



Changes in psychosis-related emergency department and hospitalization rates among youth following cannabis legalization in Colorado

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ABSTRACT

An increasing number of U.S. states have legalized cannabis, but the effect on adolescent and young adult psychosis-related hospitalizations remains under-studied. Using data from Denver Health between 2005 and 2020, we examined associations between implementation of the Ogden Memo (expanding use of medical cannabis in Colorado, October 2009) and Amendment 64 (legalizing adult-use cannabis in Colorado, November 2012) and trends in psychosis-related emergency department and hospital visits with and without cannabis use disorder (CUD) among youth aged 10–29. Patients with psychosis hospitalizations were predominately male (68 %), white (53 %), and Medicaid recipients (59 %). Significant increases ($p < 0.05$) were observed in the monthly average rate of psychosis hospitalizations between pre-Ogden memo (21.9 per 100,000) and post-Ogden memo pre-legalization (28.0 per 100,000) and post-legalization (32.3 per 100,000). Similarly, significant increases ($p < 0.05$) were observed in the monthly average rate of psychosis hospitalizations involving CUD between pre-Ogden memo (2.0 per 100,000), post-Ogden memo and pre-legalization (3.4 per 100,000), and post-legalization (8.5 per 100,000). Interrupted time series modeling found a significant difference in the trends for psychosis hospitalizations involving CUD following recreational legalization (change in average monthly rate went from 0.02/100,000 (95 % CI –0.02, 0.06) to 0.11/100,000 (95 % CI 0.09, 0.13), (difference (0.09 (95 %CI 0.05, 0.14)). Findings suggest an increase in overall hospital encounters for psychosis among youth after the legalization of recreational cannabis. Given the adoption of increasingly permissive cannabis laws, there is a need to plan effective public health responses that could mitigate unintended consequences related to cannabis use.

1. Introduction

Cannabis is currently the third most used drug worldwide after alcohol and tobacco, with growing legal status across the United States (U.S.) for medicinal and recreational use (Campeny et al., 2020). In the U.S., 38 states currently allow cannabis for medical purposes, and 24 states allow for adult-use recreational purposes (National Conference of State Legislatures, 2023). A large body of research investigating the role of cannabis legalization on population-level substance use and related outcomes in the U.S. has yielded mixed results (Hasin, 2018; Hollingsworth et al., 2022; Melchior et al., 2019; Sarvet et al., 2018). Still, studies have shown an increase in hospitalizations for cannabis-related

reasons following legalization (Roehler et al., 2022; Shen et al., 2019; Wang et al., 2021, 2018). A major concern with legalization is whether increased access to a range of cannabis products could lead to an increase in mental health conditions associated with high-potency cannabis use, notably psychosis. However, little research has investigated rates of psychosis following these legal changes.

Understanding the impact of cannabis legalization on psychosis outcomes is essential given the significant body of epidemiologic evidence linking cannabis use to increased risk of developing psychosis (Pourebahim et al., 2025). While a small proportion of all people who use cannabis (by some estimates, 2 %) go on to develop psychosis, the attributable fraction of psychosis due to cannabis use is estimated to be

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as high as 10–25 % (Gage et al., 2016). Psychosis has been repeatedly shown to be more common in people who use cannabis compared to those who do not use cannabis (Hasan et al., 2020; Livne et al., 2022). For example, one study found individuals who ever used cannabis had 41 % increased odds of psychosis outcomes (Large et al., 2011). Specific risk factors include earlier age of initiation, (Hosseini and Oremus, 2019; Le Bec et al., 2008) and use of marijuana products with a high concentration of delta-9-tetrahydrocannabinol (THC) (Di Forti et al., 2009). Greater frequency of use (especially daily (Van der Steur et al., 2020) or heavy (Marconi et al., 2016)), and longer duration (Chadwick et al., 2013) have been associated with greater risk of psychosis, suggesting a possible dose-dependent relationship.

Despite ongoing debates about the causal pathways and mechanisms between cannabis and psychosis risk, (Ganesh and D'Souza, 2022; Hamilton and Sumnall, 2021) given increased availability of cannabis, concerns arise that legalization may contribute to increased psychosis at the population-level. Some international studies have documented increases in the rates of psychosis and schizophrenia over time associated explicitly with cannabis use, including in Denmark, (Hjorthøj et al., 2021) Portugal, (Gonçalves-Pinho et al., 2020) the United Kingdom, (Boydell et al., 2006) Canada, (Myran et al., 2023) France, (Noel et al., 2019) and Switzerland (Ajdacic-Gross et al., 2007). Few studies in the U. S. have investigated the impact of medical and recreational cannabis laws on psychosis-related hospitalization outcomes among youth. A national cross-sectional study among adults found a higher proportion of hospital discharges for psychosis associated with cannabis use in regions with liberalized cannabis laws (Moran et al., 2022). Given known changes in cannabis-related perceptions and behaviors among youth following legalization, including lower perceived risk, greater access, uptake of new formulations with higher potency of THC, and a small increase in cannabis use disorder (CUD), (Misiak et al., 2018; Myles et al., 2016; Van der Steur et al., 2020) experts are calling for population-based research to answer this question and inform appropriate clinical and policy responses (Ladegard et al., 2020; Murray and Hall, 2020).

This study aims to help answer these questions by focusing on Denver, Colorado, an early adopter of cannabis legalization and expanded access to medical and recreational cannabis dispensaries. The Colorado context provides an interesting case study as adolescents and young adults in Colorado are known to have some of the highest rates of cannabis use in the nation, with growing rates of use observed among young adults over the past decades (Hinckley et al., 2024; Rocky Mountain High Intensity Drug Trafficking Area Program, 2021). Other important changes that may influence psychosis incidence specifically in Colorado include changing access to more potent products such as cannabis concentrates and changes to preferred routes of administration (Hinckley et al., 2024).

