Investigating Social Determinants of Premature Mortality in the United States

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ABSTRACT

Objective: MortalityMinder enables healthcare researchers, providers, payers, and policy makers to gain insights into where and why premature mortality rates due to all causes, cancer, cardiovascular disease, and deaths of despair rose between 2000 and 2017.

Materials and Methods: MortalityMinder is a web-based visualization tool that enables interactive exploration of social, economic, and geographic factors associated with midlife mortality among adults aged 25-64. As an open source project, we seek a community effort to improve the tool which helps stakeholders at the national, state, county and community level who strive to identify and address unmet healthcare needs.

Results: We examine the rates of midlife mortality across the United states for various causes of deaths. We find varying mortality trends and associated social determinants across different states even with similar population sizes. We identify varying county-level social determinants and examine Sierra county, New Mexico from the point of view of a health care provider and a policymaker.

Discussion: Premature mortality rates in the United States have been rising since 2000, reversing previous longevity trends. The COVID-19 pandemic has exacerbated the problem of the existing geographical health inequities that result in midlife mortality and thus, we extended our insights from MortalityMinder into CovidMinder to highlight COVID-19 regional disparities.

Conclusion: MortalityMinder, a freely available, publicly-accessible, and open source tool, can be used by county-level health care providers and state-level policymakers alike to further their understanding of the challenges facing their communities.

Key words: Mortality, Risk Factors, Cardiovascular Diseases, Premature, Cause of Death

BACKGROUND AND SIGNIFICANCE

Midlife mortality rates were rising across the United States (US) since before the COVID-19 pandemic. To understand why, we consider the environmental conditions and social determinants that contribute to health outcomes such as cancer, cardiovascular disease, and deaths of despair. Community health is affected by environmental conditions such as access to clinical care, education, employment and social connectivity which varies across different geographical regions. The health of individuals is also affected by their place of birth, age, gender, race, socio-economic status, etc. which are referred to as the social determinants of health. These factors play a significant role in health inequities across the United States. Stein et. al. 2017 found that "Deaths of Despair", which are deaths due to suicide and substance abuse, have increased dramatically among white males between the ages of 25-64, particularly those who live in rural America[1]. In 2020 we've saw that the rate of deaths due to COVID-19 varied significantly between different states and counties, and was also affected by these social determinants. For example, African Americans are dying from COVID-19 at a higher rate across the country[2].

Regional disparities exist for all causes of premature death. A person living in Alabama is more likely than someone living in California to die from heart disease or stroke before the age of 65. MortalityMinder illuminates where these health disparities exist, and what we can do about them. It visualizes how the rates of premature death have changed from 2000 to 2017 for different regions of the United States. It identifies counties with increased death rates, and analyses the social determinants that are associated with these differences in mortality rate. For example,

MortalityMinder found that deaths from heart disease and stroke increased after the start of the great recession. Further, people in counties with higher rates of diabetes, poverty, food insecurity, and mental distress rates were more likely to die under the age 65 due to heart disease or stroke. For the correlation of social determinants with mortality trends across United States' counties, MortalityMinder was awarded third place in the AHRQ's Visualization of Community-Level Social Determinants of Health Challenge[3].

Using county-level data on mortality rates from CDC WONDER[4], MortalityMinder explores mortality trends for adults of ages 25-64 in the US from 2000 to 2017. Using county-level surveillance data from County Health Rankings[5], MortalityMinder identifies social and economic factors associated with mortality trends at the county-level for US and individual states. With MortalityMinder, a user can select the region (specific state or US) and the cause of death (All Cause, Cancer, Cardiovascular, or Deaths of Despair) and the application will dynamically create three analysis and visualization infographics, each of which addresses a different question:

- What are the trends in midlife mortality rates for a selected cause of death across the United States and in a selected state?
- How do midlife mortality rates for a selected cause of death vary by county across the selected state and why?
- How are county-level social and economic factors associated with midlife mortality rates for a selected cause of death in a selected state?

An important finding from MortalityMinder and related research is that premature mortality rates for all causes of death were already rising in the US especially after the Great Recession in 2009. The COVID-19 pandemic suddenly made these social and economic determinants of mortality worse while simultaneously "crowding-out" users with non-COVID-19 related problems from the health care system. These could combine to create a surge in premature deaths from other causes besides COVID-19 that will continue after the pandemic subsides. MortalityMinder's goal is to enable healthcare researchers, providers, payers, and policy makers to gain actionable insights into how, where, and why midlife mortality rates were rising in the US pre-COVID so we can develop more effective policies and decrease health care problems post-COVID.

