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Research paper

A longitudinal study of convergence between Black and White COVID-19 mortality: A county fixed effects approach

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ABSTRACT

Background: Non-Hispanic Black populations have suffered much greater per capita COVID-19 mortality than White populations. Previous work has shown that rates of Black and White mortality have converged over time. Understanding of COVID-19 disparities over time is complicated by geographic changes in prevalence, and some prior research has claimed that regional shifts in COVID-19 prevalence may explain the convergence.

Methods: Using county-level COVID-19 mortality data stratified by race, we investigate the trajectory of Black and White per capita mortality from June 2020–January 2021. We use a county fixed-effects model to estimate changes within counties, then extend our models to leverage county-level variation in prevalence to study the effects of prevalence versus time trajectories in mortality disparities.

Findings: Over this period, cumulative mortality rose by 61% and 90% for Black and White populations respectively, decreasing the mortality ratio by 0.4 (25.8%). These trends persisted when a county-level fixed-effects model was applied. Results revealed that county-level changes in prevalence nearly fully explain changes in mortality disparities over time.

Interpretation: Results suggest mechanisms underpinning convergence in Black/White mortality are not driven by fixed county-level characteristics or changes in the regional dispersion of COVID-19, but instead by changes within counties. Further, declines in the Black/White mortality ratio over time appear primarily linked to county-level changes in COVID-19 prevalence rather than other county-level factors that may vary with time. Research into COVID-19 disparities should focus on mechanisms that operate within-counties and are consistent with a prevalence-disparity relationship.

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Research in context

Evidence before this study

COVID-19 has disproportionately impacted vulnerable populations. Mortality among non-Hispanic Black populations

is much higher than among White populations. We searched Google Scholar up to March 30, 2021 with combinations of search terms “COVID-19”, “coronavirus”, “disparities”, “mortality”, “county-level”, and “race.” Our literature review found three longitudinal studies investigating COVID-19’s impact on different populations, showing increasing burdens in White populations over time and convergence between Black and White outcomes. Existing discussion has been nearly entirely centered on the potential role of changing geographic distribution of COVID-19 as the driver of disparities assessed

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at larger measurement areas. However, this claim remains untested, and given regional shifts in prevalence to places like the South, which has a proportionately larger Black population, it is not clear a priori that changes in geography would lead to converging disparities.

Added value of this study

We use county-level mortality data disaggregated by race to assess changes in Black and White COVID-19 mortality over time, and the ratio between the two. This enables us to estimate changes in COVID-19 outcomes within counties, and accounts for all time-invariant county characteristics. We find that the primary driver of changes in COVID-19 outcomes and disparities is occurring within counties, and is not due to previously discussed changes in the spread of COVID-19 to counties and areas with heterogeneous characteristics, including demography. We also use county-level variation in prevalence to investigate the extent to which relationships between prevalence and disparities matter, rather than factors linked to time specifically, and find a strong relationship between prevalence and the Black/White mortality ratio, which nearly fully accounts for the time trends.

Implications of all available evidence

The COVID-19 pandemic has had an inordinate impact on Black populations, and joins a long list of diseases that disproportionately impact the vulnerable. As further studies investigate the potential mechanisms of changing COVID-19 disparities over time, research should focus on mechanisms that operate within small geographic areas, and on mechanisms that would be consistent with a prevalence-disparity relationship. In future public health emergencies, governments must act urgently early on, taking into account that vulnerable populations may not only be more at-risk, but especially at-risk during the early stages of health crises.

1. Introduction

Throughout the 2019 novel coronavirus disease (COVID-19) pandemic, numerous studies have documented disproportionately high numbers of COVID-19-attributed deaths in non-Hispanic Black populations, from here on referred to as Black, relative to those in non-Hispanic White populations, from here on referred to as White, in the US [1–3]. As of January 24th, 2021, the national per capita COVID-19 mortality for Black Americans was 1.47 times that of White Americans [4]. However, cross-sectional studies over different intervals during the pandemic suggest that there has been a recent convergence between White and Black mortality [5–7]. Estimates from April, May, and July 2020 document cumulative Black/White COVID-19 mortality ratios of 3.57, 2.37, and 1.97, respectively.

Interpretation of trends in COVID-19 mortality over time, as well as Black/White mortality ratios, is not straightforward. Understanding of COVID-19's impacts over time is complicated by the changing geography of COVID-19 prevalence, in particular, the spread of COVID-19 to places with different demography or structural risk factors. Rigorous understanding of the mechanisms by which COVID-19 has disproportionately impacted Black and other vulnerable populations is important to understanding its full impact, as well as providing insight into the mechanisms that may underpin disparities in other contexts. Longitudinal evidence will be key to fully unpacking the potential mechanisms at play [8]. Further understanding will hopefully allow policymakers to better address disparities head-on during future health crises.