We use Electronic Health Records (EHR) from Denver Health to examine changes in the rates of emergency department (ED) visits and inpatient hospital encounters for psychosis among adolescents and young adults before and following changes in the widespread availability of medical and recreational cannabis in Colorado. Specifically, we examine the effect of the Ogden memo (October 19, 2009), which under the Obama administration directed federal prosecutors not to file charges involving individuals or businesses who were following state law (Office of Public Affairs, 2009). The Ogden Memo shifted the regulatory structure of state medical marijuana, resulting in increased participation in state medical marijuana programs. We also examine the effect of Amendment 64 (November 6, 2012), which made cannabis legal in Colorado for 'personal use and regulation of marijuana' for adults 21 and over and for commercial cultivation, manufacture, and sale for recreational use or 'adult-use'. We hypothesized that psychosis-related visits among youth became more prevalent following each of these changes in the law, especially for patients with comorbid CUD.

2. Methods

2.1. Setting and data

We extracted retrospective Electronic Health Records (EHR) from Denver Health, a large hospital network based in Denver, Colorado. All inpatient and ED encounters (hereafter hospitalizations) were included in the analysis for January 2005–December 2020 if there was a recorded ICD-9 or ICD-10 code for psychosis or a psychotic disorder. ICD-9 and ICD-10 codes were selected using ICD crosswalks and ICD converters to ensure that all related ICD codes were included in the analysis (Supplemental Table 1). For each patient with a hospitalization with a psychosis diagnosis, we extracted information on age, gender, race/ethnicity, and insurance status. In addition, a list of all other ICD diagnoses codes from the hospitalization were provided. Hospitalizations were noted as to whether they included a comorbid CUD disorder diagnosis in addition to a psychosis diagnosis (Supplemental Table 1). Our study period from 2005 to 2020 resulted in approximately five years of data before the Ogden memo was issued and seven years before and after the legalization of adult-use cannabis in Colorado. Importantly, there were no major changes to the Denver Health system during the study period to our knowledge (e.g., serious expansions, new hospital acquisitions) that would result in a significant change in psychiatric hospitalizations recorded during the study period. However, we combined ED and inpatient encounters due to changes in facility coding in Denver EHR over time did not allow us to differentiate in what hospital unit the encounters took place. The Colorado Multiple Institutional Review Board approved this study at Denver Health.

2.2. Primary outcomes

The primary outcomes included 1) hospitalizations involving patients ages 10–29 with a psychosis diagnosis, and 2) hospitalizations involving patients ages 10–29 with a psychosis diagnosis with a comorbid cannabis diagnosis, hereinafter, "CUD". Given medical and recreational cannabis laws only apply to adults 21 +, these outcomes were also analyzed separately for age-specific groups of 10–20 and 21–29. To account for possible changes in the population size of Denver, we calculated hospitalizations as population-based rates per 100,000 for each group using the Denver city census population data 2005–2020. ("Colorado Dept of Local Affairs", 2024)

2.3. Primary exposures

We were primarily interested in examining changes in hospitalization trends involving psychosis and cannabis following two legal changes: the Ogden Memo and Amendment 64 (legalization of adult-use cannabis) (Office of Public Affairs, 2009). In Colorado, following the Ogden Memo, participation rates in state medical marijuana programs increased 10-fold in the subsequent two years (Fairman, 2016; Marijuana Policy Project, 2025; Pacula and Smart, 2017). Amendment 64 passed on November 6, 2012, and on January 1, 2014, the first outlets began selling marijuana for recreational use.

2.4. Statistical analysis

We first calculated changes in the average monthly rates of psychosis-related hospitalizations in the time periods of interest using two-sided t-tests: before and after the Ogden memo (October 19, 2009) and before and after the passage of the Colorado 64 Amendment (November 6, 2012), referred to as 'legalization' hereafter. We then utilized an interrupted time-series (ITS) design to examine the changing trends in monthly rates of hospitalizations for psychosis overall and psychosis with comorbid CUD, before and after the Ogden memo and before and after legalization. ITS can model diverse types of serial autocorrelation and provides flexibility in estimating the magnitude and

nature of intervention effects through the use of multiple transfer functions. This quasi-experimental design controls for secular trends and tests whether an intervention was associated with a change in the slope (i.e., the trend in monthly hospitalization rate). (Linden, 2015) We used Prais–Winsten regression transformation and robust S.E.s to adjust for first-order serial autocorrelation. We examined the Durbin–Watson statistic to ensure that our models adequately corrected for first-order autocorrelation. We also controlled for the time period after cannabis outlets were allowed to open for recreational sale (January 2014). All analyses were performed with Stata version 15.1 using the ‘itsa’ command, and hypothesis tests were two-sided with an a priori alpha level of 5 % (StataCorp,2017).

2.5. Sensitivity analyses

We performed the following sensitivity analyses to ensure robustness of our results: 1) For all outcomes, we considered the date of opening of recreational outlets (January 2014) instead of passage of Colorado 64 Amendment as the interruption in the ITS; 2) given medical cannabis is legal to those 18 years of age and older, we examined psychosis among those 18–29; and 3) lastly, we controlled for the enactment of the Affordable Care Act in order to assess if expansion of insurance coverage changed hospitalizations.

3. Results

3.1. Characteristics of study population

From 2005–2020, there were 9773 individual hospitalizations of patients aged 10–29 involving an ED or inpatient encounter with a psychosis diagnosis. Of these, 20.2 % of psychosis hospitalizations also had a comorbid CUD diagnosis. The sample of patients with included psychosis hospitalizations were predominately male (68 %), white (53 %), and Medicaid recipients (59 %), and the sample of patients with hospitalizations with psychosis and CUD were predominantly male (78.5 %), less likely to be white (47.2 %) and more likely to be Medicaid recipients (61.7 %). Table 1 presents the complete demographic characteristics of our sample broken down by age group.