OBJECTIVE

We propose MortalityMinder, an interactive web application that targets healthcare officials, as a tool for policymakers to gain insight into regional disparities in mortality trends across United States. We first explore the methods used for clustering various counties and states into risk groups as well as the methods for identifying key social determinants for a given state and county. Next, we highlight insights drawn from MortalityMinder through case studies which explore how the tool can be used at the national, state and county level as well as analyze the disparities between states of comparable population size. Finally, we discuss the overall analysis drawn from the application, and its correlation with the current COVID-19 pandemic.

MATERIALS AND METHODS

Data Sources

MortalityMinder uses county-level mortality rates and social and economic factors measurement data for its analysis. Mortality rates per 100K from 2000-2017 are obtained through the CDC WONDER portal[4], the definitive source of mortality information in the United States. Social determinants data for 2015-2017 are obtained through County Health Rankings (CHR)[5], an aggregate of county-level data curated by the Robert Wood Johnson Foundation. MortalityMinder considers 70+ factors from twenty sources, including datasets from BRFSS[6], the Bureau of Labor Statistics[7], the FBI[8], and many others. MortalityMinder focuses on premature midlife deaths attributed to leading causes of death including "Deaths of Despair", "Cardiovascular", "Cancer" and "All Cause". The ICD-10 definitions for the causes are taken from Stein et al 2017[1].

Data Processing

Age-specific mortality rates for the year 2000 to 2017 were aggregated into three-year chunks (2000-2002, 2003-2005,

2006-2008, 2009-2011, 2012-2014 and 2015-2017) for each cause of death at the county, state, and national levels. For privacy reasons, CDC WONDER suppresses rates for counties with too few deaths, so calculating rates over three-year chunks ensured more accurate rates.

In conjunction with three-year data aggregation, county mortality rates that were missing or suppressed were imputed using mortality rates for the state using the Amelia package[9] for R for effective visualizations. Further, as MortalityMinder aims to capture the actual mortality of Americans at the community level, our analysis is not age-adjusted and captures the real mortality trends by considering all deaths equal. The imputed data sets used for analysis are available for download from GitHub[10].

Risk Group Clustering
To create effective visualizations that depict rigorous analysis and identify similar counties, we clustered the mortality rates for the counties in a state into risk groups. Each risk group represents varying susceptibility of people towards premature death by representing similar counties with their mean mortality rates for each year group. This also smooths out the inherent noise in estimated mortality rates to better reveal mortality trends. For each state, we categorize the counties into low, medium, and high risk groups based on their mortality rates between 2000 and 2017. A similar risk group clustering is done across US where we group counties into 6 risk groups ranging from 1:low risk to 6:high risk. The risk groups are identified by clustering the counties using K-Means algorithm on the average mortality rates for each county and then ordering the clusters from low to high by the average mortality rate in 2015-2017.

Social Determinants Identification
We gathered social determinants (factors) addressing health behaviors, clinical care, education, employment, social supports, community safety, and physical environment domains from County Health Rankings[5]. From a total of 168 different social determinants, we first selected the determinants which were either rates or measurements that represented rates but did not directly reflect county population size. Through multiple hypothesis testing using the Benjamin-Hochberg Method[11], we narrowed our selected determinants to 70 which were relevant to at least one cause of death at the national level. These final set of social determinants were included as part of the socio-economic factor analysis in MortalityMinder.

MortalityMinder Application
MortalityMinder is an award-winning application aimed at healthcare researchers, providers, payers and policy makers to gain actionable insights on how, where and why mortality is increasing in the community. This shall enable them to develop policies that target causes of mortality relevant to the specific county and demographic. MortalityMinder was designed based on a formal usability study of 20+ users and recommendations from our advisory board of healthcare and design professionals.

It is available as an open source R project on GitHub[10] with full application code, data, and documentation. R was chosen due to its powerful environment for statistical computing and graphics using standard packages. MortalityMinder utilizes the R Shiny[12] and FullPage Javascript frameworks[13,14] for web interactivity. The code can be easily customized and maintained while ensuring that it can be extended to incorporate user feedback using an agile framework.

