Systematic Review and Meta-Analysis: Medical and recreational cannabis laws and cannabis use among youth in the United States.

ABSTRACT

Objectives: Dramatic changes in state-level cannabis laws (CL) over the past 25 years have shifted societal beliefs throughout the US with unknown implications for youth. In the present study we conducted an updated systematic review and meta-analysis examining estimated effects of medical CL (MCL) and recreational CL (RCL) on past-month cannabis use among US youth.

Methods: A systematic review was conducted following PRISMA guidelines followed by a subsequent meta-analysis investigating the associations between state-level cannabis laws (i.e., MCL vs. non-MCL, and RCL vs non-RCL) and past-month cannabis use prevalence among US adolescents and young adults. Supplemental analyses examined age-group effects and design-related factors.

Results: Our search identified 4604 citations, 34 and 30 of which were included in qualitative and quantitative analyses, respectively. Meta-analysis of MCL studies identified no significant association between MCL and change in past-month youth cannabis use (OR 0.981 [95% C.I. 0.960, 1.003]). Meta-analysis of RCL studies showed significantly increased odds of past-month cannabis use (OR 1.134 [95% C.I. 1.116-1.153]). Meta-analysis of more recent studies however showed a significantly increased odds of past-month cannabis use both amongst adolescents and young adults (OR 1.089[95% CI 1.015,1.169], and OR 1.221[95% CI 1.188,1.255], respectively).

Conclusions: Cannabis legalization has complex and heterogenous effects on youth use that may differ across law types. Our meta-analytic results showed modest positive effects of RCL on past-month cannabis use (more so in young adults than in adolescents) and minimal effects of MCL on these outcomes in US youth. Given the shift towards recreational legalization, additional focus on RCL effects is warranted.

INTRODUCTION

Cannabis legalization has been on the rise in the United States (US). As of August 2023, 38 states and the District of Columbia (D.C.) have passed medicinal cannabis laws (MCL), and since 2012, 23 states, and D.C. have passed recreational cannabis laws (RCL) legalizing the use of cannabis for recreational purposes for individuals ≥21 year of age.[1] Growing trends towards legalization have raised concerns regarding the effects of legalization on substance use disorders in youth. From 2007 to 2019, while the prevalence of past month alcohol and cigarette use amongst 18 to 25 year olds in the USA declined by 7% and 18% respectively, past month cannabis use increased from 16.5% to 23% possibly related to decreasing perception of risk of cannabis use (NSDUH, 2019).[2] A recent analysis of nationwide data also estimated an 80% increase in adolescents frequently using cannabis compared to their prevalence in 1996-1997, that puts them at risk of developing dependence.[3]

Cannabis use, particularly persistent heavy use during adolescence, has been associated with adverse health outcomes, such as increased motor-vehicle accidents,[4] physical health consequences, and an increased incidence of psychiatric symptoms.[5–7] Moreover, increased use in early adolescence has been linked to a high (~20%) risk of developing cannabis use disorder (CUD).[8] Legalization of cannabis is a major policy that is expected to affect these outcomes through its effects on cannabis use among youth.

Although there have been concerns about the potential health effects of cannabis use, and several studies have examined associations between passage of state cannabis laws and cannabis use among adolescents and young adults, many of them have provided mixed results. Studies have used methods such as comparing the prevalence before and after legalization[9–12] or compared the legalized states to non-legalized states.[13–16] Some of these studies have found that legalization was associated with an increase in cannabis use, [14,15,17] while the others have not found any association.[3,16] Most recent studies including large scale datasets have consistently incorporated quasi-experimental methods such as difference-in-difference

(DiD)[18], using legalization as an exposure variable and simultaneously comparing the states pre-to-post legalization, thus accounting for any changes in prevalence that were unrelated to legalization.[19–23] While these studies may provide a more robust causal inference, the results from these studies have not been consistent. Some of them have shown either a small decrease or no effect with RCL or MCL in youth, [22,24,25] others have found an increase,[26–28] while some found mixed results based on subsets of population.[29,30] Several reasons can be attributed to the inconsistency, some of them could be the difference in the covariates adjusted for (e.g. age, sex, race), difference in the periods of dataset included, or differences in the surveys used for analysis (e.g. Monitoring the future (MTF), or Youth risk behavior surveillance system (YRBS)).

Cannabis policies are changing rapidly, providing further data to inform meta-analyses in this space. Since the last meta-analysis examining this topic,[31,32] covering the years 1990s to 2018, seven more states have passed MCL and fifteen have passed RCL. Few meta-analyses have examined the full age-spectrum of youth including both 12-to-17-year-old adolescents and 18-to-25-year-old young adults. Moreover, only one meta-analysis conducted to date has examined RCL effects, with that meta-analysis being limited by the fact that all RCL studies it included were published prior to 2018 and each included study involved only one or two states with RCL.[32] To address these gaps, in the present study we conducted an updated systematic review on cannabis use parameters to identify associations between state-level cannabis laws (i.e., MCL vs. non-MCL, and RCL vs. non-RCL) and meta-analyzed changes past-month cannabis use among US adolescents and young adults. Past month use was chosen to be meta-analyzed based on the review of prior-meta-analysis that did not find other outcomes to be quantitatively meta-analyzable[31], and the exploration of available data where it was by far the most common outcome studied. If associations were identified in our meta-analyses, we sought to determine their directionality and to assess whether the magnitude of these associations

differed in relation to population characteristics (e.g., age, sex, racial and ethnic background) and study-design elements.

METHODS

A systematic review of peer-reviewed studies was conducted following the Preferred reporting Items for Systematic Review and Meta-Analysis Statement (PRISMA) guidelines and methods.[33] Only the studies that reported the effects of cannabis legalization on past-month cannabis use were used in the meta-analyses.

Search Strategy

A systematic literature search was conducted using the MEDLINE, CINAHL, and PsycINFO databases. Search was limited to articles published in peer-reviewed journals in English from January 1, 2000, till October 2022, and was periodically updated till August 2023. Google Scholar was also manually searched for the first 300 results. Alerts on respective databases, Google Scholar and EBSCOhost were also set up with respect to the search terms for any additional studies that got published till August 2023. Search terms included "cannabis legalization", "youth", “juvenile”, "teenagers," "adolescents," and "cannabis". Further details of the search with PRISMA checklist are provided in the online supplement (Supplement Methods S1). In addition, reference lists of relevant articles were reviewed to identify any other studies that were not captured in the initial search.

Study Selection

Studies were included with consensus between at least two authors if they 1.) Included youth participants between the ages of 12 and 25 years from the US, 2.) used cannabis use measures (e.g., ever-use, past-year, or past-30-day cannabis use, daily cannabis use, cannabis use frequency, or cannabis use disorder (CUD)) as their outcome of interest, 3.) compared MCL to non-MCL, or RCL to non-RCL states, and if 4.) applied difference-in-difference (DiD) or used regression analysis to adjust for changes in state legalization status over the years and

for contemporaneous change in non-legalized states, thus comparing the outcome variable of interest from before to after passage of CL within states that passed those laws and compared that rate of change contemporaneous rate of change in states that did not pass that CL over the same time period. Studies were excluded if 1.) stratified age range was not available to classify outcomes for adolescents or young adults from the whole sample, 2.) if the cannabis use or CUD was not the primary outcome studied, 3.) only assessing effects at before and after legalization but not comparing with states that did not pass respective legalization (i.e., non-MCL, non-RCL, or no-CL as comparator) or only based on CL status but not before or after legalization, 4.) assessing the exposure or outcomes only through indirect measures (e.g. number of dispensaries as effect, or cannabis related hospitalizations as the only outcome), 5.) the outcomes were limited to a very specific population (e.g. juvenile arrestees), or if 6.) only discussing decriminalization but not legalization. Unpublished studies, thesis dissertations, reviews and meeting abstracts were also excluded. Of the studies identified with the above criteria, those that reported the effects of RCL and/or MCL passage on the outcome of past-month cannabis use prevalence were used in the meta-analyses.

Data Extraction

Article abstracts and full-text articles were obtained, organized, reviewed, and coded. Data from articles that met study criteria were extracted and entered in spreadsheets for analysis. Initial independent abstract evaluations were done by two authors (AP and ES), followed by an independent review of full-text articles to determine if they met inclusion criteria based on consensus between the authors. Reasons for exclusions after full text review are given in supplemental Table S1.