Previous longitudinal evidence, has been very limited. These studies on shifts in COVID-19 mortality by race and ethnicity over time, in addition to national press reporting, have attributed convergence over time between Black and White mortality to the evolving geography of COVID-19, particularly due to regional differences in demography [9,10,11]. The “geographic drivers” theory for nationally-observed convergence in Black and White outcomes suggests that as the pandemic moved to areas of the country with different observed and unobserved characteristics (including demography or infrastructure), changes in national statistics merely reflected the changing sub-national geography of COVID-19, rather than any specific mechanism. For example, as COVID-19 prevalence shifted primarily from regions with larger Black populations to regions with proportionately smaller ones, national statistics may have recorded comparatively less Black mortality. For convenience, in the remainder of this paper we will refer to effects due to “changes in geography” as attributed to the potential role of the changing geographically-tied characteristics of areas that COVID-19 affects. However, while this theory may explain changing national statistics as COVID-19 prevalence spread from the Northeast to the West, it falls short considering prevalence during this time also drastically increased in the South, which has a substantially larger Black population. Further study of these time trends, particularly with a study design that can address the potentially changing characteristics of communities impacted by COVID-19, is essential.

These trends further highlight health disparities between Black and White people in the US. The life expectancy of Black Americans is 3.6 years less than that of White Americans, and this gap is projected to widen by 40% due to COVID-19 [12]. Black Americans also live a greater portion of their lives managing chronic conditions and disability due to differences in lifetime exposure to racism, stressors, and structural discrimination, all factors which contribute to higher COVID-19 mortality rates among Black Americans [13–17]. Cross-sectional studies have also linked disparities in COVID-19 mortality to a variety of community-level factors including population density and urbanization [18–20]. These findings suggest that disparities in COVID-19 mortality primarily reflect disproportionate COVID-19 prevalence in Black communities [21].

Nonetheless, previously identified factors such as population density, chronic comorbidities, and residential segregation have not significantly changed over the period of interest and are thus unlikely to have served as primary drivers for observed changes in COVID-19 mortality *between* racial groups. While these risk factors persist over time, population-level risk disparities due to these factors are likely not substantially changing. Further, these factors have all been previously cited as factors that put Black populations at higher risk, so even if they had effects that increased over time, they would not lead to the observed declines in disparities. Understanding of how racial, ethnic, geographic, and socioeconomic disparities have changed over the course of the COVID-19 pandemic thus remains limited [22].

Furthermore, prior evidence has an additional core limitation. Cross-sectional studies have mostly been limited to studies that correlate population racial make-up data and total COVID-19 mortality, rather than mortality data disaggregated by race. This approach may mask the true burden of COVID-19 on non-majority populations within a county.

In this paper, we provide interpretable understanding of how COVID-19 has impacted Black and White populations over time. We focus on mortality rather than case counts because deaths are less-likely to be affected by massive changes over time in testing availability [23]. Our approach centers on a county-level fixed effects method, using race-disaggregated per capita COVID-19 mortality data to study Black and White outcomes (and the Black/White death rate ratio) over time. The use of county-level data and our fixed-effects approach enables us to estimate changes

within small geographic areas, controlling for time-invariant factors that differ across counties, as COVID-19 prevalence spread to new locations¹. This includes many previously discussed structural risks that can be considered fixed over this timeframe. This approach is essential, as previous literature on convergence in Black and White outcomes has focused heavily on the potential role of changing geographically-tied characteristics, such as demography (notably race and age) or health infrastructure, that may contaminate estimates of disparities over time. We extend this model to investigate heterogeneity in these trends by region and county characteristics.

Finally, we leverage county-level variation in COVID-19 prevalence to evaluate the extent to which time trends in disparities are attributed to changes in prevalence rather than other time-varying factors. As prevalence increases over time, our approach allows us to investigate whether patterns observed in disparities are attributed primarily to time-specific effects (such as time-based shocks in policy, weather, or avoidance behavior that is time-specific, in response to a policy or event) or prevalence-trajectory effects (such as avoidance behavior related to previous community exposure, selection of individuals who either get or die from COVID-19 as the disease progresses through a community, or other mechanisms related to the progression of the disease).

2. Methods and Data

2.1. Sample and Data

National and state COVID-19 mortality data were drawn from weekly cumulative provisional death counts reported to the National Vital Statistics System (NVSS) from May 6, 2020–January 27, 2021, and were used to generate national visualizations [24]. County-level data for analytical use was available from June 24, 2020–January 27, 2021. Data was aggregated to the cumulative deaths through the last week of each month, so while weekly-release data is used, covariates reflect month-by-month changes. While smaller-area geographic data would have enabled even more robust analysis, zip-code level data is difficult to disaggregate by race due to confidentiality concerns, and county-level data enables us to investigate areas that are suitably small yet still enable race disaggregation. We restrict analysis to January to limit the impacts of widespread vaccination. Provisional death counts are incomplete, and likely undercount true COVID-19 mortality. While many deaths are processed nearly immediately, delays in reporting may lead to underestimates at a given timepoint [24]. Studies during the pandemic suggest that after five weeks, most states have reported 99% of their eventual NVSS-reported all-cause mortality for that time period, and after three weeks all but three states were over 80% complete, and most were over 90% complete [25,26]. While time delays mean our estimates are likely an undercount of mortality, it suggests that for the purposes of monthly time-trend analysis, the provisional mortality data is nearly complete, and monthly outcomes primarily reflect deaths within that month. Further, according to the NVSS, less than 0.7% of all recorded COVID-19 deaths are missing racial data [24].

