Medical marijuana laws and adolescent marijuana use in the USA from 1991 to 2014: results from annual, repeated cross-sectional surveys

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Summary

Background Adolescent use of marijuana is associated with adverse later effects, so the identification of factors underlying adolescent use is of substantial public health importance. The relationship between US state laws that permit marijuana for medical purposes and adolescent marijuana use has been controversial. Such laws could convey a message about marijuana acceptability that increases its use soon after passage, even if implementation is delayed or the law narrowly restricts its use. We used 24 years of national data from the USA to examine the relationship between state medical marijuana laws and adolescent use of marijuana.

Methods Using a multistage, random-sampling design with replacement, the Monitoring the Future study conducts annual national surveys of 8th, 10th, and 12th-grade students (modal ages 13–14, 15–16, and 17–18 years, respectively), in around 400 schools per year. Students complete self-administered questionnaires that include questions on marijuana use. We analysed data from 1 098 270 adolescents surveyed between 1991 and 2014. The primary outcome of this analysis was any marijuana use in the previous 30 days. We used multilevel regression modelling with adolescents nested within states to examine two questions. The first was whether marijuana use was higher overall in states that ever passed a medical marijuana law up to 2014. The second was whether the risk of marijuana use changed after passage of medical marijuana laws. Control covariates included individual, school, and state-level characteristics.

Findings Marijuana use was more prevalent in states that passed a medical marijuana law any time up to 2014 than in other states (adjusted prevalence 15·87% *vs* 13·27%; adjusted odds ratio [OR] 1·27, 95% CI 1·07–1·51; p=0·0057). However, the risk of marijuana use in states before passing medical marijuana laws did not differ significantly from the risk after medical marijuana laws were passed (adjusted prevalence 16·25% *vs* 15·45%; adjusted OR 0·92, 95% CI 0·82–1·04; p=0·185). Results were generally robust across sensitivity analyses, including redefining marijuana use as any use in the previous year or frequency of use, and reanalysing medical marijuana laws for delayed effects or for variation in provisions for dispensaries.

Interpretation Our findings, consistent with previous evidence, suggest that passage of state medical marijuana laws does not increase adolescent use of marijuana. However, overall, adolescent use is higher in states that ever passed such a law than in other states. State-level risk factors other than medical marijuana laws could contribute to both marijuana use and the passage of medical marijuana laws, and such factors warrant investigation.

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Introduction

In the USA, adolescent marijuana use has increased since the mid-2000s.[1,2] Adolescent use, especially regular use, is associated with increased likelihood of harmful effects, including short-term impairments in memory, coordination, and judgment, and longer-term risks of altered brain development, cognitive impairments,[3–5] unemployment,[6] psychiatric symptoms and substance addiction.[1,7] Therefore, identification of factors underlying adolescent use is of substantial importance. To affect prevalence nationally, factors must affect wide segments of the population; state laws permitting the use of marijuana for medical purposes have been proposed as one such factor.[8–10] Since 1996, 23 US states and the District of Columbia have passed medical marijuana laws, and other states are considering such laws. Although the specific provisions of state medical marijuana laws differ,[11] they all have a common purpose: to legalise the use of marijuana for medical purposes. However, by conveying a message about acceptability or an absence of harmful health consequences, passage of such laws could affect youth perception of harms, leading to increased prevalence of marijuana use in the years immediately after the law has passed, even with delayed implementation or narrow limits on use.

Whether medical marijuana laws are associated with increased use of marijuana by adolescents has been debated. Some commentators have suggested that these

Research in context

Evidence before this study

If passage of a state law legalising marijuana for medical use conveyed a public message to adolescents that marijuana use was acceptable or did not lead to adverse effects, this law could quickly increase adolescent use of marijuana, even if the law was implemented slowly or had provisions that tightly restricted marijuana use. To identify studies relevant to this issue, we searched PubMed for English-language articles with the term, "medical marijuana". As of April 6, 2015, 449 articles with this term were published, the first in 1978, and all the rest since 1994. Most articles were opinion pieces about the pros and cons of medical marijuana use, regarding either its medicinal benefits, or implications for society. To be considered relevant to the present study, we reviewed reports with empirical findings that were based on general-population surveys with state-based samples, had marijuana use as an outcome, and compared states with and without medical marijuana laws, or states before and after passage of such laws. We identified two reports showing overall higher rates of marijuana use in states with medical marijuana laws, one in adolescents and the other in adults, with one replication of the adolescent result. Comparison of Colorado, a state with a medical marijuana law, with states without medical marijuana laws found suggestive but inconclusive evidence regarding the effects of the law on adolescent marijuana use. Two studies, that in combination examined seven states that passed medical marijuana laws did not show increased prevalence of adolescent marijuana use after the laws were passed, relative to the prevalence before the laws were passed. However, limitations in the number of states examined, number of years, and sample sizes left unclear whether the absence of differences in marijuana use pre-law and post-law were real or due to limitations of the methods.

