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Effect of Washington State and Colorado's cannabis legalization on death by suicides

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ABSTRACT

In the U.S., death by suicide is a leading cause of death and was the 2nd leading cause of death for ages 15-to-34 in 2018. Though incomplete, much of the scientific literature has found associations between cannabis use and death by suicide. Several states and the District of Columbia have legalized cannabis for general adult use. We sought to evaluate whether cannabis legalization has impacted suicide rates in Washington State and Colorado, two early adopters. We used a quasi-experimental research design with annual, state-level deaths by suicide to evaluate the legalization of cannabis in Washington State and Colorado. We used synthetic control models to construct policy counterfactuals as our primary method of estimating the effect of legalization, stratified by age, gender, and race/ethnicity. Overall death by suicide rates were not impacted in either state. However, when stratified by age categories, deaths by suicide increased 17.9% among 15–24-year-olds in Washington State, or an additional 2.13 deaths per 100,000 population (p-value $\leq$0.001). Other age groups did not show similar associations. An ad hoc analysis revealed, when divided into legal and illegal consumption age, 15–20-year olds had an increase in death by suicides of 21.2% (p-value = 0.026) and 21–24-year olds had an increase in death by suicides of 18.6% (p-value $\leq$0.001) in Washington State. The effect of legalized cannabis on deaths by suicide appears to be heterogeneous. Deaths by suicide among 15–24-year-olds saw significant increases post-implementation in Washington State but not in Colorado.

1. Introduction

Death by suicide is a leading cause of death in the United States and has been increasing over the past 20 years (Stone, 2018a). Suicide remains a leading public health problem. Suicide is the second leading cause of death for those aged 10 to 44 (CDC, 2020). According to the Centers of Disease Control (CDC), there were 48,344 deaths by suicide in 2018, or 14.78 per 100,000 population (CDC, 2020).

While the literature surrounding cannabis use and death by suicide is not complete, there is much that suggests associations exist (Delforterie et al., 2015). Particularly, there is evidence that suggests a potential relationship between cannabis use disorders and suicide attempts among those with bipolar disorder (Bartoli et al., 2019). A recent meta-analysis found that the evidence supports the claim that heavy, or chronic, cannabis use is likely able to predict suicidality, though the same is not true for periodic cannabis use (Borges et al., 2016). Importantly, some research suggests the link between cannabis use and suicide may be explained by shared risk and protective factors such as depressive symptoms (Harris and Barraclough, 1997; Wilcox et al., 2010). However, it is important to note that these associations lack causal evidence.

As of June 2020, 11 U.S. states and the District of Columbia had legalized cannabis for recreational use by adults over age 21 years and a total of 33 states have legalized cannabis for medical use (National Conference of State Legislatures, 2020). Washington (WA) and Colorado (CO) legalized cannabis in 2012. Subsequent states legalized cannabis in

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2014 (AK, OR, & DC), 2016 (CA, ME, MA, & NV), 2018 (MI, & VT), and 2019 (IL). Recent research has examined the effect of medical and/or recreational cannabis legalization on cannabis consumption habits (Cerdá et al., 2017, 2020; Stolzenberg et al., 2016; Vigil et al., 2018; Wall et al., 2016; Wen et al., 2019).

Wen et al. (2019) examined the impact of medical cannabis laws on cannabis attitudes and perceptions using the National Survey on Drug Use and Health (NSDUH) data from 2004 to 2012. Results suggested that implementing medical cannabis laws increased the probability that young adults perceived no or low health risk associated with cannabis use (Wen et al., 2019). Stolzenberg et al. (2016) used NSDUH from two time periods (2002–2003 and 2010–2011) to conducted a cross-sectional pooled-time series analysis, finding medicalization increased recreational use of cannabis by young adults (Stolzenberg et al., 2016). Wall et al. (2016) replicated the study by Stolzenberg et al. (2016), finding no increase in recreational use after accounting for pre-medicalization prevalence (Wall et al., 2016). Cerdá, Wall, Feng & colleagues (2017) examined the association between adolescent cannabis use and legalization finding that adolescent cannabis use increased significantly in WA while CO did not display any changes post-legalization (Cerdá et al., 2017). Cerdá, Mauro, Hamilton & colleagues (2020) examined the impact of recreational cannabis legalization on cannabis use disorder (CUD) and cannabis use in the U.S. from 2008 to 2016 using cross-sectional surveys. The study found respondents 12 to 17 years in states with cannabis legalization had a 25% significant increase in past year CUD and respondents 26 years old had a 36% increase in past year CUD (Cerdá et al., 2020). Vigil, Van Dyke, Hall & colleagues (2018) found no change in past-30 day cannabis use rates for 18–24 year olds in CO after recreational legalization (Vigil et al., 2018).

Other research has investigated the impact of medical marijuana laws on suicide risk to conflicting ends (Anderson et al., 2014; Bartos et al., 2020; Grucza et al., 2015). Anderson, Rees, and Sabia used data from 1990 to 2007 from the National Center for Health Statistics (NCHS) - Detailed Mortality File finding suicide among males age 20–39 reduced after medicalization (Anderson et al., 2014). However, Grucza et al. (2015) replicated the work of Anderson, with additional years of data and covariates finding no significant relationship (Grucza et al., 2015). Bartos and colleagues (2020) used synthetic control method (SCM) to examine the impact of medical cannabis on suicide in California from 1970 to 2004. While the authors found significant reductions, they also couch their causal findings within the context of suicide mechanism, stating the overall reductions may be a result of reductions in gun access seen in California during the time span (Bartos et al., 2020). A recent review of the literature regarding the impact of liberalization of cannabis suggests more time is needed to fully understand the impact of laws that make cannabis more accessible, whether medically or recreationally, and calls for future policy research to evaluate the impact of law changes on other secondary-outcomes (Leung et al., 2018).

As more states choose to legalize cannabis, it is imperative to understand the range of potential health impacts. We sought to examine whether deaths by suicide increased during the 5 years post-legalization in CO and WA, the states with the earliest commercial adult cannabis programs.

