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Temporal transition of racial/ethnic disparities in COVID-19 outcomes in 3108 counties of the United States: Three phases from January to December 2020

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HIGHLIGHTS
• Early studies reported higher risk of COVID-19 for racial/ethnic minorities.
• Positive association of Black/African American with COVID-19 decreased over time.
• Positive association of Black-White segregation with COVID-19 decreased over time.
• Positive association of non-Hispanic White with COVID-19 recently emerged.
• Results suggest dynamic process of cultural, social and political environments.

GRAPHICAL ABSTRACT

ABSTRACT

Early studies reported higher risk of COVID-19 outcomes for racial/ethnic minorities in the early phase of the pandemic in the United States. While the initial surge of COVID-19 was concentrated in some areas, COVID-19 became pervasive across the entire continent with high impacts in the northern region and central region in the end of 2020. With this geographical transition, we aim to investigate patterns of these racial/ethnic disparities over time.

We assessed associations of percentage of race/ethnic minorities and racial segregation indexes with COVID-19 case and mortality rates in 3108 counties of the continental United States during the pandemic’s early phase, second, and third phase (January 21–June 15, June 16–August 31, and September 1–December 18, 2020, respectively). We adjusted for population density, age, and sex. We tested whether time-varying associations were consistent across climate regions and explained by socioeconomic variables.

In the early phase, counties with higher percentage of Black/African Americans and higher Black-White segregation had higher COVID-19 case and mortality rates. These associations decreased over time and reversed in the third phase. Associations between Hispanic and COVID-19 outcomes were positive in all periods, but more so early in the pandemic. Higher COVID-19 case rates for counties with higher non-Hispanic White population emerged in the third phase. These trends were similar across climate regions, and socioeconomic variables did not explain these trends.

In summary, county-level racial/ethnic disparities of COVID-19 are not stationary but change over the course of the pandemic, suggesting complex social, cultural, and political influences.

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1. Introduction

As of February 21, 2021 the number of the coronavirus 2019 (COVID-19) cases are over 28.1 million and COVID-19 have claimed over 498,000 lives in the United States (the New York Times, 2021). Many studies have reported that racially and ethnically marginalized groups such as Black/African American and Hispanic persons are at higher risk of COVID-19 (Adhikari et al., 2020; Bassett et al., 2020; Chen and Krieger, 2020; Gold et al., 2020; Holmes et al., 2020; Krieger et al., 2020; Labgold et al., 2021; Li et al., 2020; Muñoz-Price et al., 2020; Poteat et al., 2020; Rogers et al., 2020; Rossen et al., 2020; Selden and Berdahl, 2020). Structural racism at the root of differences in pre-existing conditions, access to health care and healthy food, and less favorable environment for social distancing such as living high dense area and working in essential industries (e.g., health sector, food services, transportation) may be related to disproportionate impacts of COVID-19 (Chowkwanyun and Reed, 2020; Krieger, 2020; Laurencin and McClinton, 2020; Poteat et al., 2020; Rogers et al., 2020; Selden and Berdahl, 2020; Yancy, 2020).

Metropolitan areas are at high risk of COVID-19 due to high population density and social/economic connections (Hamidi et al., 2020). In terms of race/ethnicity, metropolitan areas are diversifying (Farrell and Lee, 2011; Frey and Farley, 1996), and many people of color are hospital workers or low-income essential workers (e.g., grocery seller, food server, bus driver) who are more likely exposed to the virus due to the proximity to a large number of people. Although neighborhoods are more racially/ethnically integrated in some metropolitan areas, stark segregation still exists in many areas (Farrell and Lee, 2011; Iceland and Wilkes, 2006), lingering racial residential segregation may increase high risk of COVID-19 through allostatic loads from exposure to prevalent multiple stressors (Bellatorre et al., 2011), limited access to health care and healthy food, and potential viral transmissions in confined areas and long commutes from residentially segregated areas to business areas (Yang et al., 2020).

