UNIVERSITY OF CALIFORNIA SAN DIEGO

Proposed Relationship between Physical Activity and COVID-19 Mortality

A Thesis submitted in partial satisfaction of the requirements
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in

Public Health

by

Jane Moon

Committee in charge:

Professor Michael Pratt, Chair
Professor Richard Garfein
Professor Suzi Hong

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The Thesis of Jane Moon is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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DEDICATION

This work is dedicated to my academic mentors and to my parents who have provided me invaluable guidance for this thesis paper.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BRFSS	Behavioral Risk Factor Surveillance Survey
COPD	Chronic Obstructive Pulmonary Disease
CLRD	Chronic Lower Respiratory Disease
GDP	Gross Domestic Product
CDC	Centers for Disease Control and Prevention

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VITA

2016 Bachelor of Arts in Integrative Biology, University of California Berkeley

2022 Master of Public Health in Health Behavior, University of California San Diego

ABSTRACT OF THE THESIS

Proposed Relationship between Physical Activity and COVID-19 Mortality

by

Jane Moon

Master of Public Health

University of California San Diego, 2022

Professor Michael Pratt, Chair

Introduction: As the United States continues through the COVID-19 pandemic, it is important to understand the preventable behavioral factors related to COVID-19 mortality. This ecological study investigates the relationship between physical activity and COVID-19 mortality in the United States from 2020-2021. **Methods**: Data on physical activity, chronic diseases, vaccination, gross domestic product (GDP), voting results in the 2020 election, age, and COVID-19 mortality were collected from multiple datasets provided by the Centers for Disease Control and Prevention (CDC) and from internet sources. Statistical analysis was run to test the association between states with high and low proportion of each predictor variable and to test the level of correlation between all variables. **Results**: States with higher levels of physical activity

were found to be positively associated with vaccination levels and negatively associated with COVID-19 mortality, diabetes, and COPD. Similarly, physical activity, diabetes, COPD, and vaccination levels were all found to be moderately correlated with COVID-19 mortality in 2021 rather than 2020, which showed weaker correlation. **Discussion**: The relationship found between physical activity, diabetes, COPD, vaccination levels, and COVID-19 mortality suggests the importance of emphasizing physical activity as a behavioral factor to improve overall health. Furthermore, the association between these variables and how states voted in the 2020 election indicates the significance of policy and political environment in relation to health outcomes.

INTRODUCTION

During the pandemic, there has been growing concern over the increase in physical inactivity due to stay-at-home orders, closing of facilities, and increase in remote learning and work. Furthermore, there is emerging literature on the importance of physical activity in minimizing COVID-19 severity, which points to need to address physical inactivity as American society continues to transition into a new phase of the COVID-19 pandemic. In this transitionary period, understanding the relationship between physical activity, vaccination rates, and preexisting conditions will help illuminate the patterns and factors related to COVID-19 mortality across the fifty states.

This ecological study investigates the relationship between proportion of physical active adults and COVID-19 mortality across the United States with the hypothesis that higher proportion of physical active adults will be associated with lower COVID-19 mortality in the period from 2020 to 2021. This thesis study will first present a literature review of possible mechanisms that support the relationship between higher proportion of physical activity and proportion of COVID-19 mortality. This study will then examine the relationship between physical activity and COVID-19 mortality while controlling for the potential confounding effect of vaccination, and chronic diseases such as diabetes. This study will provide novel information and a bird's eye view about the potential benefit of physical activity on reducing COVID-19 mortality at the population level in the U.S. across a two-year period.

CHAPTER 1: REVIEW OF RELATED LITERATURE

This review will cover the current literature on the possible relationship between COVID-19 infection and physical activity. The knowledge gained from this review will contribute to answering the broader question of whether this relationship can be found when comparing physical activity and severe COVID-19 infection across 50 States of the United States. The findings included in this review will provide background and potential mechanisms for any identified relationship between physical activity and COVID-19 infection in the U.S.

Physical activity and chronic diseases

One proposed relationship between physical activity and COVID-19 infection is the role of physical activity in prevention of and intervention for chronic diseases. Established as risk factors for the development of severe COVID-19 infection include chronic diseases such as type 1 and 2 diabetes, chronic lung diseases, heart conditions, obesity, or immunocompromised conditions. (da Silveira et al., 2021) (CDC, May 2, 2022) Physical activity is an effective therapy and has a significant role in preventing and reducing the risk of many of these chronic diseases. (Fernández-Lázaro et al., 2020) (U.S. Department of Health and Human Services, 2018) Furthermore, physical activity is also recommended as a non-pharmacological intervention to treat anxiety and depression, which have increased due to the social and emotional disruptions caused by COVID-19 pandemic. (De Sousa et al., 2021) Therefore, physical activity can act as a protective factor against severe COVID-19 outcomes by protecting physical and mental health or combating chronic conditions, which are increased risk factors for COVID-19 severity.

Physical activity and viral infections

Another reasoning behind the proposed relationship between physical activity and COVID-19 severity is based on the evidence that physical activity is a protective factor against other viral infections. The study by Ranasinghe et al., found that physical activity can protect the host from viral infections including influenza, rhinovirus and herpesviruses. (Ranasinghe et al., 2020) Additionally, a study by da Silveira et al. found that regular exercise is related to "decreased mortality from pneumonia and influenza, improvements in cardiorespiratory function, vaccine response, metabolism of glucose, lipids and insulin" (da Silveira et al., 2021) The evidence from these studies suggest that physical activity can be a protective factor against COVID-19 infection as it is a protective factor for related viral infections. Moreover, da Silveira et al., proposed a relationship between physical activity and vaccine response, which is significant as the COVID-19 vaccination is a primary public health strategy.

Physical activity and increased immune response

Third, this review suggests that physical activity may be a protective factor against COVID-19 infection as physical activity can improve immune response. A study by Alkhatib in 2020 determined that moderate exercise improves immune response by elevating natural killer cell, neutrophil, and macrophage activity. (Alkhatib, 2020) Another proposed biological mechanism for increasing immune response was offered by a study by Heffernan et al., which found that physical activity has effects on systemic endothelial function and inflammation. (Heffernan el al., 2020) This is notable as COVID-19 is known to affect respiratory function. Finally, a study by Seman et al. stated that "Chronic controlled stress, such as that imposed as a result of exercise training, might stimulate positive adaptation to regulation of the immune response in such manner that the inflammatory response to viral infection has a lower likelihood

of being excessive, which is characteristic during the cytokine storm syndrome." (Seman et al., 2021) The results of these studies these studies indicate the relationship between physical activity and improving immune responses related to COVID-19 infection. (Nieman et al., 2019)

Discussion

This review found that there are three potential mechanisms for the relationship between physical activity and COVID-19 infection. First, physical activity decreases the severity of chronic diseases, which are risk factors for severe COVID-19 outcomes. This has important implications as chronic diseases disproportionately affect Black communities and people of lower economic status. (CDC, May 2, 2022) Second, as there is evidence that physical activity protects against other viral infections, it should be a protective factor against COVID-19 infection as well. Third, physical activity increases immune response related to COVID-19 infection. The studies included in this review covered mechanisms related to white blood cell activity, endothelial function, and regulation of the inflammatory response, which would provide a biological explanation for further evidence that increased physical activity is shown to be correlated with decreased COVID-19 infection.

Conclusion

The findings from this literature review provide evidence for the (biological mechanisms underlying the potential inverse relationship between physical activity and severe COVID-19 infection. This thesis project will further investigate this by examining the relationship between physical activity by state and COVID-19 mortality as indicated death by state. The findings from

this review and this thesis project will expand on benefits of physical activity to the individual and the population during a viral infection pandemic.

CHAPTER 2: DESIGN AND METHODOLOGY

Data on Physical Activity and Chronic Conditions

Data on the proportion of physical active adults in the 50 U.S. states came from the 2020 CDC Behavioral Risk Factor Surveillance Survey (BRFSS). The BRFSS is an annual telephone survey of U.S. residents aged 18 and older on their health behaviors, chronic health conditions, and use of preventive health services. Data collection for the BRFSS occurs monthly, and the 2020 BRFSS included responses from 401,958 persons. (CDC-BRFSS, 2022)

The following information was gathered from the BRFSS: physical activity, age group, and history of asthma, chronic obstructive pulmonary disease (COPD), and diabetes. The population percentage of leisure time physical activity engagement was determined by the percentage of respondents that answered yes to "doing physical activity or exercise during the past 30 days other than their regular job." To be comparable with data collected on COVID-19 mortality age groups, age of respondents to the BRFSS were categorized into three groups: younger age at 18-34 years, middle age at 35 to 54 years, and older age at 55 years and older. The population of each state with asthma was determined by the percentage that responded yes to "Ever told you had asthma?". Likewise, the population of each state with COPD and diabetes was determined by the percentage that responded yes to "Ever told you had chronic obstructive pulmonary disease, C.O.P.D., emphysema or chronic bronchitis?" and "Ever told you had diabetes?" respectively.

Data on COVID-19 Mortality

Data on COVID-19 mortality was collected from the CDC COVID Data Tracker. COVID Mortality was determined using the dataset, "Provisional COVID-19 Death Counts by

Week Ending Date and State" for the year 2020 and 2021. (data.cdc.gov/NCHS/Provisional-COVID-19-Death-Counts-by-Week-Ending-D/r8kw-7aab) Data on COVID-19 mortality by age and by underlying chronic conditions was collected from the dataset, "Conditions Contributing to COVID-19 Deaths by State and Age Provisional 2020-2022." (https://data.cdc.gov/NCHS/Conditions-Contributing-to-COVID-19-Deaths-by-Stat/hk9y-quqm) To match the information on age range of surveyed participants of the BRFSS, the age ranges were categorized into three groups: younger age at 18-34 years, middle age at 35 to 54 years, and older age at 55 years and older. The following chronic conditions were included in this analysis, diabetes and chronic lower respiratory diseases, which includes COPD, chronic bronchitis, emphysema, and asthma.