The user can choose to display the analysis for a specific state or the whole nation for All Cause, Cardiovascular, Cancer or Deaths of Despair causes of death. The application is split into four pages: the first three pages include specific analysis for the given state and cause of death and the last page including documentation for the application. The three analysis pages of the application are referred as "three views" as described below:

- *National View:* The view explores the mortality rates across all counties in United States for a given three-year period for a specific cause of death as a choropleth plot. The change in mortality rates for the selected state are compared with the national level across the years 2000 to 2017, split into three-year chunks.
- *State View:* The view depicts the mortality rates across all counties of the selected state. It clusters the counties into risk groups and plots them as geoplot and lineplot while comparing the results with the national average. Further, the top protective and destructive social determinants for the state are depicted with kendall correlation values.
- *Factor View:* For the selected county, this view shows a detailed description of the selected social determinant

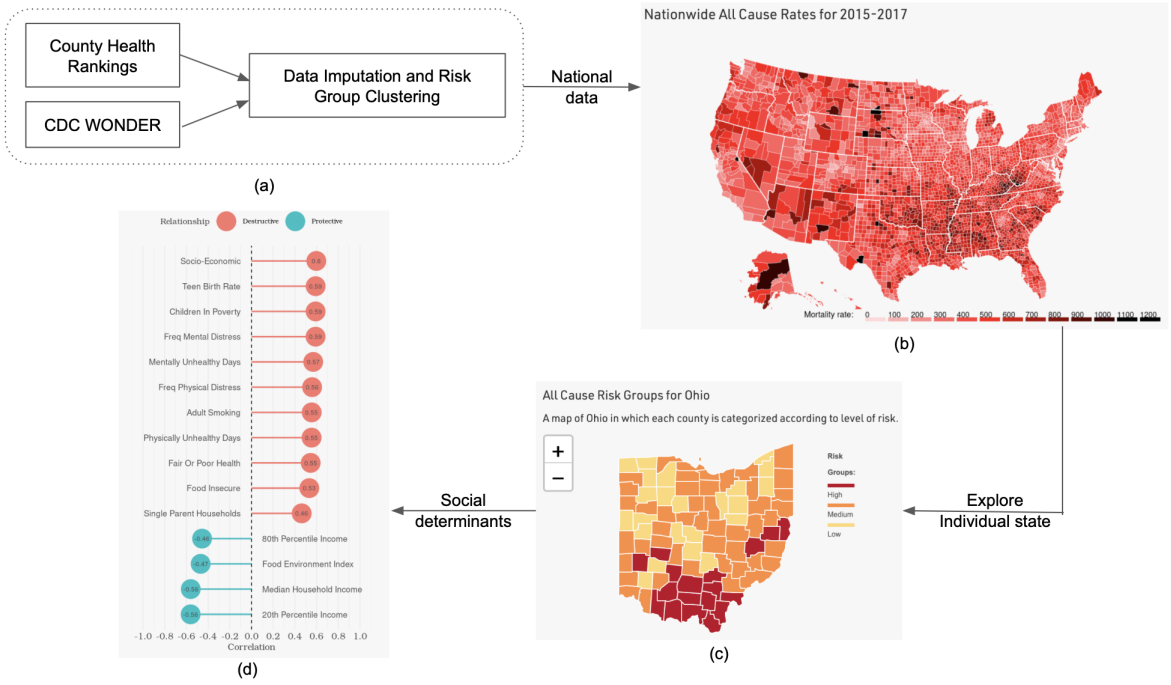


Figure 1: Flow of data through the MortalityMinder application. (a) Data is collected from Country Health Rankings (social determinants) and CDC WONDER (mortality rates). Missing data is imputed, data is clustered into 3-year chunks and risk groups are identified using K-Means. (b) The imputed mortality rates for a given three year period (e.g. 2015-2017) are plot as a choropleth plot with a darker color representing higher mortality. (c) Each state (e.g. Ohio) can then be further explored based on the risk group clusters: High (red), Medium (orange) and Low (yellow). (d) Finally, top social determinants are listed as destructive or protective factors based on their Kendall correlation number.

and plots the counties based on the risk groups.

The application is deployed on the R Shiny server. A snapshot of the application for mortality trends in Massachusetts for Deaths of Despair is shown in Figure 2. MortalityMinder can be accessed at: https://mortalityminder.idea.rpi.edu

RESULTS

MortalityMinder shows evidence that health inequities exist between different regions of the United States, at the state and county level. The data shows that there is a larger, underlying, community-based picture in all aspects of health and wellness. MortalityMinder dramatically illustrates recently reported mortality rate increases, while providing greater insights into state-level variations and their associated factors to help determine remedies. In the MortalityMinder application, we analyze mortality rate trends across Deaths of Despair, Cardiovascular diseases, Cancer, and All Causes of Death for the years 2000-2017. MortalityMinder provides an in-depth analysis and visualization of mortality trends, while highlighting key social determinants across states and counties. The depicted information enables us to draw case-by-case insights for specific counties and states and are explored as case studies in this section. First, we highlight the mortality trends across United States. Then, using the results, we compare varying social determinants across states and finally, discuss the community-level differences through the case study of the Sierra County in New Mexico.

