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CANNABIS (D D'SOUZA AND P SKOSNIK, SECTION EDITORS)

Has the Legalisation of Medical and Recreational Cannabis Use in the USA Affected the Prevalence of Cannabis Use and Cannabis Use Disorders?

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Abstract

Purpose of Review Since California legalised medical use of cannabis in 1996, 29 other US states have done so. Eight US states have legalised the retail sale of cannabis to adults over the age of 21 years since 2012. Critics of these policy changes have suggested that they will increase the prevalence of cannabis use and cannabis use disorders. This paper (1) briefly describes the types of regulatory regimes for medical and recreational cannabis use in the USA, (2) describes possible effects of these policies on cannabis use and (3) assesses the impacts to date of the legalisation of medical and recreational cannabis use on the prevalence of cannabis use and cannabis use disorders in the US population. We (1) describe the regulatory regimes for medical and recreational cannabis use in the USA, (2) make predictions about their possible effects on the price and availability of cannabis, (3) conduct a review to summarise studies of the effects of legalising medical cannabis use in the USA on rates of cannabis use and cannabis use disorders and (4) assess early indications of the effects of legalising recreational cannabis use on cannabis use and cannabis use disorders.

Recent Findings Liberal forms of medical cannabis regulation have probably reduced prices and increased the availability of cannabis. Analyses of survey data suggest that these changes have increased the prevalence and frequency of cannabis use among adults over the age of 21 years, but they have not to date increased rates of cannabis use among adolescents. Two series of epidemiological studies over a decade following the introduction of medical cannabis laws have produced inconsistent results on the effects of policy changes on the prevalence of cannabis use disorders in adults. One study found that the prevalence had increased; the other did not find an increase. An analysis of data on treatment seeking for cannabis use disorders showed an increase in states with medical cannabis laws in the number of adults seeking treatment who were not under legal coercion. There are major limitations with these studies, many of which have mistakenly assumed that all states with medical cannabis laws have similarly liberal policies.

Summary It may be a decade or more before we can fully assess the effects of liberalisation of cannabis policies on cannabis use and cannabis use disorders in the USA. It is critical that the effects of these policy changes are evaluated to ensure that cannabis is regulated in ways that minimise the harmful effects of its regular use, especially among young people.

Keywords Medical marijuana laws · Marijuana abuse · Cannabis use disorder · Health surveys · USA

This article is part of the Topical Collection on *Cannabis*

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Introduction

Since the mid-1990s, a number of US states have passed citizen-initiated referenda to legalise the medical use of cannabis. This approach was first used in California in 1996 when voters passed Proposition 215 (by 56 to 44%) which allowed the medical use of cannabis for a broad set of indications that included nausea, weight loss, pain and muscle spasm and any "serious medical condition" for which cannabis may provide relief [1]. Since then, 29 states have legalised medical use of cannabis in some form.

US medical cannabis policy is subject to conflicting state and federal laws. Federally, cannabis is listed as a Schedule I drug under the Controlled Substances Act (CSA) [2] and hence classified as having a high potential for dependency and no accepted medical use. This makes the production, distribution and use of cannabis a federal offence. Proposition 215 in California in 1996 and subsequent legislation in many states that have enacted medical cannabis laws conflict with the CSA. These laws vary in which cannabis-containing products are permitted and whether they can be obtained by home cultivation or via dispensaries. In 16 states, only products that are low in the primary psychoactive cannabinoid, delta-9-tetrahydrocannabinol (THC) and high in cannabidiol (CBD), a non-psychoactive cannabinoid, are allowed for medical use. In some states, medical use is only allowed as a legal defence. Only four states and three territories do not allow any medical cannabis use (Idaho, South Dakota, Nebraska, Kansas, American Samoa, US Virgin Islands and Northern Mariana Islands).

The conflict between federal and state policy on marijuana has resulted in a patchwork of state regulation [3–5]. For example, 29 jurisdictions (28 states and the District of Columbia) have legalised medical cannabis but only 18 mandate product safety testing before sale. Whilst the majority allow dispensaries, there is variation in their regulation. There are also large variations in the medical conditions that qualify for medical cannabis recommendations, although most jurisdictions include cancer, glaucoma and HIV/AIDS as eligible disorders. These policy variations made it difficult to map the possible influences of policy implementation on cannabis use and misuse, but they also provide opportunities to study the effects of a range of specific regulations on health outcomes. Medical marijuana policies across jurisdictions that have enacted comprehensive medical programs are highlighted in Text Box 1.

Text Box 1 Convergence and divergence of medical marijuana policy within the USA

Klieger and colleagues [5] systematically described laws and regulations guiding medical marijuana within 28 jurisdictions of the USA (27 states and DC). This analysis was completed prior to the passage of the medical marijuana program in Oklahoma. A number of points of convergence and divergence are highlighted here and have been updated to reflect the implementation of medical marijuana in Oklahoma.

On advice from the US Department of Justice, all jurisdictions had implemented or were in the process of implementing medical cannabis patient registration systems. There was less consistency with other medical cannabis regulations. Most jurisdictions (86%) had explicit mechanisms for the revocation of dispensary permits but the grounds for doing so varied. Just over half (55%) allowed revocation for failure to adhere to medical cannabis laws, but only a minority did so for fraud (41%) or sale to non-medical users (41%). Dispensary locations are limited in most jurisdictions, with proximity to schools (72%) and day care facilities (38%) the most consistently specified locations.

All jurisdictions except DC and Oklahoma specified disorders that qualify for their medical marijuana programs. No single disorder is common to all medical cannabis programs, but there is > 80% support for medical use in the treatment of cancer, glaucoma, HIV/AIDS, cachexia, epilepsy and multiple sclerosis. Medical marijuana may be prescribed for any condition in DC or Oklahoma.

Most jurisdictions (79%) have legislated for some form of product safety testing, but four only require testing after complaints or reasonable concerns about contamination. Most (82%) have product labelling requirements, but these are highly variable. There is most agreement (> 50%) on requiring that products list the amount of usable marijuana and its potency. There is less support (< 50%) for health and safety warnings or the lack of FDA approval for medical use. Legislation passed in Oklahoma requires the establishment of safety standards for the processing and handling of medical marijuana, but these have not yet been specified or implement.

Legalisation of Recreational Cannabis Use

Regulation and taxation of recreational cannabis schemes in US states and the District of Columbia are presented in Table 1. A map presenting legal status of recreational and medical cannabis within the US states and territories is presented in Fig. 1. Since 2012, Alaska, California, Colorado, Maine, Massachusetts, Nevada, Oregon and Washington State have passed referenda and legislated to allow the sale of cannabis to adults over the age of 21 years [6]. At the time of writing, Vermont and the District of Columbia have legalised personal possession and cultivation for personal use but not sale. Colorado and Washington commenced legal sales in January and July 2014 respectively [7–9], with Oregon and Alaska following in 2015. Citizens in California voted to legalise adult use in 2016 and legal sales commenced in January 2018.