3.2. Changes in average psychosis-related hospitalization rates between the three periods of study

The average rate of any psychosis-related hospitalization among patients aged 10–29 was 21.9 per 100,000 prior to the Ogden memo, 28.0 per 100,000 post-Ogden and pre-legalization, and 32.3 per 100,000 post-legalization. The average rate of psychosis with CUD-related hospitalization was 2.0 per 100,000 prior to the Ogden memo, 3.4 per 100,000 post-Ogden and pre-legalization, and 8.5 per 100,000 post-legalization. Two-sided t-tests indicate that the differences between the rates across all periods were statistically significant at the $p < 0.05$ level.

Table 1
Sociodemographic characteristics of psychosis-related hospitalizations, Denver Health System, 2005–2020.

	Age 10–29		Age 10–20		Age 21–29	
	(n = 9773)		(n = 2780)		(n = 6993)	
	All psychosis, No. (%)	Psychosis with cannabis, No. (%)	All psychosis, No. (%)	Psychosis with cannabis, No. (%)	All psychosis, No. (%)	Psychosis with cannabis, No. (%)
Total	9773	1970	2780	641	6993	1329
Visits by patient (Median, IQR)	3 (1–9)	3 (1–7)	2 (1–6)	2 (1–6)	3 (1–9)	3 (1–7)
Age (Median, IQR)	24 (20–27)	23 (19–26)	17 (15–19)	18 (17–19)	25 (23–27)	25 (23–27)
Sex						
Male	6619 (67.73)	1546 (78.48)	1649 (59.32)	476 (74.26)	4970 (71.07)	1070 (80.51)
Female	3154 (32.27)	424 (21.52)	1131 (40.68)	165 (25.74)	2023 (28.93)	259 (19.49)
Race/Ethnicity						
Non-Hispanic White	5178 (53.16)	926 (47.22)	1404 (50.81)	283 (44.36)	3774 (54.08)	643 (48.60)
Non-Hispanic Black	2371 (24.34)	543 (27.69)	560 (27)	150 (23.51)	1811 (25.95)	393 (29.71)
Non-Hispanic American Indian or Alaskan Native	60 (0.62)	9 (0.46)	22 (0.80)	3 (0.47)	38 (0.54)	6 (0.45)
Non-Hispanic Asian, Pacific Islander, or Native Hawaiian	178 (1.83)	35 (1.78)	39 (1.41)	7 (1.10)	139 (1.99)	28 (2.12)
Latinx/Hispanic	1645 (16.89)	396 (20.19)	600 (21.72)	169 (26.49)	1045 (14.98)	227 (17.16)
Non-Hispanic, Other Race	64 (0.66)	20 (1.02)	25 (0.90)	8 (1.25)	39 (0.56)	12 (0.91)
Unknown	245 (2.52)	32 (1.63)	113 (4.09)	18 (2.82)	132 (1.89)	14 (1.06)
Insurance						
Private	1756 (17.97)	424 (21.52)	861 (30.97)	180 (28.08)	895 (12.80)	244 (18.36)
Medicare	719 (7.36)	121 (6.14)	6 (0.22)	2 (0.31)	713 (10.20)	119 (8.95)
Medicaid	5720 (58.54)	1215 (61.68)	1677 (60.32)	412 (64.27)	4043 (57.83)	803 (60.42)
Self-pay	1144 (11.71)	181 (9.19)	171 (6.15)	40 (6.24)	973 (13.92)	141 (10.61)
Other	432 (4.42)	29 (1.47)	65 (2.34)	7 (1.09)	367 (5.25)	22 (1.66)
Zip Code/Area						
Denver (City)	7177 (77.15)	1355 (74.61)	1759 (69.03)	410 (70.69)	5418 (80.21)	945 (76.46)
Denver Metro Area	1280 (13.76)	269 (14.81)	488 (19.15)	104 (17.93)	792 (11.72)	165 (13.35)
Other Colorado	455 (4.89)	93 (5.12)	209 (8.20)	48 (8.28)	246 (3.64)	45 (3.64)
Other	391 (4.20)	99 (5.45)	92 (3.61)	18 (3.10)	299 (4.43)	81 (6.55)

Note: Cell values may not sum to total due to rounding or missing data. a Other insurance providers includes justice-involved (correctional facilities and immigration), Veterans Affairs, confidential teen visits, research studies, Worker’s Compensation, and Victim’s Compensation

3.3. ITS findings on changing trends in psychosis-related hospitalizations

Trends in rates of psychosis hospitalizations among all age groups during the study period are displayed in Table 2 and Fig. 1 (panel A-C). The initial rate of psychosis hospitalizations in January of 2005 was 23.76 per 100,000, with no significant change in the rate over time prior to the Ogden Memo (slope 0.06 per 100,000/month (95 % CI = -0.15, 0.04), or in the time period after the Ogden memo and before legalization (slope 0.13 per 100,000 (95 % CI -0.11, 0.38)). There was no statistically significant difference in the slope pre and post the Ogden memo (0.19 (95 % CI -0.07, 0.46)). Following legalization, the monthly change in rate of psychosis-related visits increased significantly (slope increasing 0.09 visits per 100,000/month (95 % CI = 0.04, 0.14)) but there was no significant difference in the slopes between these two periods (-0.04 (95 % CI -0.29, 0.21)).

When we analyzed these changes by age subgroups of 10–20 and 21–29 (Table 2), we observed that the increases in rates of psychosis hospitalizations post-legalization were primarily driven by hospitalizations among those aged 21–29 (slope increasing 0.15 visits per 100,000/month (95 % CI 0.08, 0.22)).

Table 2

Interrupted time series regression analysis of psychosis and psychosis with cannabis use disorder related hospitalizations before and after the ogden memo and legalization of adult-use Cannabis in Colorado, Denver Health System, 2005–2020.