To facilitate exploration and interpretation of results, relevant design features and sample characteristics from each study were extracted and used to assess study quality, characterize the degree of heterogeneity across studies, and to facilitate planned subgroup meta-analyses.

Data extracted from articles that met study criteria included study-level information on, categorical age groups, mean age, proportion of female participants, proportion of different racial and ethnic groups, source dataset, time-frame/period studied, type of legalization (i.e. RCL or MCL), states included in comparison, main and secondary outcomes and measures used to obtain those outcomes (related to cannabis use), statistical analysis approach used and individual and state-level covariates included in the statistical models. From studies that included this information, we also extracted other cannabis use measures beyond past-month cannabis use prevalence, which included other aspects of cannabis use such as past year use. the frequency of use, perception of risk with cannabis use, other substance use, and data about the effects on cannabis use outcomes of specific provisions within states that passed CL and the variability in the restrictiveness of CL across states. Quantitative effect on past month cannabis use was extracted and main findings were qualitatively summarized for each study.

Data Analysis

Data coding and preparation for meta-analysis: Studies that met all inclusion criteria and provided outcome data on differences in past-month cannabis use as a function of state legalization status were meta-analyzed. Primary outcome data, relevant sample and study features were manually extracted by two authors (AP and CJH), cross-checked for concordance, and recorded into spreadsheets for the meta-analysis. The primary outcome used for our meta-analyses was the effect of pre-to-post MCL and RCL passage on the prevalence of past-month cannabis use among US adolescents and/or young adults as measured by a prevalence difference or odds ratio (OR), for MCL and RCL separately, using contemporaneous change in past-month cannabis use in states that had not passed CL as the reference group (control exposure). Following abstraction, these primary outcomes were standardized for meta-analysis by converting OR to log(OR). For studies reporting prevalence differences, these were first converted to OR and then standardized with log transformation.

The effects were pooled to create final effect size estimates for CL effects on past month cannabis use related to MCL and RCL exposure.

Meta-analytic procedures: All analyses were conducted using Comprehensive meta-analysis software version 4 (http://www.meta-analysis.com, accessed on August 1, 2023). For our primary meta-analyses, the effects of legalization on past month cannabis use were meta-analyzed with inverse variance weighting, separately for MCL and RCL and reported as an overall estimate with 95% confidence interval (CI) in the results. Heterogeneity was anticipated considering long periods of data involved combining several states, heterogeneity was quantitatively estimated by calculating I^2 statistic and random effects model was chosen to be reported if heterogeneity was high (I^2>50%).[34,35]

Supplemental Subgroup Meta-analyses and Meta-regressions: Supplemental subgroup meta-analyses were conducted to examine the effects of age-group (adolescent vs. young adult) on associations between state-level CL and past-month cannabis use. To determine if the time period influenced observed associations, we created a dummy variable categorizing experimental contrasts as comparing CL vs. no-CL, for respective legalization (MCL vs. non-MCL or no-MCL, or RCL vs. non-RCL) from before and after 2008. We chose a single year transition point to avoid making multiple comparisons for different periods, and intended to use the cut off at few years before first RCL was implemented i.e., 2012, to keep a before and after comparison period. The year 2008 was selected as the cutoff point based on exploration of national data indicating that till 2008 there was already a trend towards decrease in youth with an inflection point in trend after 2008.[36,37] Recent studies have also used 2008 as an inflection point in data-analysis.[38,39] Preliminary exploration of data from prior meta-analysis also suggested that using any other cut-off year would not lend itself to sufficiently powered sub-groups. We then conducted subgroup meta-analyses to examine the effect of survey data source on associations between state-level CL and past-month cannabis use. If there was a

significant difference in the outcomes between the studies that had included periods before 2008 and those that included only after 2008 datasets, we further planned to run the analysis based on age-group and survey used to explore the effects on the primary outcome. We also planned to perform a meta-regression analysis focusing on mean age, sex, racial and ethnic group status using *a priori* defined variables from each study as dependent variables. Results from mixed effects analysis for each sub-group analysis were tabulated.

Sensitivity analysis: Three sensitivity tests were conducted to test the robustness of effect size estimates in our MCL and RCL analyses. First, we reran our main meta-analyses removing experimental contrasts from studies that only had a single state exposed to legalization at the time of analysis. This was done in order to ensure that results from single state effects (which may not be generalizable) were not driving our results. Our second sensitivity test paralleled our main analysis but used past-month cannabis use outcomes calculated differently, with prevalence differences standardized using arcsine transformation of prevalence to find Cohen's h, was done in one of a previous meta-analyses,[31]instead of log transformation after converting them to odds ratios as done in our analysis. Lastly, we also planned to analyze the primary outcome using both fixed and random effect modelling.

RESULTS

Systematic Review and Qualitative Analysis

The initial search identified 5491 citations, with 887 duplicates removed and 4450 were excluded following title and abstract screen. Out of the 154 studies that underwent full-text review, 34 met the main study selection criteria and were included in the qualitative analysis. A PRISMA flow diagram of the search process is presented in Figure 1.

Qualitative analysis: Thirty-four studies were included in the systematic review to examine effects of MCL and RCL passage on cannabis use in US youth (See Table 1). These studies showed significant heterogeneity in outcomes with regard to the survey source and time periods

examined. Included published articles till 2023 have analyzed data from surveys covering different time periods spanning from 1991 to 2019. There was an overlap in time periods between surveys. Due to the nature of surveys the sample size varied from few thousands to millions. For data source, most studies used self-report questions obtained from national datasets including the Monitoring the Future survey (MTF), National College Health Assessment survey (NCHA), National Longitudinal Survey of Youth survey (NLSY), National Survey on Drug Use and Health (NSDUH), Population Assessment of Tobacco and Health Study (PATHS) and Youth Risk Behavior Survey (YRBS), while others used independent state or university level surveys. A number of studies provided effects of CL on cannabis use for independent sub-groups separately (e.g., different age groups, race, or level of restrictiveness), providing more than one data-point for analysis. Table 1 presents the characteristics of included studies describing significant effects towards decrease, increase or no change in youth cannabis use outcomes based on the type of legalization. Mean age, proportion of female participants, and race and ethnic group distribution of the study population was not provided in many studies and when provided [43,57] these parameters were not weighted by outcomes (see Cerda et al., 2017[20] for example). As shown in Table 1, gender was mostly classified as binary except in studies by one group of authors that included "Trans" as a category.[40,41,52] Race, when provided was mostly classified into five categories as Whites, Black, Hispanic, Asian, and others. As too few studies reported age, sex, and racial/ethnic groups of the study population separately for legalized and non-legalized states, and as those that did could not be standardized across studies, our planned *a priori s*ubgroup meta-analyses and meta-regression analyses focused on these variables were not conducted.

Most studies used binary/categorical state-level cannabis laws (e.g., MCL = 1 vs. no MCL = 0) as the main exposure variable and did not consider variation across laws and effects of provisions in their analyses. Notably, our systematic review did identify a subgroup of cannabis

policy studies that sought to characterize the effects of variability in the restrictiveness of state-level cannabis laws and the influence of specific provisions on cannabis use outcomes. Variability in the cannabis outcomes studied and how states' restrictiveness of laws was ascertained have likely resulted in inconsistent associations. A study by Johnson and colleagues used an index (Chapman index)[61] to classify the states on the basis of restrictiveness of laws, however it is notable that the index was not designed with adolescent population in mind and may have excluded important variables, and the index was also limited to provisions of MCL. Another more recent study that classified the states on how they view cannabis use, i.e., as a pharmaceutical, as a state fiscal revenue source, or as a permissive drug of use, has shown an increase in cannabis use with more liberalized provisions of law.[28] Based on review of these studies a closer examination of variations in RCL is also warranted.

Meta-analytic Sample and Study Characteristics: Thirty studies met all eligibility criteria and were included in the meta-analytic sample to examine effects of MCL or RCL passage on past-month cannabis use in US youth. This included 21 studies providing 39 data points from quasi-experimental designs contrasting MCL to no-MCL on past-month cannabis use for US youth from independent sub-groups that were used in the MCL meta-analysis, and 14 studies providing 31 data points from experiments contrasting RCL to no-RCL on past month cannabis use for US youth from different sub-groups that were used in the RCL meta-analysis. Studies included in the meta-analytic sample had clearly stated adjustments for state level covariates, of which common co-variates included state's population, unemployment rate, state's age distribution, and alcohol or cigarette related taxes. All but three of them[18,19,28] had also adjusted for individual level covariates including age, gender, race/ethnicity, while some[48,55,58,62] did not mention adjustment for these covariates. Only one group of authors have consistently included the categories for gender and sexual orientation beyond binary categorization.[40,41,52] Primary outcome as the effect on past month use was again classified based on the studies

predominantly including adolescents or including young adults, along with respective effect sizes from each study included in the meta-analysis as presented in Supplemental Table S3.

