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Modeling dynamics of fatal opioid overdose by state and across time

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ABSTRACT

Opioid overdose fatalities include deaths from natural opioids (morphine and codeine), semi-synthetic opioids (oxycodone, hydrocodone), synthetic opioids (prescription and illicit fentanyl, tramadol), methadone, and heroin. From 1999 to 2017, there were 702,568 drug overdose deaths in the U.S., with 399,230 attributed to opioids. This study aimed to assess the dynamics of opioid related fatalities throughout the U.S. from 2006-2016. This study is a secondary analysis of data obtained through the Kaiser Family Foundation's analysis of Centers for Disease Control and Prevention data, 1999-2016. The data obtained were from all 50 states and the District of Columbia. A total of 272,130 individuals were included in the analysis. This represents the number of opioid overdose deaths in the United States from 2006-2016. Descriptive analysis of overall rates was conducted and mapped for visualization. Novel predictive models of increase for each drug overdose category were developed and used to calculate rate changes. Finally, the elasticity of change in rate for each drug category was calculated annually for the past 11 years. The highest rate of opioid overdose-related death occurred in West Virginia (40.03 per 100,000). In our secondary analysis, we explored the change in the rate of opioid-related deaths from 2015 to 2016. The changing dynamics of fatal opioid overdose at the state level is critical to guiding policy makers in addressing this crisis. Rates of fatal opioid overdose vary across the states, but we identify some trends. Regional differences are identified in states with the highest overdose rates from all opioids combined.

1. Introduction

Opioid overdose fatalities include deaths from natural opioids (morphine and codeine), semi-synthetic opioids (oxycodone, hydrocodone), synthetic opioids (prescription and illicit fentanyl, tramadol), methadone, and heroin (Mattson et al., 2018; Centers for Disease Control and Prevention., 2018; Centers for Disease Control and Prevention. Annual Surveillance Report of Drug-Related Risks and Outcomes — United States, 2017; Seth et al., 2018; Hedegaard et al., 2017). From 1999 to 2017, there were 399,230 deaths attributed to opioids in the U.S. (Centers for Disease Control and Prevention., 2018). In 2017, a total of ~ 47,600 opioid overdose deaths occurred, accounting for 67.8% of all overdose deaths, an increase of 9.6%, from 19.8 to 21.7 deaths per 100,000 (Centers for Disease Control and Prevention., 2018). From 2015 to 2016, rates of overdose deaths for synthetic opioids, natural/semisynthetic opioids, and heroin increased by 100%, 12.8%, and 19.5%, respectively (Hedegaard et al., 2017).

Although overdose mortalities increased across all categories of drugs, illicitly manufactured fentanyl has had the most detrimental impact on public health (Gladden et al., 2016). Between 2013 and 2016, the rate of synthetic opioid overdose deaths increased by ~87% per year (Centers for Disease Control and Prevention., 2018). The National Institute on Drug Abuse (NIDA) announced in 2018 that synthetic opioids, primarily fentanyl, are now the most common substances involved in opioid overdose fatalities, exceeding the rate of prescription opioids (NIDA., 2018).

As staggering as these numbers are, the actual number of opioid related deaths has come into question recently, due to underreporting

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on death certificates, Buchanich et al. (2018). In 12% of drug overdose deaths listed on the death certificate, Hedegaard et al. (2018) found no specific drug was identified and in the case where multiple drugs were present, it was difficult to know which was the actual cause of death. In 2016, nearly 70% of deaths involving fentanyl also involved one or more other drugs, such as heroin or cocaine (Hedegaard et al., 2018). The ability to track specific drugs included in opioid overdose mortality rates has steadily improved (Centers for Disease Control and Prevention., 2018).

2. The state the opioid crisis response

Several policies and strategies have been implemented at the federal, state and local levels in the past decade in response to the rising rates of fatal opioid overdose, including restricting supply, influencing prescribing practices, reducing demand, and reducing harm (Academies, 2017). For instance, all states now have authorized Prescription Drug Monitoring Programs (PDMP) to track prescriptions and the distribution of controlled substances (Mattick et al., 2009). One of the most widely accepted and frequently studied approaches to addressing illicit drug use is through methadone maintenance therapy (Mattick et al., 2009). A systematic review and meta-analysis of mortality risk during and after opioid substitution presented evidence that using opioid agonist treatments, such as methadone and possibly buprenorphine), reduced mortality by 25 deaths per 1000 person-years among opioid-dependent patients (Luis et al., 2017). Another approach the U.S. government has employed is increasing criminal penalties for unauthorized drug use and distribution (Mattick et al., 2009; Werle and Zedillo, 2018). There is limited research on the effectiveness of these strategies. However, there is a need for a consistent systemic approach to determining the most worthwhile public health efforts (Mattick et al., 2009).

This study presents exisiting state level data on fatal overdose within the last 11 years (2006–2016). Its aims were to: (1) develop novel predictive models of increase for each drug overdose category, (2) examine the elasticity of fatal overdose in relation to time.

3. Methods

Data were obtained from the Kaiser Family Foundation analysis of CDC's, National Center for Health Statistics System Multiple Cause of Death Files, 1999 – 2016 (Multiple Cause of Death, 2018; The Henry, 2018). Among the deaths with drug overdose as the underlying cause, the type of opioid involved was stratified into three categories: heroin, synthetic and semisynthetic. No IRB was required as all data were anonymized prior to receipt.

Drug overdose deaths were classified using the *International Classification of Disease, Tenth Revision* (ICD-10), based on the following ICD-10 underlying cause of death codes: X40–44 (unintentional); X60–64 (suicide); X85 (homicide); Y10–Y14 (undetermined intent). Opioid death was further described by the following multiple cause-of-death codes: opioids (T40.0, T40.1, T40.2, T40.3, T40.4, or T40.6); natural and semisynthetic opioids (T40.2); synthetic opioids, other than methadone (T40.4); and heroin (T40.1). Deaths for illegally-made fentanyl could not be distinguished from pharmaceutical fentanyl in the data source. Deaths from both legally prescribed and illegally produced fentanyl were combined in these data.

Initially, summary statistics were provided for all variables. Data were screened for quality control and checked for the presence of outlier(s) or influential observations. Continuous variables were summarized using descriptive statistics. The frequency and percentages were reported for categorical variables.