	Rates of Hospitalizations <i>b</i> (95 % CI)		
	Age 10–29	Age 10–20	Age 21–29
Psychosis Overall^a			
Intercept	23.76(20.49, 27.03)	16.13(12.91, 19.35)	29.56 (23.82, 35.28)
Pre-Ogden Memo Slope ^b	-0.06 (-0.15, 0.04)	-0.16 (-0.12, 0.08)	-0.10 (-0.27, 0.07)
Rate change first month post Ogden	5.34 (-0.28, 10.96)	0.59 (-4.94, 6.12)	8.73(0.27, 17.19)
Post-Ogden and Pre-Legalization Slope ^c	0.13 (-0.11, 0.38)	0.22 (-0.06, 0.51)	0.03 (-0.26, 0.33)
Rate change first month post legalization	-2.64 (-8.77, 3.48)	-2.41 (-9.95, 5.13)	0.11(-0.19, 0.42)
Post-Legalization Slope ^d	0.09 (0.04, 0.14)	0.02 (-0.04, 0.07)	0.15 (0.08, 0.22)
Difference in slope pre- to post- Ogden Memo	0.19 (-0.07, 0.46)	0.24 (-0.06, 0.55)	0.13 (-0.20, 0.47)
Difference in slope pre- to post- Legalization	-0.04 (-0.29, 0.21)	-0.21 (-0.50, 0.09)	0.11 (-0.19, 0.42)
Psychosis with CUD^a			
Intercept	1.99 (1.11, 2.87)	1.56 (0.55, 2.57)	2.31 (1.23, 3.39)
Pre-Ogden Memo Slope	0.001 (-0.02, 0.03)	0.002 (-0.03, 0.03)	0.00002 (-0.03, 0.03)
Rate change first month post Ogden	1.05 (-0.02, 2.12)	1.85 (0.28, 3.41)	0.51 (-0.90, 1.92)
Post-Ogden and Pre-Legalization Slope	0.02 (-0.02, 0.06)	-0.01 (-0.06, 0.04)	0.04 (-0.02, 0.09)
Rate change first month post legalization	0.09 (0.05, 0.14)	0.08 (0.02, 0.14)	-1.12 (-2.88, 0.63)
Post-Legalization Slope	0.11 (0.09, 0.13)	0.07 (0.05, 0.10)	0.10 (0.04, 0.16)
Difference in slope pre- to post- Ogden Memo	0.02 (-0.03, 0.06)	-0.01 (-0.08, 0.05)	0.04 (-0.03, 0.10)
Difference in slope pre- to post- Legalization	0.09 (0.05, 0.14)	0.08 (0.02, 0.14)	0.07 (0.01, 0.13)

Notes: Boldface indicates statistical significance ($p < 0.05$)

^a See Supplemental Table 1 for all corresponding diagnostic codes (ICD 9 & ICD 10)

^b Implementation of the Ogden memo occurred on October 19, 2009.

^c Post-Ogden and Pre-Opening Recreational Outlets refers to a time period post-October 2009 and pre-January 2014.

^d Recreational outlets were legally allowed to open on January 1, 2014

3.4. ITS findings on changing trends in psychosis-related hospitalizations involving CUD

Trends in rates of psychosis hospitalizations with comorbid CUD during the study period are presented in Table 2 and Fig. 1 (panel D-F). The initial rate of psychosis hospitalizations with CUD in January of 2005 was 1.99 per 100,000. Similar to all psychosis hospitalizations, the overall rate had been relatively stable prior to the Ogden Memo trend (slope 0.001 visits per 100,000/month (95 % CI -0.02, 0.06)) and post-Ogden pre-legalization slope (slope 0.02 visits per 100,000/month, 95 % CI = -0.02, 0.03). There was no statistically significant difference in the slope pre and post the Ogden memo (0.02 (95 % CI -0.03, 0.06)). Following legalization, however, the monthly rate of psychosis-related visits involving CUD increased significantly (slope increasing 0.11 per 100,000/month (95 % CI = 0.09, 0.13)). There was a statistically significant difference in the slope observed pre- and post-legalization, (0.09 (95 % CI = 0.05, 0.14)).

When we analyzed these changes by age subgroups of 10–20 and 21–29 (Table 2), our findings did not qualitatively differ. Sub-analyses indicate the increases in rates of psychosis with CUD hospitalizations post-legalization were experienced for both patients aged 10–20 and patients 21–29.

3.5. Sensitivity analysis

Findings of sensitivity analyses indicate similar results for models assessing interruption at opening of dispensaries (January 2014) compared to models assessing the passage of legalization = (Supplemental Table 2). Additionally, trends for those aged 18–29 were substantively similar to those aged 21–19 (Supplemental Table 3). Lastly, controlling for the expansion of insurance coverage due to the implementation of the ACA did not change findings (Supplemental Table 4).

4. Discussion

This study assessed rates of psychosis and cannabis-related hospitalizations over time in a large health system in Denver, Colorado, a region that has experienced significant changes in the cannabis landscape over the past decade. Youth are the most susceptible to the health effects of cannabis use overall, (Fergusson and Boden, 2008; Volkow et al., 2014) particularly to cannabis-associated psychosis and other mental health conditions (Hosseini and Oremus, 2019; Le Bec et al., 2008; Wang et al., 2018). Following the passage of Colorado Amendment 64, which legalized adult recreational cannabis use for those aged 21 and older, we found a rise in overall hospitalizations with any psychosis diagnosis among youth across the Denver health system. We observed that these rises were driven by young adults aged 21–29 rather than adolescents, which did not experience significant rises in overall psychosis hospitalizations. There was also an increase in psychosis hospitalizations that specifically involved a CUD diagnosis, with rates appearing to be on the rise for both older (21–29) and younger (10–20) age groups.