2. Methods

To evaluate the impact of cannabis legalization on deaths by suicide in CO and WA, we used a quasi-experimental research design with annual, state-level death by suicide rates per 100,000 population from 2000 to 2018. We used the – Limited Geography Mortality file to identify state-level suicide deaths stratified by age, sex, and race/ethnicity. NCHS - Mortality files from 2005 to 2018 were obtained via data request from the NCHS. Mortality files for 2000–2004 were ascertained from the Inter-University Consortium for Political and Social Research (ICPSR) as they were publicly available data (National Center for Health Statistics, 2007a, 2007b, 2007c). Our primary outcome was death by suicides.

2.1. Variables

To identify death by suicides in NCHS - Mortality Files across all years, we used ICD-10 codes X60-X84, Y87.0, *U03 to identify intentional self-harm events. We categorized age into six, ten-year categories: 15–24-years old, 25–34-years old, …65+ years old. Race/ethnicity was categorized into Non-Hispanic White, Non-Hispanic Black, and Hispanic. Counts of deaths by suicide stratified by sex, race/ethnicity, and age categories were then collapsed to the state-and-year-level for each year, providing a longitudinal dataset with repeated measures. We obtained total population counts for each demographic group from the Centers for Disease Controls' Web-based Injury Statistics Query Reporting System by state-and-year (CDC, 2020) and generated suicide rates per 100,000 population.

We obtained state-level demographics from the Current Population Survey microdata available through the Integrated Public Use Microdata Series (IPMUS) (Flood et al., 2020). We included state-and-year indexed percentages of the following self-reported covariates: percent of the state unemployed, served in the military, white, male, and married.

We obtained percentage of past-year marijuana use among all persons aged $\geq$12 from the National Survey of Drug Use and Health (SAMHSA, 2016). We extrapolated this data for years 2000–2002 as this information was not available. We divided the population of 18–34-year olds by the total population within each state-and-year to control for the percent population within this age range. We used a state-level estimate of household firearm ownership, produced by the RAND Corporation (Schell et al., 2020). The household firearm ownership measure uses data from surveys and administrative sources to produce an estimated proportion of adults that live in a household with a firearm (Schell et al., 2020). All data was state-year indexed from 2000 to 2013 to create synthetic control models prior to the commercial availability ot cannabis in CO and WA.

Strong mental health parity laws are associated with better access to mental health services (Barry and Busch, 2007) and potentially associated lower rates of suicide (Lang, 2013). To account for state differences in mental health parity laws, we used state report data from The Kennedy-Satcher Center for Mental Health Equity, which provides a graded (0–100) score for each state's quality of parity law statutes (Douglas, 2018).

2.2. Analysis

We employed a synthetic control method (SCM) approach to produce the best possible counterfactual for estimating the policy effect of cannabis legalization on death by suicides in both CO and WA stratified by various characteristics (Abadie et al., 2010, 2014; Galiani and Quistorff, 2016). The SCM uses a pool of "non-treated" states—states that did not adopt the policy of interest—to identify a weighted combination of states that most closely approximates the treated state during the pre-law adoption period. This weighted combination, called the "synthetic control," is a more accurate representation of the counterfactual scenario—what the state would have experienced in absence of the policy of interest. The synthetic trend is then forecasted forward, in the post-law adoption period, creating a counterfactual to which the intervention state can be compared. It is potentially preferable to a traditional comparison of two neighboring states, for example, as it is more likely to fulfill the parallel trend assumption and less subject to selection bias, thus making a difference-in-difference measure of change more valid. Each stratified outcome was evaluated separately, creating 28 individual models (14 models for CO and 14 models for WA).

To construct appropriate SCMs for both CO and WA, we excluded Alaska, California, District of Columbia, Illinois, Maine, Massachusetts, Michigan, Nevada, Oregon, and Vermont from the potential donor pool as these states have also legalized cannabis. Both CO and WA were removed from each other's potential pool of donor states. Though CO and WA legalized cannabis in 2012, cannabis was not commercially available until January 2014 in CO and July 2014 in WA. As such, years 2000 to 2013 were our pre-law period and 2014–2018 were our post-law periods. Following previous uses of SCMs for examining health outcomes, deaths by suicide rates were smoothed using a three-year moving average to ease interpretation of volatile data (Abadie et al., 2010, 2014; Abadie and Gardeazabal, 2003; Crifasi et al., 2015; Rudolph et al., 2015). Our weighted synthetic control states were created using death by suicide rate values at years 2000, 2005 and 2013 and all of the listed covariates indexed at the state and year.

We used the Stata package *synth_runner* to construct our SCM, which produced effect estimates and measures of the significance of effects (Galiani and Quistorff, 2016). This package, built on the *synth* package, (Abadie et al., 2011) provides effect estimates in the form of difference in treated and synthetic control outcomes at post-treatment time points 1,2…n, and provides pseudo *p*-values as measures of effect. Pseudo p-values are derived by comparing treated states' post-treatment root mean square prediction error (RMSPE) to other placebo estimates, scaled by pre-treatment RMSPE. They represent the proportion of placebo states that have a ratio of post-treatment RMSPE to pre-treatment RMSPE at least as big as the treated units. Placebo estimates of the treatment effect are produced by assigning the same treatment period to all other potential donor control units (Crifasi et al., 2015). We ran models specifying the *nested* option for optimal pre-treatment RMPSE matching.

For our analysis, the potential control states included in the donor pool were modeled as if they legalized cannabis in 2014 and their post-and-pre-treatment RMPSE were utilized to understand what proportion of placebo tests had similar effect sizes as the treated state given how closely their pre-treatment trends matched their synthetic controls. A significant difference ($p < 0.05$) represents a treatment state with a comparatively small RMPSE in the pre-treatment period and a comparatively large difference in the deaths by suicide rate compared to all other placebo states (Galiani and Quistorff, 2016). We produced the average effect of adult cannabis legalization using a difference-in-difference calculation.