Mortality trends across United States

In the United States, midlife deaths due to Deaths of Despair have increased by a whopping 90.4% from 2000 to 2017. Although the Southwest and southern Appalachian region experience the highest concentrations of mortality in this

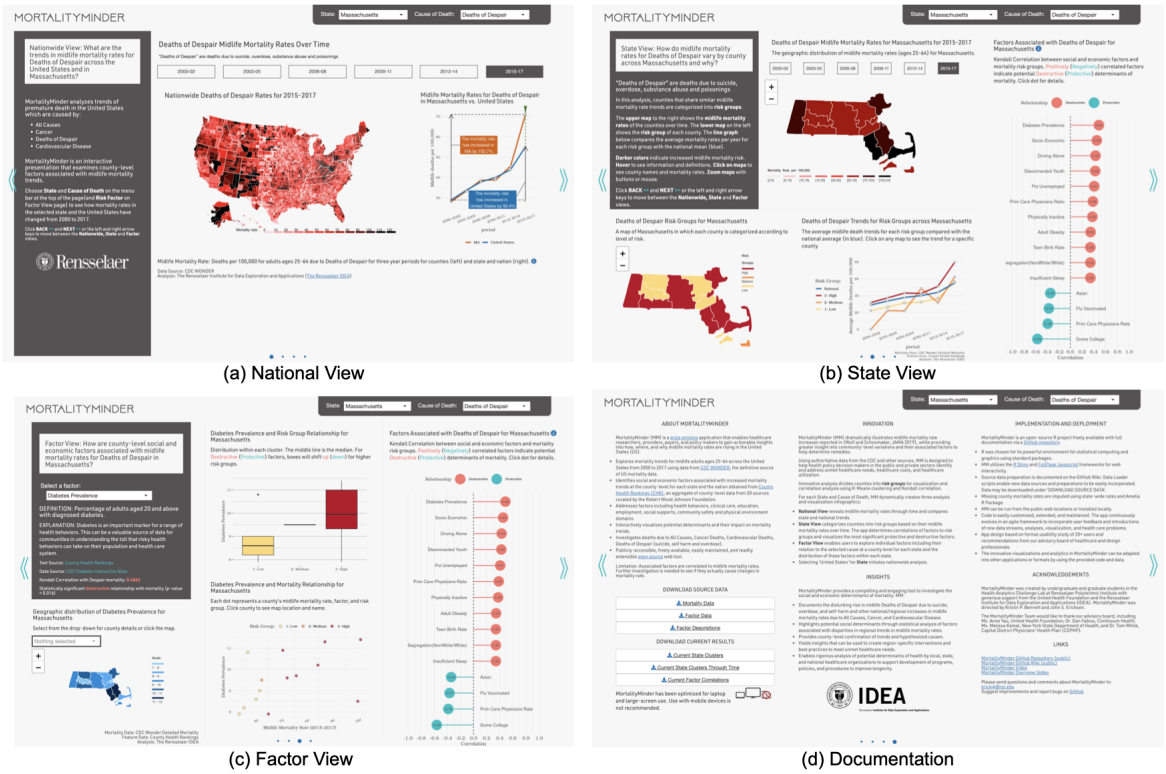
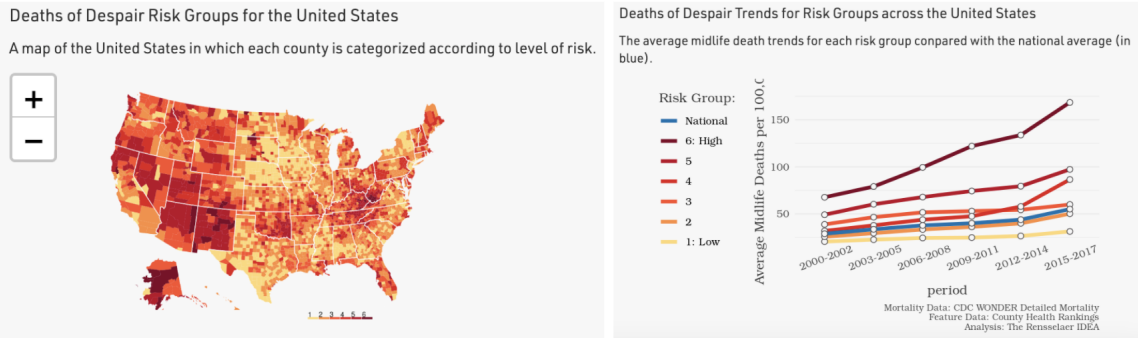