¹ We considered the alternative approach, using a random-effect, but decided to use a fixed-effect for several reasons. The random-effects approach rests on the assumption that county-level unobserved heterogeneity is uncorrelated with our time indicators, which we do not believe to be plausible. Given prior literature's argument that the spread between counties is non-random, we wanted to focus on controlling for unobserved county-level characteristics that we believe are critical to interpretable estimates of disparity trends. Further, a Hausman test on our mortality outcomes rejects the null hypothesis that errors are correlated with time regressors ($p < 0.01$), suggesting a fixed-effect is more appropriate than a random-effects approach.

To maintain confidentiality, counties with fewer than 10 deaths within a racial group are suppressed by the NVSS. This represents a key limitation of the NVSS data. Of 579 counties in our dataset, our analytical sample is 388 counties (2072 county-time observations) with mortality data for both non-Hispanic Black and White persons, representing ~209 million Americans.

County-level demographic and population information are drawn from the 2018 5-year wave of the American Community Surveys (ACS). Per-capita estimates of COVID-19 mortality by race and ethnicity are generated by dividing COVID-19-attributed deaths per 100,000 individuals within each racial group. Outcomes are recorded as the natural logarithm of per capita COVID-19 mortality (interpreted as % changes), as per capita mortality is non-normally distributed. We construct ratios of per-capita COVID-19 mortality in Black populations divided by White mortality.

Covariates for county-level household median income, age structure, population density, and occupation were drawn from the ACS data, data on diabetes and obesity prevalence was drawn from CDC Behavioral Risk Factor Surveillance System data, and supplementary county-level data on COVID-19 testing (not race specific) was drawn from USAfacts.org.

2.2. Statistical Analysis

Ordinary least squares (OLS) regression is initially used to estimate time trends and differences between groups. We then use a county-level fixed effects model to estimate time trends and differences between groups *within* counties, removing the effects of changes between regions and states with heterogeneous demography and other fixed characteristics. The county fixed-effects method has the added benefit that results can be interpreted as conditional on all time-invariant county characteristics (on this time interval), such as population structure, racial and ethnic makeup, health infrastructure, and housing supply and quality.

Indicator variables for each month are used as regression covariates in all models. For regressions on the disparity ratios, these base models are extended in two different regressions with proxies for COVID-19 prevalence. While there are well-documented challenges in estimating COVID-19 prevalence², we use two proxies that we relate to the disparity ratio: total county COVID-19 mortality and three-week lagged positive tests (lagged to reflect time between testing and mortality, net of prior mortality). As both total mortality and lagged tests are flawed measures of prevalence, by using two different prevalence proxies, we hope to draw conclusions that are not specific to the idiosyncrasies of either measure. The natural log of each prevalence measure is taken, as both are non-normally distributed.

Including the prevalence metrics alongside the time effects, we try to leverage county-level variation in prevalence over time to separate the effects of prevalence-linked forces on disparities from other time-linked factors. Specifically, these regressions let us investigate the effects of prevalence on disparities rather than other time-linked factors operating through mechanisms besides prevalence. While the fixed-effects approach accounts for many key time-invariant population characteristics (age, demography, etc), by investigating prevalence alongside time we can observe the extent to which time-varying factors, besides prevalence, that are not accounted for explicitly in the models, are still reflected in the time terms. In doing so, we hope to provide some insight to the potential mechanisms involved in the declining disparities. These factors

² While mortality over time may be a biased proxy of prevalence over time due to changes in reporting as well as in the case-fatality rate due to improved treatments, testing poses challenges due to changing availability over time and unequal distribution of tests. By using two different proxies of prevalence, we hope to draw more robust conclusions.²⁷

Table 1
Summary statistics for counties represented in the analytical sample, including COVID-19 deaths per capita as of January 27th

Table 1: Sample Characteristics		
	Mean	(Std. Error)
A. County Population		
Total Pop.	538,644	(40,446)
Pop./Sq. Mile	1,533	(246.6)
% Male	48.82	(0.0486)
% Over 85	1.936	(0.0340)
% Black	17.99	(0.713)
% White	70.86	(0.735)
% Obese	31.37	(0.277)
% Diabetic	10.12	(0.121)
B. County Economic Status		
HH Median Inc.	61,345	(901.1)
% Service Occupations	17.92	(0.142)
C. Number of Counties by Region		
Northeast	64	
Midwest	81	
West	29	
South	214	
D. COVID-19 Deaths		
COVID-19 Deaths/100k population	150.4	(4.024)
Sample Size	388	

(Standard Errors) in Parentheses

may include changes in avoidance behavior (either linked to prevalence or other time-varying factors), changing treatments, changing infection-fatality risks, or simply measurement error from the prevalence proxies [28].

Finally, heterogeneity analyses for different time trends are conducted by generating interaction terms between the time indicators and covariates for Census region, percentage of the population older than 85 years, and population density. Continuous regression covariates are de-measured, so that regression intercepts can be interpreted for the mean county. All standard errors reported are robust to heteroscedasticity. Analyses were conducted in STATA/SE version 14.2. Choropleth maps were generated using the Plotly Python graphing library.

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3. Results

3.1. Sample Characteristics

The characteristics of counties included in the analytical sample are summarized in Table 1. The mean county in this sample is 49% male, 18% Black, 71% White, 31% obese (BMI>30), 10% diabetic, and has a population of approximately 539,000. As of January 27th, the observed counties experienced an average of 150.4 COVID-19-related deaths per 100,000 individuals. These data represent nearly two-thirds of the American population.