As of December, the United States underwent a third surge of COVID-19. Fig. S1A and B show daily time-series of COVID-19 cases and deaths in the continental United States. Unlike the early phase of COVID-19 outbreak (e.g., January to June), the more recent surge of the number of COVID-19 cases is starkly different in terms of geography. Fig. 1 shows cumulative COVID-19 case rate and mortality rate for the three different phases that we categorized based on the second and third surge of COVID-19 cases in Fig. S1A. Fig. 1A and B explicitly present geographical transition of COVID-19 case and mortality rates over time. While the initial surge was concentrated in some areas with high population density, COVID-19 has become pervasive across the entire continent with high impacts in the northern region and central region in the recent phase.

As implied by Fig. 1, COVID-19 is prevalent in the entire continent, including areas where race/ethnicity profiles differ from those in metropolitan areas that experienced the initial surge of COVID-19. We hypothesize that the geographical transition of COVID-19 may also be accompanied with a transition of county-level racial and ethnic profiles of COVID-19 outcomes. Early studies on racial/ethnic disparities focused on the early pandemic or did not distinguish all phases, which may mask possible transition of COVID-19 in the analysis. In this study, we aim to identify racial/ethnic transition of COVID-19 transmission across the continental United States in terms of Black/African American, non-Hispanic White, Hispanic and Black-white segregation using cross-sectional analyses.

2. Methods

2.1. Study population and data sources

We obtained daily COVID-19 confirmed cases and deaths at 3108 counties in the continental United States from January 21 to December 18, 2020 from the New York Times COVID-19 Github (https://github.com/nytimes/covid-19-data), which were collected from state and...
local governments and health departments, and New York City Health (https://www1.nyc.gov/site/doh/covid/covid-19-data-page).

We calculated population density at the county level using ACS 2018 5-year estimates of population and land area obtained from the United States Census Bureau. We obtained American Community Survey 2018 5-year estimates of the percentage of age groups (20–44 years; 45–64 years; 65–84 years; ≥85 years), male, and population that is Black/African American, Hispanic, non-Hispanic White, or Asian from the United States Census Bureau. These age groups were chosen based on a previous study finding that age-specific COVID-19 mortality rates in the United States are similar for those 20–44 years and that rates increase with age over ≥65 years (Bassett et al., 2020), although we further divided by age to examine younger and older adults.

For racial segregation between Black/African American populations and White populations, we calculated Atkinson index and Eta-squared for each county (James and Taeuber, 1985). Atkinson index is a measure of evenness/clustering as follows (James and Taeuber, 1985).

\[
1 - \left( \frac{P}{1-P} \right) \left[ \sum_{i=1}^{n} \left( \frac{(1-P_i)^{1-b} - P_i^b}{P_i^b} \right) \right]^{1/b}
\]

\(n\) is number of census-tract in the county; \(x_i\) is minority population of census-tract \(i\); \(T\) is total population of census-tract \(i\); \(p_i = x_i / T\) is minority proportion in census-tract \(i\); \(T = \sum_{i=1}^{n} t_i\) is total population in the county;

\[P = x / n\] is minority proportion in the county; \(X = \sum_{i=1}^{n} x_i\) or total minority population in the county; \(b\) is a shape parameter. We used 0.5 for \(b\). Atkinson index ranges from 0 to 1. The higher value of Atkinson index indicates that minority population is more clustered in a county. The lower value of Atkinson index indicates that minority population is more evenly distributed in a county.

Eta-squared, also known as Correlation ratio, is a measure of exposure/isolation as follows (James and Taeuber, 1985).

\[
\text{Eta}^2 = \left( \frac{P_{t} - P}{1-P} \right)
\]

where \(P_{t} = \frac{\sum_{i=1}^{n} \left( \frac{x_{i}}{X} \right) \left( \frac{n_{i}}{T_{i}} \right)}{n}\)

Eta-squared ranges from 0 to 1. The higher value of Eta-squared indicates that minority population is more isolated in a county. The lower value of Eta-squared indicates that minority population is more exposed to majority population. The combination of Atkinson index (clustering-even distribution measure) and Eta-squared (exposure-isolation measure) shows clustered/isolated, clustered/exposed, evenly distributed/isolated, and evenly distributed/exposed Black/African American population. Black-White residential segregation is clustered or isolated Black/African population.