Additional Data Sources

Data on COVID-19 vaccination was obtained from the CDC dataset, "COVID-19 Vaccinations in the United States County" (https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-County/8xkx-amqh) except for the state of Hawaii, which lacked information on the number of people fully vaccinated within this dataset. Information for COVID-19 vaccinations in Hawaii was collected from the State of Hawaii Health Department. (https://health.hawaii.gov/coronavirusdisease2019/tableau_dashboard/21778/) For this analysis, only the number of people who had received a completed series of vaccination by the end of 2021 was included.

There is evidence in the literature that COVID-19 incidence and death is positively related with poverty levels. (Finch et al., 2020) To examine this possible relationship, data on the Gross Domestic Product (GDP) of each state was collected from the World Population Review,

(*GDP by State 2022*). To understand how politics affected COVID-19 mortality, information on what political party each state voted for the 2020 election was collected from Politico.com. (*Live election results: The 2020 presidential race*.)

Statistical Analysis

Each data point of interest was separated into 50 states, and each state was analyzed as a single sample unit. The following predictor variables were considered: proportion of physical active adults, diabetes, asthma, COPD, age, COVID-19 vaccination, income, and political affiliation. The main predictor variable of interest was physical activity. The following outcome variables were considered: COVID-19 mortality in 2020-2021, COVID-19 mortality in 2020, COVID-19 mortality in 2021, COVID-19 mortality with diabetes, COVID-19 mortality with chronic lower respiratory diseases, and COVID-19 mortality based on age. The main outcome variables of interest were COVID-19 mortality in 2020, 2021, and combined.

To determine associations, the 50 states were divided by high and low physical activity (figure 2.4), high and low diabetes (figure 2.5), high and low asthma, high and low COPD (figure 2.6), high and low age groups, high and low COVID-19 vaccination (figure 2.7), the two political parties (figure 2.8), and high and low state GDP (figure 2.9) using the mean percentage of each category. For example, the average percentage of physically active adults was found to be 75.91%. States with a percentage of physically active adults higher than 75.91% were placed in the "higher" category, and states with a percentage lower than 75.91% were placed in the "lower" category. After testing for assumptions using the Shapiro-Wilk test for normality and the Fisher's F test for equal variances, an independent t-test was performed to test associations between each of the predictor and outcome variables using the formula: $t = \frac{m-\mu}{s/\sqrt{n}}$ where $t =$

Student's t-test, m = mean, μ = theoretical value, s = standard deviation, and n = sample size. A p-value of ≤0.05 was accepted as a statistically significant difference in means indicating an association between the variables tested. To confirm the results of the independent t-test, additional nonparametric testing was performed using the Mann-Whitney U test. There were no significant differences in the results of the independent t-test and the nonparametric tests. Furthermore, to determine potential correlations, univariate linear regressions were performed with each predictor variable and each outcome variable using the formula: $y = \alpha + \beta x$ where a p-value of 0.05 and the r squared value of 0.4 to 0.7 was accepted as moderately correlated. Finally, multivariate linear regression was performed with predictor and outcome variables showing correlation after univariate linear regression. A p-value of 0.05 and the r squared value of 0.4 to 0.7 was accepted as moderately correlated. All statistical analyses were performed using R version 4.0.3 and RStudio version 1.3.1093.