Colorado and Washington introduced regulations modelled on those for alcohol. Similar models have been adopted by many states that have legalised since (with the exceptions of Washington DC and Vermont, noted above). The most common regulations have restricted sales to adults over the age of 21 years and limited amounts that can be purchased to 28.5 g from each retailer [8, 10, 11]. State regulations differ in those who have been licensed to produce cannabis and the rate at which cannabis products are taxed [7, 10, 11]. Cannabis-impaired driving is prohibited in all states that have legalised cannabis [12].

Critics argue that the legalisation of medical cannabis and recreational cannabis will increase cannabis use by making cannabis more readily accessible, at a lower price and in the absence of criminal penalties for use [13]. Much of this concern has been focused on increased uptake among young people because of their heightened risk of developing problem cannabis use [14]. There are also more immediate concerns that liberalisation of cannabis policies will increase the frequency and potency of cannabis consumed by current users [13]. In this paper, we assess these concerns by first reviewing

Table 1 Regulation and taxation of recreational cannabis schemes in US states and the District of Columbia

Jurisdiction	Legislation mechanisms	Personal purchase or possession limits	Cultivation limits	Excise taxes	Sales taxes
Alaska	2014—Legalised via ballot *Alaska Measure 2.* 2015—Alaska HB 123 established Marijuana Control Board. 2016—Alaska HB 75 elaborated regulatory structure.	1 oz. of cannabis	An individual may cultivate 6 plants, of which only 3 can be mature flowering plants. Households are additionally limited to 12 (6 mature) plants.	$50/oz. for any part of the bud or flower $15/oz. for the remainder of the plant	No specific cannabis sales tax. Whilst Alaska has no sales tax, local governments are able to levy local sales taxes (up to 5%). Local option to enact further sales taxes. 5% sales tax enacted in some cities, such as Anchorage. $25/oz. tax levied in Petersburg Borough.
California	2016—Legalised via ballot measure *Proposition 64: Adult Use of Marijuana Act.*	1 oz. of flower or 8 g of concentrated cannabis	At most, 6 plants may be cultivated at a private residence.	Cultivation tax: $9.25/oz. for flower $2.75/oz. for leaves $1.29/oz. of fresh plant Excise tax: 15% of the average market price at wholesale.	No specific cannabis sales tax. 7.25% state sales tax applies, in addition to variable local sales tax, for a total sales tax of 8–10.25%. Local governments may charge a further Cannabis Business Tax, ranging from 5 to 15%.
Colorado	2012—Legalised via ballot measure *Colorado Amendment 64*. Enacted as Article 18, section 16 of the Colorado state constitution.	1 oz. of cannabis, which is equivalent to 8 g of concentrate and 800 mg of edible product. Consumers can mix and match products but cannot exceed the 1 oz. cannabis limit.	At most 6 plants, of which 3 can be mature plants.	15% of the average market rate, imposed at wholesale.	15% sales tax on retail sales. Recreational cannabis is exempt from 2.9% state sales tax, but local sales taxes may apply. Local option for counties and municipalities to levy up to 5% additional cannabis tax.
Maine*	2016—Legalised via ballot initiative *Question 1: An Act To Legalize Marijuana*	2.5 oz. of prepared cannabis.	Individuals may cultivate no more than 6 mature flowering plants and 12 immature plants. There is no limit to the number of seedlings. Plants must not be visible from a public way without optical aids.	No excise tax has been proposed or enacted.	10% sales tax on retail sales. Exempt from general 5.5% state sales tax. No local option exists to levy further taxes at retail sale.
Massachusetts*	2016—Legalised via ballot initiative *Question 4: Massachusetts Marijuana Legalization Initiative* Implementation by state legislature is pending.	1 oz. of cannabis, of which no more than 5 g may be in the form of cannabis concentrate.	Individuals may cultivate up to 6 plants, with a total limit of 12 per residence. Cannabis from cultivated plants is not counted towards personal possession limits.	No excise tax has been proposed or enacted.	10.75% sales tax on retail sales. 6.25% Massachusetts sales tax applies to retail sales. Local option exists for an additional 3% sales tax to be levied on cannabis products.
Nevada	2016—Legalised via ballot initiative *Question 2: Initiative to Regulate and Tax Marijuana*	1 oz. of cannabis and up to 0.125 oz. of concentrated cannabis.	Private cultivation is prohibited if there is a state-licensed dispensary within 25 miles of a residence. Where cultivation is permitted, individuals may cultivate up to 6 plants, with a total limit of 12 per residence. Plants must be made inaccessible to others via a lock or security device.	15% of fair market value at wholesale.	10% of retail price is levied as retail cannabis tax. General state sales tax of 6.85% applies, with additional local sales taxes (up to a total 8.15%).

Table 1 (continued)

Jurisdiction	Legislation mechanisms	Personal purchase or possession limits	Cultivation limits	Excise taxes	Sales taxes
Oregon	2014—Legalised via ballot initiative *Measure 91: Control, Regulation, and Taxation of Marijuana and Industrial Hemp Act* 2015—Oregon SB 1511 enabled sale of recreational cannabis from dispensaries	1 oz. personal possession limit for useable cannabis. This limit is raised for products that are kept at household premises.	Households are limited to 4 plants and 10 cannabis seeds. Additionally, households are limited to 8 oz. of homegrown useable cannabis.	No excise tax has been enacted.	17% of retail sales price, charged at point of sale. Local option for an additional cannabis sales tax of up to 3% may apply. No state sales tax exists.
Vermont	2018—Legalised via Vermont HB *H.511: An act relating to eliminating penalties for possession of limited amounts of marijuana by adults 21 years of age or older.*	1 oz. of marijuana; and 5 g of hashish. Cultivated cannabis is exempt if kept on premises.	Individuals may cultivate up to 6 plants (2 mature). Premises are, additionally, limited to a total of 6 plants.	No taxation structure for retail cannabis has been enacted as of May 2018.	No taxation structure for retail cannabis has been enacted as of May 2018.
Washington, DC	2014—Legalised via ballot initiative *71: Legalization of Possession of Minimal Amounts of Marijuana for Personal Use Act of 2014.*	2 oz. of cannabis.	Personal cultivation is not allowed.	Retail sale of cannabis is prohibited.	Retail sale of cannabis is prohibited.
Washington State	2012—Legalised via ballot initiative *Washington Initiative 502.* 2015—Legislature enacted HB 2136 implementing comprehensive reforms.	1 oz. of useable cannabis, 16 oz. of marijuana-infused edibles in solid form, 72 oz. in liquid form and 7 g of concentrate.	Individuals may cultivate 6 plants, of which at most 3 can be mature. Households are further limited to a total of 12 (6 mature) plants.	Excise taxes were levied when recreational cannabis was first introduced. These have been replaced with a single retail cannabis sales tax.	37% of retail price, charged at point of sale. 6.5% general sales tax applies, with additional local sales tax (up to 3.1%).