We also obtained socioeconomic variables (i.e., poverty, educational attainment, median household income, and health insurance). We used ACS 2018 5-year estimates of the percentage of population that lives under the federal poverty line, the percentage of population ages ≥25 years whose highest level of education is less than high school diploma or General Educational Development, median household income, the percentage of civilian noninstitutionalized population without health insurance for each county from the United States Census Bureau.

This study used publicly available aggregated data collected by those who are not involved in this study, so that IRB review was not required.

### Results

Second, we applied Zero-inflated negative binomial regression with random intercept by state to estimate cross-sectional associations between county-level cumulative COVID-19 outcome rates and county-level race/ethnicity by three phases/waves of the pandemic. Dependent variables were cumulative case/death numbers and the natural logarithm of population was included as offset. Based on time-series of COVID-19 case rate and mortality rate (Fig. S1A and B), we defined the three waves as January 21–June 15, 2020, June 16–August 31, 2020, and September 1–December 18, 2020. We compared county-level associations between race/ethnicity and COVID-19 outcomes adjusted for county-level percentage of population within specific age categories, fraction of the population that is male, and population density with the associations not adjusted for those variables to see whether those variables confounded the associations. The age intervals chosen for adjustment (45–64 years and 85+ years) were selected as they were mildly correlated with each other (\(r = 0.29\)) and population density \((r = -0.12\) and \(r = -0.31\), respectively) and because these two age categories were highly correlated with the percentage of population that age 20–44 years \((r = -0.63\) and \(r = -0.57\), respectively) and age 65–84 years \((r = -0.84\) and \(r = 0.56\), respectively). We also investigated county-level associations between race/ethnicity and COVID-19 outcome rates by climate regions because temperature may be a key modifier of COVID-19 transmission (Rubin et al., 2020) and race/ethnic profiles differ (Fig. S1). We adopted nine climate regions defined as Central, East North Central, Northeast, Northwest, West, West North Central, South, Southeast, and Southwest (Karl and Koss, 1984). We combined the regions of Southwest, West, and Northwest because the number of COVID-19 outcomes is limited. To investigate whether the socioeconomic variables contribute to temporal differences in COVID-19 case rate and mortality rate by race/ethnicity, we additionally adjusted for each of the socioeconomic variables and compared changes in relative rates of race/ethnicity before and after the adjustment.

All analyses were conducted using R software 3.5.3. Zero-inflated negative binomial regression was fitted using glmmTMB package. Datasets used and R Codes are publicly available in the first author’s GitHub: https://github.com/HonghyokKim/US_COVID_RACE/

### Discussion

From January 21 to December 18, 2020, a total of 17,291,886 COVID-19 cases and 306,612 COVID-19 deaths were reported in 3108 counties of the continental United States. In the first wave (January 21–June 15, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 15,230.3 per 100,000 people (interquartile range (IQR) of 378.3 per 100,000 people) and from 0 to 351.5 per 100,000 people (IQR of 14.8 per 100,000 people), respectively. In the second wave (June 16–August 31, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (interquartile range (IQR) of 25.0 per 100,000 people), respectively. In the second wave (September 1–December 18, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (IQR of 25.0 per 100,000 people), respectively. In the third wave (September 1–December 18, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (IQR of 25.0 per 100,000 people), respectively. In the third wave (September 1–December 18, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (IQR of 25.0 per 100,000 people), respectively. In the third wave (September 1–December 18, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (IQR of 25.0 per 100,000 people), respectively. In the third wave (September 1–December 18, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (IQR of 25.0 per 100,000 people), respectively. In the third wave (September 1–December 18, 2020), county-specific cumulative case rate and mortality rate ranged from 0 to 13,620.8 per 100,000 people (IQR of 267.1 per 100,000 people) to 0 to 15,230.3 per 100,000 people (IQR of 25.0 per 100,000 people), respectively.