3.2. National Trends in COVID-19 Mortality by Race

While Black populations have cumulatively suffered far greater per capita mortality than White populations, in recent months the ratio of deaths in Black versus White populations has declined, driven by a convergence in mortality between these groups (Fig. 1a). Since November, weekly per capita mortality in White populations has surpassed that of Black populations (Fig. 1b). Although COVID-19 mortality in Black persons was mostly consistent from October to November, mortality in White persons grew significantly, and by January reached an all-time high. These results parallel similar convergence in COVID-19 prevalence by race (Appendix Fig. 1a-b).

Fig. 1c-f maps the ratio of Black versus White COVID-19 mortality per capita by state in May, July, October, and January. Racial differences in COVID-19 mortality varied substantially across states in May. For instance, COVID-19 mortality was six times greater in the Black population relative to the White population in Wisconsin, yet were approximately equivalent in Oregon, Washington, and Arizona. Nationally, the ratio of COVID-19 mortality between Black and White populations has declined and converged over time. By January, the mortality ratio in nearly all states was consistently less than three. Similar map figures (Black versus White COVID-19 mortality per capita in July, October, and January) were also generated at the county level, however due to the inclusion criteria of each county needing >10 deaths per race group, these descriptive figures are less-readily interpretable (Supp. Fig. 2a-c), even though the majority of the US population is represented. Further, small county size makes it hard to see large-picture trends visually.

3.3. County-level Results

Table 2 provides information about the magnitude and direction of county-level COVID-19 mortality trends for Black persons [Column 1-2] (natural-log outcomes interpreted as percent change), White persons [Column 3-4], as well as the mortality ratio of the Black to White population from June 2020 to January 2021 [Column 5-6]. For each outcome, the left column presents the regression coefficients for time (months) without control variables, and the right column presents the coefficients controlling for county-level characteristics.

Both White and Black populations have experienced a substantial increase in county-level total mortality over time. In June, the mortality for Black persons was greater than that for White persons; however, the increase in mortality has been much greater among White persons compared with Black persons from September onward. Relative to June, COVID-19 mortality increased by 4% by July, 24% by September, 50% by December, and 61% by January [Column 1] for Black persons; and 5% by July, 25% by September, 71% by December, and 90% by January for White persons [Column 3]. As a result of the greater increase in COVID-19 mortality among White populations, the Black/White mortality ratio has declined over time [Column 5]. These trends held even when controlling for county characteristics [Columns 2, 4, 6], though coefficients rose slightly (but not significantly) applying controls to the mortality regressions.

Table 3 presents results from the fixed-effects models in which all observed and unobserved, time-invariant, county-level characteristics are taken into account. Fixed-effects estimates show similar time trends of COVID-19 mortality within counties as the non-fixed-effects models. Columns 1 and 2 further support that total COVID-19 mortality has increased for both racial groups; however, greater increases in White mortality since September has resulted in a closing racial gap. By January 2021, the cumulative Black/White COVID mortality ratio had dropped by 0.37 (24.3%) compared to June [Column 3]. Consistency between the OLS regression and county fixed-effects models suggests that the shifting COVID mortality burden is not driven by changes in the regional distribution of COVID mortality (and associated changes in the characteristics of new locations that see large COVID increases), but rather by changes within counties. Our analysis reported similar results when a single fixed-effect model was used to estimate mortality trends for both Black and White populations together, compared to estimating the trend separately (Appendix 1).

Columns 4 and 5 include covariates to study the role of COVID-19 prevalence on the Black/White mortality ratio. Total per capita mortality and lagged positive per capita tests are both used to assess prevalence. Controlling for total mortality per capita or positive tests per capita nearly fully accounts for the downward

Table 2

County-level regressions for non-Hispanic Black and White mortality (per 100,000 individuals), as well as the mortality ratio with month indicator variables. Left column for each outcome reports time effects without covariates, and right column reports outcomes controlled for by de-meaned county-level characteristics.