Meta-analyses of Effects of MCL and RCL on Past-Month Cannabis Use in US Youth

Forrest plots visualizing the main study results for MCL and RCL meta-analyses are presented in Figures 2 and 3, respectively. Studies in MCL quantitatively yielded a moderate level of heterogeneity (I^2=55.2) while in RCL they exhibited a high level of heterogeneity (I^2=90.50). As planned due to the presence of significant heterogeneity random effects model was chosen for primary analysis.

The primary meta-analysis of MCL studies showed an overall effect size of -0.019[95% C.I. -0.041, 0.003], indicating no significant association between passage of MCL and past month cannabis use among US youth (OR 0.981 [95% C.I. 0.960, 1.003]).

The primary meta-analysis of RCL studies showed an effect size of 0.117[95% C.I. 0.053, 0.181], indicating a modest positive association between passage of state-level RCL and past-month cannabis use in US youth. This result is consistent with an approximately 13% increased odds of past month cannabis use prevalence (OR 1.125 [95% C.I. 1.055-1.199]) for US youth living in states that passed RCL compared to youth living in states with no RCL.

Supplemental Subgroup Meta-analyses and Meta-regression analyses

Subgrouping based on age-groups: Mixed effects analysis of the age-based subgroup MCL meta-analysis showed no significant association between MCL passage, and past-month cannabis use in either age group (i.e., adolescents or young adults). Additionally, no differences between age-groups were observed for these associations (all p's > 0.05). Results of the age-based subgroup RCL meta-analysis showed a significant positive association between RCL passage, and past-month cannabis use for young adults but failed to reach statistical significance in adolescents (OR 1.253 [95% C.I. 1.140, 1.378] and OR 1.041 [95% C.I. 0.966, 1.121], $p<0.05$).

Subgrouping by timeframe of study: MCL only had two studies that included datasets solely after 2008 which would have been insufficient to make appropriate comparisons, hence subgroups based on period were not created for MCL studies. Mixed effects for RCL studies showed a significant difference between the outcomes from studies that did include datasets before 2008 vs those that did not ($p<0.05$). The association between RCL and past-month cannabis use remained statistically significant for the latter, and showed a modest increase in effect magnitude (After vs. Before 2008 analysis: effect size = 0.139[95% C.I. 0.085, 0.193] vs. 0.105 [95% C.I. -0.026, 0.238], $p<0.05$), there was also a significant decrease in outcome heterogeneity (subgroup after 2008 vs. primary RCL analysis: I^2 = 66.4 vs. 90.6). Amongst studies with datasets only after 2008, the association of past-month cannabis use with RCL was significantly positive both for adolescents and young adults, with a significantly prominent increase remaining in young adults (adolescents vs young adults in studies only after 2008: OR 1.089[95% CI 1.015,1.169], and OR 1.221[95% CI 1.188,1.255], respectively, $p<0.000$).

Examining data source as moderator: When subgroup meta-analyses examining data source effects were conducted, MCL and RCL results were generally consistent with our primary outcomes but did show some variation in outcomes as a function of specific surveys used (i.e., MTF vs. NSDUH vs. YRBS or independent state surveys) in the analysis. Examining RCL with datasets only after 2008 continued to show significantly positive associations for all surveys for one outlier study that provided six datapoints from a single survey.

See supplemental Table S4 for sub-group analyses.

Meta-regression analyses: As noted above in the qualitative analysis results section, too few studies with standardizable age (mean age in years), sex, and racial/ethnic group data were identified for properly powered subgroup and meta-regression analyses on these variables.

Sensitivity analysis

Meta-analytic results from our RCL analyses were robust to sensitivity testing. Our MCL analysis did not have any study with single exposure states for removal, and thus this analysis was not run. When meta-analyzed excluding studies with single state legalization comparators, RCL associations with past-month cannabis use were unchanged and largely produced identical results as estimated in the full model (See Supplement Figure S1). Using fixed effects modelling (Supplemental Table S5) and calculating Cohen's h using arcsine transformation instead of log transformation for prevalence differences showed no significant association between MCL and past-month cannabis use while the RCL still showed significantly positive results (See Supplement Figure S2).

DISCUSSION

This systematic review and meta-analysis examined studies assessing the impact of changes in state-level cannabis-laws on past-month cannabis use prevalence among US youth in order to provide an updated effect size estimate of effects of legalization based on the type of law passed (MCL or RCL). Our search focused on studies that used difference-in-difference (DiD) or DiD-like analytic techniques, enabling us to account for secular trends in cannabis use while comparing changes in use patterns in legalized states to non-legalized states over time in our analyses. The search screened 4604 published articles and identified 30 articles that were used in our primary MCL and RCL meta-analyses. The main findings were that passage of RCL was associated with an increase (~13%) in the odds of past-month cannabis use among young adults in the US, whereas MCL showed no significant effects on this outcome. Further, the association between RCL and past-month cannabis use was more prominent in young adults but we also found a significant increase amongst adolescents in a sub-group of studies that used more recent datasets (since 2008).

Our findings are consistent with results from prior meta-analyses examining MCL[31] and RCL[32] effects on youth cannabis use. In this meta-analysis, we incorporated RCL studies that included

a median of 7.5 states (Range 1 to10). This contrasts with the earlier meta-analysis, which had a smaller number of RCL states (Range 1 to 3). Additionally, four of the MCL studies expanded their scope to include 22 to 29 states, surpassing the 21 states examined in the studies from the previous meta-analysis.[32] Moreover, some studies included in prior meta-analysis used indirect measures for cannabis use outcomes such as treatment admissions due to cannabis use, which may not represent the use in the community[63] hence these studies were excluded in our meta-analysis. Regarding MCL effects, our results are similar to results from previous meta-analyses that examined the effects of MCL on past-month cannabis use in US adolescents between 1991-2014[31] and amongst adolescents and young adults from 1996 to 2018.[32] To date, only one prior meta-analysis[32] has examined associations between RCL and youth cannabis use, showing a trend towards positive association between RCL passage and youth cannabis use. Of note, this previous meta-analysis only included studies through 2018, with latest dataset included from the year 2016. Since that time 7 and 15 states have passed MCL and RCL respectively. Thus, our meta-analysis, which draws from studies with several more RCL and MCL states, expands on these early findings and provides additional evidence for differential effects of state-level cannabis laws on past-month cannabis use prevalence in US youth as a function of the legalization (RCL or MCL). Our results likely provide a more precise estimate compared to prior meta-analyses due to larger number of studies (8 vs. 14 RCL studies, and 21 MCL studies, several of the MCL studies in prior meta-analysis were only pre-post MCL prevalence comparisons), effects may have been obfuscated by the limited samples with fewer states in prior meta-analysis, although the impact of our use of stricter selection criteria may also be contributing to reduced signal variance.

The association between RCL and past-month cannabis use was larger in magnitude for young adults compared to adolescents in our sub-group analyses. The fact that analysis accounting only for more recent trends (i.e., studies using data after 2008) showed a significant increase

in cannabis use amongst adolescents is alarming. Since neurodevelopment from adolescence continues into the early 20s and may be disrupted by chronic cannabis use,[64] based upon adolescent's developmental vulnerability and well known risks for a broad array of adverse psychosocial outcomes related to adolescent onset use,[65] small changes in the prevalence of cannabis use can have large impacts on public health outcomes for this population. While further investigation is warranted to determine if the stronger association of past month cannabis use with RCL in young adults' result is being driven by those who are older than 21-years accessing cannabis legally from dispensaries, the finding remains concerning. Young adults in general have a lowest likelihood of perceiving substances to be harmful, that with several social factors such as a tendency for more exploration, and life changes such as moving away from parental supervision have been suggested as potential reasons for this young adults to be more susceptible to substance use (SAMHSA, 2019).[66] A recent study also supported that decreased perception of risk mediates the relationship between RCL and cannabis use more strongly in young adults.[55] The decision making among both adolescents and young adults needs further exploration. Similar to adolescents, cannabis use by young adults is also associated with adverse psychosocial outcomes.[67] Our result remains consistent with national survey data showing increasing rates of past-year, past-month, and daily cannabis use among US young adults, which have recently reached 30-year highs in this age group.[68]

One of our secondary aims for this study was to examine associations between state-level cannabis laws and past-month cannabis use that varied as a function of sex and racial or ethnic background. Our interest in this was based upon emerging literature showing sex,[60] racial,[54] and ethnic differences[69,70] in cannabis use behaviors and correlates in US youth. Cannabis legalization has particular historic relevance to minoritized communities and people of color who have been disproportionately impacted by cannabis-related policing and incarceration. Given this, it is important for future studies to investigate the effects of cannabis legalization

in different racial and ethnic groups to ensure that passage of cannabis laws are benefiting these groups and not exacerbating racial and ethnic health disparities. Unfortunately, our study had insufficient data to analyze these factors.