*Retail recreational cannabis sales have not begun in Massachusetts and Maine, and tax structures are proprosed rather than implemented

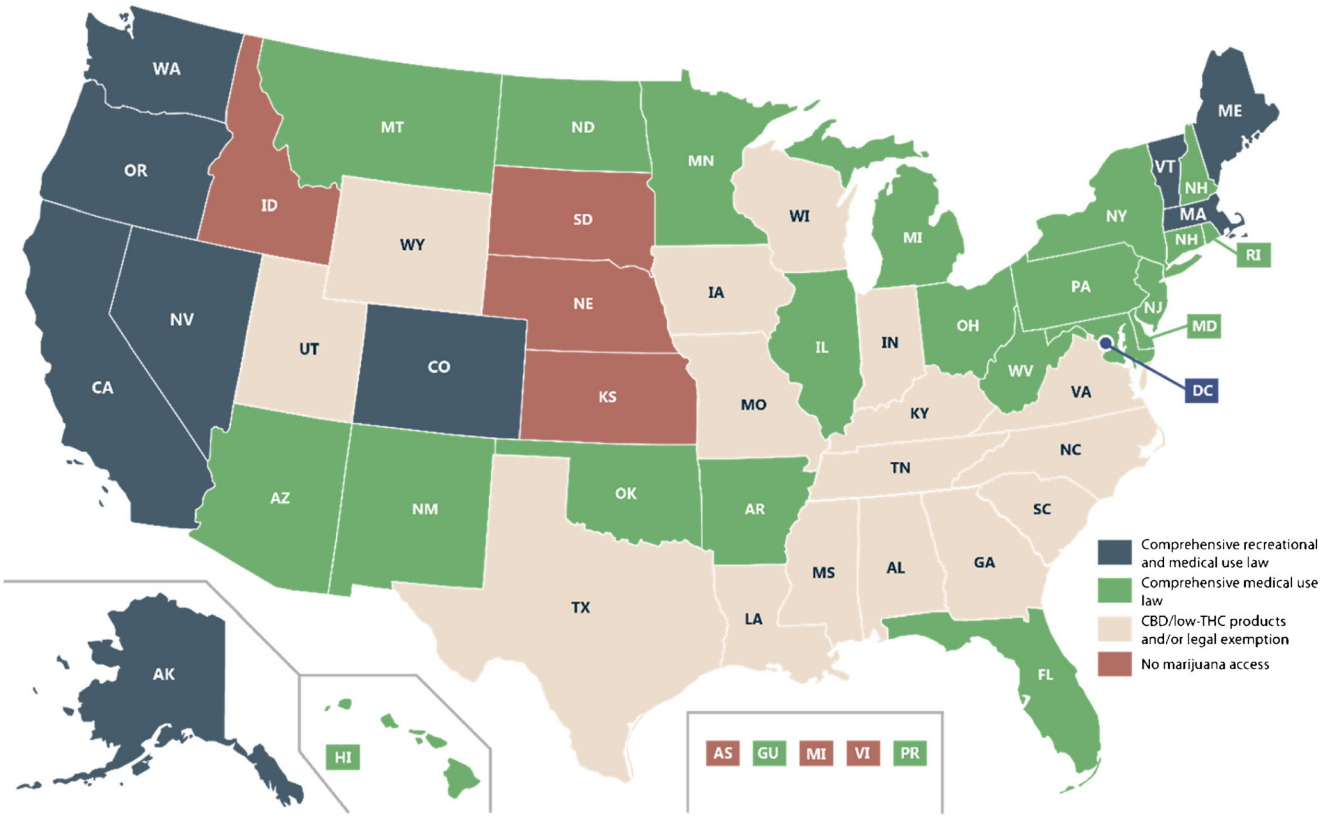

Fig. 1 Map presenting legal status of recreational and medical cannabis within the US states and territories. Legal status data reproduced with permission from the National Congress of State Legislatures (http://www.ncsl.org/research/health/state-medical-marijuana-laws.aspx). Image adapted from map of the USA created by Theshibboleth, Creative Commons Attribution-Share Alike 3.0 Unported license: https://creativecommons.org/licenses/by-sa/3.0/deed.en

evidence on the effects of legalisation of medical cannabis on rates of cannabis use and cannabis use disorders in the US population. This is the policy that has been implemented for the longest period in the most US states. We focus on studies that have evaluated these effects using well-conducted population surveys of cannabis use and cannabis use disorders. We then consider the more limited evidence on the effects of the legalisation of recreational cannabis use since 2012 on cannabis use and cannabis use disorders.

Major Surveys

Research on the effects of legalisation of medical cannabis on cannabis use has used data from representative epidemiological surveys and administrative collections. These have most often been national household surveys of drug use in the adult population and school surveys in the adolescent population. Administrative data sources include treatment data and crime reports. The major US data sources that have collected data on cannabis use are summarised in Table 2.

The key epidemiological surveys include the National Survey on Drug Use and Health (NSDUH, conducted yearly), the National Epidemiologic Survey on Alcohol and Related Conditions (NESARC) series (three surveys conducted in 2001–2002, 2004–2005, 2012–2013) and the National Comorbidity Survey (NCS) series (three surveys conducted in 1990–1992, 2001–2002, 2001–2003). An adolescent survey was conducted between 2001 and 2005. Key school-based surveys of adolescent samples include the Monitoring the Future (MTF) series (conducted yearly) and the Youth Risk Behavior Survey (YRBS, conducted biennially).