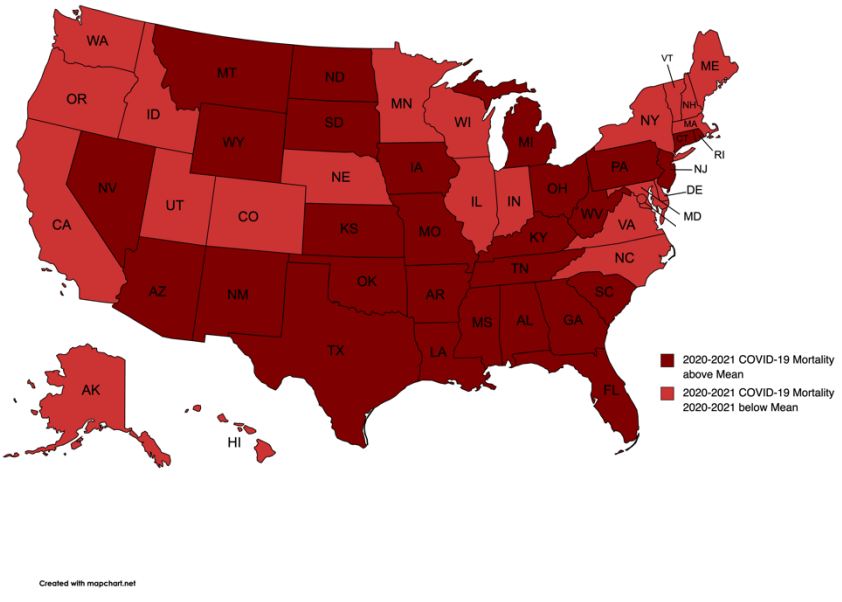

Figure 2.1: COVID-19 Mortality 2020-2021

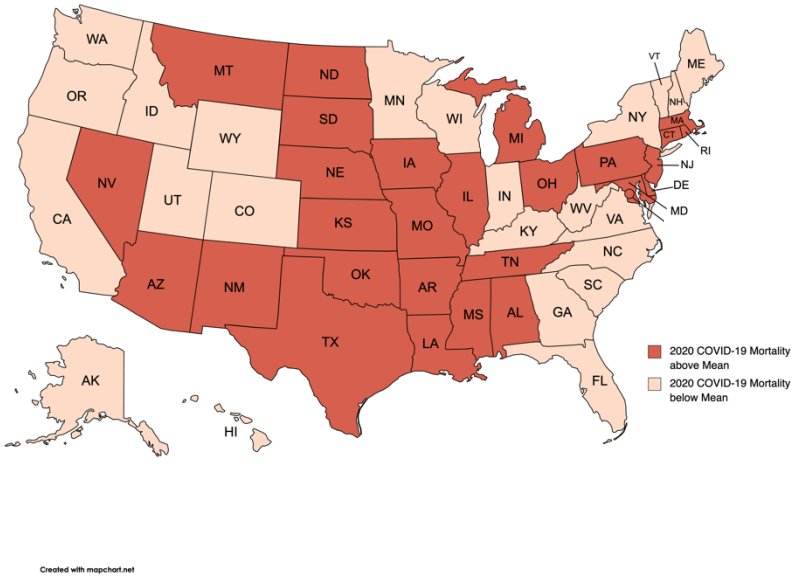

Figure 2.2: COVID-19 Mortality 2020

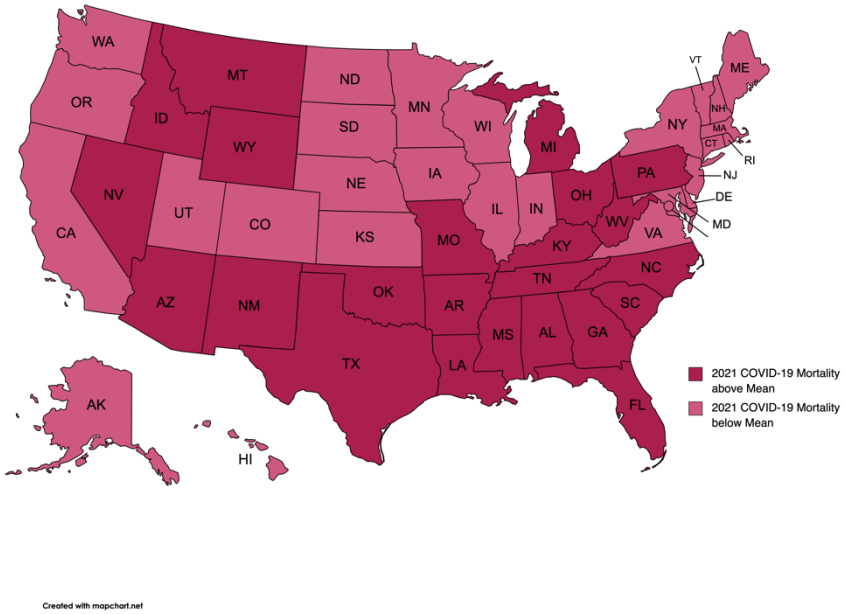

Figure 2.3: COVID-19 Mortality 2021

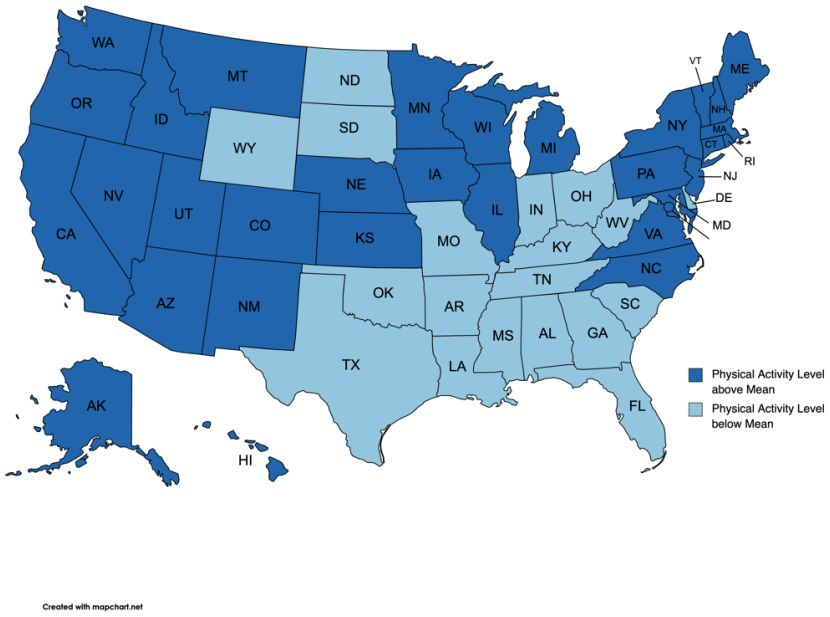

Figure 2.4: Proportion of Population Physical Active

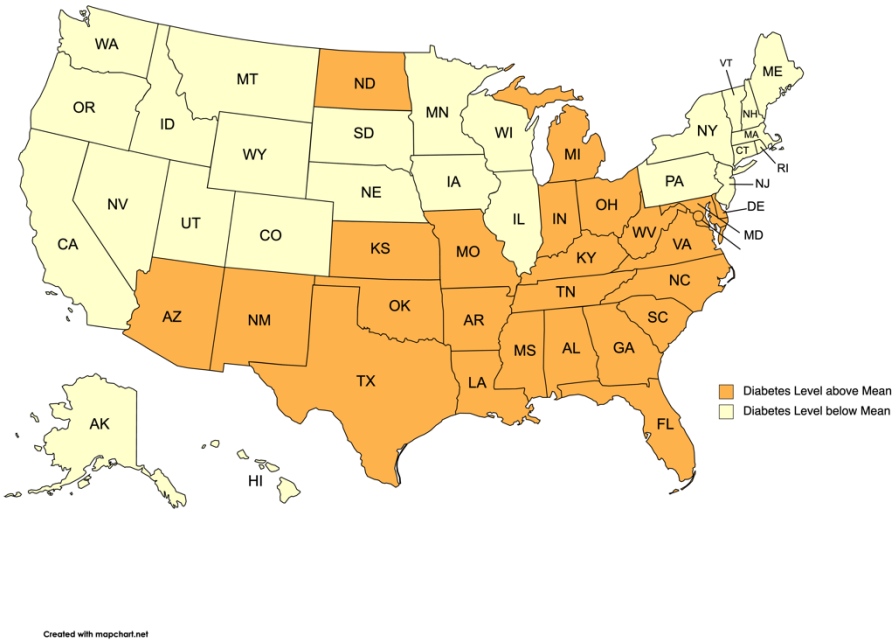

Figure 2.5: Proportion of Population with Diabetes

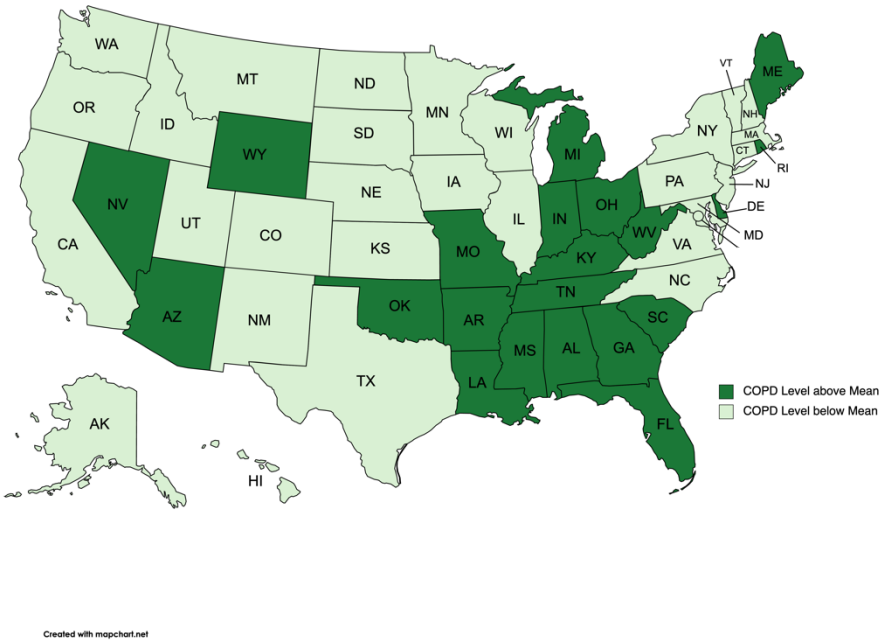

Figure 2.6: Proportion of Population with COPD

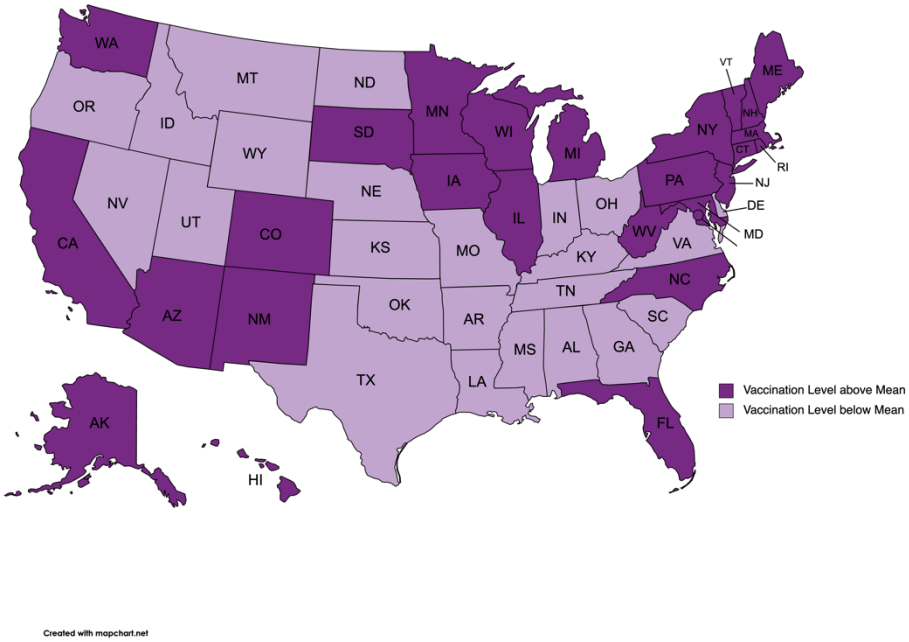

Figure 2.7: Proportion of Population Vaccinated

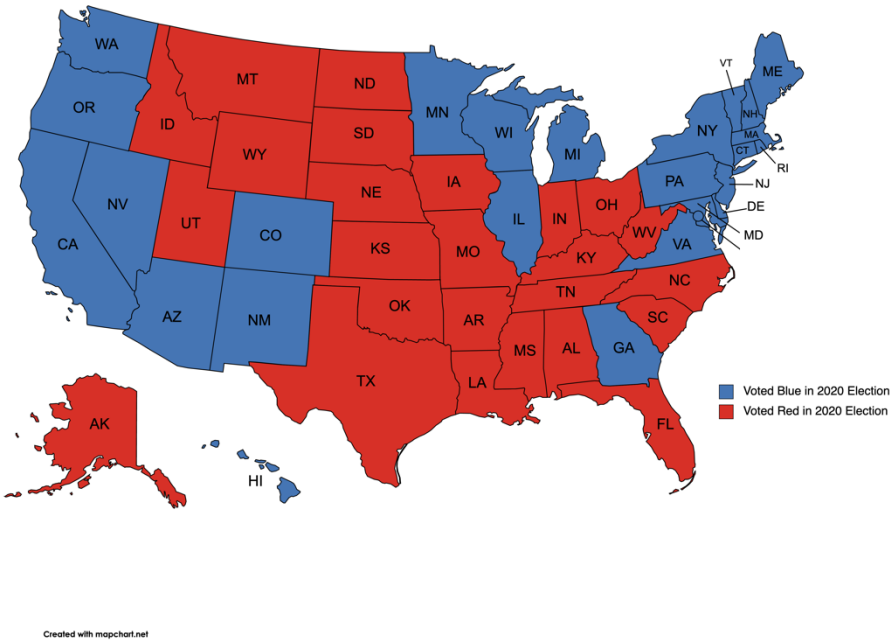

Figure 2.8: 2020 Election Voting Results

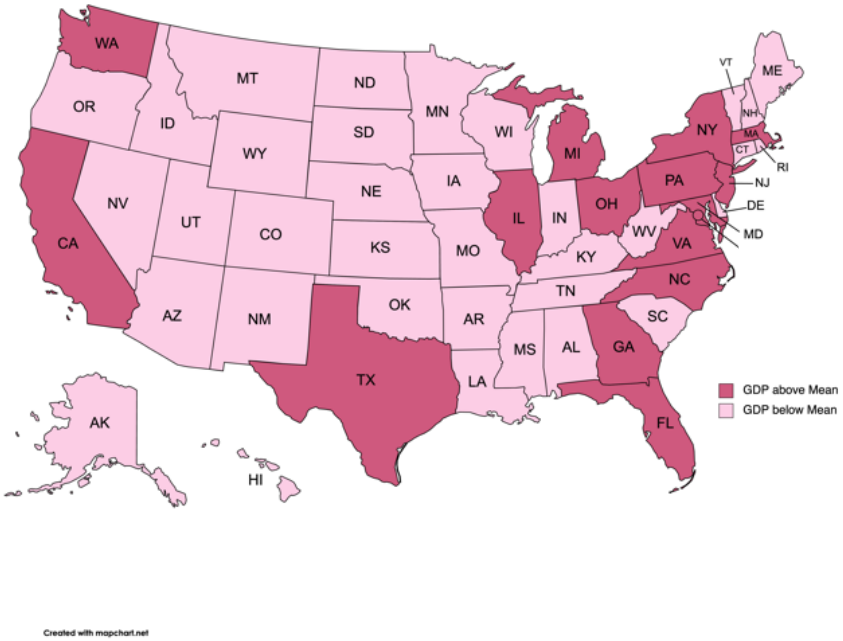

Figure 2.9: State GDP

CHAPTER 3: FINDINGS

Results

The average percent of people across the 50 states that answered yes to physical activity was 75.91% with Utah, Colorado, Oregon as the top three highest states and Arkansas, Mississippi, Kentucky as the three lowest states with the lowest percentage reporting physical activity. For diabetes, the average proportion of people across the 50 states was 13.11% with West Virginia, Mississippi, Arkansas with the highest proportion of the population with diabetes and Colorado, Massachusetts, Vermont with the lowest proportion of the population with diabetes. Likewise, for COPD, the average number of people with COPD across the 50 states was 8.11% with West Virginia, Kentucky, Arkansas with the highest proportion of COPD and Hawaii, Minnesota, Utah with the lowest. The average percent of COVID-19 vaccination was 49.65% with Maine, Hawaii, Connecticut as the highest three states and Georgia, Missouri, Nebraska as the lowest three states. The states with the highest GDP were California, Texas, New York and the lowest three states were Vermont, Wyoming, Alaska. The average COVID mortality adjusted for population across the 50 states in 2020 was 0.11% with New Jersey, North Dakota, South Dakota as the highest three states and Indiana, Vermont, Hawaii as the lowest three states. In 2021, the average COVID mortality adjusted for population across the 50 states was 0.13% with West Virginia, Mississippi, Alabama at the highest and Indiana, Vermont, Hawaii at the lowest. Across 2020-2021, the average was 0.12% with Mississippi, Alabama, Oklahoma at the highest and Indiana, Vermont, Hawaii at the lowest. The averages and the highest and lowest states for all other variables can be found in table 3.1.

Proportion of physical activity was found to be significantly negatively associated with diabetes, COPD, positively associated with COVID-19 vaccination, and negatively associated

with COVID-19 mortality in 2020-2021 and COVID-19 mortality in 2021. However, physical activity was not found to be significantly negatively associated with COVID-19 mortality when only looking at the year 2020. Likewise, when testing for associations with diabetes and COPD, both were found to be negatively associated with physical activity, COVID-19 vaccination, and positively associated with COVID-19 mortality in 2020-2021 and COVID-19 mortality in 2021 but not 2020. Percent fully vaccinated with the COVID-19 vaccine was positively associated with physical activity, and negatively associated with diabetes, COPD. COVID-19 mortality in 2021. There were no significant associations with the other variables between states with high or low asthma. There were also no associations observed with age group and the other variables. State GDP was found to only be associated with COVID-19 mortality in 2020. When dividing the states by which states voted for the two political parties in the 2020 election, there was an association with physical activity, diabetes, asthma, COPD, full COVID-19 vaccination, COVID-19 mortality in 2020-2021, COVID-19 mortality in 2021. Table 3.2 displays independent t-test results for all predictor variables.

Using actual proportions, COVID-19 mortality in 2020-2021 was found to be moderately correlated with physical activity ($R^2 = 0.33$) and diabetes ($R^2 = 0.32$), and weakly correlated with COPD ($R^2 = 0.17$). This was similar to the correlations found for COVID-19 mortality in 2021 with a stronger correlation with physical activity ($R^2 = 0.43$), diabetes ($R^2 = 0.49$), and COPD ($R^2 = 0.44$), and weakly correlated with full COVID-19 vaccination ($R^2 = 0.18$). This contrasts with COVID-19 mortality in 2020, which only had a weak correlation between the physical activity ($R^2 = 0.071$) and GDP of the state ($R^2 = 0.078$). There were no correlations observed with the age group of COVID-19 mortality nor with COVID-19 mortality and the chronic

conditions of diabetes and COPD. Table 3.3 displays univariate linear regression results for all outcome variables.