These findings suggest a small but still concerning rise in psychosis-related acute care hospitalizations among youth in the Denver health system, with a significant proportion of these hospitalizations involving cannabis use-related morbidity. While some of the upward rates in psychosis-involving cannabis diagnoses may be explained by greater attention to and screening for CUD in acute care settings, this alone may not account for the rise in overall rate of psychosis hospitalizations over time following cannabis legalization. This upward trend coincides with reports from other countries of potential increases in cannabis-associated psychosis (Ajdacic-Gross et al., 2007; Boydell et al., 2006; Gonçalves-Pinho et al., 2020; Hjorthøj et al., 2021; Myran et al., 2023; Noel et al., 2019). as well as reports of greater use of cannabis among legal-aged young adults (Chiu et al., 2021; Leung et al., 2019; Melchior

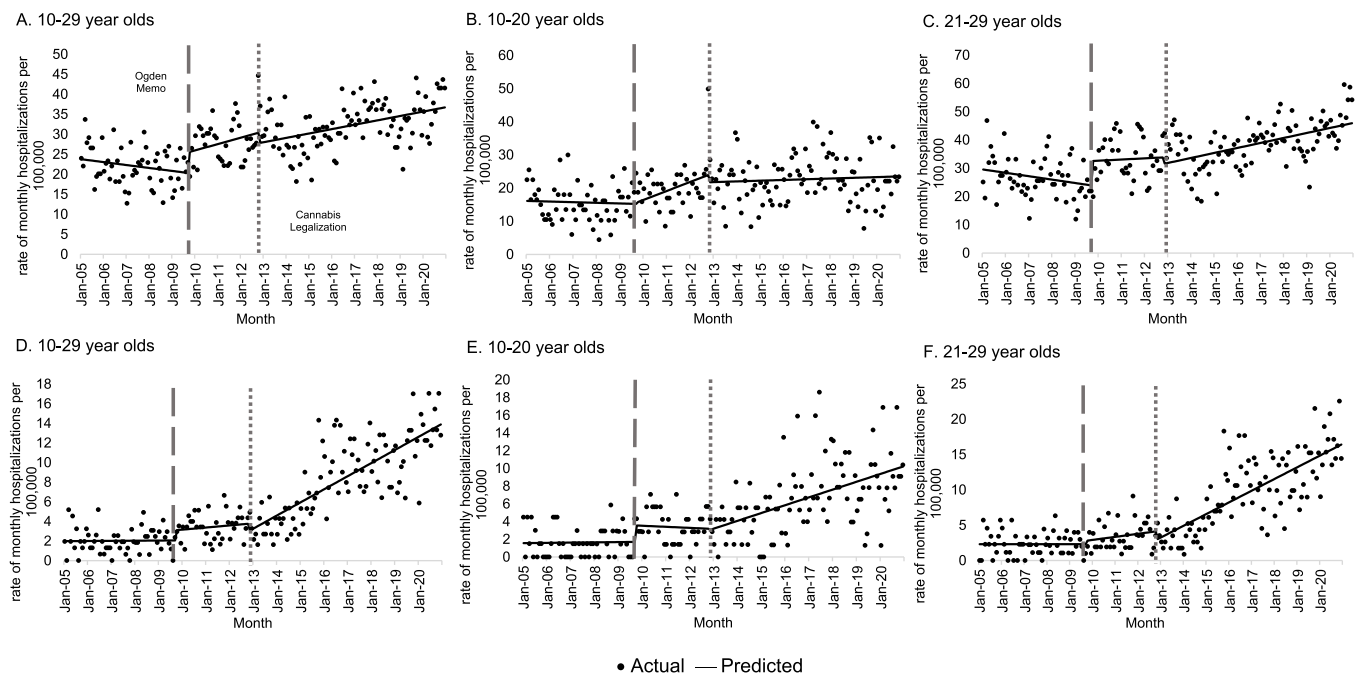


Fig. 1. Monthly rates of psychosis-related hospitalizations overall (A-C) and with cannabis use diagnoses (D-F) before and after Ogden Memo (October 2009) and Legalization of Cannabis for Adult-Use (November 2012, Denver Health System, 2005–2020).

et al., 2019). and adolescents (Cerdá et al., 2020, 2017; Sarvet et al., 2018). following cannabis recreational legalization in Colorado and other U.S. states.

Since the legal landscape is becoming increasingly permissive, (National Conference of State Legislatures, 2023) there is a need to plan effective public health responses that could mitigate unintended consequences of cannabis use, including potential rises in prevalence of psychosis. Indeed, the global trends towards cannabis legalization, which also have notable positive impacts on public health through safety and equity considerations, (Caulkins et al., 2015; Kilmer, 2019; Plunk et al., 2019). means that rather than reverse legalization, public health responses should aim to mitigate risky use via both regulation of sales and the content of products on the supply side, and via demand-side interventions to reduce risky use. In Canada, for example, research findings suggest that cannabis commercialization of higher potency products was associated with increased ED visits for cannabis-induced psychosis while earlier legalization that included store and product restrictions was not (Callaghan et al., 2022; Myran et al., 2023). The greatest links to increased psychosis incidence among people who use cannabis have also been found in those who start using earlier, use more frequently, and in high potencies (Chadwick et al., 2013; Hosseini and Oremus, 2019; Le Bec et al., 2008; Marconi et al., 2016; Van der Steur et al., 2020). Thus, harm reduction efforts to delay onset of use and reduce the frequency of use may be particularly important. Many experts, for example, have called for placing limits on marketing of cannabis products to youth, such as candy wrapper branding and flavored products that are known to enhance use of cannabis in early age groups (Caulkins et al., 2015; Firth et al., 2022; Ghosh et al., 2016; Ompad et al., 2022).

Lastly, findings may indicate a need for specific interventions around cannabis that target youth. Indeed, the large rise in visits for psychosis involving cannabis is likely not only related to cannabis-induced psychosis alone but also to potentially greater access or use of cannabis among individuals with psychotic or other mental health disorders. Many studies point to high levels of cannabis use as a form of self-medication among individuals with mental illness, which can also lead to allostasis, whereby individuals who find relief of symptoms during intoxication tend to increase use, leading to exacerbation of affective

symptoms during withdrawal and in turn increased cannabis use (Lowie et al., 2019). More research is needed to understand whether and by what mechanisms cannabis may be contributing to exacerbation or reported relief of psychosis symptoms (e.g., the role of THC vs. CBD (Patel et al., 2020)) and to inform best practices for patients with comorbid psychosis and cannabis use to identify effective therapeutic interventions and strategies. This is particularly important early on in psychosis to prevent chronic psychosis disorders and worsening symptoms (Coronado-Montoya et al., 2021).