We conducted several sensitivity analyses. First, we conducted a sensitivity analysis to estimate the immediate effect of legalization, wherein we modeled the impact of cannabis legalization starting in 2012, the year cannabis was legalized via ballot measure in both CO and WA. Second, we conducted a sensitivity analysis using injury deaths of undetermined intent as our primary outcome (defined as ICD-10 Codes: Y10-Y34, Y87.2, Y89.9). We used deaths of undetermined intent as our sensitivity outcome as evidence suggest, when intent cannot be determined or is to ambiguous due to missing data or lack of evidence, possible suicide deaths are classified as undetermined intent. This is true especially for drug intoxication deaths (Bohnert et al., 2013; Huguet et al., 2012, 2014; Rockett et al., 2010, 2018; Stone, 2018b). We also conducted an econometric time series analysis, a standard in policy evaluation, for comparison. We used a pooled, cross-sectional time series analysis using data from all 50 states to evaluate the impact of recreational cannabis availability in CO and in WA from 2000 to 2018. To do so, we created a dummy variable for each CO and WA which equaled 0 in the years 2000–2013 and equaled 1 in the years 2014–2018. To estimate the effects of cannabis legalization on death by suicides, we employed a negative binomial distribution to model each outcome due to overdispersion of variance, state- and-year fixed effects, and standard errors clustered at the state-level. Fixed effects were included to account for time-and-state invariant factors and omitted variables. We used the same covariates as the SCM models and excluded CO and WA from their respective models. This research was deemed not to be "human subjects research' by Eastern Connecticut State University. All analysis were conducted using Stata SE v. 15.0 (StataCorp., 2017).

3. Results

For both CO and WA, treatment and synthetic control states appeared similar across predictors and outcomes within the pre-treatment time period, indicating strong synthetic controls across the stratified models (Appendix Table 1). Treated states, compared to their synthetic controls, did display greater mean percentage of persons reporting cannabis use in the past year. This is logical as these early adopters of legalized cannabis likely had higher use rates prior to legalization compared to states that have not legalized cannabis.Appendix Tables 2 and 3 present states with non-zero synthetic control weights for all of the stratified SCMs for CO and WA respectively.

Overall, both CO and WA did not display an increase in deaths by suicide (Table 1). Deaths by suicides, though, when stratified by age had significant findings. In WA, the death by suicide rate among 15–24-year olds increased 17.95% on average, or an additional 2.13 deaths per 100,000 population per year (*p*-value $\leq$0.001). Fifteen-to-twenty-four-year olds in CO did not have similar findings (5.51% increase, *p* value = 0.432). Within all other strata, the death by suicide rates were not impacted by cannabis legalization, though the death by suicide rate among Males in WA increased 7.16% (p-value = 0.079).

As the legal consumption age of cannabis is 21 in both states, we performed an ad hoc analysis, splitting the age category into those of illegal cannabis consumption age (15–20-years old) and legal consumption age (21–24-years old). In WA, the positive relationship persisted across both age groups. Death by suicide among those of illegal consumption age increased 21.23% on average (p-value = 0.026). Deaths by suicide among those of legal consumption age increase 18.67% (p-value $\leq$0.001). We did not find significant associations in CO.

Fig. 1A, B, C, D and Fig. 2A, B, C, D present the SCMs for all type death by suicide rate, 15–24-year olds death by suicide rate, 15–20-year olds death by suicide rate, and 21–24-year olds death by suicide rate for CO and WA respectively. Each of the significant models displayed large deviations between the treated and control states during the post-treatment period (2014–2018), indicated by their large post-treatment RMSPE (Appendix Table 4). In the pre-treatment period, the synthetic controls accurately mirrored their treated state's suicide outcome, indicated by a small RMSPE. In all significant models, the treatment states deviated steeply from their control states, with the control states remaining relatively stable. There appears to be a slight lag before the treated and control states diverge, indicating that immediately post-legalization, there may not have been significant differences in deaths by suicide and that significant differences may have emerged 1–2-years post-implementation.

In the stratified models that did not display significant change post-implementation (Appendix Figs. 1, 2, 3, …20), either the synthetic control fit in the pre-treatment period tended to be volatile, i.e., the pre-treatment RMPSE was large, or there was limited or no deviation between the treatment and synthetic control state post-implementation, i.e., the post-treatment RMPSE was small.

The standard econometric time series analysis model (Table 2) provided similar results to the SCMs. Using this method, those 15–24 years old in Washington had 1.280 times greater expected incidence of death by suicide compared to other states (*p*-value = 0.001; 95% CI: 1.10, 1.48). Similarly, those 15–20 years old had 1.285 times greater expected incidence (p-value = 0.001; 95% CI: 1.10, 1.50) and those 21–24 years old had 1.245 times greater expected incidence of death by suicide (p-value = 0.001; 95% CI: 1.07, 1.44). All other models were not significantly different, excluding Hispanics in WA (IRR = 1.67; 95% CI: 1.16, 2.39; p-value = 0.005). The sensitivity models examining the immediate impact of cannabis legalization independent of commercial availability (Appendix Table 5) found no relationships between cannabis legalization and suicide outcomes when measuring the effect starting in 2012. There was a found relationship between cannabis legalization and injury deaths of undetermined intent among 35–44-year-olds in WA. Those 35–44 in WA saw a 37% reduction in the rate of undetermined deaths in the years after cannabis legalization (Appendix Table 6).

Table 1
Impact of cannabis legalization on death by suicides among Colorado and Washington from 2000 to 2018, stratified by sex, age, and race/ethnicity.

	Colorado				Washington			
Death by suicide, Stratified by outcome	Average difference in suicide rate	Percent change in suicide rate	*P*-value	No. states with larger pre-post treatment RMPSE ratio	Average difference in suicide rate	Percent change in suicide rate	P-value	No. states with larger pre-post treatment RMPSE ratio
All	0.091	0.52	0.789	30	0.47	3.49	0.236	10
Male	1.82	6.85	0.316	12	1.51	7.16	0.079	3
Female	−0.299	−3.85	0.474	18	−0.21	−3.66	0.158	6
15–24-year olds	0.91	5.51	0.432	16	**2.13**	**17.95**	**<0.001**	**0**
25–34-year olds	1.01	5.35	0.368	14	−1.84	−12.42	0.105	4
35–44-year olds	0.11	0.51	0.684	26	0.44	2.63	0.974	37
45–54-year olds	−0.10	−0.38	0.987	37	0.45	2.29	0.763	29
55–64-year olds	−0.01	−0.02	0.947	36	1.03	5.83	0.237	9
65+ year olds	0.45	2.12	0.763	29	0.47	2.42	0.105	4
Illegal consumption age (15–20-year olds)	2.18	16.11	0.105	4	**2.12**	**21.23**	**0.026**	**1**
Legal consumption age (21–24-year olds)	−0.22	−1.08	0.711	27	**2.72**	**18.67**	**<0.001**	**0**
Non-Hispanic White	−0.20	−0.99	0.894	32	0.34	2.21	0.342	13
Non-Hispanic Black	0.00	0.08	0.821	31	1.48	20.29	0.154	6
Hispanic	0.55	5.47	0.078	3	1.60	28.92	0.211	8