Cannabis-related attitudes and health perceptions play a role in cannabis use intentions for youth and represent key prevention targets. Studies included in our review examining the effects of MCL on perception of harm related to cannabis use among US youth have shown mixed results, with some studies showing no change,[48] decrease[26] or even an increase[21,59] in perception of harm in response to changing cannabis laws. It is expected that when youth only observe cannabis as a medicine they are likely to consider it having some adverse effects,[48] while with increasing permissiveness amongst adults with increasing RCL, adolescents are likely to perceive it as less harmful too, increasing the likelihood of future use. This could partly explain why MCL did not show an increase while RCL was associated with an increase in past month cannabis use in our meta-analysis. Further, a recent study[71] also found that RCL was associated with increased cannabis use among US youth and that this association was mediated by a decrease in perception of harm among youth living in RCL states. RCL can also incentivize marketing of cannabis that may affect the attitude of youths towards cannabis leading to an increase in use.[72] More research is needed to identify the underlying mechanisms through which state-level cannabis laws influence youth cannabis use behaviors. Through identifying and quantifying the extent of increase in cannabis use, the results of this work can inform future cannabis prevention efforts. Since the increase in permissiveness of cannabis legalization may have led to an increase in its use even amongst adolescents, psychoeducation on cannabis associated harms may be incorporated at the school level, similarly stricter regulations on retail marketing of cannabis may help reduce its exposure to youth.[73]

Cannabis use has been linked to significant adverse health effects in numerous studies. Although the medical benefits of cannabis use have been strongly questioned due to significant

placebo effects,[74] and due to the lack of evidence for efficacy[75], this still remains an area of further research especially in youth. Increased legalization of cannabis leading to increased use can pose a significant public health risk due to known adverse effects.[65,76] More research is needed into the downstream consequences of these policy changes. Studies examining cannabis policy outcomes need to consider the net health effects of these laws and examine both potential benefits and harms related to policy shifts. While cannabis legalization may have benefits, particularly related to a decrease in cannabis-related arrests which disproportionately affects minoritized populations, along with potential economic and fiscal benefits for the states, future legislations must ensure that laws promoting legalization strongly consider the potential adverse public health outcomes over the benefits from permissiveness toward commercialization of cannabis, and strengthen the cannabis prevention and treatment efforts for youth to mitigate the risk for adverse health consequences. Next stage research in this space needs to step beyond self-report measures of cannabis use frequency and conduct more detailed assessments of cannabis product features and use patterns among people who use, in order to determine if cannabis laws alter the product categories and chemotypes, methods of administration, and THC (Tetrahydrocannabinol) potency of cannabis used by US youth. Recent research also indicates that high-potency cannabis extracts pose unique risks not well-captured by current surveys.[77–79] Further studies should specifically assess their prevalence among youth.

Future studies also need to go beyond binary categorization of state-level laws and thoughtfully assess variability and effects of specific policies and provisions as they relate to different outcomes in youth. This work is especially important and will show us which product features and use patterns (at the product and consumer level) and laws and provisions (at the policy level) impact the risk for adverse outcomes in youth.

This systematic review and meta-analytic report has some limitations. Most studies in our analysis used binary state-level cannabis laws (e.g., MCL = 1 vs. non MCL = 0). Few studies considered variation across laws and effects of provisions in their analyses. This is something future research should focus on. One other limitation is that included studies applied secondary analysis and relied on national datasets which have their own inherent limitations. Self-reporting of substance use in surveys can be a limitation. Most included surveys are anonymized to improve confidentiality and are generally considered reliable,[80,81] though recent evidence has also found a significant underreporting of cannabis use by adolescents.[82] National surveys, for example, the MTF, are also not meant to be representative of a single state, and the other school-based surveys were also generally limited to public schools. [83,84]Some states do not participate consistently in the surveys leading to missing data for some years. However, it is expected that with longer duration of period from exposure to legalization, some of these limitations like missing data for some years may even out. In that context, considering that most recent RCL studies have been consistently showing an increase in cannabis use in adolescents, our estimates may be conservative. Notably, any legalization cannot have its effects in isolation. When examining the effects of legalization (for e.g. RCL), only few studies have adjusted for the presence of other cannabis policy in the same state (e.g. MCL) while assessing the effects on cannabis use outcomes in youth.[85,86] Some of this concern is mitigated by inclusion of newer studies that have classified the states based on restrictiveness of laws[28,60] or used individual level data when available.[57] Further such assessments may provide more clarity on the effects. Lastly, there is also a limitation related to outcome heterogeneity. Despite our best efforts to include high quality studies that use similar designs, there remained a moderate level of heterogeneity. Thus, we used random effect model and conducted a series of sensitivity tests and supplemental analyses to explore reasons for heterogeneity. The results

may reflect true heterogeneity of results between states or between different populations, but those potential causes could not be explored.

In summary, this article presents an updated systematic review and meta-analysis on the effect of cannabis laws on cannabis use in US youth. Our meta-analytic results indicate that recreational legalization is associated with an increase in past-month cannabis use among youth in the US. In contrast, medical legalization had negligible effects on this outcome. More research is needed to understand the long-term effects and the potential impact of cannabis legalization on youth cannabis use and other psychosocial outcomes that commonly track with cannabis use during adolescence, such as mental health, academic performance, and social/emotional processing. As cannabis legalization evolves, state legislatures should prioritize making decisions based on robust scientific evidence and empirical research findings, relying less on public sentiments. Policymakers must ensure that their decision-making is not influenced by cannabis lobbyists who may have a conflict of interest in prioritizing the commercialization of cannabis over public health. Our current results and future work in this area are of significant value to policymakers, who should take these findings into account when making policy decisions related to cannabis legalization.

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Figure 1. PRISMA diagram outlining selection procedure for studies.
Figure 2. Meta-analysis of medical cannabis legalization (MCL) effects on past month cannabis use in US youth.
Figure 3. Meta-analysis of recreational cannabis legalization (RCL) on past month cannabis use in US youth.
Table 1. Characteristics of studies included in systematic review.

