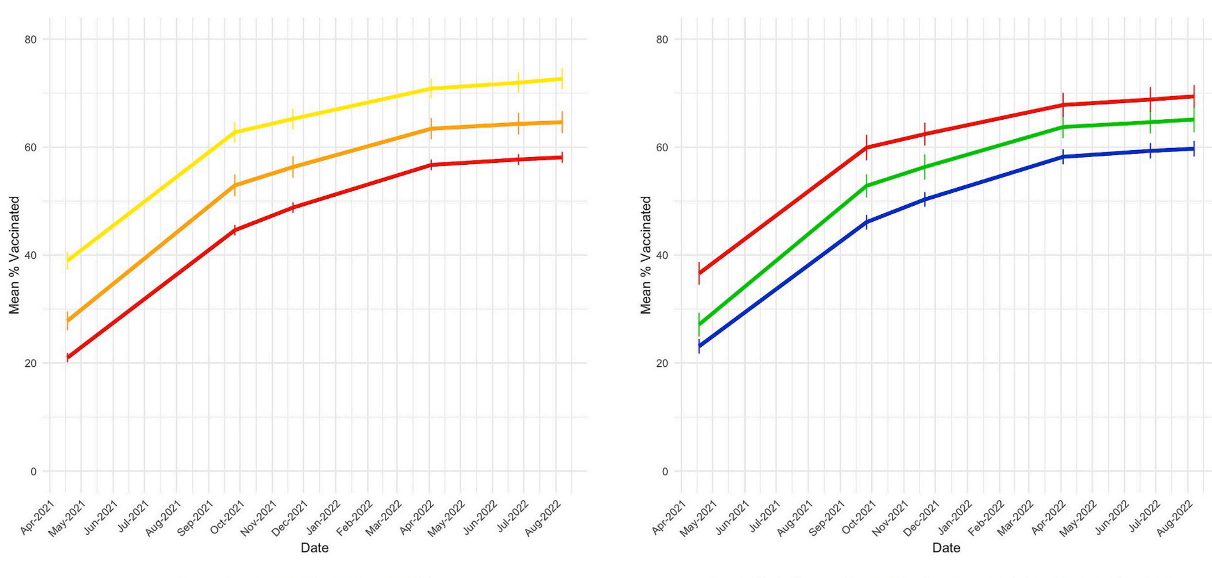

Fig. 1. Mean COVID-19 vaccination rate (%) and standard errors in Philadelphia neighborhoods, by date and neighborhood-level income tercile[1] and racial-ethnic composition[2], April 2021–August 2022[3].

[1] Terciles of low ($20,353–$41,105), medium ($44,006–$57,735), and high ($60,970–$107,388) income neighborhoods.

[2] 60 % or more non-Hispanic White, 60 % or more non-Hispanic Black, and Mixed (no majority racial-ethnic group).

[3] p-value <0.05 for all differences by income and by racial-ethnic composition; p-value corresponds to the two-way ANOVA tests of differences in average vaccination rates between neighborhoods by income and racial-ethnic composition for each date.

Table 1
Absolute and relative differences in COVID-19 vaccination (%) by neighborhood race and income in Philadelphia, by date April 2021–August 2022.