Note: Rates calculated as per 100,000 population. Bold indicates pseudo p-values significant at less than 0.05, p-values obtained from placebo ratio comparison of model performance to treatment state. Average difference in suicide rate found using difference-in-difference calculation. Each model includes percent population veteran, white, male, unemployed, 18–34 years old, married, living in a metropolitan statistical area, past year marijuana use 12 years and older, proportion of household firearm ownership, and a mental health parity score.

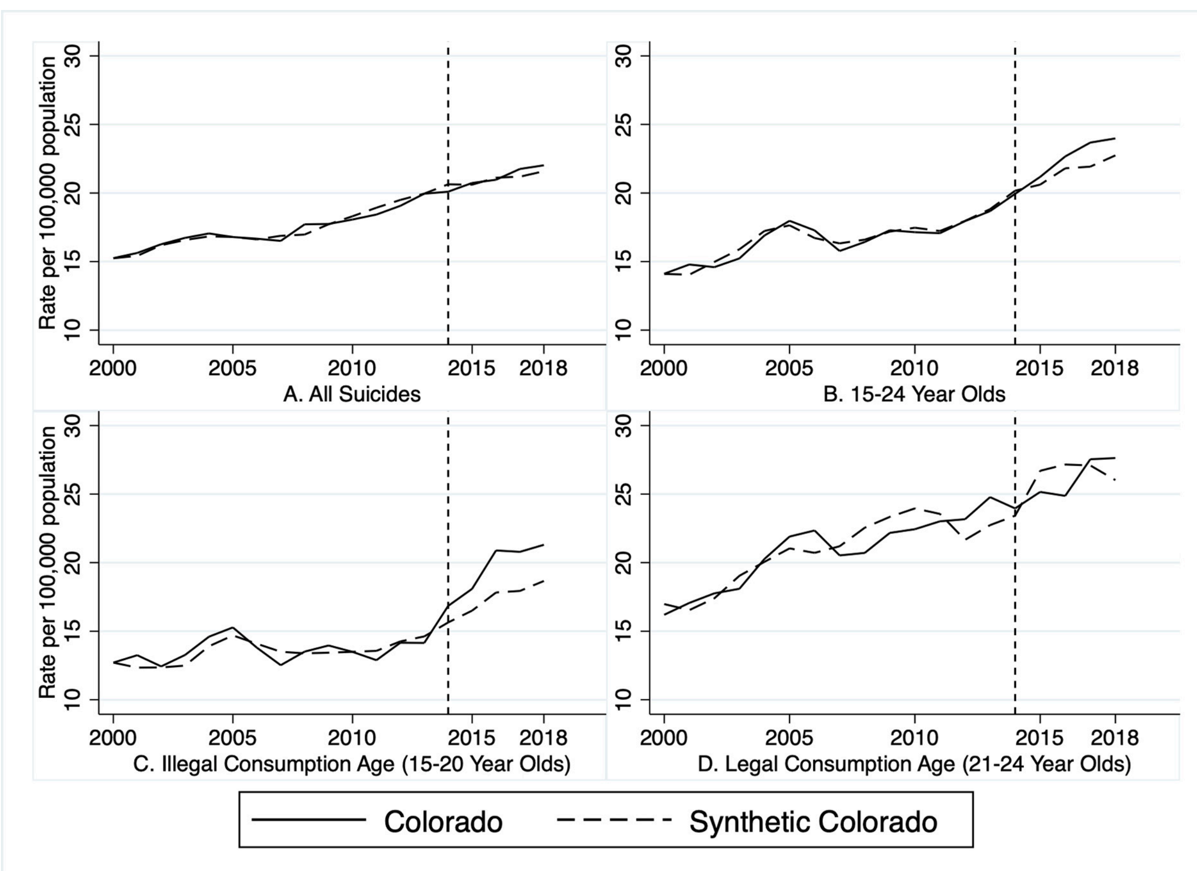

Fig. 1. Synthetic control analysis of Colorado's cannabis legalization, by select characteristics 2000–2018.

4. Discussion

This study is among the first to estimate the impact of cannabis legalization on deaths by suicide stratified by age, sex, and race/ethnicity among early adopter states, CO and WA. These results suggest that the overall impact of recreational cannabis on deaths by suicide is heterogenous. While neither state saw significant impact on death by suicide post legalization overall, WA did see significant increases in the