Outcome Controls Applied?	[1]	[2]	[3]	[4]	[5]	[6]
	ln(Black COVID-19 Mortality per capita) No	ln(Black COVID-19 Mortality per capita) Yes	ln(White COVID-19 Mortality per capita) No	ln(White COVID-19 Mortality per capita) Yes	Black/White per capita COVID-19 Mortality No	Black/White per capita COVID-19 Mortality Yes
July	0.04 [-0.18 - 0.25]	0.07 [-0.11 - 0.25]	0.05 [-0.14 - 0.24]	0.08 [-0.07 - 0.22]	-0.04 [-0.25 - 0.17]	-0.03 [-0.23 - 0.17]
August	0.11 [-0.09 - 0.30]	0.18 [0.01 - 0.34]	0.09 [-0.08 - 0.27]	0.16 [0.02 - 0.29]	-0.02 [-0.22 - 0.17]	-0.02 [-0.21 - 0.17]
September	0.24 [0.05 - 0.43]	0.33 [0.17 - 0.48]	0.25 [0.08 - 0.42]	0.33 [0.20 - 0.46]	-0.07 [-0.26 - 0.12]	-0.06 [-0.25 - 0.12]
October	0.31 [0.12 - 0.49]	0.40 [0.24 - 0.55]	0.35 [0.19 - 0.52]	0.44 [0.31 - 0.56]	-0.12 [-0.30 - 0.06]	-0.11 [-0.29 - 0.07]
November	0.38 [0.20 - 0.56]	0.47 [0.32 - 0.63]	0.49 [0.33 - 0.65]	0.57 [0.45 - 0.70]	-0.20 [-0.38 - -0.01]	-0.19 [-0.37 - -0.01]
December	0.50 [0.32 - 0.68]	0.60 [0.44 - 0.75]	0.71 [0.55 - 0.87]	0.79 [0.67 - 0.92]	-0.31 [-0.49 - -0.12]	-0.30 [-0.49 - -0.12]
January	0.61 [0.43 - 0.78]	0.71 [0.56 - 0.86]	0.90 [0.74 - 1.06]	0.98 [0.86 - 1.11]	-0.40 [-0.58 - -0.22]	-0.40 [-0.58 - -0.22]
Constant (June Base Level)	4.34 [4.18 - 4.51]	4.13 [3.97 - 4.28]	4.03 [3.89 - 4.18]	3.79 [3.66 - 3.91]	1.55 [1.39 - 1.71]	1.66 [1.48 - 1.84]
Observations	2,072	2,072	2,072	2,072	2,072	2,072
R-Squared	0.08	0.33	0.19	0.52	0.03	0.13
County FE?	NO	NO	NO	NO	NO	NO

[95% Confidence Intervals] in Brackets

June Reference Group

Controlled columns include de-meaned covariates for % of a County that is Black, % of people over 85, % male, median household income, % Obese, % Diabetic, population density, % in a service occupation, and US Census region indicators

Table 3

County-level fixed-effects regressions for non-Hispanic Black and White mortality (per 100,000 individuals), as well as the mortality rate ratio with month indicator variables. Columns 4 and 5 add covariates for COVID-19 disease prevalence at the county level.

Outcome	[1] ln(Black COVID-19 Mortality per capita)	[2] ln(White COVID-19 Mortality per capita)	[3] Black/White per capita COVID-19 Mortality	[4] Black/White per capita COVID-19 Mortality	[5] Black/White per capita COVID-19 Mortality
ln(Total Mort. Per Cap.)				-0.21 [-0.29 - -0.13]	
ln(Lag Pos. Tests Per Cap.)					-0.19 [-0.26 - -0.12]
July	0.12 [0.07 - 0.18]	0.11 [0.06 - 0.16]	0.01 [-0.03 - 0.05]	0.03 [-0.01 - 0.07]	0.07 [0.03 - 0.11]
August	0.25 [0.19 - 0.32]	0.23 [0.16 - 0.30]	0.01 [-0.04 - 0.06]	0.06 [0.02 - 0.11]	0.12 [0.07 - 0.16]
September	0.41 [0.34 - 0.49]	0.42 [0.34 - 0.50]	-0.04 [-0.09 - 0.02]	0.06 [0.00 - 0.11]	0.13 [0.08 - 0.19]
October	0.48 [0.40 - 0.55]	0.51 [0.43 - 0.60]	-0.08 [-0.14 - -0.03]	0.03 [-0.03 - 0.09]	0.11 [0.06 - 0.17]
November	0.56 [0.48 - 0.64]	0.64 [0.56 - 0.73]	-0.16 [-0.21 - -0.10]	-0.02 [-0.09 - 0.04]	0.08 [0.01 - 0.14]
December	0.70 [0.61 - 0.78]	0.88 [0.79 - 0.98]	-0.29 [-0.35 - -0.22]	-0.11 [-0.19 - -0.03]	0.03 [-0.05 - 0.12]
January	0.82 [0.73 - 0.91]	1.07 [0.98 - 1.17]	-0.37 [-0.44 - -0.31]	-0.16 [-0.25 - -0.07]	0.01 [-0.10 - 0.12]
Constant (June Base Level)	4.18 [4.11 - 4.25]	3.89 [3.81 - 3.97]	1.52 [1.47 - 1.57]	1.41 [1.35 - 1.46]	1.30 [1.24 - 1.36]
Observations	2,072	2,072	2,072	2,072	2,072
R-Squared	0.60	0.68	0.37	0.41	0.41
County FE?	YES	YES	YES	YES	YES
Number of Counties	388	388	388	388	388