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
Alley et al., 2020[40]	48 US states/ 867502	*Age group:* 18 to 26 y.o. *Mean age:* not specified. *Females:* 68.1% (RCL), 66.8% (non-RCL) *Race:* White: 62.4% (RCL), 77.2% (non-RCL) Black:4.0%(RCL)7.0% (non-RCL) Hispanic:18.7%(RCL), 7.4%(non-RCL) Asian:17.8%(RCL), 9.1%(non-RCL) Native American:2.1%(RCL), 1.7%(non-RCL) Biracial:6.0%(RCL), 3.5%(non-RCL) Other:3.5%(RCL), 2.2%(non-RCL)	NCHA II 2008-2018	Seven RCL states till 2018, one RCL state was excluded due to lack of enough data, the exact state was not given, compared to non-RCL states	Past month cannabis use, past month other drug use including nicotine, binge drinking, sedatives, and stimulants	RCL implementation was associated with an increase in cannabis use, with decrease in binge drinking and increase in sedative misuse but did not influence other drug use.[Cannabis use data same as in Bae and Kerr 2020[41]]
Anderson et al., 2021[24]	All 49 states and DC grades 9-12 graders. 1919239 (National YRBS) and 1418682 (State YRBS)[d]	*Age group:* ~13 to 18 y.o. *Mean Age*:16.06 y.o.(National YRBS) y.o and 16.03 y.o. (State-YRBS) *Females:*49.1% (National YRBS) and 49.8% (State YRBS) *Race:* Non-Hispanic Whites:61% (National YRBS), 59%. (State YRBS)	YRBS 1993-2019	Ten RCL and 29 MCL states providing pre- and post-legalization data, compared to non-RCL and non-MCL states respectively.	Past month cannabis use, frequent cannabis use	RCL or MCL enactment were not associated with any changes in cannabis use in analyses using either state level or national level YRBS.
Anderson, et al., 2015[42]	All 49 States and DC YRBS:862795, NLSY 97:40986, TEDS:3493	*Age groups:* 12-17 y.o. (National and State YRBS) , 12-19 y.o. (NLSY97), 12 to 20 y.o. (TEDS). *Mean age:*16.0 y.o. (National YRBS MCL)16.2 y.o.(National YRBS Non-MCL), 15.8 (State YRBS MCL), 16.0 y.o.(State YRBS Non-MCL), 16.8 y.o.(NLSY97 MCL) and 16.6 y.o.(NLSY97 non-MCL) *Females:*51.5% (National YRBS MCL), 51.0% (National YRBS Non-MCL), 51.1% (State YRBS MCL), 51.6% (State YRBS Non-MCL).	YRBS, NLSY97, TEDS YRBS: 1993-2011, NLSY97:1997-2003, TEDS 1992-2009	Nineteen MCL states: AL, AR, AZ, CA, CO, DE, DC, HI, ME, MI, MT, NV, NJ, NM, NM, OR, RI, VT, and WA, compared to non-MCL states	Past month cannabis use, frequency of cannabis use, cannabis use at school, use of other	MCL passage was not associated with any significant change in cannabis use parameters or other substance use in state YRBS, or NLSY97, but was associated with a small decrease in cannabis use in adolescents when national YRBS was used. Age and Gender did not show any associations with cannabis use parameters comparing MCL to non-MCL states in any dataset

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
		Race: White:32.4% (National YRBS MCL), 43.5% (National YRBS Non-MCL), 70.2% (State YRBS MCL), 64.0% (State YRBS Non-MCL) Black:7.9% (National YRBS MCL), 2.61% (National YRBS Non-MCL), 4.0%(State YRBS MCL),15.6%(State YRBS non-MCL). *%Female and race distribution for NLSY97*: not specified.			substances, cannabis use reported on admission (from TEDS)	except for a statistically significant decrease amongst adolescents in national YRBS.
Bae and Kerr, 2020[41]	Young adult college students in 48 US states 834274	Values same as in Alley et al., 2020[40]	NCHA II 2012-2017	Seven RCL: AK, CA, CO, DC, MA, ME, NV, WA, and OR compared to non-RCL states.	Past month cannabis use, Frequent cannabis use.	Cannabis use showed a continuously increasing growth over the years in the earliest states that had implemented RCL compared to non-RCL. Effects were more pronounced for women, >21 years of age and for those who lived off-campus. Being White was a risk factor while being Asian presented as protective factor for RCL related increase in cannabis use. MCL status of the states did not affect the outcomes.
Cerda et al., 2017[43]	8th, 10th and 12th graders in WA (30 schools), CO (17 schools) with 45 other states. 253902 [8th grade: 89316, 10th grade 85110, 12th grade 79476]	[e]*Age group:*~13 to 18 y.o. [e]*Mean Age:*15.7 (CO 2010-2012), 14.9 (CO 2013-2015), 15.5 (WA 2010-2012) and 15.1 y.o.(WA 2013-2015), 15.6 (Non-RCL or MCL), 15.6 (MCL Only) [e]*Female:*50.5% (CO 2010-2012), 49.1 (CO 2013-2015), 48.6 (WA 2010-2012 and 48.4 y.o.(WA 2013-2015), 51% (non-RCL or MCL), 51%(MCL Only) [e]*Race:* White:57.1% (CO 2010-2012), 20.8% (CO 2013-2015), 67.2%(WA 2010-2012 and 55.1% y.o.(WA 2013-2015), 57% (non-RCL or MCL), 52%(MCL Only) Black: 3.9 (CO 2010-2012), 7.6% (CO 2013-2015), 3.5%(WA 2010-2012 and 4.0% y.o.(WA 2013-2015), 15.5% (non-RCL or MCL), 7.7%(MCL Only) Hispanic: 22.8% (CO 2010-2012), 54.1% (CO 2013-2015), 11.6%(WA 2010-2012 and 17.0% y.o.(WA 2013-2015), 12% (non-RCL or MCL), 21.5%(MCL Only) Asian: 4.3%(CO 2010-2012), 2.4% (CO 2013-2015), 6.2%(WA 2010-2012 and 7.5% y.o.(WA 2013-2015), 2.6% (non-RCL or MCL), 6.5%(MCL Only) Multiple: 9.6%(CO 2010-2012), 13.2% (CO 2013-2015), 8.3%(WA 2010-2012 and 12.5% y.o.(WA 2013-2015), 9% (non-RCL or MCL), 10%(MCL Only) Other:2.3% (CO 2010-2012), 1.8% (CO 2013-2015), 3.2%(WA 2010-2012 and 3.8% y.o.(WA 2013-2015), 1.7% (non-RCL or MCL), 2.4%(MCL Only)	MTF 2010-2015	Two RCLs WA, and CO. comparing with non-RCL states.	Past Month cannabis use, perceived harm due to cannabis use	Cannabis use increased, and perceived risk decreased in 8th and 10th graders in WA, compared to non-RCL states. It remained unaffected in 12th graders and in another RCL-state (CO).Perceived risk decreased with RCL enactment, except for no change in 12th graders in WA and in all grades in CO.
Cerda et al., 2018[30]	8th, 10th and 12th graders in 48 contiguous US states. 1179372 [423899 8th graders, 386596 10th graders, and 368877 12th graders]	*Age group:* 12-20 y.o. *Mean age:* 15.4 y.o.(both MCL and non-MCL) *Females*: 51.5% (MCL), 51.7%(non MCL) *Race:* White: 66.2% (MCL), 57.7% (non-MCL) Black:15.9% (MCL), 9.4%(non-MCL) Hispanic:8.9%(MCL), 16.5% (non-MCL) Asian:2.0%(MCL), 6.3%(non-MCL) Multiple:2.9%(MCL), 3.4%(non-MCL) Other:4.2%(MCL), 6.7%(non-MCL)	MTF 1991-2015	Twenty-one MCLs till 2015: AR, CA, CO, CT, DE, IL, ME, MD, MA, MI, MN, MT, NV, NH, NJ, NM, NY, OR, RI, VT, and WA, compared to non-MCL states	Past month cannabis use, other substance use, any Past two weeks binge drinking	MCL enactment was associated with a decrease in use of cannabis, cigarettes, binge drinking, and non-medical opioid and illicit substance use in early adolescents (8th graders) but did not show any change in 10th graders, and only showed an increase in non-medical opioid use and cigarette use in 12th graders.