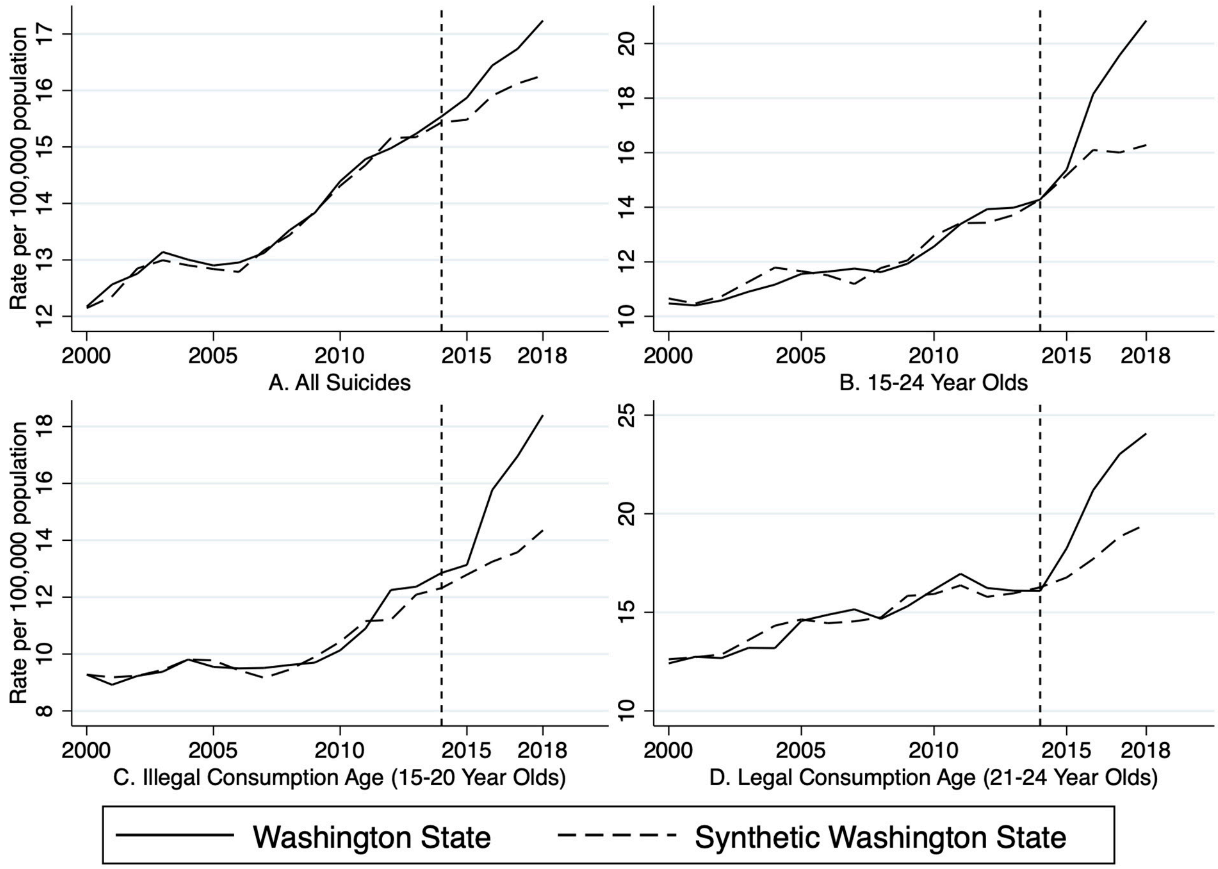

Fig. 2. Synthetic control analysis of Washington State's cannabis legalization, by select characteristics 2000–2018.

Table 2
Standard econometric analysis of Impact of cannabis legalization on Colorado and Washington's Death by Suicide, 2000–2018.

	Colorado			Washington		
Death by suicide, Stratified by outcome	Incidence rate ratio	95% confidence interval	P-value	Incidence rate ratio	95% confidence interval	P-value
All	1.054	0.837, 1.320	0.653	1.075	0.919, 1.259	0.363
Male	1.083	0.868, 1.351	0.477	1.065	0.913, 1.243	0.418
Female	0.974	0.761, 1.247	0.838	1.106	0.933, 1.310	0.243
15–24-year olds	1.141	0.949, 1.374	0.160	**1.280**	**1.105, 1.482**	**0.001**
25–34-year olds	1.150	0.923, 1.434	0.211	1.046	0.900, 1.217	0.552
35–44-year olds	1.068	0.853, 1.337	0.564	1.054	0.899, 1.236	0.514
45–54-year olds	0.982	0.769, 1.255	0.888	1.056	0.894, 1.248	0.516
55–64-year olds	1.039	0.819, 1.318	0.751	1.121	0.949, 1.324	0.178
65+ year olds	1.007	0.803, 1.264	0.946	0.987	0.817, 1.190	0.900
Illegal consumption age (15–20-year olds)	1.159	0.963, 1.394	0.117	**1.285**	**1.104, 1.496**	**0.001**
Legal consumption age (21–24-year olds)	1.116	0.924, 1.348	0.251	**1.245**	**1.073, 1.444**	**0.004**
Non-Hispanic White	1.013	0.813, 1.263	0.902	1.012	0.872, 1.173	0.872
Non-Hispanic Black	1.216	0.704, 2.098	0.482	1.259	0.849, 1.868	0.251
Hispanic	0.966	0.633, 1.473	0.873	**1.665**	**1.162, 2.385**	**0.005**

Note: Each model includes percent population veteran, white, male, unemployed, 18–34 years old, married, living in a metropolitan statistical area, past year marijuana use 12 years and older, proportion of household firearm ownership, and a mental health parity score. Each model also includes state and year fixed effects, standard errors clustered at the state level and a log transformed population exposure to transform counts into incidence rate ratios. P-values significant <0.05.

suicide rate per 100,000 population among adolescents and young adults.

We used a relatively novel approach that has been previously applied to the examination of the effect of state policy on suicides (Bartos et al., 2020; Crifasi et al., 2015) and other public health related outcomes (Abadie et al., 2010; Donohue et al., 2019). We found evidence that cannabis legalization may be associated with increased deaths by suicide among those age 15–24 years old in WA. WA experienced a post-implementation increase in death by suicides among 15–24-year-olds larger than any other placebo state (Table 1). Similar death by suicide rate increases post-implementation were seen among 15–20-year-olds and 21–24-year-olds (Table 1). When we modeled an immediate effect of the law independent of commercial availability, there were no significant relationships between suicide outcomes and cannabis legalization which suggests that the commercial availability associated with legalization is likely the driver of increased suicide rates among young adults in WA.

Our findings were replicated using standard econometric analysis. The Poisson models used data from all 50 states to generate treatment effects of cannabis legalization in CO and WA. However, the synthetic control models may produce less biased estimates of cannabis legalization as the synthetic control is selected based on covariable weights during the pre-treatment period. Our analysis of injury deaths of undetermined intent found only 35–44-year-olds in WA had a significant increase in mortality. As suicide by drug self-intoxication and other poisonings can be susceptible to misclassification (Donaldson et al., 2006), it is notable that trends seen in death by suicide were not borne out for deaths of undetermined intent.