Figure 2: MortalityMinder Application overview. (a) National View: Distribution of Deaths of Despair mortality rates across United States and its comparison with Massachusetts (b) State View: Mortality rates and risk groups for counties of Massachusetts for Deaths of Despair (c) Factor View: Exploring Diabetes as a prominent social determinant for Deaths of Despair mortality in Massachusetts (d) Documentation about the application with links to data and application code

category, the Deaths of Despair mortality rates for United States have been increasing across the board. Figure 3(a) highlights this variation in the risk groups across various states and counties with a darker color (6, red) indicating high risk and a lighter color (1, yellow) indicating low risk. Figure 3(b) shows the mortality trends for various county-level risk groups identified based on the mortality rates. The plot highlights that some counties are performing worse than the national average, urging the need to diagnose the causes and focus on specific regions of high mortality. With the prevalence of individuals expiring prematurely due to suicide and substance abuse affecting communities nationwide, it is important to consider the factors associated with Deaths of Despair which could underscore the underlying causes behind the loss of life.

At the national level, there are several social determinants that are associated with Deaths of Despair mortality. The top destructive and protective factors are listed in Table 1 along with their Kendall correlation number, where a higher absolute value indicates a stronger correlation. These factors can be grouped into: mental health (Mentally Unhealthy Days, Frequent Mental Distress, Mental Health Provider Rate), physical health (Physically Unhealthy Days, Adult Smoking, Frequent Physical Distress, Other primary Care Provider Rate, Diabetes Prevalence, Insufficient Sleep), and socio-economic status (Percent Unemployed, Segregation, Socio-Economic, Non-Hispanic White). The correlations reveal that the Deaths of Despair mortality is particularly impacted by mental health, physical health, and socio-economic status of a community at the national level as shown by high correlation values of mentally unhealthy days, frequent mental distress, physically unhealthy days, percentage of people who are unemployed and adult smoking.

During the 2009 economic recession, many communities experienced an economic downturn. This impacted the health and well being of many individuals who were now unable to provide for their families and in turn, experienced poor mental and physical health. This is reflected in the rise of Deaths of Despair mortality seen at that time. Today,



(a) (b)

Figure 3: Deaths of Despair Nationwide Analysis (a) Counties across the United States are clustered into 6 risk groups (1: Low to 6: High) based on the Deaths of Despair mortality trends (b) The risk group trends are plot against the national average demonstrating the rise of mortality rates across years.

Table 1: Social determinants affecting Deaths of Despair mortality across United States. A destructive determinant is positively correlated while a protective determinant is negatively correlated.

Relationship	Name	Correlation
Destructive	Mentally Unhealthy Days	.22
Destructive	Frequent Mental Distress	.19
Destructive	Physically Unhealthy Days	.17
Destructive	Pct Unemployed	.15
Destructive	Adult Smoking	.15
Destructive	Segregation(Black/White)	.15
Destructive	Freq. Physical Distress	.15
Destructive	Mental Health Prov. rate	.14
Destructive	Socio-Economic	.14
Destructive	Other Prim. Care Prov. Rate	.12
Destructive	Non-Hispanic White	.11
Destructive	Diabetes Prevalence	.11
Destructive	Insufficient Sleep	.11
Protective	Younger than 18	-.11
Protective	Mental Health Prov. Ratio	-.13

we have seen many of the same issues being exaggerated due to the global COVID-19 pandemic. The unemployment numbers hit record highs within a number of days[15], and collective anxiety about the virus took over. With the nation locked down, mental and physical health plummeted. Since the pandemic has led to decreased mental and physical health, and has dramatically affected the socio-economic status of millions, we expect a spike in midlife deaths due to suicide, and substance abuse.

State-level comparison for Deaths of Despair mortality

National trends of midlife mortality due to Deaths of Despair are on the rise primarily due to the increased mortality rates across counties and states. However, not all the states are experiencing the same rate of mortality increase over time. Thus, to understand the underlying trends in mortality across states, we compared Washington, Arizona, New Jersey, and Massachusetts due to their similar population sizes. We wanted to gauge the effect of population size on social determinants and understand the mortality rates for Deaths of Despair in these states. The original expectation was that states with similar population sizes would attract the same community types and thus, will all be affected by same determinants. However, in contrast to our expectation of having multiple shared determinants, the results were quite different. Each state proved to have a unique community that in turn produced distinct determinants with only slight overlap. The top 4 destructive determinants for each of these states are shown in Table 2 and the top 4 protective

determinants are shown in Table 3.