This study is marked by the following limitations that dampen our ability to draw causal conclusions. First, all data were from one health system - Denver Health- which only represents a portion of the Denver metropolitan area. Although there was no known expansion in psychiatric care service capacity during our study period, it is still possible that the increases observed partially relate to increases in healthcare utilization for these conditions in this health system. Second, we only had encounter-level information, meaning we could not assess the temporality between cannabis use and psychosis. We could not ascertain if psychosis visits were first-time episodes or recurrent episodes of psychosis. Third, substance use disorders are generally under-reported, and CUD likely only captures people with more severe cannabis use than those who may use cannabis less frequently or have not been diagnosed. The increase in cannabis use diagnosis over time may also be due to growing awareness and may explain the increased rates of CUD in Denver EHR seen here. Fourth, while we did not observe a significant change in psychosis visits during 2020, the COVID-19 pandemic may have impacted both cannabis use and interactions with acute care settings during this time. Lastly, our analysis only captured the legal landscape of one state without a control state. Further and long-term research is needed to compare the rates of psychosis across different states with distinct legalization landscapes.

5. Conclusion

The findings of this study suggest a modest increase in overall emergency department and hospitalization visits with any psychosis diagnosis among youth after legalization of recreational cannabis. These increases were primarily among young adults aged 21–29, rather than

younger age groups. We also found a significant rise in psychosis hospitalizations that specifically contain a CUD diagnosis following legalization across all age groups. Given the adoption of increasingly permissive cannabis laws, there is a need to plan effective public health responses that could mitigate unintended consequences related to cannabis use.

CRediT authorship contribution statement

Kyle M. Snyder: Writing – review & editing, Formal analysis, Data curation. **Spruha Joshi:** Writing – original draft, Methodology, Formal analysis. **Bianca D. Rivera:** Writing – review & editing, Formal analysis, Data curation. **Christian Thurstone:** Writing – review & editing, Project administration, Data curation, Conceptualization. **Magdalena Cerdá:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Justin Feldman:** Writing – review & editing, Methodology. **Noa Krawczyk:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization.

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Declaration of Competing Interest

None to disclose.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.drugalcdep.2025.112719](https://doi.org/10.1016/j.drugalcdep.2025.112719).