3.1. Descriptive analyses

The 2016 state opiod overdose death rates were mapped per 100,000 persons for heroin, synthetic and semisynthetic opioids. Percentage change of rate from 2015 to 2016 for each opioid drug class is reported as well as geospatial mapping using ESRI ArcGIS 10.5, with a base US state map obtained from the United States Census Bureau (Cartographic Boundary Shapefiles – States, 2017). Choropleth maps for rate analysis were built using quantile optimization. The mean, median and range of fatal opioid overdose death rates for each state are reported over a 1-year reporting period.

3.2. Predictive modelling and elasticity analysis

Predictive models of overdose death rates per 100,000 were estimated using third degree polynomial. Increasing and decreasing direction of estimated predictive curves indicated overdose death rates progression or regression, respectively. The performance of the predictive model was assessed by examining the F-statistic as well as the coefficient of determination (R^2). The opioid overdose death rate for each U.S. state as a function of time is denoted by R(t) and has the following mathematical formula:

$$R(t) = at^3 + bt^2 + ct + d$$

where a, b, c, and d are model parameters and t stands for time (Nievergelt, 1983). In the above equation, $t = 1$ corresponds to the year 2006 and $t = 11$ corresponds to the year 2016.

Elasticity of opioid overdose death rates by time is defined here as the absolute value of the product of the rate of change of opioid overdose death rate with respect to time (denoted in differential calculus as $\frac{dR(t)}{dt}$), and the ratio of time to overdose death rate is denoted by $\frac{t}{R(t)}$. Simply, elasticity here means the percentage change in the overdose death rates for each 1 percentage change in time. Elasticity is denoted by E(t) and is symbolically written as:

$$\mathrm{E}(t) = \left|\frac{dR(t)}{dt}.\frac{t}{R(t)}\right| = \left|(3at^2 + 2bt + c)\frac{t}{at^3 + bt^2 + ct + d}\right| = \left|\frac{3at^3 + 2bt^2 + ct}{at^3 + bt^2 + ct + d}\right|$$

Opioid overdose death rate at a specific time point is said to be: (a) inelastic if the elasticity at that point of time is less than 1; (b) elastic if the elasticity at that point of time is greater than one; or (c) unitary elastic if the elasticity at that point of time is equal to one. An inelastic opioid overdose death rate changes less than proportionally in response to time change. An elastic opioid overdose death rate changes more than proportionally to time change. A unitary elastic opioid overdose death rate is one in which percent change in opioid overdose death rate and percentage change in time are equal.

4. Results

In 2016, the national mean opioid overdose death rate in the U.S. was 14.98 per 100,000, with a median of 13.88 deaths per 100,000. Fig. 1 shows the 2016 opioid overdose death rates per state for heroin, synthetic, and semi-synthetic respectively. Opioid overdose-related deaths stratified by state yielded remarkable regional differences in mortality rates. After ranking each state, we identified the regions and states with the highest over all opioid death rate, as well as those with the lowest rates. The highest rate of opioid overdose-related death occurred in West Virginia (40.03 per 100,000), New Hampshire (32.74), Ohio (31.11), Maryland (30.27), and Massachusetts (29.21). West Virginia's rate of opioid deaths was ~169% higher than the national average in 2016, while Massachusetts was approximately double. In contrast, the lowest opioid mortality rates were found in Texas (4.93 per 100,000), Kansas (5.02), California (5.13), Hawaii (5.39) and Arkansas (5.66). Each of these states had rates that were approximately three times lower than the national average. Table 1, represents each of the opioid types and the associated death rates for each type.