Only the NSDUH and NESARC surveys have used standardised diagnostic criteria to assess Cannabis Use Disorders (CUD; abuse and dependence). The NCS series measured cannabis usage and used the Composite International Diagnostic Interview short-form (CIDI-SF) [15] to assess mental disorders. However, NCS only assessed drug use disorders as a group. It did not report data separately on CUDs. The population surveys have a large sample size that is designed to be nationally representative and so may not collect enough data for analysis at state level. A common approach has been to categorise states into those with and those without medical marijuana laws (MML) by year and compare survey data on rates of cannabis use and CUDs between these groups of states. Studies have often combined

Table 2 Major US surveys that collected data on cannabis use and cannabis use disorders

Data source: years of data collection	Funder	Age of sample (years)	Sample size	Response rate (%)	Setting	Cannabis use measures	Cannabis use disorders measures
Population surveys							
National Survey on Drug Use and Health (NSDUH): yearly survey from 2002	SAMHSA	12–17 Youths and 18+ adults	~55,000–70,000 per survey	~70–80%	National self-report cross-sectional survey; civilian, non-institutionalized population	Marijuana age at first use, lifetime, past 12 months and past-month use	DSM-IV abuse, dependence, use disorder
National Epidemiologic Survey on Alcohol and Related Conditions (NESARC) series							
NESARC: 2001–2002	NIAAA; NIDA	18+ Adults	43,093	81%	Nationwide household survey with a probability sample representative of US adults	Marijuana use lifetime, last 12 months	DSM-IV abuse, dependence, use disorder
NESARC-II: 2004–2005	NIAAA	21+ Adults	34,653	86.70%	Follow-up of the same sample of respondents in NESARC wave 1	Marijuana use lifetime, last 12 months	DSM-IV abuse, dependence, use disorder
NESARC-III: 2012–2013	NIAAA	18+ Adults	36,309	72%	Cross-sectional, based on a nationally representative sample of the civilian non-institutionalized population	Marijuana use lifetime, last 12 months	DSM-IV abuse, dependence, use disorder; DSM-5 use disorder
National Comorbidity Survey (NSC) series							
National Comorbidity Survey (NCS; baseline): 1990–1992	ADAMHA (former name of SAMHSA); W.T. Grant Foundation	15 to 54	8098	82.40%	Nationally representative mental health survey	Marijuana/hashish age first use, ever use, past year use, past month, frequency of use	x
National Comorbidity Survey-2 (NCS-2): 2001–2002	NIDA	25 to 64	5001	72.20%	Follow-up of NCS; respondents of the baseline NCS were re-interviewed (NCS-2)	Marijuana/hashish age first use, ever use, past year use, past month, frequency of use	x
National Comorbidity Survey—Replication survey (NCS-R): 2001–2003	NIMH; NIDA; SAMHSA; Robert Wood Johnson Foundation; John W. Alden Trust	18+ Adults	9282	70.90%	Cross-sectional national survey	Marijuana/hashish age first use, ever use, past year use, past month, frequency of use	x
National Comorbidity Survey Replication Adolescent Supplement (NCS-A): 2001–2002 to 2004–2005	NIMH; NIDA; SAMHSA; Robert Wood Johnson Foundation; John W. Alden Trust	13–17	10,148	74.7–85.9%	Cross-sectional dual frame household and school samples	Marijuana/hashish age first use, ever use, past year use, past month, frequency of use	x
School surveys							
Monitoring the Future (MTF): yearly survey from 1991	NIDA	Students grades 8, 10 and 12	~50,000 per survey	~80–90%	Cross-sectional self-report school survey sampling 8th, 10th and 12th grade students	Lifetime, past year, past 30-day use; frequency of use	x
Youth Risk Behavior Survey (YRBS): biennially survey from 1991	CDC	Students grades 9–12	Average sample size 14,517	~71%	Cross-sectional school-based surveys of representative samples of high school students	Marijuana use lifetime, past 30 days, age first use, frequency of use	x

ADAMHA Alcohol, Drug Abuse and Mental Health Administration, *CDC* Centers for Disease Control and Prevention, *NIDA* National Institute on Drug Abuse, *NIAAA* National Institute on Alcohol Abuse and Alcoholism, *NIMH* National Institute of Mental Health, *SAMHSA* Substance Abuse and Mental Health Services Administration

data from multiple survey years to ensure an adequate sample size for analysis. Since 2014, NSDUH yearly surveys have included targeted sample sizes by states as part of the sampling strategy to ensure that the data are representative at the state level. Below, we review studies using these data sources to examine the effects of MML on cannabis use and disorders in the US population.

Review of Studies on How Legalisation of Medical and Recreational Cannabis Use Affected the Prevalence of Cannabis Use and Cannabis Use Disorders

Relevant papers on the impact of legalisation of medical or non-medical adult recreational use of cannabis on prevalence of use and cannabis use disorders in the USA were identified by searching PubMed up to May 2018. Papers were selected for inclusion if they contained relevant data on regulatory regimes for legal medical and recreational cannabis use in US states, effects of the establishment of these regimes on price and availability of cannabis in the USA or effects of legalising medical or recreational cannabis use in the USA on rates of cannabis use and cannabis use disorders. Papers were also identified from authors' hand search and from references cited in relevant articles (see Appendix for flowchart of search results). Studies conducted outside of the USA and studies on non-representative samples were excluded. The characteristics of the included studies are presented in Table 3.

Adolescent Use

The biennial Youth Risky Behavior Surveys (YRBS) include data from national, state and local school-based surveys of 9th to 12th grade students in private and public school in the USA. It was developed to monitor risky behaviour during adolescence, and several studies have drawn upon these data to investigate the relationship between MMLs and youth cannabis use.

Lynne-Landsman et al. [16] examined the effect of MML adoption in Montana in 2004 by comparing trends in lifetime and past 30-day use of cannabis among high school students in Montana between 2003 and 2009 and in Rhode Island, Michigan and Delaware as states without MML over the same time period. They found no measurable effect of MMLs on cannabis use but the short time since the passage of the MML limited the ability of the study to detect any effects on adolescent cannabis use.

Choo et al. [17] later expanded the study period from 1991 to 2011 and compared trends in five states with MMLs (Maine—1998; Montana—2004; Nevada—2000; Rhode Island—2006; and Vermont—2004) with trends in neighbouring states that did not pass MML during the same period. There was no significant change in youth cannabis use after MML adoption. The study was limited by the fact that the enactment of MML in three of the five states was close to the end of the study period. The biennial collection of data also meant that there may not have been sufficient data to detect any effects of MML adoption. During this period, there were also no medical cannabis dispensaries in states with MML, limiting access to cannabis.

Anderson, Hansen and Rees [18] also found little evidence that MMLs affected adolescent cannabis use. They controlled for factors associated with cannabis use including gender, age and accessibility and did not find any effects of MML on cannabis use among adolescents. The authors also examined national longitudinal survey data from a cohort of adolescents aged 12–17 years when first interviewed in 1997 (NLSY97) and substance abuse treatment data and did not find any effect on youth cannabis consumption that was related to whether or not a state had passed MML.

A more recent study by Johnson et al. [19] analysed YRBS data from 1991 to 2011 in 45 states. They reported a significantly higher prevalence of past 30-day cannabis use (22.7 vs 19.8%) and past 30-day heavy use (7.0 vs 5.6%) in states with MMLs than in states without these laws. However, these differences were no longer significant when they adjusted for the differences in MML policies between states. Although nine of the 12 MML states investigated had provisions allowing dispensary operation, dispensaries were only operating in two states (Colorado and Maine) by 2011.