It is unclear why previous research (Cerdá et al., 2017) and our current research found similar heterogeneity in policy effects across CO and WA by age groups. The process of cannabis legalization in CO and WA were similar; the 2012 election saw cannabis legalization pass ballot measures with strong support and both states implemented commercial availability in 2014. Cerdá et al. (2017) found an increase in adolescent use post legalization of cannabis in WA but not CO. Our current findings indicate a possible relationship between cannabis legalization and death by suicide among adolescents in WA but not CO. Cerdá et al. (2017) hypothesize, and we agree, that the effect seen in WA, and the lack of effect seen in CO, may be a function of exposure to medical cannabis prior to legal cannabis availability. CO had a mature medical cannabis dispensary system prior to legalization to which youth were exposed (Davis et al., 2016). WA did not provide legal protection to medical cannabis dispensaries and therefore the patronage and advertisement was lower than in CO (Cerdá et al., 2017). Our lack of findings in CO may be a reflection of a more mature commercial market prior to legalization, and thus a smaller shock in cannabis use among adolescents. Other research found a 36% increase in cannabis use disorders among 26-year-olds in states post-legalization compared to states did not legalize cannabis, however we did not find evidence that death by suicide had increased in either CO or WA for 25–34-year-olds.

The relationship between cannabis, recreational or medical use laws, and death by suicide is complex and currently unresolved (Anderson et al., 2014; Borges et al., 2016; Buckner et al., 2017; Grucza et al., 2015; Leite et al., 2015). Results here indicate a possible relationship between cannabis legalization and suicide rates among adolescents in WA may be present. However, it is important to note this study presents associations and there are myriad of causal pathways that could potentially explain the found relationship. One possible causal pathway is alcohol consumption as WA privatized alcohol consumption starting in 2012. This new law increased alcohol availability in WA. Given the strong relationship between alcohol consumption and suicde, this law may have increased the risk of suicide as well. A recent evaluation of this policy suggests it may have had no effect on alcohol consumption habits in the years since passing (Kerr et al., 2018). The research also found cannabis users reported consuming less alcohol after the alcohol privatization law was passed. As laws legalizingcannabis for recreational use and privatizing alcohol sales were passed in the same year in WA, it is possible the decrease in alcohol consumption by cannabis users is a substitution affect. More research is needed to understand the relationship between cannabis legalization and suicides and alcohol

Future studies should include additional years and new legalization adopters to track the impact of recreational cannabis on death by suicides. Other statistical approaches should be utilized. Additionally, researchers should use emergency department data to examine the association between these laws and non-fatal suicide attempts to better understand if these laws influence suicidal behavior.

4.1. Limitations

SCMs provide the best possible counterfactual model to compare changes in death by suicide post-cannabis legalization in early adopter states. The methodology is not without limitations. Our SCMs could be potentially biased if legalization of cannabis had a spillover effect, i.e., neighboring states for the early adopters also experienced increases in cannabis consumption, albeit illegally; if donor states had poor pre-treatment match on predictor variables; and if the possible donor states were selectively constricted (McClelland and Gault, 2017; Powell, 2018). To the spillover effect, there is limited research that suggests states that did not also legalize cannabis and that neighbor CO and WA also had large increases in cannabis consumption. Additionally, states with non-zero synthetic control weights for both CO and WA by-in-large did not share boarders with these states (Appendix Tables 2 and 3). Appendix Table 1 shows that, for almost all pre-treatment predictor variables, the treatment and control states had nearly identical average mean values. We included all states that have not legalized cannabis up until 2020, providing a robust potential donor pool. Though, it is likely that the relative success of CO and WA cannabis legalization caused national attitudes towards recreational cannabis to become more favorable. Important to also note is that WA first opened cannabis retail stores in July of 2014, meaning commercial availability existed for only 6 of the 12 months of 2014. While this could potentially bias our analysis towards the null, it is important to note that the SCM effect estimates were averaged over the 5-year post-treatment period, making the impact of this limitation minimal. When using SCM to estimate social policy impact, it is important to select a donor pool of states which have not 'received' the treatment, or policy, of import so as not to contaminate your treatment state (Abadie et al., 2010, 2011). However, this may bias the donor pool of states as late adopters of cannabis legalization may prove different systematically from CO and WA in terms of culture and thus merit inclusion.

As with most public policy evaluations, unmeasured or omitted covariates could confound the significant relationship between cannabis legalization and death by suicides among 15–24-year olds found in Washington. Laws typically take long periods of time to pass and it is unlikely that there is a specific confounder that impacts both death by suicides and the legalization of cannabis. It is also possible that laws, such as alcohol privatization in WA, passed at the same time as cannabis legalization could provide an exogenous shock related to suicides. Additionally, our standard econometric analysis produced nearly similar results while controlling for possible omitted variable bias through the use of state-and-year fixed effects.

5. Conclusions

The findings of this study suggest cannabis legalization may be associated with increases in deaths by suicides among teens and young adults. The current understanding of the relationship between cannabis consumption and suicides, as well as the knowledge that cannabis consumption increased among adolescents in WA after legalization, contribute to the plausibility of our findings. States with legalized cannabis, and states considering similar policy changes, should attempt to offset any increases in cannabis consumption among teens associated with legalization with increased access to mental health services.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2021.106548.

References

Abadie, A., Gardeazabal, J., 2003. The economic costs of conflict: a case study of the Basque Country. Am. Econ. Rev. 93 (1), 113–132. https://doi.org/10.1257/000282803321455188.

Abadie, A., Diamond, A., Hainmueller, J., 2010. Synthetic control methods for comparative case studies: estimating the effect of California's tobacco control program. J. Am. Stat. Assoc. 104 (490), 493.

Abadie, A., Diamond, A., Hainmueller, J., 2011. "SYNTH: Stata module to implement Synthetic Control Methods for Comparative Case Studies," Statistical Software Components S457334, Boston College Department of Economics revised 09 May 2020.

Abadie, A., Diamond, A., Hainmueller, J., 2014. Comparative politics and the synthetic control method. Am. J. Polit. Sci. 59 (2), 495–510.

Anderson, D.M., Rees, D.I., Sabia, J.J., 2014. Medical marijuana laws and suicides by gender and age. Am. J. Public Health 104 (12), 2369–2376. https://doi.org/10.2105/AJPH.2013.301612.