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
Cerda et al., 2019[44]	All 50 states 303330	[f]*Age groups:* 12-17 y.o., 18 to 25 y.o. [f]*Mean age:* not specified. [f]*Females*:51.51% [f]*Race:* White: 65.3% Black:11.90% Hispanic:15.36% Other:7.31%	NSDUH 2008-2016	Four RCLs: AL, CO, OR, WA, compared to non-RCL states	Past-month cannabis use, frequent cannabis use, past-month frequent use among past-month users, past-year CUD, and past-year CUD among past-year users.	RCL enactment was associated with a small but significant increase in past year CUD amongst adolescents, a similar increase in CUD was also found in past-year users, but not in past month cannabis use, or frequent use. It was not associated with any changes in cannabis use amongst young adults.
Choo et al., 2014[45]	9th to 12th graders from five MCL states matched in pairs to five non-MCL state in geographic proximity. 11703100	*Age group:* ~14 to 18 y.o. *Mean Age:* not specified. *Females:*48.8% (MCL) and 49.4% (non-MCL) *Race:* White:81.8% (MCL) and 70%(non-MCL) Other:19.2% (MCL) and 30% (non-MCL).	YRBS 1991-2011	Five MCL: MT, RI, ME, NV, VT and 5 non-MCL states, ID, MA, NH, UT, NY.	Ever and past month cannabis use	MCL did not affect cannabis use from pre to post-MCL implementation in any state pairings
Coley et al., 2019[46]	9th to 12th graders from 45 US states 861082 (including decriminalization states).	*Age group:* 14-18+ y.o. [g]*Mean age:*15.9 y.o. [g]*Females:*51.9% [g]*Race:* White:60.9% Black:13.3% Hispanic:13.4% Other:12.5%	YRBS 1999-2015	Eighteen MCL: AZ, AK, CA, CT, DE, IL, MA, MD, ME, MI, MT, NH, NJ, NY, NM, NV, VT and RI, to non-MCL states	Past month cannabis use. Heavy cannabis use, and frequency of cannabis use.	MCL enactment showed small but definite reduction in cannabis use. Larger declines were seen in males, Black, and Hispanic population, and the association was stronger with increase in the years of exposure but not with the number of ounces allowed (greater or lesser than 2.5 ounces). Effects of decriminalization were non-significant with some inconsistency on stratifying the based-on age and race/ethnicity. Heavy use and frequency of use were unaffected with MCL policy.
Coley et al., 2021[47]	9th to 12th graders in 47 states with 1077938 cannabis users.	*Age group:* ~14 to 18 y.o. [g]*Mean age:*16.8 y.o. [g]*Females:*45% [g]*Race:* White:55.8% Black:16.6% Hispanic:21.0% Other:6.6%	YRBS 1999-2017	Six RCL: AK, CA, CO, MA, ME, and NV compared to non-RCL states.	Past Month cannabis use, alcohol use, cigarette, and e-cigarette use.	RCL enactment was not associated with a significant change in cannabis or alcohol use, but there was a small significant decline among prior cannabis users, and a small increase in the odds of e-cigarette use.
Harper et al., 2012[48]	All 50 States and DC 357 person-years	*Age group:* 12-17 y.o. *Mean age, %Females, Race: Not* specified	NSDUH 2002-2009	Seven MCL:D.C., MI, MT, NM, MI, RI, VT compared to non-MCL states.	Past month cannabis use, perceived harm due to cannabis use	Passage of MCL decreased past-month cannabis use among adolescents .No discernible effect on the perceived riskiness of monthly use.
Hasin et al., 2015[19]	8th to 12th grade students from 48 contiguous states 1098270	*Age group:* 12 to 17 y.o. [h]*Mean age, %Females, Race*: Not specified.	MTF 1991-2014	Twenty-one MCL states: AZ, CA, CO, CT, DE, IL, ME, MD, MA, MI, MN, MT, NV, NH, NJ, NM, NY, OR, RI, VT, and WA, versus non-MCL states	Past year cannabis use, Past month cannabis use	Cannabis use decreased in 8th graders post-MCL passage. No significant change in cannabis use in 10th or 12th graders post MCL

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
Johnson et al., 2017[49]	45 US states 715014	*Age group:* 12 to 17 y.o. [h]*Mean age, %Females, Race:* Not specified.	YRBS 1991-2011	Twelve MCL states: AK, AZ, CO, DE, ME, MI, MT, NV, NJ, NM, RI, and VT, versus non-MCL states.	Past month cannabis use, Heavy cannabis use	MCL enactment, years since enactment and more liberalized provisions were associated with a slightly lowered odds of cannabis use and were not associated with any difference in the heavy use. Higher possession limits and voluntary registration were associated with a significantly higher odds of cannabis use and its heavy use.[Cannabis use data is same as in Johnson et al., 2018[50]]
Johnson et al., 2018[50]	9th-12th graders from 45 US states 715014	*Age group:* 13 to 18 y.o. [h]*Mean age, %Females, Race*: Not specified.	YRBS 1991-2011	Twelve MCL states, AL, AZ, CO, DE, ME, MI, MT, NV, NJ, NM, RI and VT (Excluded early adopter states CA, WA, OR, and HI, and only used post-enactment dates for CO and VT), versus non-MCL states.	Past month cannabis use without alcohol use, Past month alcohol use, binge drinking, alcohol use without past month cannabis use, past month alcohol and cannabis co-use.	MCL enactment was not associated with change in cannabis use without alcohol use but was associated with lower odds of alcohol use both with or without cannabis use, and with lower odds of binge drinking, and these associations were stronger in less restrictive states.
Johnson et al., 2021[51]	9th to 12th graders in 45 US states and DC 1091723	*Age group:* ~13 to 18 y.o. [h]*Mean age, %Females, Race:* Not specified.	YRBS 1991-2015	Nineteen MCL: AL, AZ, CA, CO, CT, DE, IL, MA, MD, ME, MI, MT, NH, NJ, NV, NY, NM, RI, and VT, versus non-MCL states.	Past month cannabis use, daily cannabis use	Past month cannabis use was lower in MCL states and in states with operational dispensaries in 2015. MCL enactment had no effect on heavy Cannabis use.
Kerr et al., 2017[29]	Undergraduates at seven US universities, [comparing Oregon (RCL) to 6 universities in non-RCL states] 10924	*Age group:*~18 to 25 y.o. *Mean age:* not specified. *Females:*49.3% (OR pre-RCL) 46.0% (OR post RCL), 56.3% (pre-RCL for non-RCL states), 53.3% (post-RCL for non-RCL states), and 55.3% (pre-RCL all states), 51.9% (post RCL all states). *Race:* White: 68.3% (OR pre-RCL), 58.0% (OR post RCL), 68.2% (pre-RCL for non-RCL states), 62.7% (post-RCL for non-RCL states), 68.2% (pre-RCL all states), 61.8% (post RCL all states). Black:0.7% (OR pre-RCL), 2.3% (OR post RCL), 3.7% (pre-RCL for non-RCL states), 4.2% (post-RCL for non-RCL states), 3.2% (pre-RCL all states), 3.9% (post RCL all states). Asian:14.1%(OR pre-RCL), 16.5% (OR post RCL), 12.4% (pre-RCL for non-RCL states), 16.8% (post-RCL for non-RCL states), 12.7% (pre-RCL all states), 16.7% (post RCL all states). Hispanic: 4.5% (OR pre-RCL) 7.0% (OR post RCL), 3.8% (pre-RCL for non-RCL states), 5.9% (post-RCL for non-RCL states), 3.9% (pre-RCL all states), 6.1% (post RCL all states). Multi-racial:8.3% (OR pre-RCL) , 8.1% (OR post RCL), 8.6% (pre-RCL for non-RCL states), 6.1% (post-RCL for non-RCL states), 8.5%(pre-RCL all states), 6.4% (post RCL all states).	Oregon Healthy Minds Study 2012-2016	One RCL state, OR vs 6 non-RCL states.	Past month cannabis , past month cigarette and heavy alcohol use.	RCL implementation was associated with an increase in cannabis only in students with recent heavy alcohol use, the effect was stronger amongst <21 years of age. Factors increasing the risk included male gender, and identifying as bisexual, while being Asian was associated with lower rates of cannabis use. RCL was not associated with any change in cigarette or heavy alcohol use.