Table 2: Top four destructive social determinants for Washington, Arizona, New Jersey and Massachusetts

Washington	Arizona	New Jersey	Massachusetts
#1 Older than 65	#1 Segregation (Black/White)	#1 Mentally Unhealthy Days	#1 Diabetes Prevalence
#2 Diabetes Prevalence	#2 Single Parent Household	#2 Limited Access to Healthy Food	#2 Socio-Economic
#3 Non-Hispanic White	#3 Food Insecure	#3 Pct Unemployed	#3 Driving Alone
#4 Food Insecure	#4 American Indian / Alaskan Native	#4 Adult Smoking	#4 Disconnected Youth

Table 3: Top four protective social determinants for Washington, Arizona, New Jersey and Massachusetts

Washington	Arizona	New Jersey	Massachusetts
#1 Younger than 18	#1 Food Environment Index	#1 Food Environment Index	#1 Some college
#2 Not Proficient in English	#2 Hispanic	#2 80th Percentile Income	#2 Prim Care Physicians Rate
#3 Hispanic	#3 Native Hawaiian Islander	#3 Asian	#3 Flu Vaccinated
#4 Sexual Trans Infect	#4 Air Quality	#4 Dentist Rate	#4 Asian

The top destructive determinants did have some similar determinants across pairs of states but no single factor was common among all states. For example, food insecurity was top destructive factor for both Washington and Arizona and the prevalence of diabetics was common between Washington and Massachusetts. However, all other factors were unique to the individual state and its community. The same results are also evident in the top protective factors. Being Hispanic or Asian is a protective factor across all four states, with food environmental index being common only between Arizona and New Jersey. Apart from these, there were no other common determinants, again underscoring the effect of uniqueness of each community and state on mortality rates. While there was some common determinant across pairs of states, there is not enough evidence to show that comparable population sizes have an effect on the social determinants.

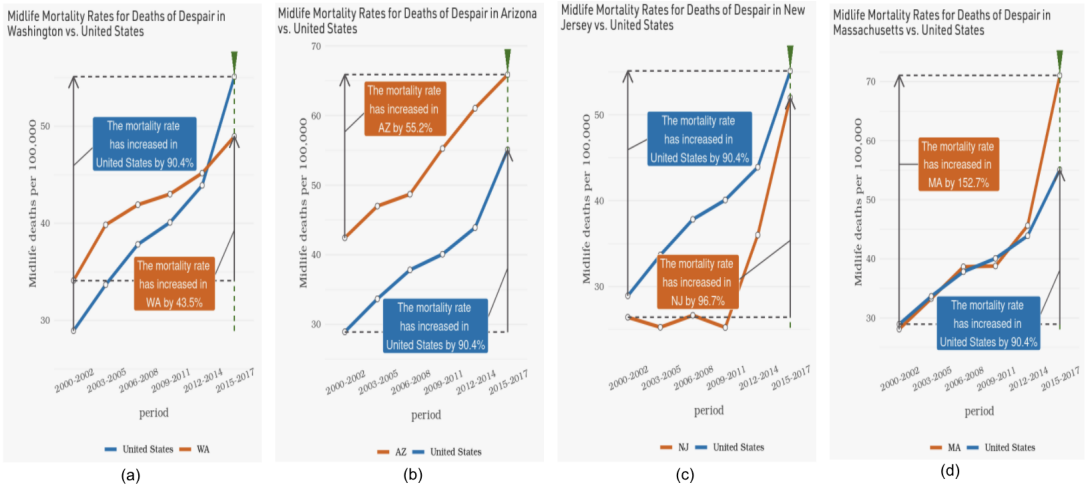


Figure 4: Mortality trends for the years 2000-2017 in comparison with the national trends for (a) Washington (b) Arizona (c) New Jersey and (d) Massachusetts

Using MortalityMinder, we observed the effect of population sizes on the increased rate of Death of Despair in these

states and found that population size has little to no correlation on the rate experienced between states with similar populations. From Figure 4, we see that Washington state has had a 43.5% increase in Death of Despair mortality rates since 2000. Comparatively, Arizona had 55.2% increase, New Jerseys had 96.7% increase, and Massachusetts had an astonishing 152.7% increase. While the rates show little correlation between the states, the pattern of the trends observed across these states tell a more interesting story.