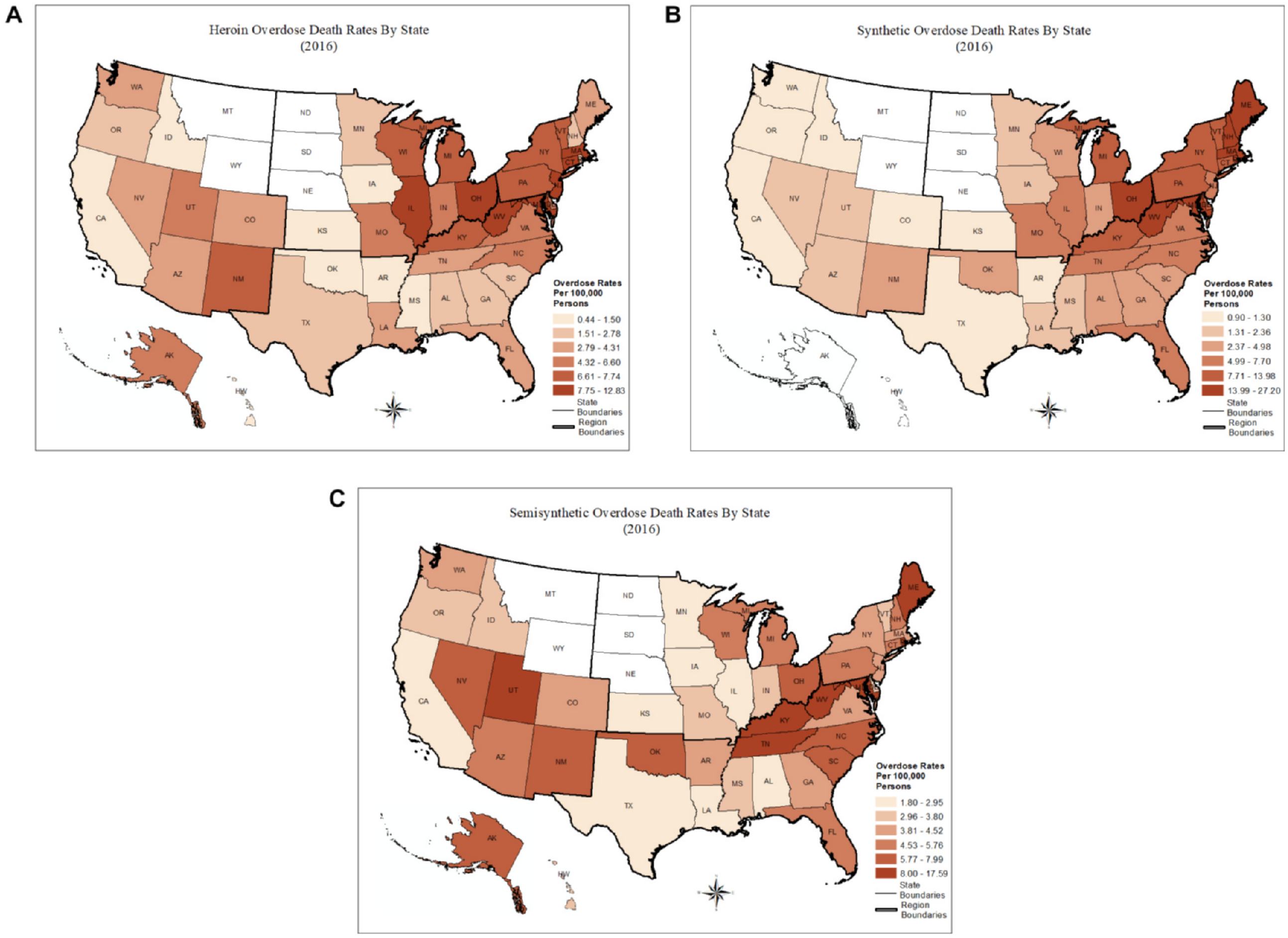

Fig. 1. A–C. Illustrate the heroin, synthetic, and semi-synthetic opioid overdose death rate per 100 k respectively.

4.1. Change in overdose death from 2015 to 2016

We explored the change in the rate of opioid-related deaths from 2015 to 2016 and ranked the states according to proportional change. States with the most substantial change included Maryland with a 67% increase in opioid overdose-related death rate from 2015 to 2016, Pennsylvania (+64%), New Jersey (+63%), Florida (+49%) and Indiana (+48%).

4.2. Semisynthetic

Not only did opioid overdose-related death rates differ across states, but also across the type of opioid. In 2016, the national average rate of semisynthetic opioid overdose deaths in the U.S. was 5.37 per 100,000, with a median of 4.41 deaths per 100,000. When stratified by state, we determined that the highest rates of semisynthetic opioid overdose occurred in West Virginia (17.59 per 100,000), Maryland (11.07), Utah (10.55), Tennessee (10.21) and Maine (9.91). Markedly, West Virgina's rate was over three times that of the national average.

Similar to the "all opioid overdoses" category, the northeast region had some of the highest rates of change, see Fig. 2. For example, Maryland saw a 67% increase, while New Jersey saw a 46% increase. However, unlike other opioid categories, states in the midwest, such as Indiana, Michigan and Illinois also encountered significant rises (58%, 47%, 40% respectively). States with the largest decline in opioid mortality rates from 2015 to 2016 were Arkansas (−21%), Colorado (−20%), Oregon (−16%), Delaware (−15%), and Alaska (−12%).

4.3. Heroin

In 2016, the national mean rate of heroin overdose deaths in the U.S. was 4.98 and the median was 4.22 per 100,000. Similar to the semisynthetic opioid category, the highest rates of heroin overdose death were in West Virginia (12.83 per 100,000), Ohio (12.73), Connecticut (12.58), Maryland (10.80) and New Jersey (9.50). Likewise, West Virginia had the largest difference, about 2.5 times above the national average. In contrast, the lowest heroin mortality rates were found in southern and midwestern regions of the U.S., including Arkansas (0.44 per 100,000), Kansas (1.10), Mississippi (1.10), Oklahoma (1.35), and Hawaii (1.40).

States with substantial reductions included New Hampshire (−57%), Rhode Island (−44%), Delaware (−13%), Mississippi (−13%), and Washington (−8%). These changes are demonstrated in Fig. 3. The states with the highest rate of change in heroin overdose from 2015 to 2016 were not region-specific. Idaho had a 53% increase in heroin-related mortality rate from 2015 to 2016, Kansas (+52%), and Oklahoma (+47%). Similar to the semisynthetic category, Maryland saw a 60% increase (from 405 to 650), while New Jersey saw a considerably higher percent change, 67% (508 to 850). Idaho's rates per 100,000 went from 16 to 25, Kansas 21 to 32, and Oklahoma 36 to 53. Ohio had the highest raw number of heroin overdose fatalities in 2016 at 1478.

4.4. Synthetic

Illinois saw the largest increase in synthetic opioid overdose deaths (227%), followed by Pennsylvania, and Maryland (both at 205%).

Table 1
Overdose rates per 100,000.