Table 1 shows descriptive statistics of county-level variables. Percentage of population that is Non-Hispanic White in a county ranged from 0.7% to 100% with a mean of 76.8%. Percentage of population that is Black/African American ranged from 0% to 87.4% with a mean of 9.1%. Percentage of population that is Hispanic ranged from 0% to 99.1% with a mean of 9.3%. Atkinson index ranged from 0 to 1, with a mean of 0.550. Eta-squared ranged from 0 to 0.640 with a mean of 0.057. Maps of these variables are provided in Fig. S2.

Pearson correlations between race/ethnicity variables and population density are provided in Fig. S3. Correlations over ±0.4 are as follows. Population density was positively correlated with percentage of population that is Black/African American (\(r = 0.49\), Atkinson index
(r = 0.57), and Eta-squared (r = 0.65). Percentage of population that is Black/African American is correlated with percentage of population that is non-Hispanic white (r = −0.63) and Eta-squared (r = 0.81). Percentage of population that is non-Hispanic white was correlated with percentage of population that is Hispanic (r = −0.62) and Eta-squared (r = −0.46). Atkinson index was correlated with Eta-squared (r = 0.42).

Table 2 shows percentage change of COVID-19 case rate and COVID-19 mortality rate by one standard increase of county-level variables. For all of county-level variables, we found that transitions over time for patterns of COVID-19 case rate and mortality rate by quintiles of county-level variables. From January to March 2020, COVID-19 outcome rates rapidly increased in counties with the highest quintile of population density (Fig. 2A and B), percentage of population that is Black/African American (Fig. 2E and F) or Hispanic (Fig. 2G and Fig. 2H), Atkinson index (Fig. 2I and J), and Eta-squared (Fig. 2K and L), and the lowest quintile of percentage of population that is non-Hispanic white (Fig. 2C and D). In contrast, from September to December, COVID-19 outcome rates increased higher in counties with the lower quintile of population density (Fig. 2A and B), percentage of population that is Black/African American (Fig. 2E and F), percentage of population that is Hispanic (Fig. 2G and H), Atkinson index (Fig. 2I and J), and the and Eta-squared (Fig. 2K and L), and higher quintile of percentage of population that is non-Hispanic White (Fig. 2C and D).

Table 2 shows percentage change of COVID-19 case rate and COVID-19 mortality rate by one standard increase of county-level race/ethnicity variables. Consistent with Fig. 2, associations between race/ethnicity variables and COVID-19 outcomes changed over time. In the main text, we report the numbers of adjusted associations. One standard deviation increase in percentage of the population that is non-Hispanic White (19.9%) was associated with 45.7% (95% CI: 42.7, 48.5%) decrease of COVID-19 case rate and 45.0% (95% CI: 40.7, 48.9%) decrease of COVID-19 mortality rate in the first wave of the pandemic but, in the second wave, the third wave of the pandemic, was associated with 1.6% (95% CI: −0.2, 3.3%) increase of COVID-19 case rate and 4.0% (95% CI: 0.6, 7.4%) decrease of COVID-19 mortality rate. One standard deviation increase of percentage of population that is Black/African American (14.6%) was associated with 41.7% (95% CI: 34.8, 49.0%) increase of COVID-19 case rate and 57.1% (95% CI: 46.7, 68.3%) increase of COVID-19 mortality rate in the first wave. These associations decreased over time and reversed in the second and third wave. One standard deviation increase of percentage of population that is Hispanic (13.9%) was associated with 42.5% (95% CI: 34.6, 51.0%) increase of COVID-19 case rate and 15.2% (95% CI: 6.1, 25.0%) increase of COVID-19 mortality rate in the first wave. These associations decreased to 6.8% (95% CI: 4.9, 8.7%) increase of COVID-19 case rate and 5.5% (95% CI: 1.7, 9.4%) increase of COVID-19 mortality rate in the third wave.