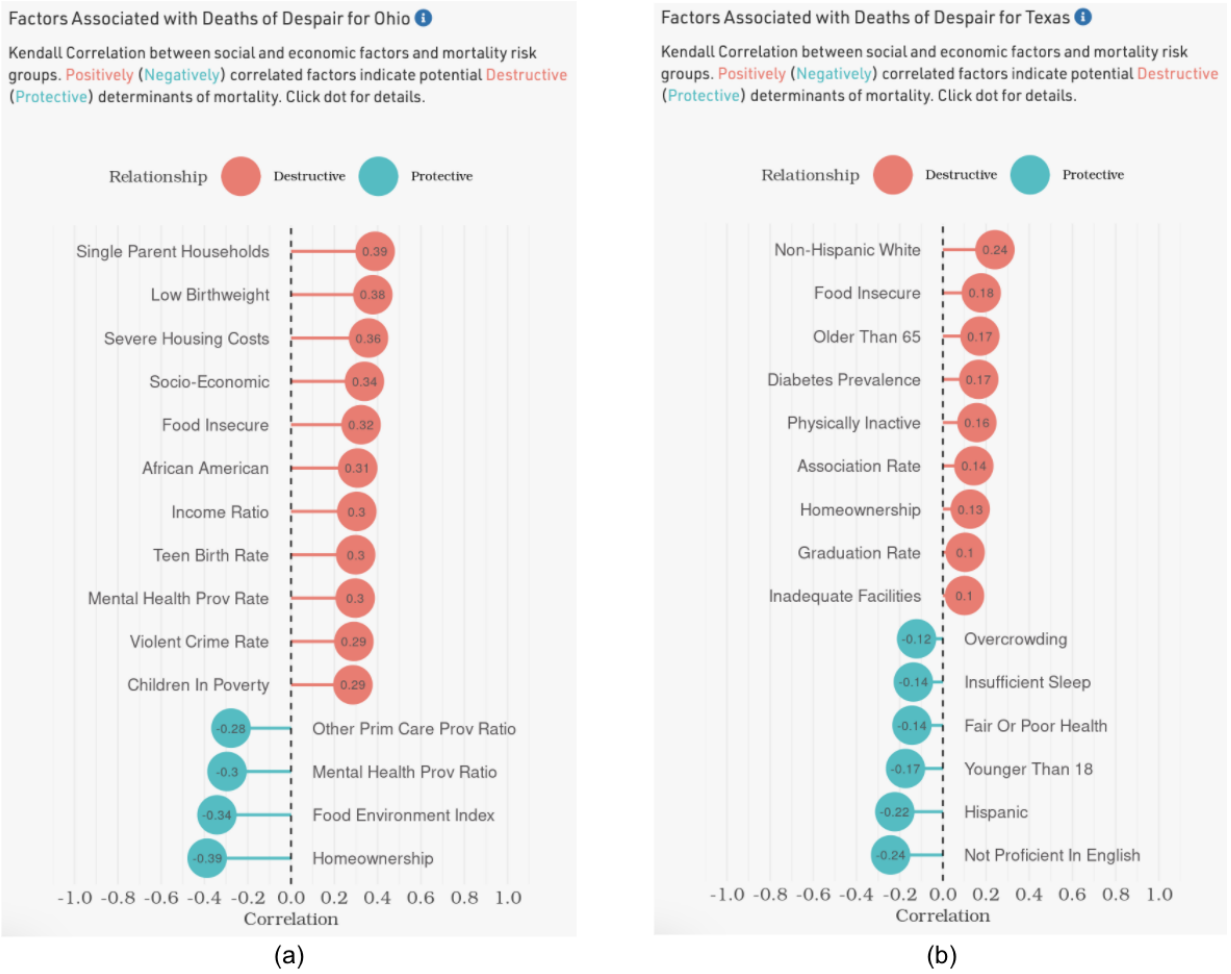


Figure 5: Comparing the top destructive and protective social determinants across the states with (a) the highest increase in Deaths od Despair mortality (Ohio) and (b) the lowest increase in Deaths of Despair mortality (Texas)

Using MortalityMinder, we can see that Ohio had the largest change with a 224.5% increase in Death of Despair mortality rate since 2000. Comparatively, Texas had the smallest change with a 39.5% increase in Death of Despair mortality within the same time frame. Surprisingly, these two states have no more determinants in common than states of similar population sizes. Figure 5 shows the prominent determinants of Ohio and Texas. Food insecurity is shared as a destructive factor for both states. However, home ownership is a determinant that is shared on different relationship categories for each state. It is suspected that the large difference in rates can be attributed to the location of the state, and the "weight" of the determinant. In short, the determinant had greater "weight" in Ohio due to a greater amount of cases for the determinant. The determinants are a driving force for the individual states mortality rate but they are not the factor that creates the difference in mortality rates between states. Other unexplored factors unique to each community contribute to the differences as we shall explore in the next case study.

Sierra County in New Mexico

New Mexico experiences midlife mortality rates far higher than the national average. In New Mexico, the midlife mortality rate increased by 25.6% from 2000 to 2017, whereas the United States as a whole increased 8.2%. For this reason, New Mexico stands out as a state in desperate need of policy intervention to address midlife deaths. The leading factor positively associated with all cause midlife deaths in New Mexico is children in poverty.