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
		Other:4.2%(OR pre-RCL), 8.1% (OR post RCL), 3.4% (pre-RCL for non-RCL states), 4.3% (post-RCL for non-RCL states), 3.5% (pre-RCL all states), 5.0% (post RCL all states).				
Kerr, Bae, & Koval, 2018[52]	Undergraduate students in two OR institutions and 123 non-RCL states' institutes 281752	*Age group:* 18-26 y.o. *Mean age:* not specified. *Females:*60.1% (OR) vs. 66.4% (non-RCL) *Race:* White:77.9% (OR), 69.6% (non-RCL) Asian:11.1% (OR), 12.8% (non-RCL) Black:1.0% (OR), 5.1% (non-RCL) Hispanic:4.0% (OR), 8.6% (non-RCL) Others/multi: 6.0% (OR), 4.0% (non-RCL)	NCHA-II 2008-2016	One RCL state OR versus non-RCL states.	Past month use of cannabis, frequency of cannabis use, past month tobacco, alcohol, and other drug use.	RCL implementation was associated with significant increase in cannabis use and frequency of sporadic (1-5 days/month) use compared to non-RCL states, RCL was also associated with a decrease in tobacco use prevalence and frequency of use, but there was no significant effect on the use of other substances. Male gender and being white were associated with higher risk of cannabis use while unlike Kerr et al., 2017[29] , sexual orientation, alcohol use and legal age were not.
Keyes et al., 2016[21]	8th, 10th, 12th graders in 48 states 973089	*Age group*: ~12 to 18 y.o. [h]*Mean age, %Females, Race*: Not specified.	MTF 1992-2014	Twenty-one MCL states: AZ, CA, CO, CT, DE, IL, ME, MA, ND, MI, MN, MT, NV, NH, NJ,NM, NY, OR, RI, VT, and WA, versus non-MCL states	Past month cannabis use, perception of harm with cannabis use.	MCL passage was significantly associated with lower cannabis use among 8th graders but not among 10th and 12th graders. Among 8th graders, perceived harmfulness significantly increased post-MCL passage, but it did not change significantly among 10th and 12th graders. Results were the same on sensitivity analysis including states with dispensary allowance only.
Kim et al., 2021[22]	All 50 States and DC ~490000[i]	*Age group*: ~12 to 18 y.o. [h,j]*Mean age, %Females, Race:* Not specified.	NSDUH 2004-2017	Nine RCL: AK, CA, CO, DC, MA, ME, NV, OR, and WA to non-RCL states. 23 MCL: AZ, AK, CT, DC, DE, DE, FL. IL, LA, MA, MD, MI, MN, MO, NH, ND, NJ, NM, NY, OH, PA, RI, VT, and WV to non-MCL states.	Past month use of cannabis without alcohol use, past month use of cannabis with alcohol use, past month non-use of cannabis or alcohol, and past month only alcohol use.	Results varied by age strata and the type of legalization enacted (RCL or MCL), with MCL only showing a significant decrease in cannabis use in adolescents, while RCL showed no significant effects.
Lynn-Landsman et al., 2013[53]	Four US MCL states. Range:4319 to 12563[k]	*Age group:* ~12 to 18 y.o. [h]*Mean age, %Females, Race:* Not specified.	YRBS 2003-2011	Four MCL: MT, RI, MI, DE compared to each other with their non-MCL status.	Ever use of cannabis, past month use of cannabis, frequency of cannabis use	MCL passage was not associated with change in cannabis use except for once in ever use on twenty separate between-state comparisons which can be attributed to chance alone. There was no significant effect of MCL on frequency of cannabis use.

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
Martins et al., 2016[39]	All 50 US states ~450000[i,l]	*Age groups:* ~12 to 17 y.o., 18 to 25 y.o. [h]*Mean age, %Females, Race*: Not specified.	NSDUH 2004-2013	Ten MCL: AZ, CT, DE, IL,MA,MI, NH, NJ, NM, RI versus non-MCL states.	Past month cannabis use, perceived availability of cannabis	MCL passage was not associated with any change in cannabis use among adolescents and young adults. Perceived cannabis availability was associated with increased risk of cannabis use and was higher in states that eventually passed MCL in 2013 than those that did not.
Martins et al., 2021[54]	All 50 US states 142400	*Age group:* 12-20 y.o. [m]*Mean age:*43 y.o. (in total sample with age>65y.o.) [m]*Females:*51.5% (in total sample with age >65 y.o.) [m]*Race:* (in total sample only) Non-Hispanic White:61.0% Non-Hispanic Black:11.8% Hispanic:9.4% Other:17.8% (Native American/Pacific Islander/Asian/Multi)	NSDUH 2008-2017	Nine RCL: AL, CA, CO, DC, OR,MA, ME, NV, WA versus non-RCL states.	Past Year cannabis use, Past Month cannabis use, daily cannabis use, CUD	No change in Cannabis use after RCL vs before-RCL enactment in any racial/ethnic group in 12-20 y.o. (Above 20 age groups not stratified to give data for 18 to 25 y.o.).
Mauro et al, 2019[38]	All 50 US states except DC ~350,000[i,l]	*Age groups*: 12-17 y.o., 18-25 y.o. [h]*Mean age, %Females, Race*: Not specified.	NSDUH 2004-2013	Seven MCL RI, NM, MI, AZ, NJ, DE, CT, MA, IL, and NH versus non-MCL states	Past month cannabis use, daily cannabis use over past year, CUD.	MCL enactment was not associated with any increase in past month use, and CUD in men or women between 12 to 25 years of age. Daily use increased in men aged 18 to 25 years only.
Mennis et al., 2023[55]	All 50 US states 55000	*Age groups:* ~12 to 17 y.o.,18 to 24 y.o. [h]*Mean age, %Females, Race*: Not specified.	TEDS-A correlated with NSDUH data 2008-2019	Eight RCL: AL, CO, ME, MA, NC, OR, WA, DC versus non-RCL states.	Past month cannabis use, Treatment admissions for cannabis use disorder, perception of harm with cannabis use.	RCL enactment was associated with increased past month cannabis use in adolescents and young adults. Treatment admissions for cannabis use decreased in both age groups, with a stronger association in adolescents Association of decreased perception of harm with increased cannabis use strengthened in both age groups with RCL passage.
Miller et al., 2017[56]	Undergraduates at Washington state university(WSU) 13335 WSU students, compared to 609755 National NCHA and 75101 NSDUH students	[n]*Age group:*~18 to 25 yo *Mean age:*20.49 y.o.(WSU NCHA), 21.09 y.o. (National NCHA), and 20.84 y.o. (NSDUH) *Females:*58% (WSU NCHA), 65% (National NCHA), and 55% (NSDUH) *Race:* White:80% (WSU NCHA), 77%(National NCHA), and 61% (NSDUH) Black:3%(WSU NCHA), 6% (National NCHA), and 3% (NSDUH) Asian:12% (WSU NCHA), 10%(National NCHA), and 14% (NSDUH) Hispanic:8%(WSU NCHA), 8%(National NCHA), and 6% (NSDUH) Other:<5% (American Indian/Hawaiian/Alaskan Native and others)	WSU NCHA, National NCHA, NSDUH WSU NCHA: 2005-2011, National NCHA: 2005-2011, NSDUH: 2005-2015	One RCL:WA versus national datasets used as counterfactuals representing non-RML status.	Past month cannabis use, frequency of cannabis use, past month other substance use.	RCL passage was associated with increase in cannabis use in WSU undergraduates and was also associated with increased frequency of use when comparing with national datasets. Male gender, black, and white race were associated with an increased risk of cannabis use, while Asian race was a protective factor from the effect of RCL.
Neeley and Richardson, 2022[28]	All 50 states. ~665000[i]	*Age groups:* ~12 to 17 y.o., 18 to 25 y.o. [h]*Mean age, %Females, Race*: Not specified	NSDUH 2000-2019	Eight RCL: AL, CO, ME, MA, NC, OR, WA, DC, and all 33 MCL states till 2019, compared to their non-MCL and non-RCL status.	Past month cannabis use, incidence of cannabis use, other illicit drug use	States with higher 'pharmaceutical score'(MCLs) had lower cannabis use in adolescents and young adults, while those with permissive and fiscal approach (predominantly RCLs) had higher rates of cannabis use [Exact states not provided].