The direction of the associations between Black–White residential segregation indexes and COVID-19 outcomes changed over time (Table 2). One standard deviation increase of Atkinson index (0.219) was associated with 12.1% (95% CI: 7.0, 17.3%) increase of COVID-19 case rate and 25.8% (95% CI: 16.1, 36.3%) increase of COVID-19 mortality rate in the first wave but, in the third wave, was associated with 1.0% (95% CI: 0.3, 2.4%) decrease of COVID-19 case rate and 10.2% (95% CI: 7.4, 12.9%) decrease of COVID-19 mortality rate. One standard deviation increase of Eta-squared (0.086) was associated with 24.7% (95% CI: 19.2, 30.4%) increase of COVID-19 case rate and 28.8% (95% CI: 21.6, 36.4%) increase of COVID-19 mortality rate in the first wave. In the second wave, it was associated with 1.3% (95% CI: −0.1, 2.6%) increase of COVID-19 case rate and 6.0% (95% CI: 3.6, 8.4%) decrease of COVID-19 mortality rate.

We found that the transitions of the aforementioned associations were generally consistent across seven climate regions although the magnitude of the associations were somewhat different (Fig. S4). Exceptions include the Atkinson index in Southeast region, which was negatively associated with COVID-19 case rate in the first wave but was positively associated with the rate in the third wave, as well as Eta-squared in the Southeast region, which was only significantly associated with the rate in the second wave (Fig. S4). When we additionally adjusted for poverty rate, educational attainment, health insurance, or median household income, we found that the strength of the association between race/ethnicity variables (not racial segregation variables) and COVID-19 outcomes slightly decreased, suggesting that these variables partially captured the causal role of socioeconomic in racial/ethnic disparities of COVID-19 outcomes. Nevertheless, we did not find differences in the temporal transitions of the associations, suggesting that they may not explain these transitions (Figs. S5–8).

4. Discussions

In the early phase of COVID-19 pandemic, the disease had higher case and mortality rates in counties with high population density, where many Black-African American and Hispanic populations live, and where Black and White populations are more segregated. As the pandemic progressed, the disease case and mortality rates were higher in other counties with low population density, high percentage of...
population that is non-Hispanic White, and less segregation, so that county-level racial/ethnic disparities of COVID-19, which were prominent in the first wave, diminished through the third wave. This pattern was robust to different climate regions in the United States. Our findings confirm that Black-African American and Hispanic populations are more vulnerable to infectious diseases early in the pandemic, and that such county-level disparities changed over the course of the pandemic. This transition seems that COVID-19 was propagated to other racial/ethnic populations and communities as well.

The geographical transition of COVID-19 in the recent phase, which is a stark increase of COVID-19 outcomes in areas that are less densely populated and have higher percentage of non-Hispanic White warrants

Fig. 2. Daily COVID-19 case rate and mortality rate by quintiles of county-level variables in 3108 counties in the continental United States.

Note. Quantile cut-points (20th, 40th, 60th, and 80th percentile): population density (4.6, 12.2, 24.3, and 62.6 persons/km²); percentage of non-Hispanic White population (60.3, 77.5, 88.1, and 93.8%); percentage of Black/African American population (0.5, 1.3, 4.1, and 14.1%); percentage of Hispanic population (1.8, 3.1, 5.4, and 12.2%); Black–White residential segregation (Cluster-Evenness, Atkinson index) (0.39, 0.52, 0.62, and 0.73); Black–White residential segregation (Isolation-Exposure, Eta-squared) (0.003, 0.012, 0.032, and 0.095)
Table 2
Percentage change of COVID-19 case rate and mortality rate by one standard deviation increase of county-level race/ethnicity variables over three waves (January 21–June 15, June 16–August 31, and September 1–December 18, 2020) at 3108 counties in the continental United States. Adjusted associations represent associations adjusted for age, sex, and population density. Standard deviations of county-level variables are listed in Table 1.