[95% Confidence Intervals] in Brackets

June Reference Group

ln(Total Mort.) and ln(Lag Pos.) de-meaned

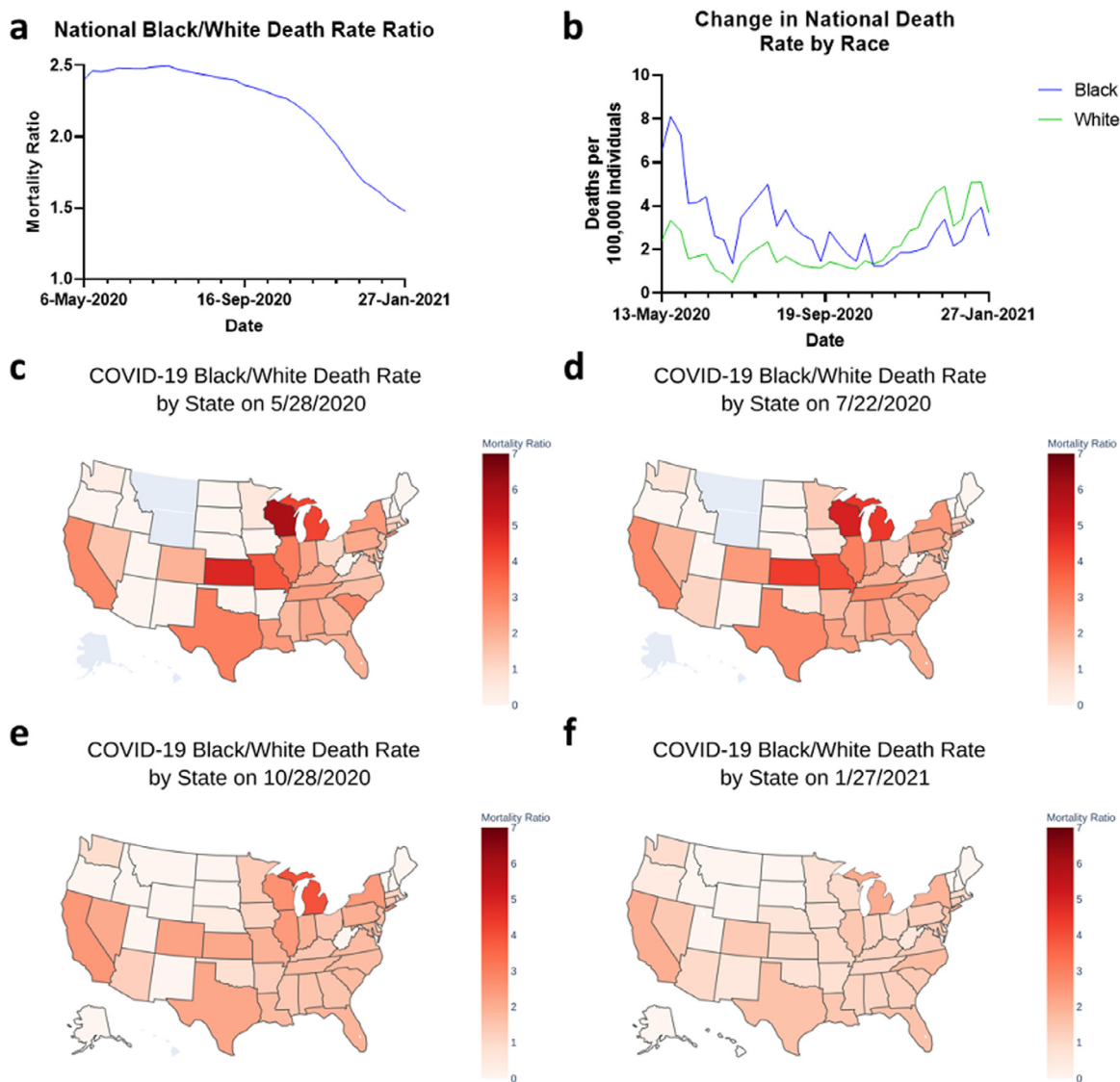


Figure 1. National Trends in COVID-19 Mortality by Race. (a) Weekly Cumulative Black/White Death Rate (Mortality per 100,000 individuals) Ratios were calculated by date and subsequently plotted from 5/6/2020-1/27/2021. (b) Weekly Change in COVID-19 Death Rate (deaths per 100,000 individuals) by race was calculated by date and subsequently plotted from 5/13/2020-1/27/2021. US maps were generated to visualize Black Over White Death Rate Ratio by state on (c) 5/28/2020, (d) 7/22/2020, (e) 10/28/2020, and (f) 1/27/2021.

trend in racial difference: coefficients over time approach 0, though some small time-effects persist. These residual time effects may represent several different forces. It could represent time-shocks (such as time-specific avoidance behaviors, or weather), that lead to deviations from the prevalence-disparity relationship, or larger time-varying changes that have shaped the pandemic, like changing treatment and infection-fatality rates, or gradual returns to work and school. It may also represent changing measurement errors in the prevalence or disparity metrics over time. Nonetheless, the residual time effects are comparatively small using either prevalence measure. County-level variation in infection prevalence seems to act as the primary driver of time-based declines in Black/White COVID-19 mortality ratio.

3.3. Heterogeneity by Age, Population Density, and Region

Assessment of heterogeneity in the mortality time trends by population density revealed a strong negative interaction between time and population density from September 2020 onward, indicating that counties with higher population density experienced

relatively smaller increases in mortality (Appendix 3). Conversely, regarding the racial gap, the positive interaction between time and population density suggests that counties with higher population density experienced less cumulative convergence between Black and White COVID-19 mortality since September.

Investigating heterogeneity by age revealed similar results (Appendix 2). Areas with larger shares of population over age 85 observed both smaller increases in Black and White mortality since June, as well as a positive interaction between time and older age proportion with respect to disparities. These results suggest that counties with older populations experienced comparatively less convergence over time.