	Absolute Difference[1] (%) [95 % CI]						Relative Difference[2] [95 % CI]					
	2021			2022			2021			2022		
	Apr. 18	Sept. 26	Nov. 21	Apr. 3	June 26	Aug. 7th	Apr. 18	Sept. 26	Nov. 21	Apr. 3	June 26	Aug. 7th
Median Household Income												
Low	−17.9 [−49.6, 13.8]	−18.1 [−52.6, 17.0]	−16.4 [−50.8, 18.0]	−14.1 [−47.6, 19.4]	−14.2 [−47.4, 19.0]	−14.5 [−47.6, 18.6]	0.5 [0.17, 1.69]	0.7 [0.36, 1.39]	0.8 [0.40, 1.40]	0.8 [0.47, 1.37]	0.8 [0.48, 1.36]	0.8 [0.48, 1.35]
Medium	−11.1 [−44.6, 22.4]	−9.8 [−45.0, 25.4]	−8.9 [−43.7, 25.9]	−7.4 [−40.9, 26.1]	−7.6 [−40.8, 25.6]	−8.0 [−41.1, 25.1]	0.7 [0.25, 2.01]	0.8 [0.46, 1.56]	0.9 [0.48, 1.54]	0.9 [0.54, 1.48]	0.9 [0.55, 1.46]	0.9 [0.55, 1.45]
High (ref. group)	0						1					
Majority Racial-Ethnic Composition												
Non-Hispanic Black	−13.5 [−47.0, 19.8]	−13.8 [−50.5, 22.9]	−12.1 [−48.7, 24.5]	−9.6 [−45.3, 26.1]	−9.5 [−45.0, 26.0]	−9.7 [−45.1, 25.7]	0.6 [0.19, 2.08]	0.8 [0.38, 1.58]	0.8 [0.41, 1.59]	0.9 [0.48, 1.53]	0.9 [0.49, 1.52]	0.9 [0.49, 1.50]
Mixed	−9.5 [−41.4, 22.4]	−7.1 [−41.0, 26.8]	−6.1 [−39.7, 27.5]	−4.1 [−36.5, 28.3]	−4.2 [−36.4, 28.0]	−4.3 [−36.4, 27.8]	0.7 [0.27, 2.03]	0.9 [0.48, 1.61]	0.9 [0.51, 1.60]	0.9 [0.57, 1.54]	0.9 [0.58, 1.52]	0.9 [0.58, 1.51]
Non-Hispanic White (ref. group)	0						1					

[1] Absolute Difference = percentage fully vaccinated for COVID in the group shown - percentage fully vaccinated for COVID in reference group.
[2] Relative Difference = percentage fully vaccinated for COVID in the group shown ÷ percentage fully vaccinated for COVID in reference group.

differences in vaccination coverage by both income and racial-ethnic composition ($p < 0.05$); rates were highest in NHW neighborhoods, followed by mixed and NHB, and high-income followed by medium- and low-income (Table A.1). Absolute inequities did not change between certain dates, e.g., between April 18th and September 26th of 2021 for low-income and NHB neighborhoods compared to high-income and NHW, respectively; however, relative inequities reduced over the study period, especially among low-income and NHB neighborhoods, which went from having 54 % to 80 % and 63 % to 86 % the coverage observed in high-income and NHW neighborhoods, respectively (Table 1).

At both the start and end of the study period, there were apparent clusters of neighborhoods with either NHW race-ethnicity and high coverage, or NHB and low coverage, or in which both income and vaccination was high or low (Fig. A.1-A.2).

4. Discussion

Average COVID-19 vaccination varied significantly over time and by neighborhood income and racial-ethnic composition in Philadelphia. Rates were highest in high-income and NHW neighborhoods, a finding consistent with research earlier in vaccination availability (Bilal et al., 2022; Brown et al., 2021; Rich et al., 2022; Sacarny and Daw, 2021). For example, Sacarny and Daw found that through April 13th, 2021 in 9 US cities, including Philadelphia, neighborhoods with higher vaccination rates had greater mean income, more White residents, and fewer Black residents than neighborhoods with lower vaccination rates (Sacarny and Daw, 2021).

The persistance of these patterns over time compound existing inequities, as low-income, racially-segregated areas experience higher rates of poor health outcomes (Abraham et al., 2021; Bailey et al., 2017), and individuals living in these areas have experienced a disproportionate risk of COVID-19 outcomes since the beginning of the pandemic and vaccine rollout (Johns Hopkins University of Medicine Coronavirus Resource Center, 2023). Our findings of shrinking but persistent inequities aligns with findings documenting that White populations have higher COVID-19 vaccination rates than Blacks, and while these inequities have narrowed over time, they remained as of July of 2022 (Ndugga et al., 2022). Even with substantial progress (e.g., a 112 % increase in coverage among low-income neighborhoods), these neighborhoods still reached just 71 % of the rates observed in high-income neighborhoods, demonstrating the effects of starting from a disadvantaged baseline.