The largest study to date [20] of adolescent cannabis use analysed data from Monitoring the Future Surveys between 1991 and 2014 to compare trends in past 30-day cannabis use in the 21 states that had legalised medical cannabis with those in the 27 mainland US states which had not. These analyses controlled for social, economic and demographic differences between states and schools. States that had passed MMLs had higher rates of past 30-day cannabis use *before* the laws were passed (15.9% vs 13.3%) than states without MMLs but there was no change in adolescent cannabis use after the passage of MMLs (16.3% pre to 15.5% post). Indeed, they found a *reduction* in rates of cannabis use in 8th grade students in states with MMLs.

Similar findings are reported by Wen et al. [21] using data from NSDUH data between 2004 and 2012. There was a marginal increase in cannabis use observed among young people aged 12 to 20 years in the year after the MMLs were passed, but there was no increase in cannabis use in the past 30 days or in daily use.

These studies suggest that passage of MMLs has not increased cannabis use among teenagers during the periods after their passage that has been studied to date. Many of the studies (with the exception of Lynne-Landsman et al. [16] and Johnson et al. [19]) used aggregated YRBS data and ignored variations in MML policies between states that may have

Table 3 Summary of studies that examined the effects of MML on cannabis use and cannabis use disorders in the USA

Author, year	Data source (years of data collection)	Age of sample	Analyses method	Findings
Wall et al., 2011	NSDUH (2002–2008)	12–17 years old	2-Sample *t* test and longitudinal analysis (random intercept for state and a fixed linear trend for year)	States with MML have a higher prevalence of adolescent cannabis use compared to sates without MML.
Cerda et al., 2012	NESARC (2004–2005); NSDUH (2004–2005)	NESARC (18+ years old); NSDUH (12+ years old)	(1) A state-level regression; (2) a multilevel regression model of individual-level data nested within states.	Both NESAR and NSDUH indicated residents of states with MML had higher odds of marijuana use, a risk factor that would increase the risk of marijuana abuse/dependence.
Harper, Strumpf and Kaufman, 2012	NSDUH (2002–2009)	12 to 17 years old; 18 to 25 years old; 26+ years old	D-in-D (random effect regression model)	Adolescent cannabis use decreased, but the effect was non-significant.
Lynne-Landsman, Livingston and Wagenaar, 2013	YRBS (2003–2009)	12 to 18 years old	D-in-D (linear regression model)	Effect of MML on adolescent cannabis use was non-significant.
Choo et al., 2014	YRBS (1991–2011)	9th to 12th graders	D-in-D (fixed effect regression model)	Effect of MML on adolescent cannabis use was non-significant.
Chu, 2014	UCR (1988–2008); TEDS (1992–2008)	18+ years old	D-in-D (linear or quadratic regression—fixed effects model)	Cannabis-related arrest among adult males increased by 15–20%; cannabis-related treatment referral among adult males increased by 10–20%.
Pacula, Powell, Heaton and Sevigny, 2015	TED (1992–2011); NLSY97 (1997–2011)	TED: all ages under 21 years; NLSY97: 12 to 17 years old	D-in-D (fixed effect regression model)	Admission to treatment reduced by 14%; the generic MML did not have significant effect on cannabis use at individual level, but a significant effect associated with dispensary protection
Anderson, Hansen and Rees, 2015	YRBS (1993–2011); NLSY97 (1997); TED (1992–2009)	YRBS: 9th–12th graders; NLSY97: 12 to 19 years old; TED: 15 to 20 years old	Standard linear regression framework (fixed effects model)	Effect of MML on adolescent cannabis use was non-significant.
Hasin et al., 2015	MTF (1991–2014)	8th, 10th and 12th graders	Multilevel logistic regression	Effect of MML on adolescent cannabis use was non-significant; indeed, the study found a reduction in rates of cannabis use in 8th grade students in states with MMLs.
Wen, Hockenberry and Cummings, 2015	NSDUH (2004–2012)	12 to 20 years old; 21+ years old	Non-linear regression model (two-way fixed effect)	Increased past-month cannabis use among 21+ years old; Cannabis use among those below 21 years is inconsistent.
Davis, et al., 2016	Medical marijuana registration, hospital discharge record and poison centre calls related to cannabis abuse/dependence in Denver (CO) (2000–2010)	Not mentioned	Durbin–Watson statistic (linear model)	The increased prevalence of hospital discharges related to CUD and poison centre calls are parallel to MML adoption.
Mauro et al., 2017	NSDUH (2004–2013)	12 to 17 years old; 18 to 25 years old; 26+ years old	Multilevel linear regression	Increased past-month and daily cannabis use among those aged 26+ years; overall cannabis use among 18 to 25 years old remained stable; the number of male daily users is higher than that of female among the 18–25 years age group.
Johnson, Hodgkin and Harris, 2017	YRBS (1991–2011)	9th to 12th graders	Multilevel logistic regression	Effect of MML on past-month or heavy cannabis use was non-significant

Table 3 (continued)

Author, year	Data source (years of data collection)	Age of sample	Analyses method	Findings
Cerda et al., 2017	MTF (2010–2015)	8th, 10th and 12th graders	D-in-D (logistic regression model)	Prevalence of cannabis use among 8th and 10th graders increased in WA; CO did not exhibit any significant change in the prevalence of past-month cannabis use for any of the 3rd graders.
Williams et al., 2017	NSDUH (2004–2013)	12 to 17 years old; 18 to 25 years old; 26+ years old	D-in-D (multilevel linear regression model)	States with loosely regulated MML has a higher prevalence of past-month use and heavy use compared to states with restricted MML. However, there was no associated increase in the prevalence of CUD within the study period.
Hasin et al., 2017	NLAES (1991–1992); NESARC (2001–2002); NESARC-III (2012–2013)	18+ years old	D-in-D (multilevel logistic regression model)	Illicit cannabis use increased significantly more in states that passed MML than in other states, as did cannabis use disorders.

reduced statistical power to detect any effects. Other risk factors for cannabis use among adolescents were not investigated in all studies, e.g. the perceived riskiness of cannabis use, cannabis accessibility and prices. The limited evidence suggests that the perceived riskiness of monthly cannabis use remained high after MML adoption among high school students, which may have deterred many from using cannabis.