The variables of diabetes, vaccination, and COPD were controlled for using multivariate linear regression. It was found that physical activity was moderately correlated with COVID-19 mortality in 2020-2021 when the effects of COPD ($R^2 = 0.32$) and vaccination ($R^2 = 0.31$) were controlled for. Physical activity was weakly correlated with COVID-19 mortality in 2020 when controlling for COPD ($R^2 = 0.17$). Physically activity was moderately correlated with COVID-19 mortality in 2021 when controlling for vaccination ($R^2 = 0.44$). The model where physical activity was found to be significantly correlated with COVID-19 mortality 2020-2021 controlled for COPD and vaccination ($R^2 = 0.30$). When controlling for diabetes, physical activity was not found to be correlated with COVID-19 mortality in any of the models. The results of the multivariate linear regression are displayed in tables 3.4 and 3.5.

Table 3.1: Summary table of averages and highest and lowest 3 states for each variable

Variable	Mean	Highest 3 states	Lowest 3 states
Physical Activity	75.91%	Utah (83.1%), Colorado (82.7%), Oregon (82.2%)	Arkansas (66.7%), Mississippi (67.3%), Kentucky (68.1%)
Diabetes	13.11%	West Virginia (18.9%), Mississippi (18.8%), Arkansas (17.7%)	Colorado (9.2%), Massachusetts (9.3%), Vermont (9.8%)
Asthma	13.57%	Rhode Island (16.5%), West Virginia (15.6%), Kentucky (15.6%)	Nebraska (10.0%), North Dakota (10.4%), South Dakota (11.2%)
COPD[1]	8.11%	West Virginia (15.0%), Kentucky (13.4%), Arkansas (12.3%)	Hawaii (4.7%), Minnesota (5.1%), Utah (5.2%)
Vaccination	49.65%	Maine (65.9%), Hawaii (63.8%), Connecticut (63.8%)	Georgia (24.7%), Missouri (38.4%), Nebraska (39.3%)
GDP[2] (millions in USD)	$418,146	California ($3,120,386), Texas ($1,772,132), New York ($1,705,127)	Vermont ($33,278), Wyoming ($36,000), Alaska ($50,413)
18-34 Age Group	17.32%	California (28.6%), Utah (23.0%), Illinois (21.8%)	Wyoming (9.8%), New Hampshire (10.5%), Maine (11.0%)
35-54 Age Group	27.98%	Texas (32.8%), New Jersey (32.7%), Minnesota (32.2%)	Wyoming (21.4%), Arkansas (21.7%), North Dakota (22.2%)
55+ Age Group	54.70%	Wyoming (68.7%), Arkansas (67.2%), Maine (66.7%)	California (41.3%), Utah (45.0%), Texas (45.4%)
COVID Mortality (2020-2021)	0.12%	Mississippi (0.2%), Alabama (0.2%), Oklahoma (0.2%)	Indiana (0.03%), Vermont (0.04%), Hawaii (0.04%)
COVID Mortality 2020	0.11%	New Jersey, North (0.1%) Dakota (0.1%), South Dakota (0.1%)	Indiana (0.02%), Vermont (0.02%), Hawaii (0.03%)
COVID Mortality 2021	0.13%	West Virginia (0.2%), Mississippi (0.2%), Alabama (0.2%)	Indiana (0.04%), Vermont (0.05%), Hawaii (0.05%)
COVID Mortality with diabetes	4.30%	Illinois (4.9%), Minnesota (4.6%), North Carolina (4.6%)	South Dakota (3.9%), Nebraska (3.9%), Hawaii (4.0%)
COVID Mortality with CLRD[3]	4.33%	Indiana (4.7%), Minnesota (4.7%), North Dakota (4.7%)	Wyoming (3.9%), Delaware (4.0%), California (4.0%)
Percent of total COVID mortality Age 0-34	22.89%	Rhode Island (27.0%) , Delaware (27.0%), New Hampshire (26.8%)	Texas (13.9%), California (14.3%), Florida (16.3%)
Percent of COVID mortality Age 35-54	17.61%	New Hampshire (23.4%), Vermont (22.6%), Maine (22.5%)	North Carolina (14.4%), Alabama (14.8%), Indiana (14.8%)
Percent of COVID mortality at Age 55+	34.24%	California (44.1%), Texas (43.8%), Florida (43.6%)	Delaware (28.0%), Nebraska (28.6%), Rhode Island (28.8%)

[1]chronic obstructive pulmonary disease
[2]gross domestic product
[3]chronic lower respiratory disease

Table 3.2: Independent t-test results between predictor and outcome variables

	High/Low Physical Activity		High/Low Vaccination		High/Low Diabetes		High/Low Asthma		High/Low COPD	
	P Value	*T Score*	*P Value*	*T Score*	*P Value*	*T Score*	*P Value*	*T Score*	*P Value*	*T Score*
Proportion of Physically Active Adults	-	-	<0.001*	3.83*	<0.001*	6.74*	0.22	1.25	<0.001*	6.63*
Population with Diabetes	<0.001*	8.03*	<0.001*	3.63*	-	-	0.97	0.041	<0.001*	6.42*
Population with Asthma	0.43	0.80	0.41	0.83	0.81	0.25	-	-	0.060	1.93
Population with COPD[1]	<0.001*	6.56*	0.020*	2.41*	<0.001*	5.30*	0.28	1.09	-	-
Population age 18-34	0.049*	2.02*	0.76	0.30	0.29	1.08	0.67	0.44	0.021*	2.39*
Population age 35-54	0.069	1.86	0.61	0.51	0.14	1.51	0.68	0.41	0.019*	2.43*
Population age 55+	0.041*	2.10*	0.95	0.068	0.18	1.37	0.65	0.46	0.012*	2.61*
COVID Death (2020-2021)	<0.001*	3.66*	0.08	1.81	<0.001*	3.60*	0.36	0.93	<0.001*	3.21*
COVID Deaths in 2020	0.11	1.62	-	-	0.20	1.29	0.09	1.73	0.51	0.66
COVID Death In 2021	<0.001*	4.52*	0.005*	2.94*	<0.001*	4.96*	0.86	0.18	<0.001*	5.25*
COVID Death with Diabetes	0.21	1.26	0.86	0.18	0.035*	2.17*	0.23	1.23	0.52	0.65
COVID Death with CLRD[2]	0.61	0.51	0.26	1.14	0.19	1.33	0.69	0.40	0.98	0.026
COVID Death age 0-24	0.18	1.35	0.64	0.48	0.020*	2.40*	0.63	0.48	0.36	0.93
COVID Death age 35-54	0.25	1.16	0.61	0.52	<0.001*	3.18*	0.87	0.16	0.17	1.38
COVID Death age 55+	1.40	0.17	0.39	0.86	0.028*	2.27*	0.62	0.50	0.33	0.98
Population Fully Vaccinated	<0.001*	4.67*	-	-	<0.001*	3.13*	0.09	1.72	0.014*	2.55*
GDP[3] of State (Millions)	0.71	0.37	0.57	0.57	0.91	0.11	0.29	1.08	0.87	0.17