State	Semisynthetic			Synthetic			Heroin		
	Mean (SD)	Median	Range	Mean (SD)	Median	Range	Mean (SD)	Median	Range
AL	1.62	1.71	0.88	0.88	0.62	2.90	1.36	0.83	2.34
AK	5.77	5.59	6.51	1.98	1.89	1.75	3.85	3.33	4.94
AZ	4.34	4.37	2.00	0.90	0.85	1.22	1.99	1.54	3.49
AR	3.81	3.88	2.43	1.28	1.10	1.36	0.44*	0.44*	0*
CA	2.71	2.71	0.83	0.51	0.46	0.52	1.08	0.95	0.76
CO	3.81	3.85	2.24	1.14	1.17	0.95	1.87	1.54	3.41
CT	2.42	1.15	4.89	2.48	0.61	13.67	5.18	3.07	10.43
DE	3.82	3.81	5.67	2.91	2.13	6.90	3.68	3.20	5.63
D.C.*	3.07	2.45	6.09	8.26	3.88	16.97	7.03	5.39	15.27
FL	4.53	4.39	2.99	1.71	0.84	6.88	1.07	0.52	2.98
GA	2.97	3.09	2.99	1.21	0.86	2.18	0.79	0.35	2.09
HI	2.81	2.60	1.43	0.91*	0.91*	0	1.00	0.95	0.69
ID	2.70	2.67	1.76	0.85	0.83	0.52	1.04	0.97	0.81
IL	1.58	1.40	2.11	1.67	0.87	6.43	2.91	1.31	7.63
IN	2.05	2.16	2.71	1.24	0.80	4.07	1.89	1.39	4.20
IA	2.58	2.61	1.72	1.08	1.03	1.31	0.91	1.00	1.17
KS	2.46	2.44	1.43	1.00	0.93	0.90	0.64*	0.60*	0.71*
KY	7.59	7.93	6.73	2.97	1.60	9.61	3.36	3.26	6.73
LA	1.72	1.63	1.10	0.60	0.46	1.68	1.35	0.74	2.94
ME	5.10	4.59	6.90	4.06	1.58	13.82	2.60*	2.86*	3.23*
MD	4.73	4.07	9.13	3.21	0.94	17.52	3.78	2.72	9.18
MA	2.71	2.59	1.74	4.75	1.15	21.92	3.66	2.18	8.77
MI	2.82	2.47	3.96	2.13	0.90	8.57	3.48	2.66	6.18
MN	1.90	1.88	1.42	0.78	0.70	1.31	1.33*	1.28*	2.40*
MS	1.91	1.84	2.32	0.88	0.80	1.13	0.87*	0.94*	0.94*
MO	3.56	3.78	1.55	2.08	1.53	6.31	3.52	3.49	5.19
MT	2.72	2.59	3.12	1.46*	1.37*	1.12*	**	**	**
NE	1.47	1.58	1.15	0.73*	0.68*	0.61*	**	**	**
NV	8.96	8.68	4.21	1.24	1.11	0.92	1.69	1.61	2.22
NH	4.41	4.63	3.27	6.62	1.82	26.13	3.40	2.95	6.54
NJ	2.14	2.45	3.71	1.45	0.43	7.48	3.11	1.48	9.29
NM	8.11	8.41	5.18	1.65	1.18	2.79	3.96	3.27	6.72
NY	2.89	3.08	3.05	1.78	0.89	7.72	2.63	1.71	6.04
NC	4.40	4.48	3.27	2.06	1.61	4.75	1.76	0.85	4.95
ND	2.06	1.98	0.52	1.67*	1.67*	0.63*	1.58*	1.58*	0*
OH	4.21	4.47	4.58	4.08	1.40	18.98	5.77	3.79	11.65
OK	8.32	9.07	4.17	2.38	2.28	3.05	0.72*	0.67*	0.98*
OR	3.30	3.33	1.67	0.75	0.75	0.57	2.73	2.78	1.80
PA	2.73	2.58	3.84	1.96	0.83	9.58	2.64	1.88	6.56
RI	5.33	5.89	7.39	5.70	2.14	16.18	3.43*	2.85*	5.32*
SC	3.91	3.08	4.37	1.68	1.05	3.99	0.89	0.41	2.08
SD	2.23	2.35	2.03	1.32*	1.32*	0.33*	**	**	**
TN	6.81	7.05	6.58	1.98	1.36	4.94	1.50*	0.91	3.64
TX	1.96	1.84	0.71	0.55	0.50	0.54	1.34	1.39	1.01
UT	10.12	9.94	4.87	1.87	2.00	1.38	3.04	2.59	3.62
VT	4.32	4.31	2.55	3.60	2.56	6.57	4.50*	5.26*	5.61*
VA	3.18	3.30	1.89	1.96	1.09	6.88	2.09	1.31	4.79
WA	4.31	4.27	1.29	0.89	0.86	0.70	2.26	2.17	3.38
WV	15.57	18.40	18.47	7.01	5.29	21.48	5.08	2.67	11.81
WI	4.03	4.01	2.83	1.58	1.16	4.04	2.84	2.36	6.23
WY	4.20	4.44	2.81	2.01*	2.01*	0*	**	**	**

*Denotes states with more than three years reporting data missing.
**Denotes there were no data within this category and thus mean, median, nor mode could be calculated.

While not representing the highest change in rates, Ohio reported the highest number of synthetic opioid overdoses in 2016 at 2296. Notably, states in the southeast region that had previously not seen rapid growth in fatal overdose in other opioid categories such as Alabama (124% increase), Florida (152%), Louisiana, (134%) and North Carolina (98%) saw large increases from approximately 1 to 1.5 times the number from the previous year. In contrast to other opioid categories, very few states saw declines in synthetic opioid overdose rates from 2015 to 2016 (see Fig. 4) including Arkansas (−14%), Georgia (−4%), Kansas (−25%), and Nebraska (−1%). Synthetic opioid death rates in these states were already low in 2015 and had been low across the 10-year period examined for this study. Several of the states that saw large increases in fatal synthetic opioid overdose also experienced rises in semi-synthetic and heroin overdose. However, the proportional rise in synthetic overdose dwarfed the other opioid types. For instance, Maryland saw a 67% and 60% increase in deaths attributed to semi-synthetic and heroin overdoses, respectively, and a 205% increase in synthetic overdose. States like New Hampshire and Rhode Island, while reporting decreases in the other two overdose categories, saw modest rises in deaths attributable to synthetic overdose (27% and 33% respectively).

4.5. Prediction models for opioid overdose death rates

Fig. 5 shows the predicted synthetic opioid overdose death rates per 100,000 for New Hampshire, West Virginia, Massachusetts, Maryland, Ohio, and Pennsylvania. For the 2012–2016 period, all six of these states experienced an increase in synthetic opioid overdose death rates. Among these six states, the highest rate for synthetic opioid overdose

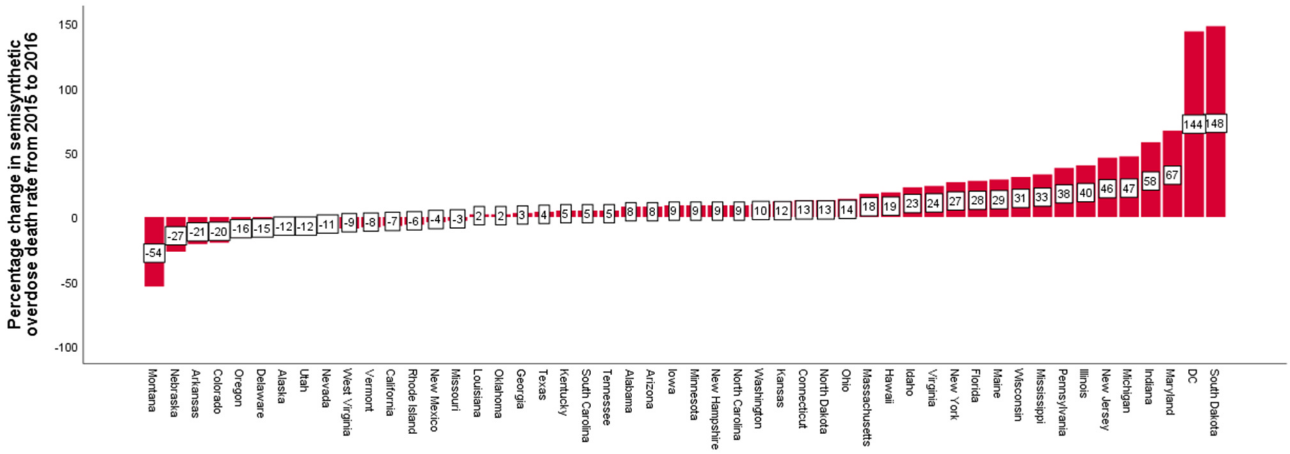

Fig. 2. Displays the percentage change in semi-synthetic overdose death rate from 2015 to 2016 for each state.