Barry, C.L., Busch, S.H., 2007. Do state parity laws reduce the financial burden on families of children with mental health care needs? Health Serv. Res. 42 (3p1), 1061–1084. https://doi.org/10.1111/j.1475-6773.2006.00650.x.

Bartoli, F., Crocamo, C., Carrà, G., 2019. Cannabis use disorder and suicide attempts in bipolar disorder: a meta-analysis. Neurosci. Biobehav. Rev. 103, 14–20. https://doi.org/10.1016/j.neubiorev.2019.05.017.

Bartos, B.J., Kubrin, C.E., Newark, C., McCleary, R., 2020. Medical marijuana laws and suicide. Arch. Suicide Res. 24 (2), 204–217. https://doi.org/10.1080/13811118.2019.1612803.

Bohnert, A.S.B., McCarthy, J.F., Ignacio, R.V., Ilgen, M.A., Eisenberg, A., Blow, F.C., 2013. Misclassification of suicide deaths: examining the psychiatric history of overdose decedents. Injury Prev. J. Int. Soc. Child Adolescent Injury Prev. 19 (5), 326–330. https://doi.org/10.1136/injuryprev-2012-040631.

Borges, G., Bagge, C.L., Orozco, R., 2016. A literature review and meta-analyses of cannabis use and suicidality. J. Affect. Disord. 195, 63–74. https://doi.org/10.1016/j.jad.2016.02.007.

Buckner, J.D., Lemke, A.W., Walukevich, K.A., 2017. Cannabis use and suicidal ideation: test of the utility of the interpersonal-psychological theory of suicide. Psychiatry Res. 253, 256–259. https://doi.org/10.1016/j.psychres.2017.04.001.

CDC, 2020. WISQARS - Fatal Injury and Violence Data. https://www.cdc.gov/injury/wisqars/fatal.html.

Cerdá, M., Wall, M., Feng, T., Keyes, K.M., Sarvet, A., Schulenberg, J., O'Malley, P.M., Pacula, R.L., Galea, S., Hasin, D.S., 2017. Association of state recreational marijuana laws with adolescent marijuana use. JAMA Pediatr. 171 (2), 142–149. https://doi.org/10.1001/jamapediatrics.2016.3624.

Cerdá, M., Mauro, C., Hamilton, A., Levy, N.S., Santaella-Tenorio, J., Hasin, D., Wall, M. M., Keyes, K.M., Martins, S.S., 2020. Association between recreational marijuana legalization in the United States and changes in marijuana use and cannabis use disorder from 2008 to 2016. JAMA Psychiatry 77 (2), 165–171. https://doi.org/10.1001/jamapsychiatry.2019.3254.

Crifasi, C.K., Meyers, J.S., Vernick, J.S., Webster, D.W., 2015. Effects of changes in permit-to-purchase handgun laws in Connecticut and Missouri on suicide rates. Prev. Med. 79, 43–49. https://doi.org/10.1016/j.ypmed.2015.07.013.

Davis, J.M., Mendelson, B., Berkes, J.J., Suleta, K., Corsi, K.F., Booth, R.E., 2016. Public health effects of medical marijuana legalization in Colorado. Am. J. Prev. Med. 50 (3), 373–379. https://doi.org/10.1016/j.amepre.2015.06.034.

Delforterie, M.J., Lynskey, M.T., Huizink, A.C., Creemers, H.E., Grant, J.D., Few, L.R., Glowinski, A.L., Statham, D.J., Trull, T.J., Bucholz, K.K., Madden, P.A.F., Martin, N. G., Heath, A.C., Agrawal, A., 2015. The relationship between cannabis involvement and suicidal thoughts and behaviors. Drug Alcohol Depend. 150, 98–104. https://doi.org/10.1016/j.drugalcdep.2015.02.019.

Donaldson, A.E., Larsen, G.Y., Fullerton-Gleason, L., Olson, L.M., 2006. Classifying undetermined poisoning deaths. Injury Prev. 12 (5), 338–343. https://doi.org/10.1136/ip.2005.011171.

Donohue, J.J., Aneja, A., Weber, K.D., 2019. Right-to-carry laws and violent crime: a comprehensive assessment using panel data and a state-level synthetic control analysis. J. Empir. Leg. Stud. 16 (2), 198–247. https://doi.org/10.1111/jels.12219.

Douglas, M., 2018. The Mental Health Parity and Addiction Equity Act 10th Anniversary. https://www.paritytrack.org/mhpaea-10th-anniversary/.

Flood, S., King, M., Rodgers, R., Ruggles, S., Warren, J.R., 2020. Integrated Public Use Microdata Series, Current Population Survey (IPUMS). Version 6.0.

Galiani, S., Quistorff, B., 2016. The synth_runner package: utilities to automate synthetic control estimation using. Stata J. 17 (4), 834–849.

Grucza, R.A., Hur, M., Agrawal, A., Krauss, M.J., Plunk, A.D., Cavazos-Rehg, P.A., Chaloupka, F.J., Bierut, L.J., 2015. Medical marijuana laws and suicide. Am. J. Public Health 105 (8), e3. https://doi.org/10.2105/AJPH.2015.302745.

Harris, E.C., Barraclough, B., 1997. Suicide as an outcome for mental disorders: a meta-analysis. Br. J. Psychiatry 170 (3), 205–228. https://doi.org/10.1192/bjp.170.3.205.

Huguet, N., Kaplan, M.S., McFarland, B.H., 2012. Rates and correlates of undetermined deaths among African Americans: results from the National Violent Death Reporting System. Suicide Life-Threat. Behav. 42 (2), 185–196. https://doi.org/10.1111/j.1943-278X.2012.00081.x.

Huguet, N., Kaplan, M.S., McFarland, B.H., 2014. The effects of misclassification biases on veteran suicide rate estimates. Am. J. Public Health 104 (1), 151–155. https://doi.org/10.2105/AJPH.2013.301450.