*Statistically significant

[1]chronic obstructive pulmonary disease

[2]chronic lower respiratory disease

[3]gross domestic product

Table 3.2: Independent t-test results between predictor and outcome variables (continued)

	High/Low GDP		High/Low Younger Age Group		High/Low Middle Age Group		High/Low Older Age Group		Red/Blue State	
	P Value	*T Score*	*P Value*	*T Score*	*P Value*	*T Score*	*P Value*	*T Score*	*P Value*	*T Score*
Proportion of Physically Active Adults	0.32	1.00	0.037*	2.14*	0.17	1.40	0.074	1.83	<0.001*	5.22*
Population with Diabetes	0.42	0.81	0.012*	2.60*	0.11	1.61	<0.001*	2.80*	<0.001*	4.00*
Population with Asthma	0.98	0.022	0.75	0.32	0.023*	2.35*	0.30	1.05	0.020*	2.41*
Population with COPD[1]	0.30	1.06	0.010*	2.67*	0.058	1.95	<0.001*	2.69*	<0.001*	3.37*
Population age 18-34	0.52	0.65	-	-	-	-	-	-	0.47	0.72
Population age 35-54	0.98	0.031	-	-	-	-	-	-	0.24	1.19
Population age 55+	0.72	0.37	-	-	-	-	-	-	0.32	1.00
COVID Death (2020-2021)	0.066	1.88	0.48	0.71	0.29	1.08	0.48	0.72	0.012*	2.60*
COVID Deaths in 2020	0.017*	2.47*	0.55	0.60	0.58	0.56	0.85	0.19	0.37	0.90
COVID Death In 2021	0.52	0.64	0.57	0.57	0.23	1.22	0.32	1.01	<0.001*	3.53*
COVID Death with Diabetes	0.30	1.05	0.25	1.17	0.014*	2.56*	0.14	1.48	0.88	0.16
COVID Death with CLRD[2]	0.30	1.04	0.85	0.18	0.97	0.033	0.36	0.93	0.13	1.54
COVID Death age 0-24	0.79	0.26	0.46	0.74	0.031*	2.22*	0.30	1.06	0.78	0.29
COVID Death age 35-54	0.11	1.62	0.24	1.18	0.016*	2.51*	0.46	0.74	0.76	0.30
COVID Death age 55+	0.83	0.22	0.67	0.43	0.058	1.94	0.39	0.87	0.84	0.20
Population Fully Vaccinated	0.24	1.19	0.72	0.37	0.54	0.62	0.31	1.03	<0.001*	3.88*
GDP[3] of State (Millions)	-	-	0.21	1.27	0.24	1.20	0.56	0.59	0.57	0.57

*Statistically significant
[1]chronic obstructive pulmonary disease
[2]chronic lower respiratory disease
[3]gross domestic product

Table 3.3: Univariate linear regression results between predictor and outcome variables

	COVID Mortality (2020-2021)		COVID Mortality (2020)		COVID Mortality (2021)		COVID Death with Diabetes	
	P Value	R^2	*P Value*	R^2	*P Value*	R^2	*P Value*	R^2
Proportion of Physically Active Adults	<0.001*	0.33	0.035*	0.071	<0.001*	0.43	0.070	0.048
Population with Diabetes	<0.001*	0.32	0.077	0.044	<0.001*	0.49	0.13	0.026
Population with Asthma	0.65	-0.016	0.13	0.026	0.44	<0.001	0.97	-0.021
Population with COPD[1]	<0.001*	0.17	0.76	-0.019	<0.001*	0.44	0.24	<0.001
Population age 18-24	0.71	-0.02	0.86	-0.020	0.66	-0.017	0.046*	0.061
Population age 35-54	0.34	-0.0014	0.89	-0.020	0.14	0.024	0.10	0.035
Population age 55+	0.50	-0.011	0.86	-0.020	0.34	-0.0012	0.049*	0.059
Population Fully Vaccinated	-	-	-	-	<0.001*	0.18	0.30	<0.001
GDP (millions)	0.12	0.03	0.028*	0.078	0.74	-0.018	0.27	<0.001

*Statistically significant

[1]chronic obstructive pulmonary disease

	COVID Death with CLRD		COVID Death at Age 0-34)		COVID Death at Age 35-54		COVID Death at Age 55+	
	P Value	R^2	*P Value*	R^2	*P Value*	R^2	*P Value*	R^2
Proportion of Physically Active Adults	0.72	-0.018	0.17	0.018	0.10	0.036	0.18	0.017
Population with Diabetes	0.26	<0.001	0.12	0.029	0.015*	0.10	0.17	0.020
Population with Asthma	0.52	-0.012	0.65	-0.016	0.72	-0.018	0.67	-0.017
Population with COPD[1]	0.52	-0.012	0.43	<0.001	0.21	0.013	0.30	0.0019
Population age 18-24	0.87	-0.020	<0.001*	0.16	<0.001*	0.12	0.019*	0.090
Population age 35-54	0.89	-0.020	0.037*	0.069	0.015*	0.10	0.074	0.045
Population age 55+	0.87	-0.020	<0.001*	0.1327	<0.001*	0.13	0.025*	0.082
Population Fully Vaccinated	0.62	-0.016	0.47	<0.001	0.22	0.012	0.74	-0.019
GDP (millions)	0.55	-0.013	0.91	-0.021	0.27	<0.001	0.95	-0.021

*Statistically significant

[1]chronic obstructive pulmonary disease

Table 3.4: Multivariate linear regression results R^2 and p values

	COVID Mortality (2020-2021)		COVID Mortality (2020)		COVID Mortality (2021)	
	P Value	*R^2*	*P Value*	*R^2*	*P Value*	*R^2*
Proportion of Physically Active Population and Proportion of Population with Diabetes	<0.001*	0.33	0.11	0.052	<0.001*	0.49
Proportion of Physically Active Population and Proportion of Population with COPD[1]	<0.001*	0.32	0.0049	0.17	<0.001*	0.47
Proportion of Physically Active Population and Proportion of Population Vaccinated	<0.001*	0.31	-	-	<0.001*	0.44

*Statistically significant

[1]chronic obstructive pulmonary disease

Table 3.5: Multivariate linear regression results coefficient and significance values

		Coefficient	*Sig*
Model 1[1]	Physical Activity	-0.0055	0.20
	Diabetes	0.0087	0.25
Model 2[2]	Physical Activity	-0.012	0.0015
	COPD[10]	-0.004	0.56
Model 3[3]	Physical Activity	<0.001	<0.001
	Vaccination	<0.001	0.98
Model 4[4]	Physical Activity	-0.0037	0.25
	Diabetes	-0.001	0.85
Model 5[5]	Physical Activity	-0.008	0.0012
	COPD[10]	-0.012	0.013
Model 6[6]	Physical Activity	-0.0018	0.42
	Diabetes	0.0098	0.015
Model 7[7]	Physical Activity	-0.0036	0.052
	COPD[10]	0.008	0.032
Model 8[8]	Physical Activity	-0.006	<0.001
	Vaccination	<0.001	0.2
Model 9[9]	Physical Activity	<0.001	0.0033
	COPD[10]	<0.001	0.57
	Vaccination	<0.001	0.97

[1] Model 1: COVID Mortality (2020-2021) ~ Proportion of Physically Active Population and Proportion of Population with Diabetes
[2]Model 2: COVID Mortality (2020-2021) ~ Proportion of Physically Active Population and Proportion of Population with COPD
[3]Model 3: COVID Mortality (2020-2021) ~ Proportion of Physically Active Population and Proportion of Population Vaccinated
[4]Model 4: COVID Mortality (2020) ~ Proportion of Physically Active Population and Proportion of Population with Diabetes
[5]Model 5: COVID Mortality (2020) ~ Proportion of Physically Active Population and Proportion of Population with COPD
[6]Model 6: COVID Mortality (2021) ~ Proportion of Physically Active Population and Proportion of Population with Diabetes
[7]Model 7: COVID Mortality (2021) ~ Proportion of Physically Active Population and Proportion of Population with COPD
[8]Model 8: COVID Mortality (2021) ~ Proportion of Physically Active Population and Proportion of Population Vaccinated
[9]Model 9: COVID Mortality (2020-2021) ~ Proportion of Physically Active Population and Proportion of Population with COPD and Proportion of Population Vaccinated
[10]chronic obstructive pulmonary disease

Discussion

Since the beginning of the COVID-19 pandemic, scientists have been working to better understand the disease and factors that contribute to severe outcomes of COVID-19. The results of this study show correlations between states with a higher percentage of physically active population and lower COVID-19 mortality (figure 3.1). Contributing to this is the negative association between physical activity with the chronic conditions: diabetes and COPD. Notably, physically activity had a stronger negative correlation with COVID-19 mortality in 2021 (figure 3.3) than in 2020 (figure 3.2). Diabetes (figure 3.4) and COPD (figure 3.5) only had statistically significant positive correlation with COVID-19 morality in 2021. When controlling for the effect of diabetes, COPD, and vaccination, physical activity was found to be negatively correlated with COVID-19 mortality in 2020-2021 (figure 3.8).