Analysis by region revealed large geographic differences (Appendix 4). Compared to the time trends for the Northeast, COVID-19 mortality increased more rapidly in the West and the South, for both Black and White populations. Similar to the national time trends shown in Table 3, COVID-19 mortality increased more among White persons in the Midwest, the West, and the South, resulting in larger declines in the racial gap over time. For example, among White persons living in the Midwest, total COVID mor-

tality in January 2021 increased 132% relative to June 2020, while mortality among Black persons increased 90%. The considerable reduction in the Black/White COVID-19 mortality ratio by December reflects this increase in COVID-19 mortality among White persons in the Midwest.

In order to assess whether the regional trends in disparities were driven by regional differences in pandemic stage (as suggested by the differing intercepts in June), prevalence covariates were added to an interacted model with regional coefficients (Appendix 5). This additional analysis revealed that differences between regions at each time point approach zero when accounting for COVID-19 prevalence, and most interaction terms are no longer significant, suggesting that differences in the Black/White mortality ratio by region primarily reflect different stages of the pandemic rather than differences in inherent regional characteristics.

4. Discussion

Our study set out to understand changes over time in the burdens of COVID-19 mortality in non-Hispanic Black and White populations, and the ratio between the two. This study makes three key contributions to the literature.

First, we investigate these trends over a comparatively long time period, from June 2020 through January 2021, during which an additional surge in cases occurred. Our results show that the national convergence between Black and White COVID-19 mortality outcomes was primarily driven by trends within counties. Previous work has argued that changes in the regional dispersion of COVID-19 between regions with different characteristics was driving national changes in the relationship between Black and White mortality [9,10]. In sharp contrast, our fixed-effects approach reveals that the driving force for the observed mortality convergence is occurring *within* counties.

Second, we show that the observed time trends can be almost entirely accounted for by the relationship between COVID-19 prevalence and the Black/White mortality ratio. Variation in COVID-19 prevalence at the county level enable us to separate the effects of changing prevalence from other time-specific factors that are not accounted for, allowing us to identify a strong negative relationship between changes in COVID-19 prevalence and the Black/White mortality ratio that nearly fully accounts for the observed trends over time. This has important implications for understanding observed disparities in COVID-19 mortality as linked to the trajectory of disease prevalence, rather than to any specific activity at certain timepoints. Nonetheless, there remain some residual time-based effects on disparities that are not fully accounted for by the prevalence changes, which may suggest either smaller, but nonetheless relevant time-specific shocks, or measurement error, and warrant further investigation.

Third, we document heterogeneity in the time trends observed. We show that in younger populations, the Black/White mortality ratio fell the most. In addition, we find that places with higher population density experienced smaller COVID-19 mortality increases, and less convergence between Black and White outcomes. Finally, we show census-region level geographic variation in the time trend even with the county-fixed effect, which can be nearly fully accounted for by changes in COVID-19 prevalence, providing further evidence for the core role of prevalence in driving mortality disparities rather than time-specific shocks or mechanisms linked to the geographic characteristics specifically.

Several potential mechanisms could explain the convergence over time between Black and White mortality, including changes in exposure between populations or vulnerability of individuals affected by COVID-19 over time. Potential mechanisms for changes in disparities can generally be attributed to either changes in exposure or changes in mortality conditional on exposure. Our results

suggest that both sets of factors may be at play, as the mechanism driving convergence in disparities is primarily affecting mortality within the county level, and is potentially linked to changes in cumulative COVID-19 prevalence rather than time. Further research should focus on mechanisms consistent with within-county changes and prevalence-based mechanisms, rather than the geographic variation theory.

Most discussion on COVID-19 mortality outcomes over time has focused on the potential role of geography in explaining trends. Our results suggest that geographic changes in prevalence of COVID-19, and specifically, changes in the characteristics of areas where COVID-19 is prevalent, are not the primary driver of convergence in racial mortality. Our findings instead suggest that the primary mechanisms involved are taking place within smaller geographic areas, and that shifts in mortality trends are not accounted for by time-invariant county characteristics (such as population density or demographic composition).

While changes in exposure between populations is a difficult potential mechanism to assess, particularly due to changing COVID-19 testing availability, the convergence over time between national per capita positive tests in Black and White populations parallels our core results, suggesting prevalence-disparities are likely linked to changing mortality disparities (Appendix Figure 1). Changes over time in exposure to COVID-19 between the two populations is likely one of the driving forces in the observed mortality trends. Our results on the relationship between population density and mortality are consistent with evidence from other studies that areas of greater population density had both more effective and more persistent social distancing over time [29]. While high density is related to increased risk, particularly early on in the pandemic, more persistent behavioral avoidance in those areas could lead to an attenuated time trend (especially when log-outcomes assessing percentage change are used) [30].

Another potential mechanism includes temporal differences in mortality among generally vulnerable populations. This may manifest in either of two ways: comparatively increased exposure among vulnerable populations, or comparatively increased mortality conditional on exposure. It is possible that vulnerable groups may have had less control over exposure, particularly earlier in the pandemic, resulting in disproportionate COVID-19 infections and deaths early on, “front-loading” mortality in socially and medically vulnerable groups. A wealth of literature has shown how systematic forces place Black populations at higher risk of exposure, including prevalence of “essential worker” classifications [21]. Furthermore, while prior literature has shown that pre-existing conditions do not fully explain racial mortality disparities [31], pre-existing conditions that could increase an individual’s likelihood of dying due to COVID-19 are more prevalent in Black populations, and early mortality selection on pre-existing conditions may magnify disparities early on in the pandemic. A combination of these health and socioeconomic factors may have resulted in increased vulnerability of Black populations relative to White populations early in the pandemic, contributing to the observed time trends. Prior evidence from persons with kidney failure is consistent with this theory: amongst this at-risk population, Black mortality exceeded White mortality by the largest margin early on in the pandemic [32]. This mechanism would also be consistent with a prevalence-disparity relationship.