Kerr, W.C., Williams, E., Ye, Y., Subbaraman, M.S., Greenfield, T.K., 2018. Survey estimates of changes in alcohol use patterns following the 2012 privatization of the Washington liquor monopoly. Alcohol Alcohol. (Oxford, Oxfordshire) 53 (4), 470–476. https://doi.org/10.1093/alcalc/agy004.

Lang, M., 2013. The impact of mental health insurance laws on state suicide rates: the impact of mental health insurance laws. Health Econ. 22 (1), 73–88. https://doi.org/10.1002/hec.1816.

Leite, R.T.P., Nogueira, S. de O., Nascimento, J.P.R. do, Lima, L.S. de, Nóbrega, T.B. da, Virgínio, M. da S., Moreno, L.M. da C., Sampaio, B.H.B., Souza, F.G. de M.e., 2015. The use of cannabis as a predictor of early onset of bipolar disorder and suicide attempts. Neural Plast. 2015, 1–13. https://doi.org/10.1155/2015/434127.

Leung, J., Chiu, C.Y.V., Stjepanović, D., Hall, W., 2018. Has the legalisation of medical and recreational cannabis use in the USA affected the prevalence of cannabis use and cannabis use disorders? Curr. Addict. Rep. 5 (4), 403–417. https://doi.org/10.1007/s40429-018-0224-9.

McClelland, R., Gault, S., 2017. The Synthetic Control Method as a Tool to Understand State Policy. In: Urban Institute: Research Report, p. 46. https://www.urban.org/sites/default/files/publication/89246/the_synthetic_control_method_as_a_tool_1.pdf.

National Center for Health Statistics, 2007a. Multiple cause of death public use files, 2000-2002. In: United States Department of Health and Human Services. Inter-University Consortium for Political and Social Research. https://doi.org/10.3886/ICPSR04640.v1.

National Center for Health Statistics, 2007b. Multiple cause of death public use files, 2003. In: United States Department of Health and Human Services. Inter-University Consortium for Political and Social Research. https://doi.org/10.3886/ICPSR20540.v1.

National Center for Health Statistics, 2007c. Multiple cause of death public use files, 2004. In: United States Department of Health and Human Services. Inter-University Consortium for Political and Social Research. https://doi.org/10.3886/ICPSR20623.v1.

National Conference of State Legislatures, 2020. State Medical Marijuana Laws. https://www.ncsl.org/research/health/state-medical-marijuana-laws.aspx.

Powell, D., 2018. Imperfect Synthetic Controls: Did the Massachusetts Health Care Reform Save Lives? RAND Labor and Population. https://www.rand.org/pubs/working_papers/WR1246.html.

Rockett, I.R.H., Hobbs, G., De Leo, D., Stack, S., Frost, J.L., Ducatman, A.M., Kapusta, N. D., Walker, R.L., 2010. Suicide and unintentional poisoning mortality trends in the United States, 1987-2006: two unrelated phenomena? BMC Public Health 10, 705. https://doi.org/10.1186/1471-2458-10-705.

Rockett, I.R.H., Caine, E.D., Connery, H.S., Greenfield, S.F., 2018. Mortality in the United States from self-injury surpasses diabetes: a prevention imperative. Injury Prev. https://doi.org/10.1136/injuryprev-2018-042889 injuryprev-2018-042889.

Rudolph, K.E., Stuart, E.A., Vernick, J.S., Webster, D.W., 2015. Association between Connecticut's permit-to-purchase handgun law and homicides. Am. J. Public Health 105 (8), e49–e54. https://doi.org/10.2105/AJPH.2015.302703.

SAMHSA, 2016. National and State-level Marijuana Trends From 2002–2014. https://www.samhsa.gov/data/nsduh/national-state-level-marijuana-trends.

Schell, T.L., Peterson, S., Vegetabile, B.G., Scherling, A., Smart, R., Morral, A.R., 2020. State-Level Estimates of Household Firearm Ownership. RAND Corporation. https://www.rand.org/pubs/tools/TL354.html.

StataCorp, 2017. Stata Statistical Software: Release 15. StataCorp LLC, College Station, TX.

Stolzenberg, L., D'Alessio, S.J., Dariano, D., 2016. The effect of medical cannabis laws on juvenile cannabis use. Int. J. Drug Policy 27, 82–88. https://doi.org/10.1016/j.drugpo.2015.05.018.

Stone, D.M., 2018a. Vital signs: trends in state suicide rates—United States, 1999–2016 and circumstances contributing to suicide—27 states, 2015. MMWR. Morbid. Mortal. Week. Rep. 67 https://doi.org/10.15585/mmwr.mm6722a1.

Stone, D.M., 2018b. Vital signs: trends in state suicide rates—United States, 1999–2016 and circumstances contributing to suicide—27 states, 2015. MMWR. Morbid. Mortal. Week. Rep. 67 https://doi.org/10.15585/mmwr.mm6722a1.

Vigil, D.I., Van Dyke, M., Hall, K.E., Contreras, A.E., Ghosh, T.S., Wolk, L., 2018. Marijuana use and related health care encounters in Colorado before and after retail legalization. Int. J. Ment. Heal. Addict. 16 (4), 806–812. https://doi.org/10.1007/s11469-018-9901-0.

Wall, M.M., Mauro, C., Hasin, D.S., Keyes, K.M., Cerda, M., Martins, S.S., Feng, T., 2016. Prevalence of marijuana use does not differentially increase among youth after states pass medical marijuana laws: commentary on Stolzenberg et al. (2015) and reanalysis of US National Survey on drug use in households data 2002–2011. Int. J. Drug Policy 29, 9–13. https://doi.org/10.1016/j.drugpo.2016.01.015.

Wen, H., Hockenberry, J.M., Druss, B.G., 2019. The effect of medical marijuana laws on marijuana-related attitude and perception among US adolescents and young adults. Prev. Sci. 20 (2), 215–223. https://doi.org/10.1007/s11121-018-0903-8.

Wilcox, H.C., Arria, A.M., Caldeira, K.M., Vincent, K.B., Pinchevsky, G.M., O'Grady, K.E., 2010. Prevalence and predictors of persistent suicide ideation, plans, and attempts during college. J. Affect. Disord. 127 (1), 287–294. https://doi.org/10.1016/j.jad.2010.04.017.