An additional factor to consider in 2021 compared to 2020 was the availability of COVID-19 vaccines for the general public. Considering that the percentage of fully vaccinated individuals for each state showed an association with physical activity levels, diabetes, and COPD, it may be that COVID-19 vaccinations contributed to physical activity having a stronger negative correlation with COVID-19 mortality in 2021 (figure 3.6). It is possible that those engaging in healthy behaviors such as physical activity were more likely to seek vaccination, which has been proven to reduce COVID-19 severity. (CDC, June 29, 2022) As physical activity was still found to be negatively correlated with COVID-19 mortality after controlling for the effect of vaccination, there is still a significant relationship between having more physically active adults and lower COVID-19 mortality in a state. When controlling for diabetes in the multivariate model, it is likely that physically activity was no longer found to be correlated with

COVID-19 mortality due to the complex interconnected nature of physical activity and diabetes so that variance in COVID-19 mortality is explained equally by physical activity and diabetes.

Additionally, when separating the states by how each state voted in the 2020 election to gain a proxy for the political climate that could have affected COVID-19 and other health policies, the association with physical activity, diabetes, COPD, and COVID-19 mortality in 2021 indicates the significance of policies in 2021 related to physical activity and vaccination. The GDP of each state was not correlated with COVID-19 mortality nor associated with the predictor variables. This may suggest the importance of how state funding was utilized in the COVID-19 pandemic rather than just having more gross resources to devote to physical activity and vaccination.

The results of this study are consistent with similar emerging research. A review by the CDC looking at studies comparing physical activity and severe COVID-19 outcomes found that physical inactivity is related to increased mortality and physical activity is related to decreased mortality, among people with COVID-19. (CDC, May 20, 2022) A retrospective observational study conducted in Southern California found that the odds of death were 2.49 times greater in physically inactive patients compared to those meeting physical activity guidelines. (Sallis et al., 2021) Finally, an analysis of county level data in the United States examining the relationship between physical activity participation rates with COVID-19 cases and deaths found that physical activity had a significant negative association with death. (Cunningham, 2021) Our current ecological study using state-based data has findings consistent with the current literature.

Study Limitations

There are several limitations to this study. First, this study is an observational ecological study. As such, predictor and outcome measures are generalized for the larger population of each state and are unable to take into account individual variations. It is also not possible to infer causality, only correlations, with this study design as the data is not truly longitudinal. Second, there were multiple datasets from different sample units used to compile information for the 50 states rather than a single dataset. The lack of data from a single sample with information on both COVID-19 mortality and physical activity is the reason for the ecological study method using each state as a sample unit. Furthermore, the 2020 BRFSS data was used as a measure for overall state physical activity for the time period of 2020-2021 as 2021 specific data was not available. However, as physical activity levels have not varied drastically in the past few years, it is unlikely that this had a significant impact on this study's findings. (CDC, May 9, 2022) Third, this study could have been strengthened by the presence of more nuanced data on state specific COVID-19 physical distancing, masking, and vaccination policies that would have affected COVID-19 related outcomes as well as physical activity policy data. While this study cannot provide causal evidence of an association between physical activity and COVID-19 mortality, these findings suggest that such a relationship exists and should be evaluated through more rigorous studies that can assess causal links.

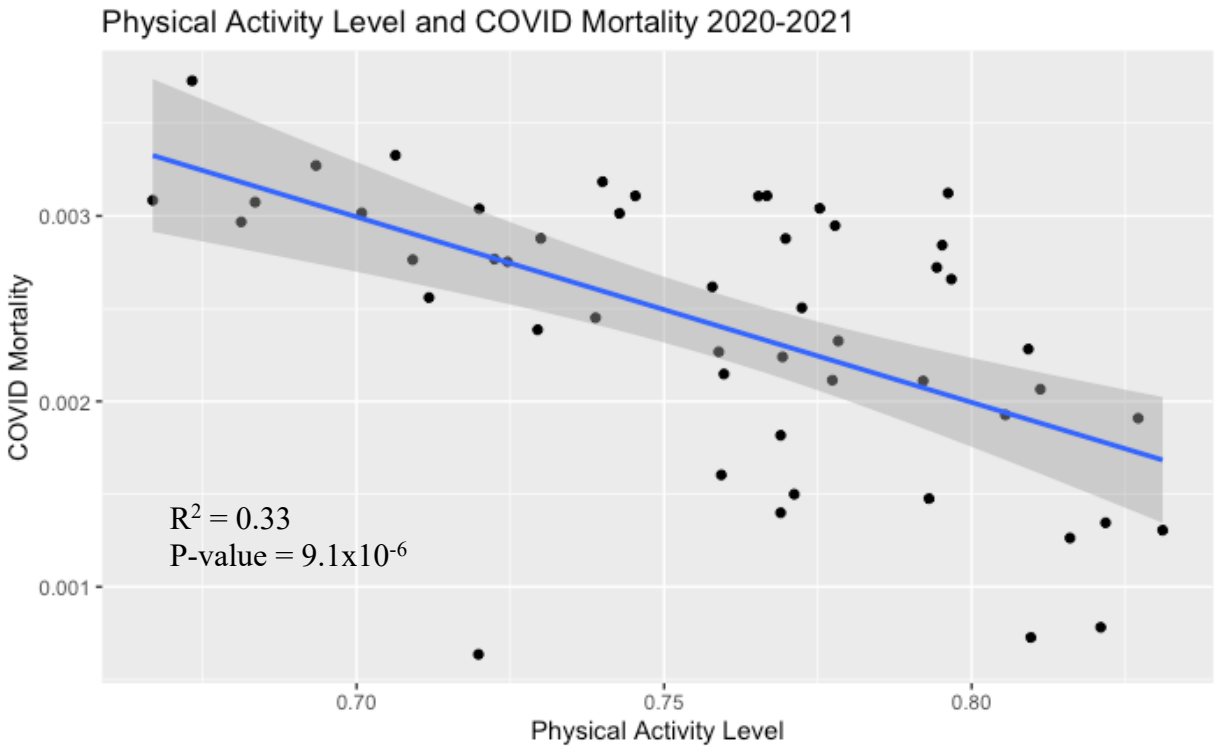

Figure 3.1: Correlation between physical activity and COVID-19 mortality 2020-2021