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
Orsini et al., 2023[57]	Adolescents participating in a national tobacco survey from all 50 states. 72884	*Age group:* 12 to 17 y.o. [g]*Mean Age:*14.6 y.o. [g]*Females:*48.3% [g]*Race:* Non-Hispanic White: 47.9% Non-Hispanic Black:13.3% Hispanic:29.1% Other:9.7%	PATH 2013-2019	Eight RCL: AL, CO, ME, MA, NC, OR, WA, DC, and all 33 MCL states till 2019 versus non-RCL and non-MCL states respectively.	Past month cannabis use	Odds of cannabis use were significantly higher when cannabis use was legalized (MCL as well as RCL enactment) versus when it was decriminalized or criminalized
Pacula et al., 2015[18]	All 49 States and DC 46375	*Age group:* ~12 to 21 y.o. [h,o]*Mean age, %Females, Race:* Not specified.	NLSY97, and TEDS NLSY97:1997-2011, TEDS: 1992-2011;	Seven MCL states: CO, ME, MD, MT, NV, OR, WA and VT versus non-MCL states.	Past months cannabis use, frequent cannabis use, number of days cannabis used in past month, treatment rates and non-criminal justice referred treatment rates for cannabis related admissions.	Passage of MCL either had no impact or led to slightly reduced cannabis use and treatment admissions. Certain aspects of MCL such as dispensary allowance were at greater risk of an increase in use.
Schmidt et al., 2019[27]	All 50 States and DC 450300	*Age groups:* 12-14 y.o., 15 to 17, y.o, and 18 to 25 yo *Mean age:* not specified. *Females*:48.8%(12 to 14 you MCL), 47.8(12 to 14 yo non-MCL), 49%(15 to 17 yo MCL), 50.1%(15 to 17 you non-MCL), 49.5%(18 to 25 you MCL), 49.8%(18 to 25 yo non-MCL) *Race:* White:47.4%(12 to 14 you MCL), 58.0% (12 to 14 you non-MCL), 48.6%(15 to 17 yo MCL), 59.5% (15 to 17 yo non-MCL), 49.9%(18 to 25 yo MCL), 59.7%(18 to 25 yo non-MCL) Black:7.9%(12 to 14 you MCL), 16.3% (12 to 14 you non-MCL), 8.2%(15 to 17 yo MCL), 18.2% (15 to 17 yo non-MCL), 8.6%(18 to 25 yo MCL), 17.8%(18 to 25 yo non-MCL) Hispanic:32.4%(12 to 14 you MCL), 18.3% (12 to 14 you non-MCL), 29.8%(15 to 17 yo MCL), 16.2% (15 to 17 yo non-MCL), 28.8%(18 to 25 yo MCL), 16.1(18 to 25 yo non-MCL) Other: 12.3%(12 to 14 you MCL), 7.5% (12 to 14 you non-MCL), 13.5%(15 to 17 yo MCL), 6.1% (15 to 17 yo non-MCL), 12.7%(18 to 25 yo MCL), 6.3(18 to 25 yo non-MCL)	NSDUH 2004-2013	Twenty-Seven MCL: AL, AR, AK, CA, CO, CT, DE, DC, FL, HI, IL, ME, MD, MA, MI, MN, MT, NC, NH, NJ, NM, NY, ND, OR, RI. VT, and WA versus non-MCL states.	Past month cannabis use, past year initiation of cannabis use	Overall passage of MCL was not associated with any change in past month cannabis use. Cannabis use initiation in past year was more likely in young adults (18-25) in MCL states. Lesser restrictiveness in laws independently did not change the impact of MCL. Effects of race and gender varied significantly between different age groups for each outcome.

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
Schuermeyer et al., 2014[26]	CO vs 34 other states ~283500[p]	*Age groups:* 12-17y.o., 18-25 y.o. [h]*Mean age, %Females, Race:* Not specified	NSDUH 2003-2011	One MCL:CO versus non-MCL states.	Past year cannabis use, abuse and dependence, frequent use, perceived harm of cannabis use, and perceived accessibility	Passage of MCL showed significant increase in cannabis use, abuse and dependence in adolescents compared to non-MCL states over time, along with significantly lower perception of risk. No changes were observed in other parameters and amongst young adults. Males, and white race were at higher risk of cannabis use and dependence in past year.
Wall et al., 2016[58]	All 50 US states ~112500[q]	*Age group:* 12 to 17 yo. *Mean age:* Not specified. *Females:* 48.9% *Race:* White:67.9% Other:32.1%	NSDUH 2002-2011	Eight MCLs: AZ, DE, MI, MT, NJ, NM, RI and VT versus non-MCL states	Past month cannabis use	Passage of MCL was not associated with any significant change in cannabis use amongst adolescents.
Weinberger et al, 2022[23]	All 50 US states ~490000[d,i]	*Age groups:* 12-17 yo, and 18-25 yo Values not specified in the article though used individual level (e.g., age, gender, race) covariates.	NSDUH 2004-2017	Twenty-two MCL states: AR, AZ, CT, DC, DE, FL, IL, LA, MA, MI, MN, MO, NH, NJ, NM, NY, ND, OH, PA, RI, VT, and WV; and 9 RCL states: AK, CA, CO, DC, MA, ME, NV, OR, and WA, compared to non-RCL and non-MCL states respectively.	Past month cannabis use, past month cigarette use, past month co-use of cigarette and cannabis	MCL enactment was associated with a significant decrease in cannabis -only, and cannabis and cigarette co-use among adolescents but showed no associations among young adults. Both RCL and MCL showed a significant decrease in cigarette only use in both age groups. RCL had similar results as MCL for adolescents though showed a minimal but statistically significant decrease in co-use amongst young adults.
Wen et al., 2015[59]	All 50 States and DC 269500	*Age group:*12-20 y.o. *Mean age:* 16.0 y.o. (both for MCL and no or always MCL) *Females:*48.6%(MCL), 48.8%(non-MCL) *Race:* White:60.79% (MCL),58.82% (no or always MCL) Hispanic:18.8%(MCL),19.1%(no or always MCL) Black:12.8%(MCL),15.0%(no or always MCL) Asian:3.46%(MCL),4.37%(no or always MCL) Other:4.15%(MCL),2.71%(no or always MCL)	NSDUH 2004-2012	Ten MCL:VT, MT,RI,NM,MI,NJ, DC,AR,DE, and CT, compared to non-MCL states	Past month cannabis use, daily use, frequency of use, first use in last one year, cannabis abuse or dependence, co-use of alcohol or cannabis in last month, alcohol use (including binge drinking or dependence), Other Substance use	MCL passage was associated with an increase only in the last year cannabis initiation among 12 to 20 years. Having a retail dispensary independently predicted an increased past month use. MCL overall did not influence alcohol use and other substance use (cocaine, heroin, non-medical prescription opioids) in adolescents and young adults but increase in binge drinking, combined cannabis, and alcohol use in >21yo [data was not stratified to give results for young adults].
Williams et al., 2017[60]	All 50 states ~325000[i]	*Age groups*: 12-17 y.o., 18-25 y.o. [h]*Mean age, %Females, Race:* Not specified	NSDUH 2004-2013	Twenty-three MCL states :8 'medicalized' more regulated MCLs: CT, DE, IL, MA, MN,NH, and NY; and 15 'non-medicalized' less regulated MCL states AK, AZ, CA, CO, HI, MD, ME, MI, MT, NJ, NM, NV, OR, RI, VT,	Past month cannabis use, heavy cannabis use, cannabis use disorder	MCL enactment was not associated with an increase in active cannabis use amongst youth. However, there was slightly lower prevalence of cannabis use disorder among young adults after enactment and there was a decrease in prevalence of heavy use amongst adolescents in less regulated states.

Study Name	Sample/Sample size	Socio-demographics[a] Age group (y,o,: years old)/Mean age/%Females/Race or ethnicity	Source of data[b] /Period included	Legalization and states included[c]	Measures studied	Main findings[c]
				and WA, were each compared to non-MCL states.		

[a]Only the age group included in this review is shown. Race/ethnicity categorized as given in each individual article. [b]Abbreviations used: MCL, Medical Cannabis Legalization; RCL, Recreational Cannabis Legalization, MTF, Monitoring the Future survey; NCHA, National College Health Assessment survey, NLSY97, National Longitudinal Survey of Youth 1997 survey; NSDUH National Survey on Drug Use and Health; PATHS, Population Assessment of Tobacco and Health Study, TEDS Treatment Episode Data Set; WSU, Washington State University Survey, YRBS, Youth Risk Behavior Survey; [c]Two letter standard state abbreviations used for US states. Passage of law refers to the first stage where a bill is introduced for legislation, followed by enactment when passed through executive to become a law, followed by implementation when the law is put into practice by relevant bodies. Two studies (Cerda et al, 2017 and Kim et al, 2019) also compared RCL to MCL only states, effect size from RCL to MCL-only comparisons were not used. [d]Not stratified by legalization.[e]Age, sex, race distribution not given by grades, while main effects were provided for each grade. [f]Gender and race not specified by age group or by legalization and included total sample with 77.2% being > 26 y.o. Age 12-17 were 9.55% and 18 to 25 were 13.21% of total sample.[g]Only given for total sample, not separated by legalization status.[h]Age, sex, and racial distribution not provided in the article though these were used as individual covariates. [i]Approximately ~17500 adolescents and ~17500 young adults each year. [j]Effects of categorical age-groups, gender, and race were provided for total sample that included >25 y.o. [k]Different values for different comparisons. [l]Approximately ~17500 adolescents and ~17500 young adults each year, data not given for men or women separately. [m]Only total sample (including >65 y.o.) values given as data on mean age, gender and race was not stratified for included age group (12 to 20 yo), though for total sample age, gender and racial distribution was also given separately for non-legalized, MCL only and RCL states which is not shown here.[n]Based on being undergraduates and mean age of all samples being 20 yo. [o]Used individual level covariates for NLSY97 (age and gender only).[p]Estimated from NSDUH (450 per state*35(states)*2(age groups)*9 years)). [q]From NSDUH average, 22500*10/2, as data aggregated two yearly.