Sierra County in New Mexico is at high risk for all causes of midlife deaths. The highest rates of midlife mortality in New Mexico are in Sierra County with approximately 1100 deaths per 100,000. The lowest risk group cluster of counties in New Mexico has an average rate of 250 deaths per 100,000 while the medium risk groups are around 625 per 100,000. The leading factors of midlife deaths in Sierra County are children in poverty, free or reduced lunch, socio-economic status, and mentally unhealthy days.

Sierra County has seen growing rates of All Cause midlife mortality, and has consistently been in the high risk group from 2000 to 2017. Midlife deaths in Sierra County due to Cancer has also risen at alarming rates. They experienced a peak in 2008 with rates as high as 250 per 100,000. The leading factors associated with midlife deaths due to Cancer are teen birth rate, primary care physicians ration, children in poverty, and single parent households. Deaths due to Cardiovascular disease are also high in Sierra county, and chart higher than the high risk group cluster average. The leading factors associated with deaths due to Cardiovascular disease are the primary care physician's ratio, teen birth rate, diabetes prevalence, and mental health provider ratio. The primary care physician's ratio stands out as a very important determinant across various causes of deaths as most of New Mexico has a low number of primary care physicians[16]. Further, Sierra County has also experienced a shocking spike in Deaths of Despair mortality in 2009, reaching a peak of nearly 200 deaths per 100,000, compared to the national level of about 25 deaths per 100,000 and the high risk cluster average in New Mexico of 130 per 100,000.

DISCUSSION

Overall, mortality rates due to Deaths of Despair have shown the most dramatic increase over time compared to other causes of death. Stein et al. found that deaths of despair have increased dramatically amongst white males between the ages of 25-64 particularly in rural America[1], and MortalityMinder results agree. For instance, in the State of California, MortalityMinder found that the factors associated with mortality due to deaths of despair are living in rural areas, being non-Hispanic white, food insecurity and many others. An article in the New York Times by Kristof and WuDunn also highlights how Americans in rural areas are dying of despair and the wrong people are getting the blame for it[17]. The article cites unemployment as the one of the causes for the problem, and again MortalityMinder agrees. MortalityMinder picked up the percentage of people who are unemployed as one of the top factors for Deaths of Despair in the nation. As we can see from this example, MortalityMinder helps to identify the factors associated with mortality at both the community and national-level, so that policy makers and other responsible stakeholders can take action and address these problems.

The recent emergence of COVID-19 is changing the statistics on the leading cause of death in the United States. According to an article published in the Washington Post, COVID-19 is "rapidly becoming America's leading cause of death"[18]. COVID-19 has caused deaths of over 80,000 people in less than 3 months in the United States and the numbers keep rising everyday. We have developed COVIDMINDER to reveal the regional disparities in outcomes, determinants, and mediations of the COVID-19 pandemic. Outcomes are the direct effects of COVID-19, whereas social and economic determinants are pre-existing risk factors that impact COVID-19 outcomes and mediations are resources and programs used to combat the pandemic. As a future work for COVIDMINDER, we are interested to see how the COVID-19 pandemic will affect death rates due to other causes because COVID-19 has affected the ability for people with health conditions like heart disease and diabetes to frequently visit the hospitals for regular checkups and prescription refills. Also, COVID-19 is dramatically exacerbating social determinants associated with "Deaths of Despair". According to an article by the Hudson Valley 360, there is a rise in drug overdoses linked to COVID-19[19]. The AMA also reports a dramatic increase in fatalities involving illicit opioids, stimulants (e.g. methamphetamine), heroin and cocaine and a similarly dramatic drop in the use of prescription opioids[20]. Another part of the future work is to use the analysis methods that we developed for MortalityMinder to investigate the social determinants of COVID-19.

Social determinants play a huge role in the geographic disparities in COVID-19 mortality and cases in the United

States[21]. MortalityMinder finds community health inequities like race and access to health care as significant determinants which also appear to play a role in COVID-19 deaths. Therefore, it is important for stakeholders at the national, state, county, and community levels to investigate these social determinants so that they can address them.

CONCLUSION

In this work, we introduced MortalityMinder, a web-based visualization tool that enables interactive exploration of social, economic and geographic factors associated with premature mortality among mid-life adults ages 25-64 across the United States. Using authoritative data from the CDC and other sources, MortalityMinder is developed as a freely available, publicly-accessible, and open source application. The goal of MortalityMinder is to enable healthcare researchers, providers, payers, and policy makers to gain actionable insights into how, where, and why midlife mortality rates are rising in the United States. It is designed to help healthcare payers, providers and policymakers at the national, state, county and community levels identify and address unmet healthcare needs.

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