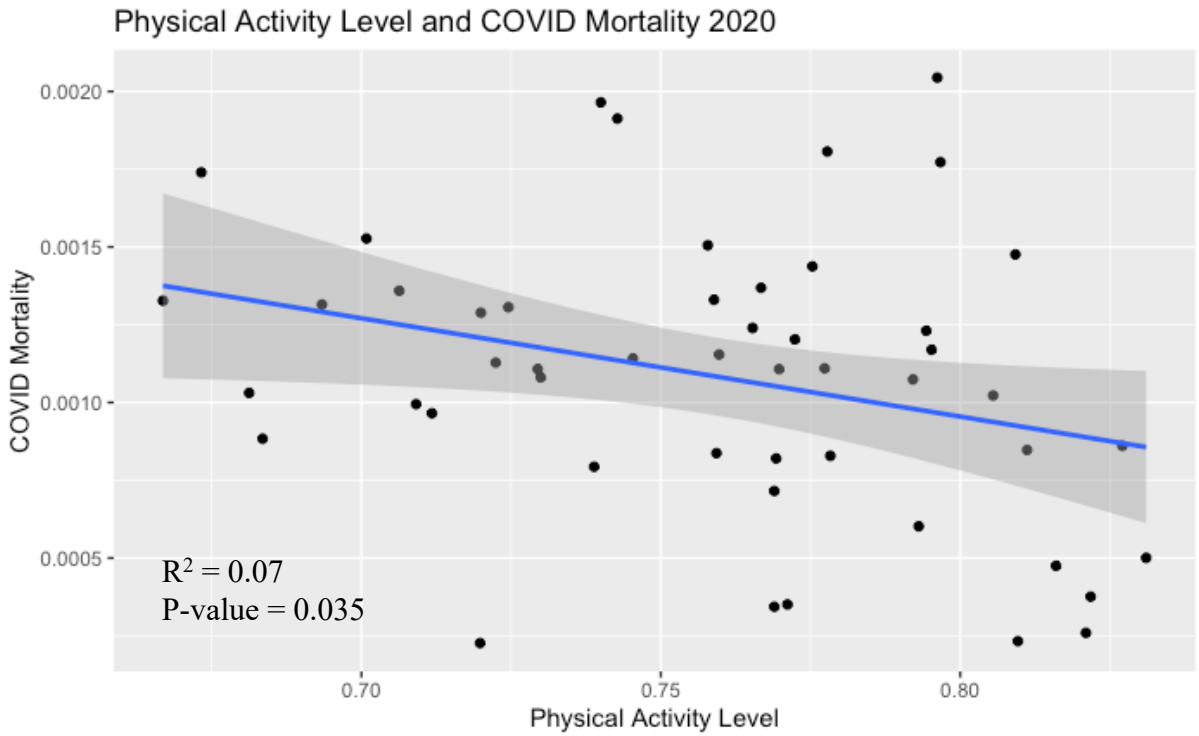

Figure 3.2: Correlation between physical activity and COVID-19 mortality 2020

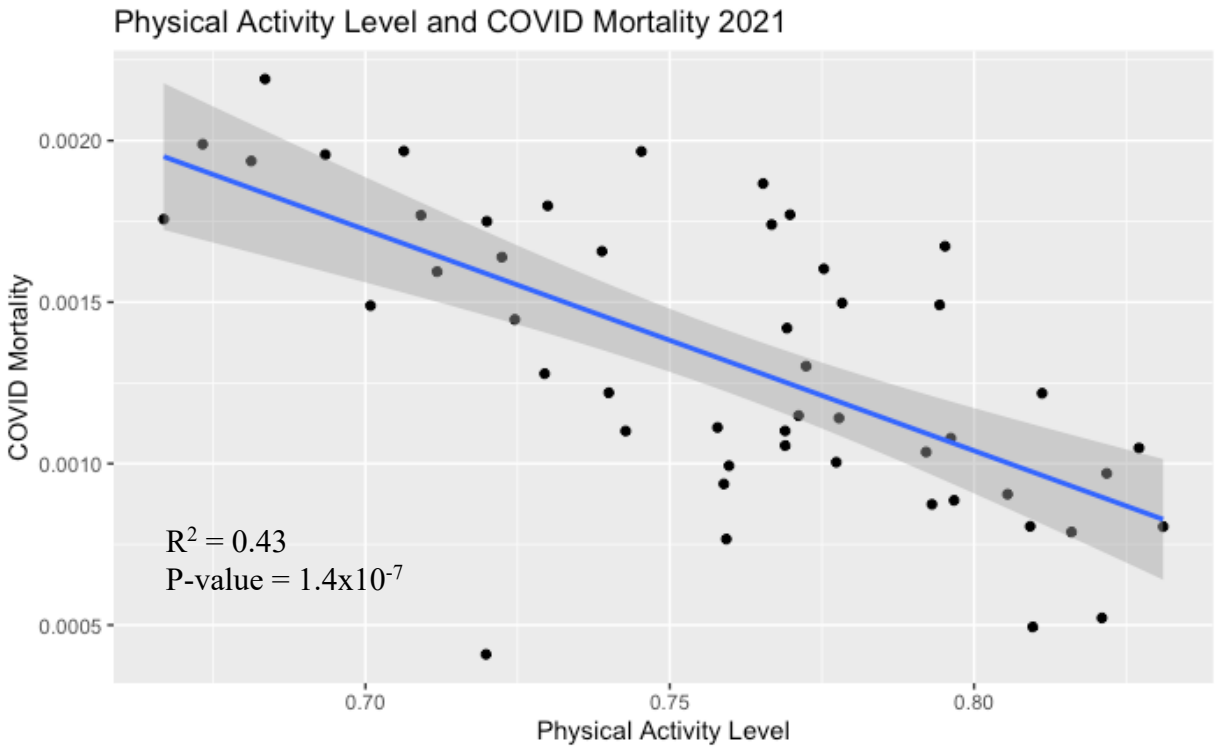

Figure 3.3: Correlation between physical activity and COVID-19 mortality 2021

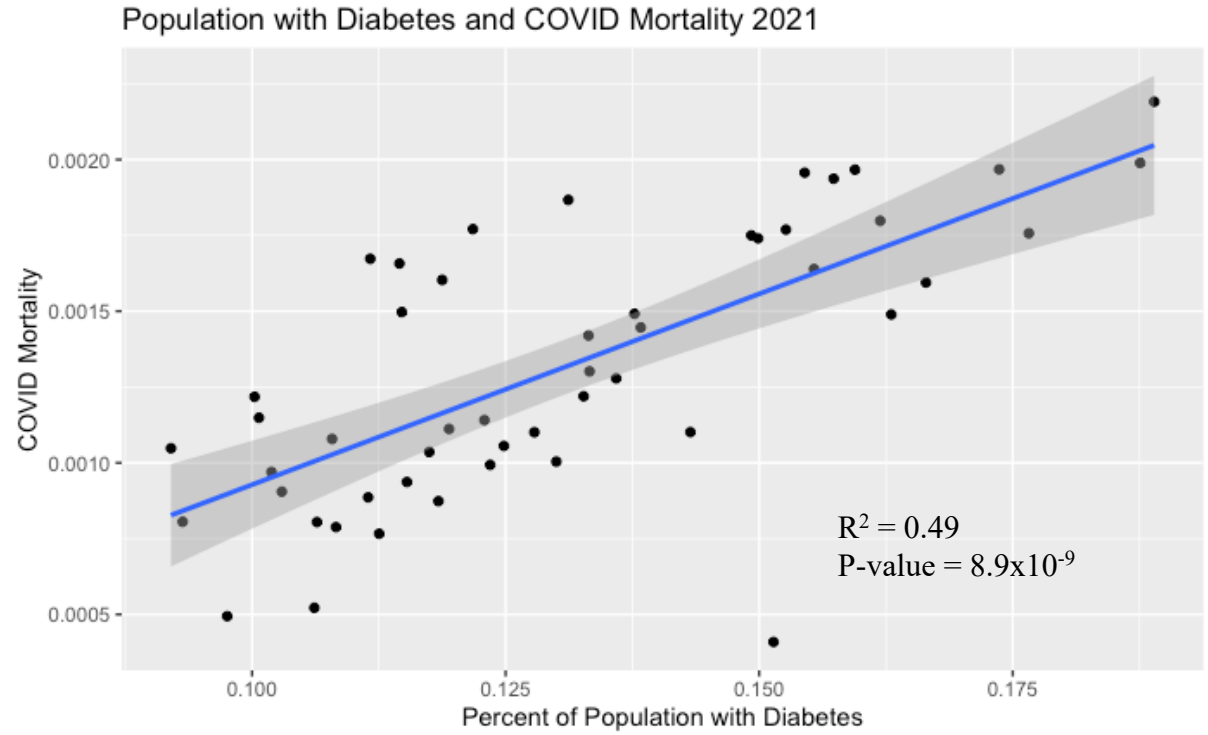

Figure 3.4: Correlation between the proportion of the population with diabetes and COVID-19 mortality 2021

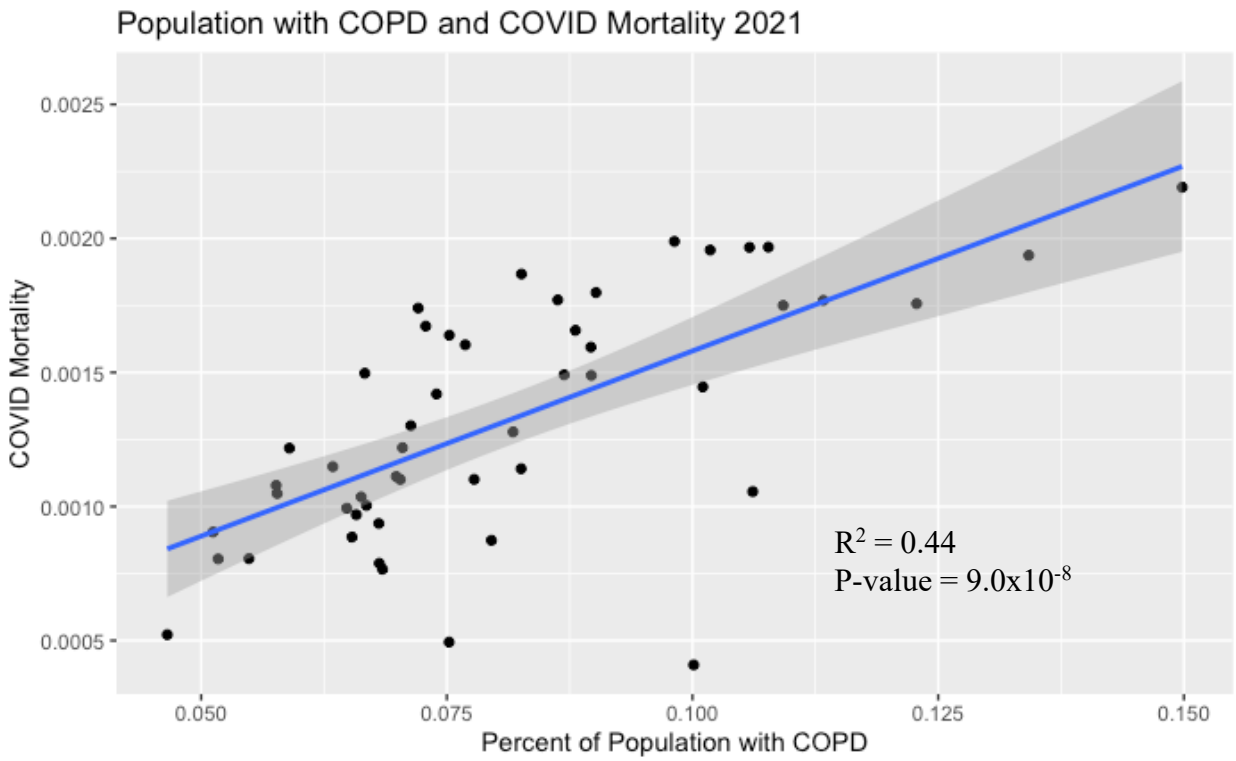

Figure 3.5: Correlation between proportion of population with COPD and COVID-19 mortality 2021