Added value of this study

Our study, which included data from annual national surveys spanning 24 years (1991–2014) for 1 098 270 adolescents in 48 US states, provides two pieces of definitive evidence about medical marijuana laws and adolescent use of marijuana. First, across all survey years, overall adolescent marijuana use was higher in states that had ever passed medical marijuana laws than in states that did not have these laws, but the increased use was present in states both before and after the laws were passed. Second, our comprehensive study showed no evidence for an increase in adolescent use of marijuana in the year of passage of a medical marijuana law, or in the first or second years after passage. These results were consistent across several sensitivity analyses that used a different definition of the marijuana outcome variable, that removed one state at a time from the sample to establish whether one state was unduly affecting the overall results (none did), or whether a state medical marijuana law provided for dispensaries.

Implications of all the available evidence

Our two main findings, in conjunction with other evidence, suggest that state-level factors other than medical marijuana laws influence adolescent marijuana use. Because both human studies and animal models show that early adolescent use of marijuana increases the risk of important adverse effects in adulthood, the identification of large-scale societal factors that increase the risk of early use is crucial. Our study findings suggest that the debate over the role of medical marijuana laws in adolescent marijuana use should cease, and that resources should be applied to identifying the factors that do affect risk.

laws have no effect, or actually discourage use.[12,13] Others suggest that these laws increase adolescent use of marijuana through various mechanisms,[8] such as sending a message that use is acceptable.[9,10] In 2013, 19% of high school seniors (generally aged 17 and 18 years) reported that they would try marijuana or use it more often if it were legalised for general use.[14] In a study of adolescents in paediatric practices in states that had not passed medical marijuana laws,[15] 55% thought that passing such a law would "make it easier for teens to start to smoke marijuana for fun". These findings suggest that the legal status of marijuana, including medical marijuana laws, could increase adolescent use of marijuana.

Previously, we showed that adolescent[16] and adult[17] marijuana use was more prevalent in US states with medical marijuana laws than in states without such laws. However, we examined only fairly short periods, and the studies did not address whether this increased prevalence preceded or followed passage of the law.[18,19] One study suggested that after 2009, a confluence of federal and local factors predicted greater adolescent marijuana use in Colorado, a state with a medical marijuana law, than in 39 other states without such laws.[20] Other studies (of four[21] and five states;[22] seven states in total because of overlap) did not show increased adolescent use after medical marijuana laws were passed. All these studies were limited by the small sample sizes, the few states included with medical marijuana laws, and years examined, leaving questions about whether the absence of effect might be due to insufficient statistical power or the particular states studied. Examination of a greater number of participants, years, and states should more definitively establish whether the passage of medical marijuana laws predicts a subsequent increase in adolescent marijuana use.

We therefore examined the relationship between state medical marijuana laws and adolescent marijuana use using 24 years of yearly survey data (1991–2014) from repeated annual, cross-sectional surveys that included more than 1 million adolescents in the 48 contiguous states, of which 21 had passed medical marijuana laws

by 2014 (figure 1). Controlling for individual-level, school-level, and state-level factors, we addressed two questions. The first was whether adolescents were generally at higher risk for marijuana use in states that ever passed a medical marijuana law by 2014 than adolescents in other states. This question extends our previous work[16,17] by greatly increasing the number of years considered and controlling for potentially important state and individual covariates. The second question was whether adolescents in states that had passed medical marijuana laws were at higher risk of marijuana use in the years immediately after passage of the law than adolescents in those states before passage of the law.