death rate was observed in New Hampshire, followed by West Virginia, Massachusetts, Maryland, Ohio, and Pennsylvania. From 2014 to 2016, the velocity of the overdose death rates for synthetic opioids was approximately equal for New Hampshire, West Virginia, and Massachusetts. Pennsylvania had the lowest velocity for synthetic overdose death rate among the top six states. Nebraska, Texas, California, Kansas, and Oregon had the lowest overall synthetic opioid overdose death rate in 2016.

Fig. 6 depicts predictive curves for semisynthetic opioid overdose death rates for the US, as well as for states with high semisynthetic opioid overdose death rates. Following West Virginia, which has the highest rates, are Utah, Tennessee, Maryland and Maine. Although West Virginia has maintained highest semisynthetic overdose rate throughout the observation period, its rate has been decreasing with the highest velocity since 2013. The graph for Utah shows a decreasing rate of semisynthetic deaths since 2013. The rates for Tennessee, Maryland and Maine all increased. Since, 2012, Maryland and Maine had a higher velocity of increase than Tennessee.

In Fig. 7**,** graphs for the five states with the lowest opioid semisynthetic overdose death rates, compared with the US average are depicted. In 2016, the lowest rate was reported by Texas followed by Alabama, Louisiana, California and Minnesota. Both California and Texas had decreasing rates of semisynthetic opioid death rates, and since 2009 the state of California had higher velocity of decrease in semisynthetic death rates when compared to Texas.

The states with the highest mortality rates for heroin overdose are shown in Fig. 8. Since 2009, heroin overdose death rates were highest in Ohio, West Virginia, Connecticut, Maryland, and New Jersey. In recent years, all five states, as well as the United States' heroin overdose rates, have been increasing, year after year. The highest velocity of heroin overdose rate from 2015 to 2016 was in Maryland. Louisiana, Kansas, Iowa, Texas, and Indiana had the lowest overall heroin overdose death rates.

Overall, West Virginia had the highest opioid overdose death rate statistics when compared to other US states. Fig. 9 illustrates West Virginia overdose death rates for semisynthetic, synthetic and heroin. In 2016, the highest overdose death rate in West Virginia was synthetic followed by semisynthetic and heroin. Both synthetic and heroin overdose rates have been increasing in West Virginia with synthetic having the higher velocity for death rate.

4.6. Sensitivity of opioid overdose death rates with respect to time

Fig. 10 shows the time elasticity of synthetic opioid overdose rate for the state of West Virginia. As the figure shows, the synthetic overdose death rate was elastic in 2006 and thereafter became inelastic for all subsequent years until year 2012. In 2012 and thereafter, it became sharply elastic. In 2016, the elasticity for the state of West Virginia was approximately 5.06, illustrating the rapid increase in synthetic opioid overdose death rates in the state.

Fig. 11 depicts the time elasticity of synthetic opioid overdose death rates for the state of Kansas. It is inelastic for the entire period of study. In 2016, the synthetic overdose elasticity of death rate for the state of Kansas was approximately 0.41. In the same year, the elasticity for West Virginia in 2016 was approximately 12.3 times the elasticity in Kansas.

Fig. 12 shows the time elasticity for semisynthetic opioid overdose

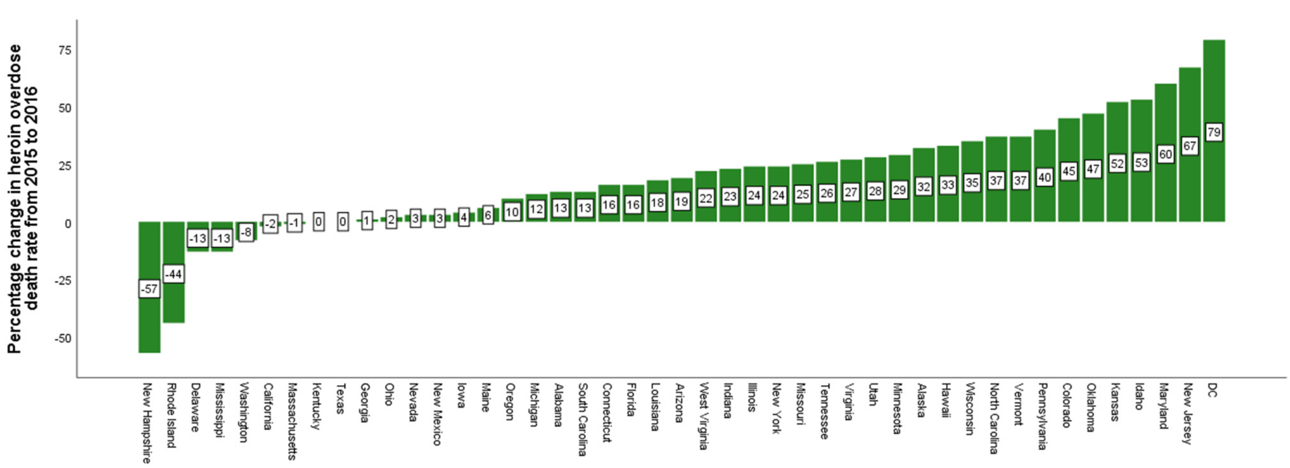

Fig. 3. Ranks the percent change in heroin overdose death rate from 2015 to 2016 for each state.