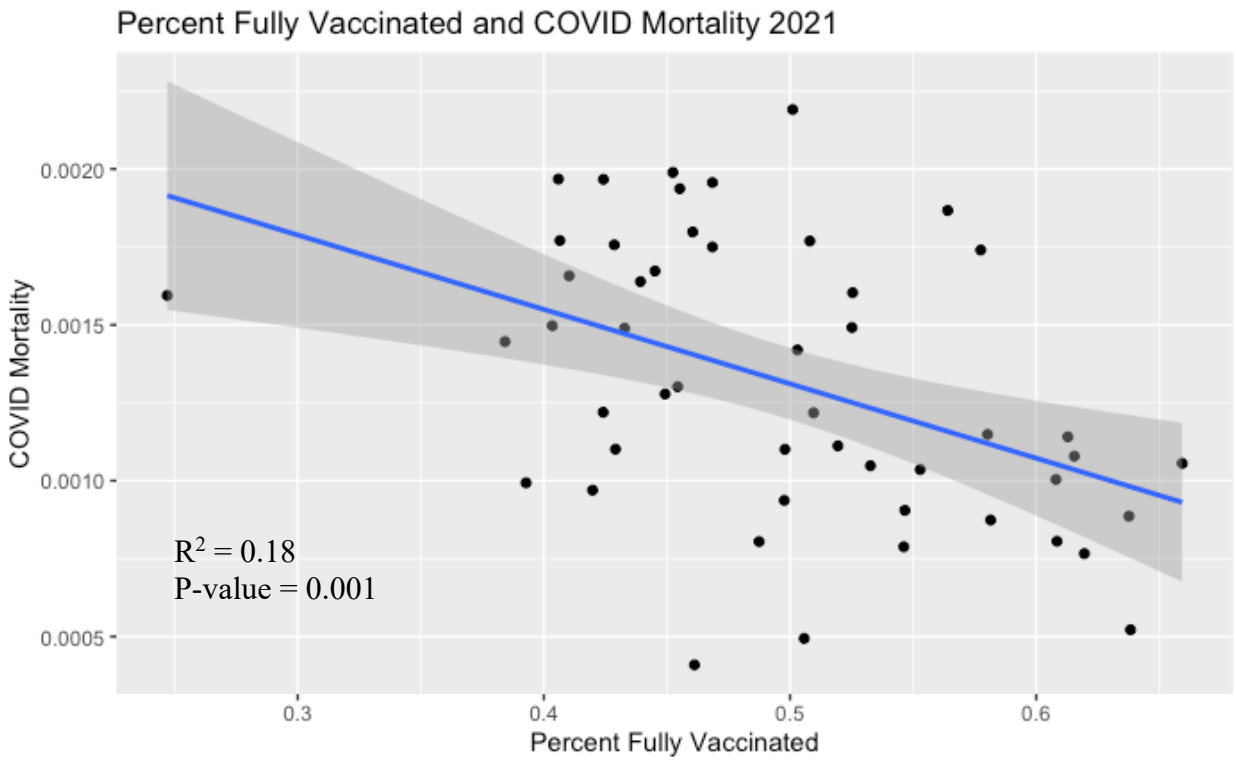

Figure 3.6: Correlation between proportion vaccinated and COVID-19 mortality 2021

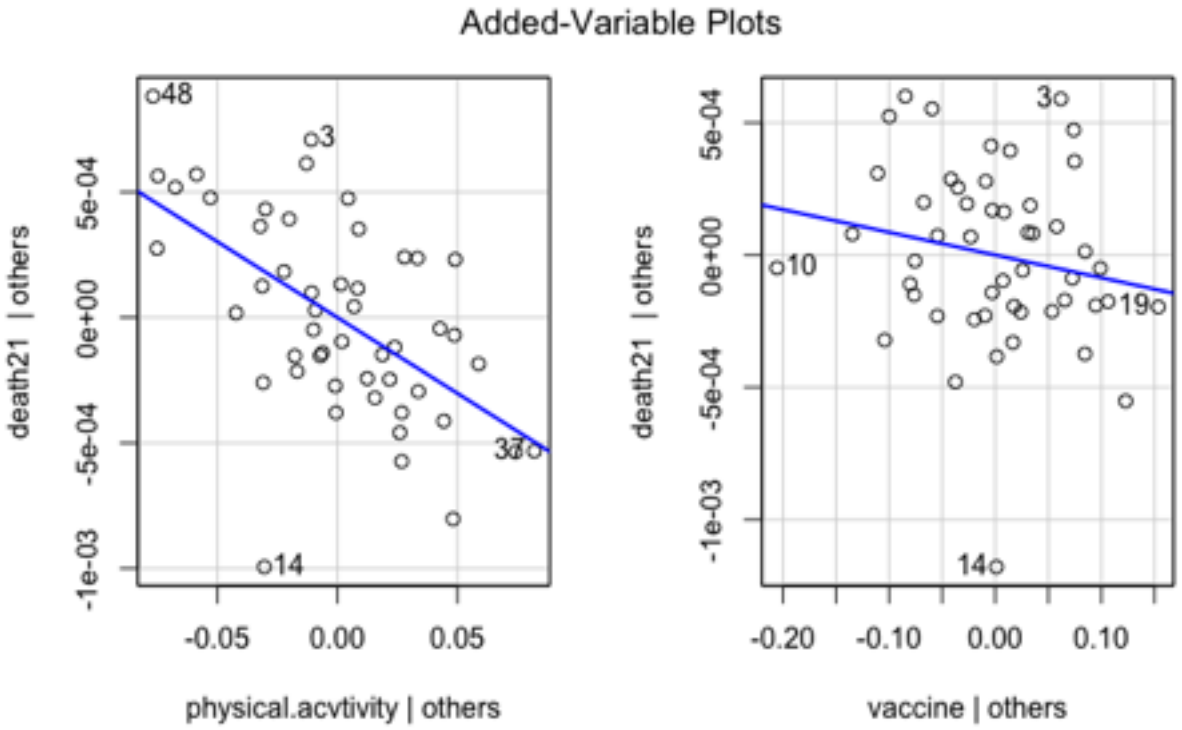

Figure 3.7: Correlation between physical activity, proportion vaccinated, and COVID-19 mortality 2021

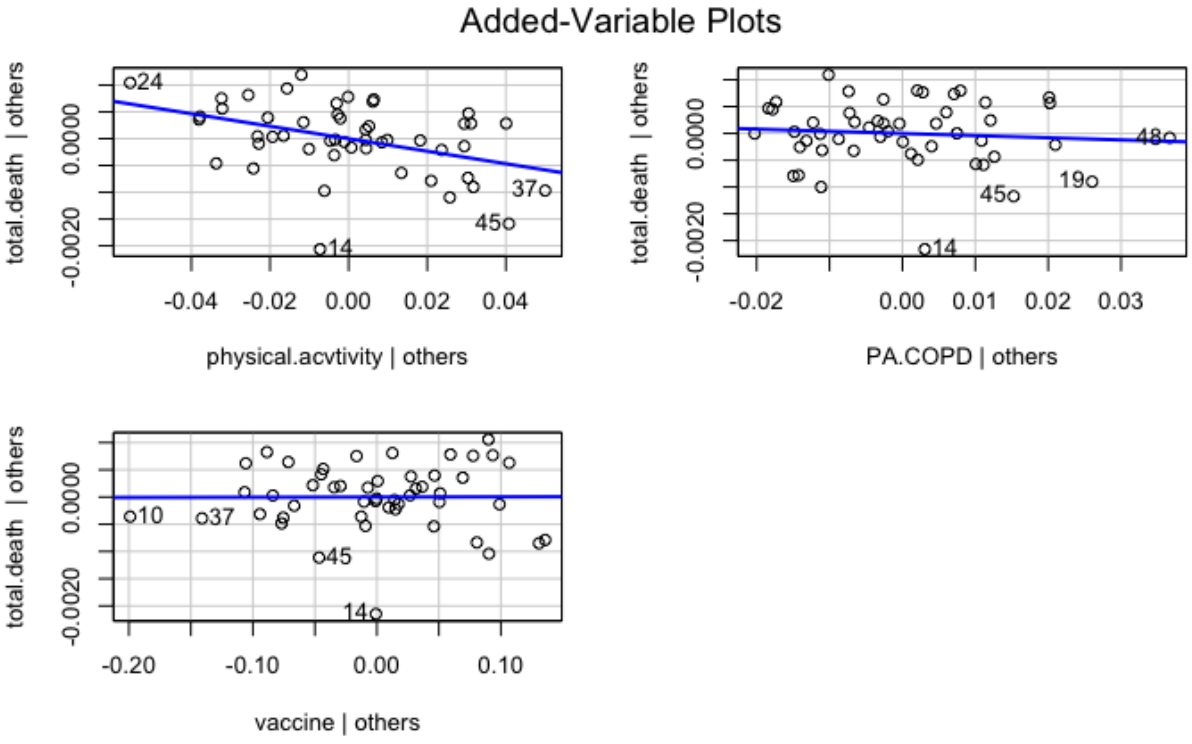

Figure 3.8: Correlation between physical activity, population with COPD, and proportion vaccinated and COVID-19 mortality 2020-21

CHAPTER 4: CONCLUSION

In this ecologic analysis of physical activity and COVID mortality in the 50 US states an association was observed between higher proportion of physical activity and lower 2020-2021 COVID-19 mortality. This relationship is in conjunction with the association between higher proportion of physical activity with lower proportion of diabetes, lower proportion of COPD, and higher proportion of vaccination in each state. When controlling for COPD and vaccination, a higher proportion of physical activity was still found to be correlated with a lower proportion of COVID-19 mortality in 2020 to 2021. A recommendation for future research would be to implement increased physical activity surveillance that would allow for more nuanced analysis between the correlation found between physical activity, COVID-19 mortality, vaccination, and chronic conditions. In conclusion, the results of this study support the importance of prioritizing physical activity and the importance of being fully vaccinated against COVID-19. Considering the social ecological model, it is vital that states promote policies and programs that continue to encourage people to get vaccinated and to remain physically active as the U.S. transitions through the COVID-19 pandemic in 2022.

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