Sarvet and colleagues [22•] conducted a meta-analysis of 11 studies of the effects of MML on cannabis use among adolescents in large national surveys. They included all the studies described above. Meta-analyses can potentially detect weak effects that may not be present in all or any of the individual studies. When the data were pooled, however, the results supported the findings of the individual studies. There was no evidence that the passage of MMLs was associated with an increase in cannabis use among adolescents. Additionally, analyses that took account of variations in laws between states (i.e. if dispensaries are allowed or not within a specific state) and subgroup analyses (i.e. gender or by perceived risk) did not generally find differences. This suggests that changes in cannabis use prevalence in adolescents were unrelated to the passing of MMLs or their specific form of implementation.

There were a number of limitations to this meta-analysis. First, all 11 studies used data from the same four surveys. The lack of independence across studies was offset to a degree by variations in study design, sampling frame, study period and methods of analyses. Ideally, future studies would incorporate different designs and distinct sampling timeframes, whilst using the large sample sizes and national representation in the surveys.

Adult Cannabis Use

Data from the NSDUH has been used to study trends in cannabis use among both adolescents and adults. The survey is representative at the national and state level and so has been a primary source of data on trends in substance use among non-institutionalised US residents aged 12 years and above.

Harper et al. [23] found that passing MMLs had no effects on cannabis use or the perceived risk of use among adolescents or adults during the period 2002–2009. Conflicting results were reported by Wen et al. [21] who found an increase in past 30-day cannabis use among adults aged 21 years and older after the adoption of MMLs in the NSDUH from 2004 to 2012. They found no differences in rates of new adult cannabis users between MML- and non-MML states but adults in MML states reported more cannabis use in the past 30 days (an increase of 1.32%), more daily cannabis use (an increase of 0.58%) and higher rates of cannabis abuse/dependence (an increase of 10%) than adults who lived in states that had not passed MMLs. Using the same data source, Williams et al. [24] found that past-month cannabis use among adults aged 26 years and older who lived in states with MMLs increased from 4.13 to 6.59% from 2004 to 2013, with heavy use increasing from 14.94 to 17.30%.

Other studies have examined the effects of MMLs on perceived availability and prevalence of cannabis use among adolescents (12 to 17 years), young adults (18 to 25 years) and older adults (26 years and older). Martin et al. [25] reported that MML adoption increased cannabis use among those over the age of 26 and among each of three subgroups among those over this age (26 to 39, 40 to 64 and 65+ years). They argued

that these changes reflect increased accessibility of cannabis for older adults after MMLs were passed.

These findings were replicated by Mauro et al. [26] who stratified the data by gender and age (12 to 17, 18 to 25 and 26+ years). The 26+ years age group showed an increased level of past 30-day use in both men (7% before and 8.7% after) and women (3.1% before and 4.3% after). MML adoption also increased the prevalence of daily cannabis use in both sexes.

These studies suffer from similar limitations to those of adolescents. Many have simply compared rates of cannabis use among adults in states with and without MMLs, without taking account of the very different ways in which MMLs have been implemented.

These patterns of cannabis use in surveys—a lack of change in youth cannabis use and increased cannabis use among adults upon MML adoption—are inconsistent with limited evidence on arrestees and patients receiving treatments. Chu [27], for example, found that medical cannabis legalisation was associated with an increase in arrests among male adults for cannabis possession. The study first assessed the uniform crime reports (UCR) from 1988 to 2008 and found that the number of cannabis-related offences was generally higher in MML states than non-MML states (the analysis excluded Colorado and California which had legalised adult use). The effect was more prominent in younger adults and consistent between minority groups. The second part of the study assessed treatment episode data (TEDS) from 1992 to 2008. This showed a 10–20% increase in CUD treatment seeking among adolescents and adults after the passage of MMLs. Both arrest and treatment positive estimates could have been influenced by other factors that were not controlled for in these analyses. These include changes in police enforcement or a change in the attitudes of healthcare providers towards accepting CUD referrals.

Pacula et al. [28•] used data from the NLSY97 and TEDS (1992–2011) to examine the relationship between MMLs and cannabis consumption among persons under 21 years of age. They assessed cannabis use in the pre- and post-legalisation data in states and found that MML adoption was not associated with changes in cannabis use or abuse among youth. However, the authors concluded that MML states that provided legal protection for dispensaries had more non-medical use of cannabis in adults and adolescents than states without dispensaries.

There are other indices of cannabis use that have not been explored in studies to date. These include daily cannabis use, the incidence of cannabis use disorders, the intensity of cannabis use, routes of administration and type of cannabis product used (e.g. flower, edibles or extracts). Lastly, these studies have not examined the effects of specific policies at the state and federal level. They also assume that MMLs only affect individuals in the states that pass them, whereas individuals in neighbouring states that do not have MMLs may be influenced by MMLs in nearby states, by shifts in federal enforcement (e.g. the Ogden memorandum [29]), broader shifts in culture or attitudes towards cannabis use [30] and the diversion of medical cannabis for sale in other states [31]. Future studies will need to examine the effects of MMLs on cannabis use in bordering states and larger shifts in public attitudes towards cannabis to properly evaluate the effects of MMLs on cannabis use.

Effects on Cannabis Use Disorders in Adults

Cannabis use disorders comprise a constellation of behavioural and biopsychosocial impairments associated with frequent cannabis use. Rates of CUD have been increasing in the US over the past decade [32, 33], coinciding with decreases in the perceived risks, increased acceptability of cannabis use and changes in its legal status. It is accordingly important to ask whether increased rates of CUD are associated with changes in the legal status of medical and recreational cannabis uses at state level.

Three national surveys over 20 years (1991–1992, 2001–2002 and 2012–2013) have shown an increase in the prevalence of cannabis use and CUDs [33]. Comparisons of trends in rates of these disorders between states that have and have not enacted MMLs suggest that MMLs may have contributed to increased rates of CUDs. Overall, from 1991–1992 to 2012–2013, cannabis use increased significantly more in states that passed MML than in other states (1.4% greater). The same was true for CUD (0.7% greater). Because of variations in the implementation of MML across states, it is not clear how specific regulations have affected cannabis use and CUD or what effects other state-level policy changes may have had.

Two national survey series have produced conflicting results on whether CUDs have increased in the US adult population in the two decades since MMLs were first passed. In the National Epidemiologic Survey of Alcohol and Related Conditions (NESARC) surveys, the prevalence of CUDs increased between 1991–1992 and 2001–2002 [34] despite no change in rates of cannabis use over this period. The prevalence of CUDs in these surveys increased again between 2001 and 2002 and 2012–2013 and so did the prevalence of cannabis use [20]. In a recent review, Hasin found that CUDs increased in states with early MMLs from 1991–1992 to 2001–2002 [35•]. From 2001–2002 to 2012–2013, CUD rates increased overall and there were larger increases in states with late MMLs, such as California and Colorado.