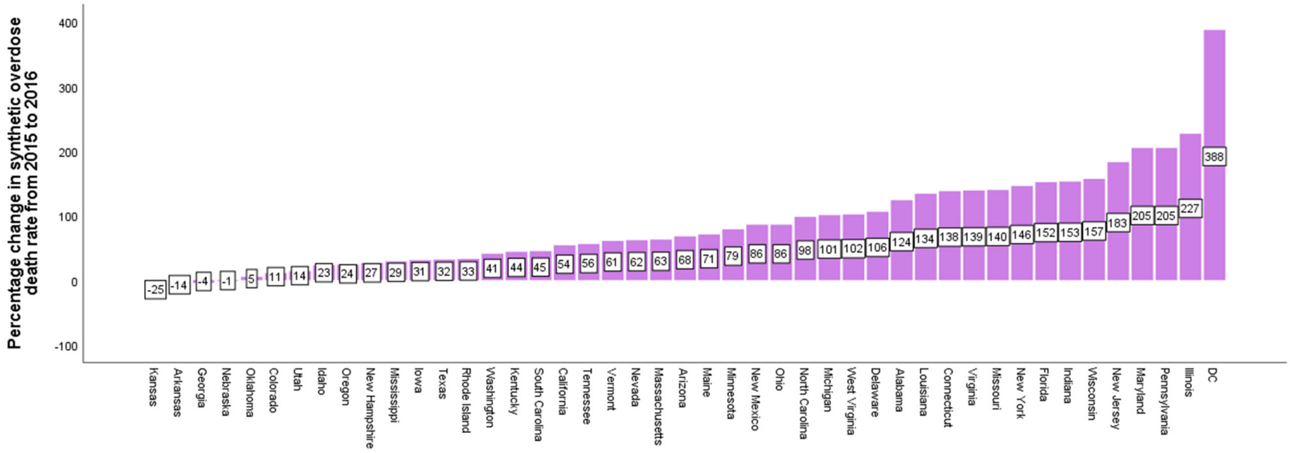

Fig. 4. Shows the percentage change in synthetic overdose death rate from 2015 to 2016 for each state.

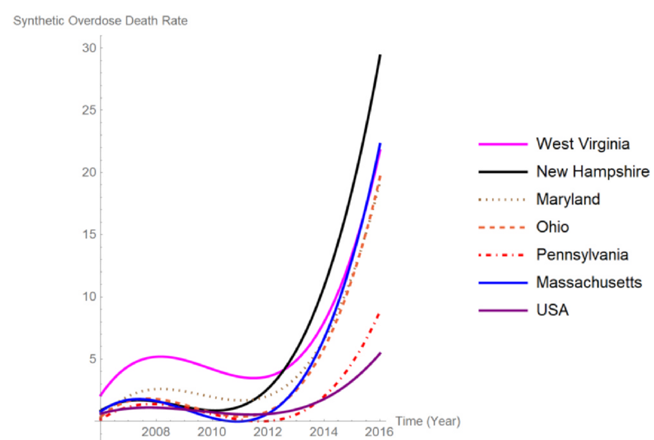

Fig. 5. Underlines the differences in synthetic overdose death rates among West Virginia, New Hampshire, Maryland, Ohio, Pennsylvania, Massachusetts, and the USA as a whole.

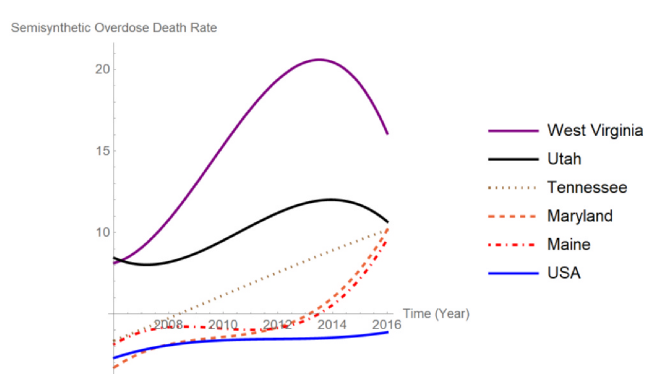

Fig. 6. Highlights the semi-synthetic overdose death rates in West Virginia, Utah, Tennessee, Maryland, Maine, and the USA as a whole.

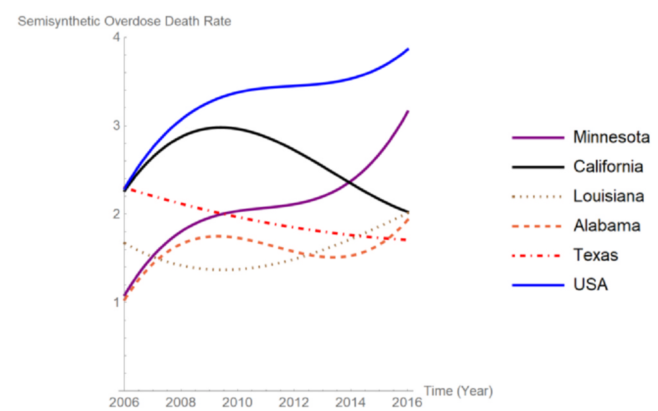

Fig. 7. Models the semi-synthetic overdose death rates in Minnesota, California, Louisiana, Alabama, Texas, and the USA as a whole.

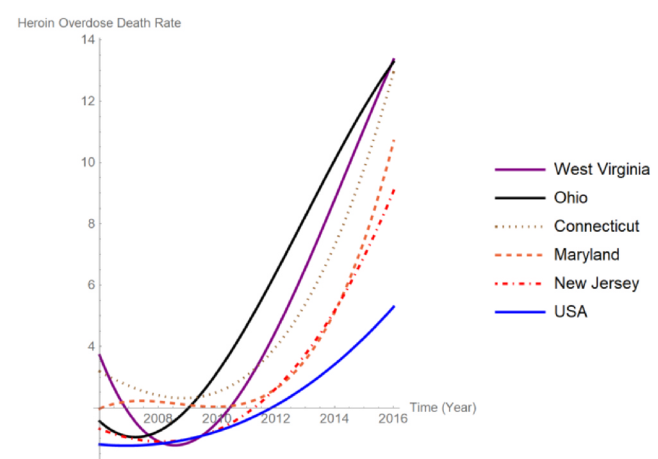

Fig. 8. Compares the heroin overdose death rates in West Virginia, Ohio, Connecticut, Maryland, New Jersey, and the USA as a whole.

death rates for the state of West Virginia. In 2016, the elasticity for semisynthetic opioid overdose death rate in the state of West Virginia was approximately 2.71, which places West Virginia in the elastic category. The semisynthetic elasticity of overdose death in West Virginia was uniformly inelastic from 2006 to 2014, after which it became sharply elastic.