Several structural factors likely contribute to the inequities documented in this study, including differences in access to healthcare and vaccination clinics; barriers related to employment, such as fear of side effects and lack of paid leave; and misinformation regarding eligibility and costs, especially that targeted at socioeconomic and racially minoritized groups (Bilal et al., 2022). For example, while COVID-19 vaccines were federally funded, uninsured individuals or those without a regular healthcare provider may have had difficulty navigating the vaccination process or receiving reliable information (Peña et al., 2023). Structural barriers such as appointment scheduling systems, documentation requirements, and limited vaccine availability in lower-income neighborhoods may have further exacerbated disparities (Bilal et al., 2022; Peña et al., 2023). Additionally, hesitancy is often used to explain low uptake among communities of color, but many factors, including SES, race, ethnicity, age, history of loss of loved ones, and political ideologies are associated with differences in vaccine uptake (Agarwal et al., 2021; Bilal et al., 2022; Corbie-Smith, 2021). These inequities may be amplified in Philadelphia, where the poverty rate is about twice the US average, and a large proportion of the population belongs to racially minoritized groups (e.g., 40 % of Philadelphia residents are Black, compared to just 14 % of the US population) according to the 2019–2023 ACS (U.S. Census Bureau, 2023).

While the use of vaccination campaigns targeting vulnerable populations increased over time in US cities (e.g., expanded mobile vaccination clinics, targeted vaccinations by zip code, walk-in and same-day appointments), these resources were often misused by other populations (Bilal et al., 2022). Community outreach efforts such as the Black Doctors COVID Consortium in Philadelphia helped to address inequities by providing testing and vaccinations to unvaccinated communities of color (Bilal et al., 2022). At the city level, paid sick leave policies have been associated with higher vaccination rates and narrower vaccination inequities between socioeconomic and racial-ethnic groups; paid sick leave policies are especially beneficial in vulnerable communities where lack of paid time off for vaccination and recovery from side effects acts as a structural barrier to vaccination (Schnake-Mahl et al., 2022).

4.1. Limitations

Our study uses aggregated surveillance data from the PDPH, which does not include individuals who reside in Philadelphia but were vaccinated outside of the city (Philadelphia Department of Public Health, 2023). Second, performing analysis at the ZCTA-level may be imprecise as these areas are not designed for sociodemographic analyses and are large and heterogeneous. Third, this analysis only included data through August 2022, as the Philadelphia Department of Public Health stopped reporting COVID-19 vaccination data after this date; vaccination trends and inequities may have evolved further after this date. Finally, while Philadelphia had similar inequities in COVID-19 outcomes (Bilal et al., 2021) and vaccinations (Bilal et al., 2022) as cities like Chicago and New York, respectively, its healthcare infrastructure, local policies, community outreach efforts, history of systemic racism, and residential segregation may differ from those in other cities and limit generalizability of findings.

5. Conclusions

This study identifies the persistence of inequities in vaccination in a large US city, but encouragingly finds declines over time. Future research should investigate patterns in other cities and factors that contribute to the narrowing of vaccination inequities, e.g., paid sick leave policies (Schnake-Mahl et al., 2022) and early access to vaccination. Racially-minoritized and low-income populations have experienced a disproportionate impact from the pandemic, which are not exclusive to COVID-19, as previous influenza pandemics have shown similar inequities (D'Adamo et al., 2023). Addressing the factors linked to differences in vaccination is fundamental to protecting vulnerable populations and lessening the impact of infectious diseases.

CRediT authorship contribution statement

Angela D'Adamo: Writing – original draft, Methodology, Formal analysis, Data curation. **Alina Schnake-Mahl:** Writing – review & editing, Validation, Project administration. **Usama Bilal:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Jane Miller:** Writing – review & editing, Supervision, Resources, Project administration, Methodology.

Funding

Usama Bilal was supported by the Office of the Director of the National Institutes of Health under award number DP5OD26429. Alina Schnake-Mahl was supported by the National Institutes of Allergy and Infectious Disease under award number K01AI168579–03. Angela D'Adamo and Jane Miller have no funding disclosures.

Declaration of competing interest

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

Acknowledgment

We would like to thank the Philadelphia Department of Public Health for making vaccination data by neighborhood publicly available.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2025.103091.

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