5. Limitations

This study has several limitations. We used provisional COVID-19 mortality data in which counties may have had differential delays in reporting deaths. Further, provisional death counts are incomplete, and so our study likely underestimates the cumulative number of deaths for any given interval.

Additionally, due to confidentiality concerns, only counties with more than 10 deaths for both Black and White individuals are included. Although the counties used in the study comprise the majority of the U.S. population, they do not constitute a random subset of U.S. counties, and tend to have greater absolute populations and more COVID-19 deaths per capita than the average U.S. county. Therefore, while using the county fixed-effects approach controls for all fixed factors related to a county's inclusion in our data, mitigating the effects of selection, our results may not generalize to counties not included in the sample. Selection may affect the size of the disparities estimated – since our data suggests that county-level disparities fall as disease prevalence increases over time, selection into our sample of counties with larger prevalence that meet the 10-death threshold may in fact have smaller disparities than average when they enter our sample. However, examining trends within-county over time would account for this, and would provide robust results of trends after entry into our sample.

A third potential concern is that our results may be hard to interpret if the time interval between COVID-19 diagnosis, mortality and reporting differ significantly by race. While such differences could exist, the county fixed-effects approach ensures our estimates are robust as long as between-race differences in measurement error or reporting lags do not vary substantially over time *within counties*. Nonetheless, there is limited evidence that timelines between diagnosis, hospitalization, and mortality vary substantially by race [33], and our analyses (Figure 1B) clearly indicate that Black and White COVID-19 mortality surges occur at the same time, suggesting minimal differences by race in both reporting time and mortality.

The prevalence variables used in this paper and linked to the disparity measures – total COVID-19 mortality and lagged positive tests, are also imperfect estimates of prevalence. By utilizing two different proxies for prevalence, we hope to draw more robust conclusions that do not fully depend on the potential biases of either specific measure.

A fifth limitation is the lack of county-level data disaggregated by both age and race. Because our estimates are not age-adjusted, our findings likely understate the true difference in outcomes between Black and White populations. While we are able to posit potential mechanisms, lack of fine-grained data on exposure and mortality rates over time prevents us from decomposing convergence in disparities to changes in exposure or infection-fatality rate specifically.

In addition, despite the use of a county fixed-effects framework, there may still be confounding factors that remain unaccounted for. Finally, our analysis also does not explore disparities in other vulnerable populations within the US, including Hispanic populations.

6. Conclusions

Between June 2020 and January 2021, per capita COVID-19 mortality increased more substantially for White populations than for Black populations, resulting in a declining Black/White COVID-19 mortality ratio. These effects persist even when controlling for all county-specific time-invariant factors, and are not driven by changes in the regional presence of COVID-19 prevalence. The majority of the observed trends in disparities over time, including regional variation in the time trends, can be explained by changes in cumulative COVID-19 prevalence at the county level, suggesting that the primary driver of cumulative convergence between Black and White mortality outcomes is due to the 'stage' of infection prevalence, rather than other time-linked factors that aren't measured in our analysis. However, the exact mechanism by which this occurs is not clear. Further research should investigate mechanisms consistent with these results.

Our findings provide direct evidence to reject the commonly-discussed 'geographic' theory of converging COVID-19 disparities, showing that the mechanisms that drive differences in mortality over time in Black and White populations are occurring primarily within small geographic areas and are linked to changes in COVID-19 prevalence, rather than other time-varying factors. Further research into potential mechanisms consistent with these criteria, such as changes in exposure and behavioral responses to prior mortality, or potential 'front-loading' of more-vulnerable patients, would be of high value and may allow for greater understanding of how such mechanisms can be addressed to minimize disparities in health crises. For policymakers, our work re-emphasizes the importance of not only protecting vulnerable populations, but taking decisive action early on, as vulnerable populations may be especially vulnerable early in a public health emergency. This type of research will be important for fully understanding COVID-19-related mortality disparities, and may shed light on some of the mechanisms driving health disparities broadly.

Contributors

R.L., K.Z., and E.H. conceived of the study. R.L. and D.Z. generated data constructs. R.L., K.Z., and D.Z. analyzed the data. R.L., K.Z., D.Z., and E.H. wrote the paper. All authors discussed the results and reviewed the manuscript.

Declaration of interests

I have read the journal's policy and the authors of this manuscript have the following competing interests: E.H. is a non-executive founder of Stratus Medicine, KelaHealth, and MedBlue Data, and is the Chief Innovation Officer at Onduo.

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Data and materials availability

All data is available in the manuscript or the supplemental materials. Data and materials will be fully available upon reasonable request.

Editor's note

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.lana.2021.100011](https://doi.org/10.1016/j.lana.2021.100011).

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