Fig. 13 illustrates the time elasticity of semisynthetic opioid overdose death for the state of Nebraska. From 2006 to 2015, the State of Nebraska sensitivity measure indicated an inelastic mode. In 2016, the semisynthetic elasticity for the opioid overdose death rate in the state of Nebraska was approximately 1.12. West Virginia semisynthetic elasticity in 2016 was 2.4 times the semisynthetic elasticity of Nebraska. By comparing the two elasticity graphs, we observe that the elasticity for semisynthetic opioid moratlity rate in the state of West Virginia is 2.4 times larger than the state of Nebraska.

Fig. 14 shows the elasticity graph for heroin for West Virginia. West Virginia had elastic heroin sensitivity at almost all times during study period except for a short period of time after 2008 but before 2009. Shortly before 2011, the heroin elasticity reached its peak and

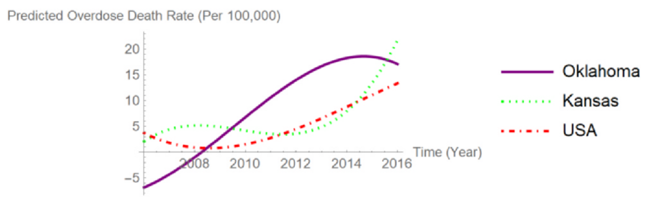

Fig. 9. Presents the predicted overdose death rates per 100 k for Oklahoma, Kansas, and the USA as a whole.

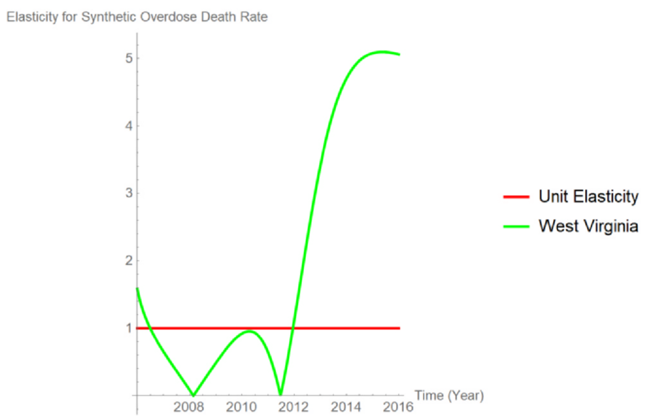

Fig. 10. Reveals a dissimilarity between the unit elasticity and the elasticity for synthetic overdose death rate in West Virginia.

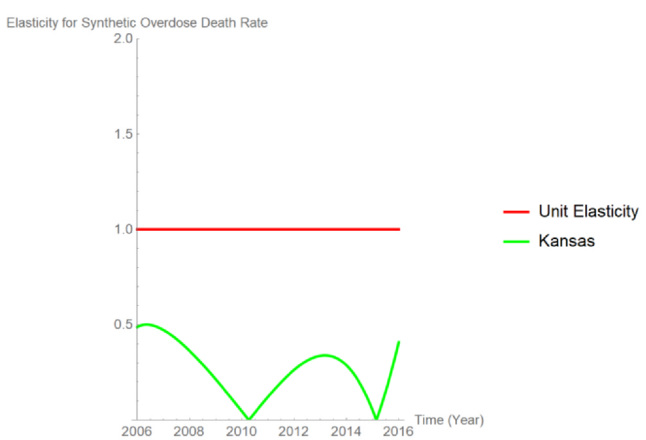

Fig. 11. Indicates a stark contrast in the unit elasticity and the elasticity for synthetic overdose death rate in Kansas.

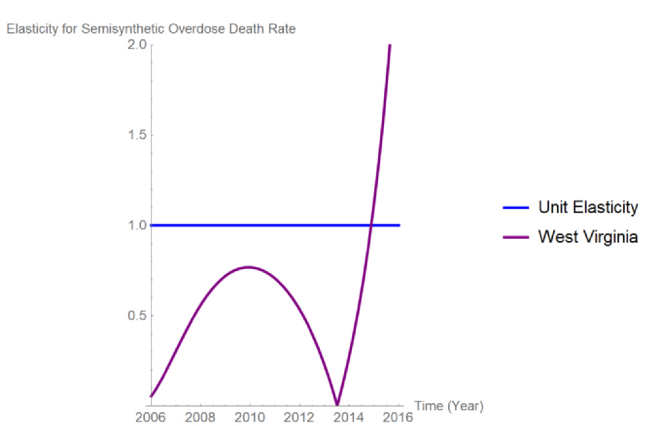

Fig. 12. Reflects a distinct difference between the unit elasticity and the elasticity for semi-synthetic overdose death rate in West Virginia.

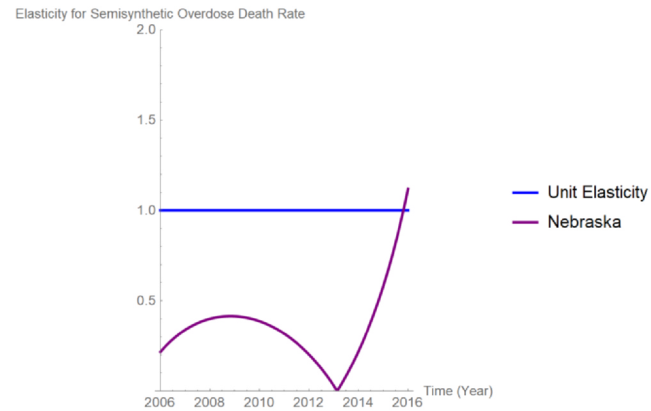

Fig. 13. Unveils the difference between the unit elasticity and the elasticity for semi-synthetic overdose death rate in Nebraska.

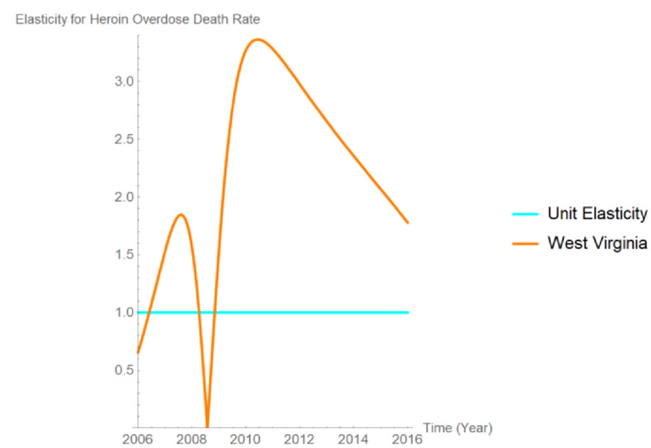

Fig. 14. Demonstrates the contrast between the unit elasticity and the elasticity for heroin overdose death rate in West Virginia.