References

- Ajdacic-Gross, V., Lauber, C., Warnke, I., Haker, H., Murray, R.M., Rössler, W., 2007. Changing incidence of psychotic disorders among the young in Zurich. *Schizophr. Res.* 95, 9–18.
- Boydell, J., van Os, J., Caspi, A., Kennedy, N., Giouroukou, E., Fearon, P., Farrell, M., Murray, R.M., 2006. Trends in cannabis use prior to first presentation with schizophrenia, in South-East London between 1965 and 1999. *Psychol. Med.* 36, 1441–1446. <https://doi.org/10.1017/S0033291706008440>.
- Callaghan, R.C., Sanches, M., Murray, R.M., Konefal, S., Maloney-Hall, B., Kish, S.J., 2022. Associations between Canada's Cannabis legalization and emergency department presentations for transient cannabis-induced psychosis and schizophrenia conditions: Ontario and Alberta, 2015–2019. *Can. J. Psychiatry* 67, 616–625. <https://doi.org/10.1177/07067437211070650>.
- Campeny, E., López-Pelayo, H., Nutt, D., Blithikioti, C., Oliveras, C., Nuño, L., Maldonado, R., Florez, G., Arias, F., Fernández-Artamendi, S., 2020. The blind men and the elephant: systematic review of systematic reviews of cannabis use related health harms. *Eur. Neuropsychopharmacol.* 33, 1–35.
- Caulkins, J.P., Kilmer, B., Kleiman, M.A., MacCoun, R.J., Midgette, G., Oglesby, P., Pacula, R.L., Reuter, P.H., 2015. Options and issues regarding marijuana legalization. Rand Corporation.
- Cerdá, M., Mauro, C., Hamilton, A., Levy, N.S., Santaella-Tenorio, J., Hasin, D., Wall, 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, 165–171.
- 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, 142–149.
- Chadwick, B., Miller, M.L., Hurd, Y.L., 2013. Cannabis use during adolescent development: susceptibility to psychiatric illness. *Front. Psychiatry* 4, 129.
- Chiu, V., Leung, J., Hall, W., Stjepanović, D., Degenhardt, L., 2021. Public health impacts to date of the legalisation of medical and recreational cannabis use in the USA. *Neuropharmacology* 193, 108610. <https://doi.org/10.1016/j.neuropharm.2021.108610>.
- Coronado-Montoya, S., Morissette, F., Abdel-Baki, A., Fischer, B., Côté, J., Ouellet-Plamondon, C., Tremblay, L., Jutras-Aswad, D., 2021. Preventive interventions targeting cannabis use and related harms in people with psychosis: a systematic review. *Early Interv. Psychiatry* 15, 1439–1453.
- Colorado Dept of Local Affairs Single Year of Age Lookup [WWW Document], URL 2024. Single Year of Age Lookup [WWW Document] URL (https://demography.dola.colorado.gov/assets/lookups/county_sya_lookup.html) (accessed 5.4.25)..
- Di Forti, M., Morgan, C., Dazzan, P., Pariante, C., Mondelli, V., Marques, T.R., Handley, R., Luzzi, S., Russo, M., Paparelli, A., 2009. High-potency cannabis and the risk of psychosis. *Br. J. Psychiatry* 195, 488–491.
- Fairman, B.J., 2016. Trends in registered medical marijuana participation across 13 US states and District of Columbia. *Drug Alcohol Depend.* 159, 72–79. <https://doi.org/10.1016/j.drugalcdep.2015.11.015>.
- Fergusson, D.M., Boden, J.M., 2008. Cannabis use and later life outcomes. *Addiction* 103, 969–976.
- Firth, C.L., Carlini, B., Dilley, J., Guttmanova, K., Hajat, A., 2022. Retail cannabis environment and adolescent use: the role of advertising and retailers near home and school. *Health Place* 75, 102795.
- Gage, S.H., Hickman, M., Zammit, S., 2016. Association between cannabis and psychosis: epidemiologic evidence. *Biol. Psychiatry* 79, 549–556.
- Ganesh, S., D'Souza, D.C., 2022. Cannabis and psychosis: recent epidemiological findings continuing the Causality Debate. *Am. J. Psychiatry* 179, 8–10. <https://doi.org/10.1176/appi.ajp.2021.21111126>.
- Ghosh, T., Van Dyke, M., Maffey, A., Whitley, E., Gillim-Ross, L., Wolk, L., 2016. The public health framework of legalized Marijuana in Colorado. *Am. J. Public Health* 106, 21–27. <https://doi.org/10.2105/AJPH.2015.302875>.
- Gonçalves-Pinho, M., Bragança, M., Freitas, A., 2020. Psychotic disorders hospitalizations associated with cannabis abuse or dependence: a nationwide big data analysis. *Int J. Methods Psychiatr. Res.* 29, e1813. <https://doi.org/10.1002/mpr.1813>.
- Hamilton, I., Sumnall, H., 2021. Are we any closer to identifying a causal relationship between cannabis and psychosis? *Curr. Opin. Psychol.* Cannabis 38, 56–60. <https://doi.org/10.1016/j.copsyc.2020.07.027>.
- Hasan, A., von Keller, R., Friemel, C.M., Hall, W., Schneider, M., Koethe, D., Leweke, F.M., Strube, W., Hoch, E., 2020. Cannabis use and psychosis: a review of reviews. *Eur. Arch. Psychiatry Clin. Neurosci.* 270, 403–412.
- Hasin, D.S., 2018. US epidemiology of cannabis use and associated problems. *Neuropsychopharmacology* 43, 195–212.
- Hinckley, J., Bhatia, D., Ellingson, J., Molinero, K., Hopfer, C., 2024. The impact of recreational cannabis legalization on youth: the Colorado experience. *Eur. Child Adolesc. Psychiatry* 33, 637–650. <https://doi.org/10.1007/s00787-022-01981-0>.
- Hjorthøj, C., Larsen, M.O., Starzer, M.S.K., Nordentoft, M., 2021. Annual incidence of cannabis-induced psychosis, other substance-induced psychoses and dually diagnosed schizophrenia and cannabis use disorder in Denmark from 1994 to 2016. *Psychol. Med.* 51, 617–622.
- Hollingsworth, A., Wing, C., Bradford, A.C., 2022. Comparative effects of recreational and medical marijuana laws on drug use among adults and adolescents. *J. Law Econ.* 65, 515–554.
- Hosseini, S., Oremus, M., 2019. The effect of age of initiation of cannabis use on psychosis, depression, and anxiety among youth under 25 years. *Can. J. Psychiatry* 64, 304–312.
- Kilmer, B., 2019. How will cannabis legalization affect health, safety, and social equity outcomes? It largely depends on the 14 Ps. *Am. J. Drug Alcohol Abus.* 45, 664–672. <https://doi.org/10.1080/00952990.2019.1611841>.
- Ladegard, K., Thurstone, C., Rylander, M., 2020. Marijuana legalization and youth. *Pediatrics* 145, S165–S174. <https://doi.org/10.1542/peds.2019-2056D>.
- Large, M., Sharma, S., Compton, M.T., Slade, T., Nielsen, O., 2011. Cannabis use and earlier onset of psychosis: a systematic meta-analysis. *Arch. Gen. Psychiatry* 68, 555–561.
- Le Bec, P., Fatséas, M., Denis, C., Lavie, E., Auriacombe, M., 2008. Cannabis and psychosis: search of a causal link through a critical and systematic review. *L'Enceph.* 35, 377–385.
- Leung, J., Chiu, V., Chan, G.C.K., Stjepanović, D., Hall, W.D., 2019. What have been the public health impacts of cannabis legalisation in the USA? A review of evidence on adverse and beneficial effects. *Curr. Addict. Rep.* 6, 418–428. <https://doi.org/10.1007/s40429-019-00291-x>.
- Linden, A., 2015. Conducting interrupted time-series analysis for single- and multiple-group comparisons. *Stata J.* 15, 480–500. <https://doi.org/10.1177/1536867X1501500208>.
- Livne, O., Shmulewitz, D., Sarvet, A.L., Wall, M.M., Hasin, D.S., 2022. Association of cannabis use-related predictor variables and self-reported psychotic disorders: U.S. Adults, 2001–2002 and 2012–2013. *Am. J. Psychiatry* 179, 36–45. <https://doi.org/10.1176/appi.ajp.2021.21010073>.
- Lowe, D.J.E., Sasiadek, J.D., Coles, A.S., George, T.P., 2019. Cannabis and mental illness: a review. *Eur. Arch. Psychiatry Clin. Neurosci.* 269, 107–120. <https://doi.org/10.1007/s00406-018-0970-7>.
- Marconi, A., Di Forti, M., Lewis, C.M., Murray, R.M., Vassos, E., 2016. Meta-analysis of the association between the level of cannabis use and risk of psychosis. *Schizophr. Bull.* 42, 1262–1269.
- Marijuana Policy Project, 2025. Medical Cannabis by the Numbers [WWW Document]. MPP. URL (<https://www.mpp.org/issues/medical-marijuana/medical-marijuana-numbers/>) (accessed 5.4.25).
- Melchior, M., Nakamura, A., Bolze, C., Hausfater, F., El Khoury, F., Mary-Krause, M., Azevedo Da Silva, M., 2019. Does liberalisation of cannabis policy influence levels of use in adolescents and young adults? A systematic review and meta-analysis. *BMJ Open* 9, e025880. <https://doi.org/10.1136/bmjopen-2018-025880>.
- Misiak, B., Stramecki, F., Gawęda, L., Prochwicz, K., Sasiadek, M.M., Moustafa, A.A., Frydecka, D., 2018. Interactions between variation in candidate genes and environmental factors in the etiology of schizophrenia and bipolar disorder: a systematic review. *Mol. Neurobiol.* 55, 5075–5100. <https://doi.org/10.1007/s12035-017-0708-y>.
- Moran, L.V., Tsang, E.S., Ongur, D., Hsu, J., Choi, M.Y., 2022. Geographical variation in hospitalization for psychosis associated with cannabis use and cannabis legalization