These findings are inconsistent with analyses of trends in cannabis use in US adults aged 18 years and older in annual household surveys between 2002 and 2014 [36]. The prevalence of past year cannabis use increased from 10.4% in 2002

to 13.3% in 2014 and the steepest increase occurred after 2007. Rates of initiation of cannabis use in the past 12 months increased from 0.7 to 1.1%, and the prevalence of daily or near daily cannabis use increased from 1.9 to 3.5%, again beginning in 2007.

Despite the increase in the prevalence of adult cannabis use, the prevalence of cannabis use disorders among adults in the past year did not change (remaining at 1.5% over this period). More surprisingly still, the prevalence of CUDs among adults who used cannabis in the past year *declined* from 14.8% in 2002 to 11.0% in 2014. One would normally expect the prevalence of CUD among cannabis users to increase as the prevalence and frequency of cannabis use increased, especially when the use of more potent cannabis products increased over this period in the USA [37, 38].

There are a number of possible explanations for these puzzling findings. First, they could reflect a difference in cannabis use between age cohorts. Grucza et al. [39], for example, found that cannabis use declined among 12–17 year olds. This is an age group who would be at higher risk of developing CUDs if they used cannabis than are older adults. Compton et al. [34] only found an increase in cannabis use among those aged over 18 years. A second possibility is that more liberal cannabis policies have increased cannabis use among older adults for medical or non-medical reasons. The latter would occur if older persons who had used cannabis as young adults resumed using after cannabis use was legal or quasi-legal [40]. If older adults used cannabis less often than younger users, whether for medical or recreational reasons, this would reduce the proportion of current cannabis users who meet criteria for CUDs.

Apart from national surveys, administrative data sources have been used to examine the public health effects of MML. Mair et al. [41] used panel hospital data in California from 2001 to 2012 to examine the association between CUD-related hospitalisations and density of dispensaries. They found a positive association between higher densities of dispensaries with cannabis-related hospitalisations. Davis et al. [42] used hospital data to examine CUD-related hospital discharges using data from 2007 to 2013 in Colorado. They found that hospital discharges coded as cannabis abuse and dependence increased over time. Comparing data before and after 2009, cannabis-related hospital discharges increased by 44% (95% CI = 35.2 to 52.3%, $p < 0.001$) for cannabis abuse and by 57% (43.4%, 72.0%, $p < 0.001$) for cannabis dependence.

Other researchers have examined trends in the number of persons presenting to treatment services with CUDs in US national treatment data. They have used the number seeking treatment for CUD who has not been legally coerced into treatment in US states where cannabis use remains a criminal offence. Chu [27] compared the number of persons seeking first time treatment for cannabis problems between 1992 and 2011 in states that did and did not have MMLs. He found a 15–21% increase in new treatment episodes after MMLs were passed for persons with primary cannabis use problems who had *not* been referred by the criminal justice system.

Effects of Legal Recreational Cannabis

The effects of legalising recreational cannabis use have been explored as more US states have allowed the sale of cannabis products for adult use. To date, only Uruguay and eight US states have legalised cannabis production and sale for recreational use. Canada established a task force in 2016 to create a framework for commercial production and sale of recreational cannabis which is to be introduced nationally in late 2018. Other jurisdictions may follow, making it critical that the effects of legalising recreational use on cannabis markets and consumers' behaviour are better understood. Very few studies have been done and these focus on Washington State and Colorado, which were the first US states to legalise recreational cannabis in 2012.

Smart and colleagues [43] analysed trends in the legal retail recreational cannabis market by examining more than 30 million cannabis purchases in Washington State. They found that cannabis flowers made up the majority of sales but their market share declined significantly over the first 2 years of the legal market as sales increased of extracts for inhalation and other cannabis products (edibles, tinctures, etc.). They also found that the THC content of cannabis flower increased, with the proportion having a THC content of greater than 15% increasing over 2 years from 79.6 to 92.5%. As the THC content of cannabis products has increased, the contribution of taxes to the price per gram of cannabis has more than halved. This trend is inconsistent with the "Iron Law of Prohibition" (Cowan [44]) according to which increased drug potency is an effect of tougher enforcement of criminal laws. The increased potency of legal cannabis products raises concerns about an increase in adverse health effects, such as cannabis dependence, poor mental health and psychotic symptoms [45–47].

Analyses of the effects of legalisation on cannabis products are limited by the short period that policies have been in place. Policies in Washington State and other states that have legalised cannabis continue to be modified, so it remains to be seen what the long-term trends in the potency of retail cannabis sales will be. Furthermore, it may be unwise to translate US findings to jurisdictions where cannabis potency may not be shaped solely by markets. To date, US states that have allowed for the sale of recreational cannabis have not attempted to discourage heavy use or impose limits on the potency of cannabis products, with the exception of maximum serves of high-potency edible products. It is difficult to predict what may happen in legal markets in which cannabis potency may be regulated, as may occur in Canada.

A major concern about cannabis legalisation is its potential effects on adolescents' cannabis use. Factors that may increase adolescent use that may accompany legalisation include reductions in price, increases in potency and changing social perceptions of the safety and acceptability of using cannabis. Studies of these factors have been limited. Survey data collected 4 and 5 months after retail sales of cannabis found no changes in the prices of common cannabis brands [48]. Investigations of the perceived harmfulness of cannabis use among adolescents in Colorado and Washington State, immediately before and after legalisation, found state differences in the perceived harmfulness and acceptability of using cannabis [49]. In Washington State, the perceived harmfulness of cannabis use decreased and cannabis use increased in eighth and tenth grade students. In Colorado over the same period, however, past-month cannabis use and its perceived harmfulness remained stable in these age groups. It remains to be seen if the legalisation of recreational cannabis use in other states will produce changes in perceived risk and use of cannabis.

A final concern in legalising adult cannabis use is the potential increase in cannabis intoxicated driving and cannabis-related motor vehicle accidents and fatalities. Couper and Peterson [50] assessed the effect of legalisation on cannabis use among adults involved in DUI cases in Washington State. The team compared the number of cannabinoid-positive cases between 2009 and 2012 with that in 2013 and found no significant difference of cannabis-related DUI from 1 year to the next. However, there was a significant increase of cannabinoid positive cases in 2013 compared to 2011. Similar observations have been reported in Colorado by Urfer et al. [51] where cannabis-related-DUI cases increased from 28% in 2011 to 65% in 2013. Given these limited data, and the likelihood that testing for cannabis has increased after legalisation, it is too early to assess the impact of cannabis legalisation on cannabis-related-DUI.