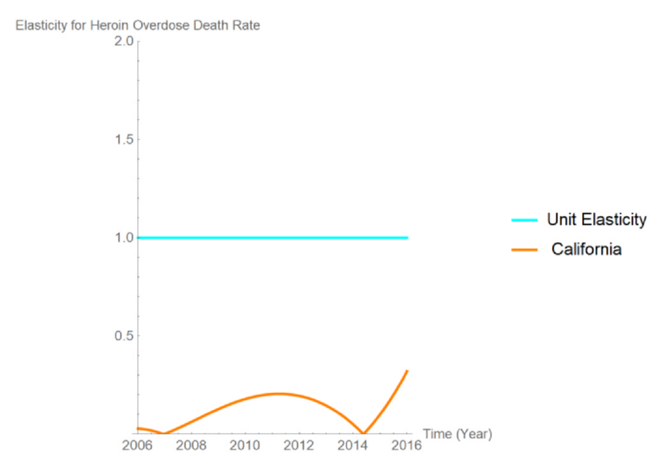

Fig. 15. Signals a strong difference between the unit elasticity and the elasticity for heroin overdose death rate in California.

thereafter had a downward trend. In 2016, the heroin elasticity was approximately 1.78.

As shown in Fig. 15, the state of California heroin had an inelastic sensitivity throughout the study period (0.32). West Virginia's heroin elasticity in 2016 was approximately 5.6 times, when compared to California.

5. Discussion

According to the CDC, past misuse of prescription opioids is the strongest risk factor for starting heroin use, especially among people who became dependent upon or abused prescription opioids in the past year. Unnecessary prescribing by health care providers, as well as a reduction in the duration of initial prescriptions, could reduce the addiction rate, and subsequently the fatal overdose rate.

Understanding the changing dynamics of fatal opioid overdose at the state level is critical to guiding state and federal policy. Because of the low cost of heroin compared with prescription opioid analgesics, some people may migrate to heroin use as a low cost option for pain management. Further, in illicit markets, heroin is often adulterated with fentanyl and its deriviatives to increase profits, which can also result in increased fatal overdose.

Rates of fatal opioid overdose are variable across the states, but some trends can be identified. Regional differences are identified in states with the highest overdose rates from all opioids combined. Several potential reasons for this have been posited in the available literature. These include economically depressed areas affected by what has been coined "diseases of despair," (Meit et al., 2017) of which opioid use disorder is one. Another reason that has been put forward is the increased availability that resulted from focused marketing of opioids in these economically depressed areas (Hadlad et al., 2019; Hadland et al., 2018; Van Zee, 2009). More research is needed in these areas to identify factors that may be related to the consistently high rates found.

There was also variation in velocity of the last recorded year of change and elasticity of opioid overdose deaths among the three categories of drug overdose studied here. In general, semisynthetic and synthetic overdose rates were found to be more elastic in most states. However, synthetic rates were elastic in the sense that rates were rising steeply in most states while only four states reported drops in overdose rates from synthetic opioid use, and the drops were modest. It should be noted that these states reported consistently lower rates than the national mean rate of overdose across the period of study. Conversely, semisynthetic opioid overdose derived elasticity predominantly from reductions, with 11 states reporting reductions in 2016, the last reporting year. Rates of fatal heroin overdose dropped in only four states as well, but the decreases were more significant.

5.1. Limitations

In assessing the opioid responsible for the fatal overdose, there may be some differences from state to state particularly during the earlier years of analysis and this may affect the findings here. The drug categories typically reported nationally, it is not possible to differentiate prescribed from illicit fentanyl. This lack of specificity regarding illicit fentanyl overdose renders unclear the exact number of deaths caused by this drug in this analysis.

6. Conclusion

While these data do not reveal what is causing the increases and decreases in rates or elasticity, one hypothesis is that the impact of supply side policy interventions such as establishment of prescription drug monitoring programs (PDMP), increased law enforcement (Dowell et al., 2016; National Alliance for Model State Drug Laws, 2016; Rutkow et al., 2015; Office of National Drug Control Policy, 2018), drug take back programs (Gray and Hagemeier, 2012; Fass, 2011), and dose limit laws may be underlying factors (Barth et al., 2017; Davis et al., 2018; National Conference of State Legislators, 2018). Previous research indicates that these approaches may have a moderate effect (3.0–5.3% reduction) on fatal opioid overdose (Bao et al., 2016; Brady et al., 2014; Moyo et al., 2017; Yarbrough, 2018; Wen et al., 2017; Sun et al., 2018; Haffajee et al., 2018). However, it is unclear what the effect of these interventions may have been on fatal overdose rates. One qualitative study reported a lack of access and cost as the key reasons from prescription to illicit opioids (Cicero et al., 2015).

Other policy changes that may have an impact on fatal overdose include the institution of medical marijuana legalization Powell et al., 2015; Smart, 2015; Bradford and Bradford, 2016) naloxone laws (Doe-Simkins et al., 2009; Straus et al., 2013) and access to Medicaid (Cher et al., 2019; NIDA Opioid Summaries). Medical marijuana studies have shown associations between lower prescribing rates and overdose (Powell et al., 2015; Bradford and Bradford, 2016), but have been associated with increased drug use in adolescents (Smart, 2015). Naloxone laws have been studied in smaller scale studies, and the findings indicate this could be part of a viable strategy to reduce overdose on a large scale. This study's findings reveal that the states lacking access to Medicaid have higher rates of fatal overdose (Doe-Simkins et al., 2009; Straus et al., 2013) due to illicit drug use.

Author contributions

Conceived and designed the study: RLC, MT. Analyzed the data: RLC, RE, JW, JT, MT. Contributed to writing of the manuscript: RLC, RE, JW, JT, SAM, PJ, PMJ, MT, MK, MMH, KPS. Planning, execution, and interpretation of the data: RLC, RE, MT, KPS.

Declaration of Competing Interest

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

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