- in the United States: submit to. *Psychiatry Res.* *Psychiatry Res.* 308, 114387. <https://doi.org/10.1016/j.psychres.2022.114387>.
- Murray, R.M., Hall, W., 2020. Will legalization and commercialization of cannabis use increase the incidence and prevalence of psychosis? *JAMA Psychiatry* 77, 777–778. <https://doi.org/10.1001/jamapsychiatry.2020.0339>.
- Myles, H., Myles, N., Large, M., 2016. Cannabis use in first episode psychosis: meta-analysis of prevalence, and the time course of initiation and continued use. *Aust. N. Z. J. Psychiatry* 50, 208–219. <https://doi.org/10.1177/0004867415599846>.
- Myran, D.T., Gaudreault, A., Pugliese, M., Manuel, D.G., Tanuseputro, P., 2023. Cannabis-involved traffic injury emergency department visits after cannabis legalization and commercialization. *JAMA Netw. Open* 6, e2331551. <https://doi.org/10.1001/jamanetworkopen.2023.31551>.
- National Conference of State Legislatures, 2023. State medical cannabis laws. *Natl. Conf. State Legis.*
- Noel, G.N., Maghoo, A.M., Franke, F.F., Viudes, G.V., Minodier, P.M., 2019. Increase in emergency department visits related to cannabis reported using syndromic surveillance system. *Eur. J. Public Health* 29, 621–625. <https://doi.org/10.1093/eurpub/cky272>.
- Office of Public Affairs, 2009. Memorandum for Selected United State Attorneys on Investigations and Prosecutions in States Authorizing the Medical Use of Marijuana [WWW Document]. URL (<https://www.justice.gov/archives/opa/blog/memorandum-selected-united-state-attorneys-investigations-and-prosecutions-states>) (accessed 5.4.25).
- Ompad, D.C., Snyder, K.M., Sandh, S., Hagen, D., Collier, K.J., Goldmann, E., Goodman, M.S., Tan, A.S., 2022. Copycat and lookalike edible cannabis product packaging in the United States. *Drug Alcohol Depend.* 235, 109409.
- Pacula, R.L., Smart, R., 2017. Medical Marijuana and Marijuana Legalization. *Annu Rev. Clin. Psychol.* 13, 397–419. <https://doi.org/10.1146/annurev-clinpsy-032816-045128>.
- Patel, S., Khan, S., Saipavankumar, M., Pousettef, Hamid, Pousette, Hamid, 2020. The association between cannabis use and schizophrenia: causative or curative? A systematic review. *Cureus* 12.
- Plunk, A.D., Peglow, S.L., Harrell, P.T., Grucza, R.A., 2019. Youth and adult arrests for cannabis possession after decriminalization and legalization of cannabis. *JAMA Pediatr.* 173, 763–769.
- Pourebrahim, S., Ahmad, T., Rottmann, E., Schulze, J., Scheller, B., 2025. Does cannabis use contribute to Schizophrenia? A causation analysis based on epidemiological evidence. *Biomolecules* 15, 368. <https://doi.org/10.3390/biom15030368>.
- Rocky Mountain High Intensity Drug Trafficking Area Program, 2021. The Legalization of Marijuana in Colorado: the impact. *Mo Med* 118, 534–535.
- Roehler, D.R., Hoots, B.E., Holland, K.M., Baldwin, G.T., Vivolo-Kantor, A.M., 2022. Trends and characteristics of cannabis-associated emergency department visits in the United States, 2006–2018. *Drug Alcohol Depend.* 232, 109288.
- Sarvet, A.L., Wall, M.M., Fink, D.S., Greene, E., Le, A., Boustead, A.E., Pacula, R.L., Keyes, K.M., Cerdá, M., Galea, S., Hasin, D.S., 2018. Medical marijuana laws and adolescent marijuana use in the United States: a systematic review and meta-analysis. *Addiction* 113, 1003–1016. <https://doi.org/10.1111/add.14136>.
- Shen, J.J., Shan, G., Kim, P.C., Yoo, J.W., Dodge-Francis, C., Lee, Y.-J., 2019. Trends and related factors of cannabis-associated emergency department visits in the United States: 2006–2014. *J. Addict. Med.* 13, 193–200.
- StataCorp, L.L.C., 2017. Stata statistical software. release 15.
- Van der Steur, S.J., Batalla, A., Bossong, M.G., 2020. Factors moderating the association between cannabis use and psychosis risk: a systematic review. *Brain Sci.* 10, 97.
- Volkow, N.D., Baler, R.D., Compton, W.M., Weiss, S.R., 2014. Adverse health effects of marijuana use. *N. Engl. J. Med.* 370, 2219–2227.
- Wang, G.S., Buttorff, C., Wilks, A., Schwam, D., Tung, G., Pacula, R.L., 2021. Changes in emergency department encounters for vomiting after cannabis legalization in Colorado. *JAMA Netw. Open* 4, e2125063–e2125063.
- Wang, G.S., Davies, S.D., Halmo, L.S., Sass, A., Mistry, R.D., 2018. Impact of marijuana legalization in Colorado on adolescent emergency and urgent care visits. *J. Adolesc. Health* 63, 239–241.