| Variables                         | Wave | Unadjusted | Adjusted | Unadjusted | Adjusted |
|-----------------------------------|------|------------|----------|------------|----------|
| % of Non-Hispanic White           | 1    | −50.8 (−53.1, −48.4) | −45.7 (−48.5, −42.7) | −44.1 (−47.7, −40.2) | −45.0 (−48.9, −40.7) |
|                                  | 2    | −27.7 (−29.6, −25.9) | −22.8 (−25.0, −20.6) | −30.9 (−33.7, −28.0) | −34.9 (−37.9, −31.8) |
|                                   | 3    | −2.3 (−3.9, −0.7) | 1.5 (−0.2, 3.3) | 1.7 (−1.6, 5.0) | −4.0 (−7.4, −0.6) |
| % of Black/African American       | 1    | 52.0 (44.1, 60.4) | 41.7 (34.8, 49.0) | 62.3 (51.7, 73.8) | 57.1 (46.7, 68.3) |
|                                  | 2    | 18.7 (15.3, 22.2) | 15.4 (12.3, 18.6) | 22.4 (17.2, 27.9) | 21.4 (16.1, 26.9) |
|                                  | 3    | −5.9 (−7.6, −4.3) | −7.1 (−8.6, −5.5) | −2.4 (−5.8, 1.1) | −1.3 (−4.6, 2.1) |
| % of Hispanic                     | 1    | 67.1 (58.0, 76.7) | 42.5 (34.6, 51.0) | 24.9 (15.8, 34.8) | 15.2 (6.1, 25.0) |
|                                  | 2    | 30.8 (27.0, 34.6) | 20.2 (16.6, 23.9) | 29.6 (24.5, 34.4) | 30.5 (24.3, 37.0) |
| Eta-squared                       | 1    | 10.4 (8.4, 12.3) | 6.8 (4.9, 8.7) | 2.3 (−1.2, 6.0) | 5.5 (1.7, 9.4) |
|                                  | 2    | 9.1 (6.7, 11.7) | 4.2 (1.8, 6.7) | −1.0 (−5.5, 3.6) | −5.6 (−10.3, −0.7) |
| Atkinson index                    | 3    | −2.2 (−3.5, −0.9) | −1.0 (−2.4, 0.3) | −1.3 (−1.5, 0.7) | −10.2 (−12.9, −7.4) |

5. Conclusions

Our findings suggest that Black-American and Hispanic populations are at higher risk of COVID-19, particularly in the early phase of the pandemic. Many of these susceptible populations live in metropolitan areas that are vulnerable environments for the viral transmission. As the pandemic lingers, COVID-19 also became pervasive in other neighborhoods, resulting in higher risk for other racial/ethnic groups and suburban and rural areas, so that county-level racial/ethnic disparities of COVID-19 are not stationary but change over time. However, our findings do not address racial/ethnic disparities within a county, which may still exist in those areas affected in later stages of the pandemic. Future studies are needed to investigate complexity of race/ethnicity and racial segregation with respect to COVID-19 outcomes in both the individual and neighborhood levels. For this, data that permit analyses at both individual level and neighborhood level of race/ethnicity should be publicly available.

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CRediT authorship contribution statement

Honghyok Kim conceived the study, designed the study and data-analysis, obtained data, conducted data-analysis, interpreted results, wrote a draft of the manuscript and edited the manuscript. Antonella Zanobetti reviewed data-analysis, interpreted results, and edited the manuscript. Michelle Bell supervised the study, reviewed data and data-analysis, interpreted results, and edited the manuscript.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.148167.

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