Attitudes and Perceived Harms

The growing number of states supporting legalisation of medical and recreational cannabis reflects changing public attitudes towards the perceived safety and social acceptability of using cannabis. Studies of Monitoring the Future survey data have consistently found a relationship between adolescent cannabis use and their beliefs about the risks of use. This may not be the case because there has been a lack of an increase in adolescent use to date despite declining perceptions of the risks of using cannabis among adolescents [52]. Miech et al. [53] and Fleming et al. [54] have argued that adolescent cannabis use has not increased despite these reductions in perceived risk because the prevalence of cigarette smoking and alcohol use among adolescents has declined. Without these offsetting trends, Miech et al. suggested cannabis use among adolescents would now be at or near the highest level reported in 1991.

Changes in the perceived risks of cannabis are aligned with states' policies on cannabis legalisation [55, 56]. In the USA, daily or nearly daily cannabis use is concentrated in states in which cannabis use is legal for medicinal or recreational purposes. Unlike tobacco marketing, which has been restricted for several decades, cannabis product marketing is not well regulated and cannabis packs do not yet include detailed health warnings. This has created opportunities for retail cannabis businesses to promote cannabis use to the general public at the time when lenient laws in some states have made cannabis products more affordable and accessible. Educational campaigns about the risks of daily and near daily cannabis use will need to target different age groups to provide critical information for decision making about use.

Conclusion

The evidence from large nationally representative surveys has not consistently demonstrated that MMLs have increased adolescent cannabis use. Adolescent use is higher in states that have passed MMLs, but this reflects higher rates of use before the passage of MMLs. Early evidence suggests that the frequency of cannabis use increased among adults who already use cannabis after the legalisation of medical cannabis use.

Population surveys until very recently have primarily been designed to provide nationally representative samples and so have not provided data for analysis at state level. This has made it difficult to track the effects of cannabis policy changes in individual states. Studies of the effects of these policy changes have often crudely categorised states as either having MMLs or not and examined changes in the prevalence of use immediately before and after the introduction of MMLs. These research strategies ignore variations in state MML policies and have not allowed for differences in the time required for these polices to be fully implemented [57]. Future studies will need to focus more on specific details of state policies to better understand how policies, such as regulation of dispensaries, may affect cannabis use and disorders in adolescents and adults.

It will also be important to evaluate the effects of any future changes in cannabis policies. For example, no US state has, thus far, regulated the THC content of cannabis products or imposed higher taxes on more potent cannabis products. This could change if there were evidence of greater health risks from using high THC cannabis products. If so, it will be critical to evaluate the effects of any changes in THC regulation or taxation on cannabis use and harm. The implementation of a national medical and recreational cannabis market in Canada may provide an opportunity to do so if the Canadian

government sets limits on the THC content of many (though not all) cannabis products [58].

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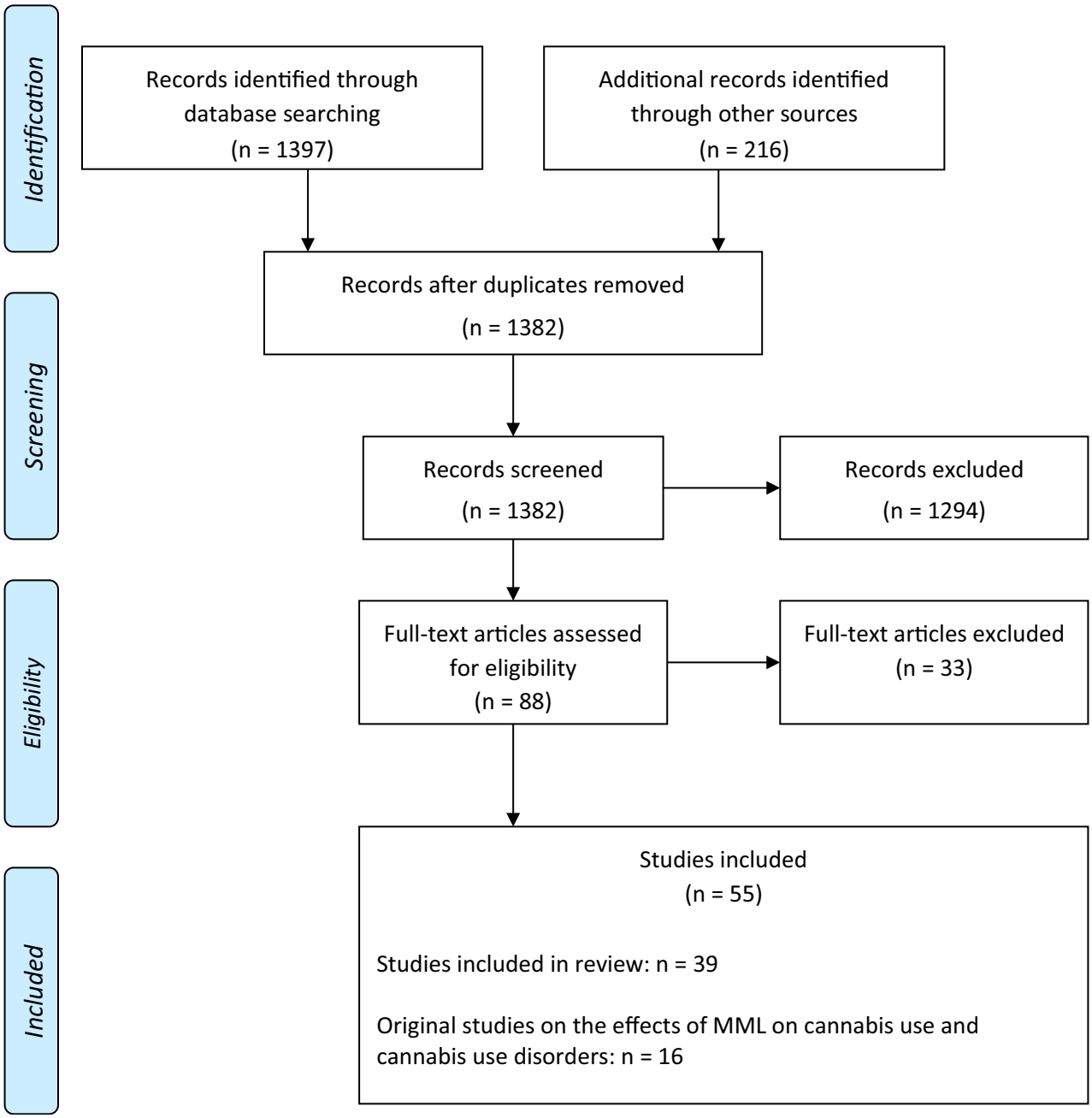
Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Appendix. Flowchart of search results for literature on how legalisation of medical and recreational cannabis use affected the prevalence of cannabis use and cannabis use disorders



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