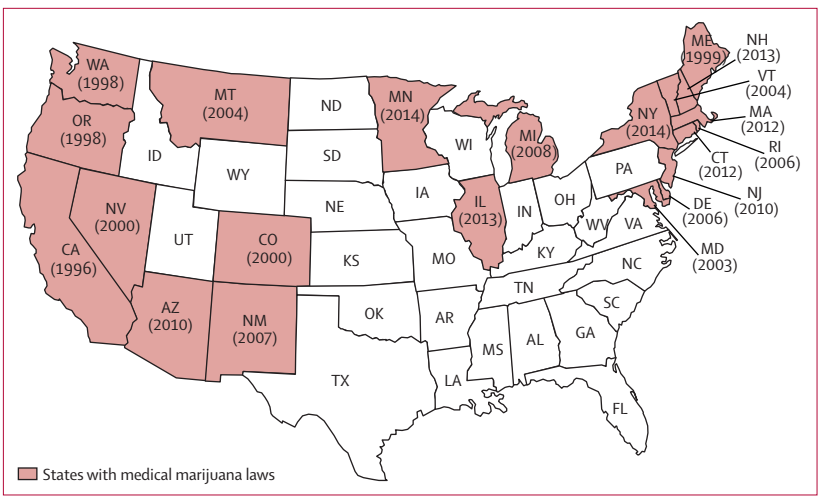

Figure 1: **US states with medical marijuana laws as of 2014, and years of passage**

Methods

Study design and participants

Since 1991, the Monitoring the Future study has conducted national, annual cross-sectional surveys of adolescents in school grades 8, 10, and 12 (modal ages 13–14, 15–16, and 17–18 years, respectively), in about 400 schools each year (mean schools per year 409·3 [SD 17·34]; range 377–435 schools per year) in the 48 contiguous US states. Monitoring The Future surveys use a multistage, random sampling design with replacement. The stages include geographical area, schools within area (with probability proportionate to school size), and students within school. Up to 350 students per grade, per school are included, with classrooms randomly selected within schools. Schools participate for two consecutive years. Non-participating schools are replaced with others matched for location, size, and urbanicity.

Data were collected from students via self-administered questionnaires.[23] Measures[24] and data collection procedures have remained consistent across years.[14] Students completed questionnaires in classrooms or larger group administrations. Monitoring the Future study representatives distributed and collected questionnaires using standardised procedures to maintain confidentiality.[14] Self-administered forms and the data collection procedures are designed to maximise the validity of substance use reporting. Low quantities of non-responses, high proportions of students consistently reporting illicit drug use, and strong construct validity have previously been reported for the Monitoring the Future study.[21]

Advance notice to parents and students about the study included that participation was voluntary and responses were either anonymous (for 8th and 10th graders) or confidential (for 12th graders; responses of 12th graders are not anonymised so that they can participate in follow-up studies).[14] All Monitoring the Future study procedures were reviewed and approved by the University of Michigan Institutional Review Board.[14]

Measures

The primary outcome was any marijuana use within the previous 30 days versus no use, a binary individual-level variable previously used in time-trend analysis of Monitoring the Future data.[25] We also examined any marijuana use within the past 12 months, similarly dichotomised, in sensitivity analyses.

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Our main exposure was "state-level medical marijuana law", represented in the analysis by two state-level variables. The first was a binary variable that showed whether a state passed a medical marijuana law by 2014 (21 had passed such laws), irrespective of the year that it passed. We used this variable to compare risk of adolescent marijuana use in states that had ever passed a medical marijuana law with risk in states that had not. The second was a time-varying binary variable for each year (1991–2014) and state (48 states) indicating whether the state had passed a medical marijuana law that year or not, as established through review of state policies by legal scholars, economists, and policy analysts at the RAND Corporation.[11] We defined the variable for state–year as the year that the law was passed (appendix p 1). This variable enabled us to examine adolescents within states before and after passage of medical marijuana laws, in conjunction with adolescents in states that never passed a medical marijuana law.

See **Online** for appendix

States that have passed medical marijuana laws permitting medical marijuana dispensaries might differ from states whose medical marijuana laws do not permit dispensaries in terms of marijuana availability, public perceptions, and potency.[26] We therefore explored an alternative definition[11] of our yearly state medical marijuana law variable, re-coding it as a three-level variable: no medical marijuana law, a medical marijuana law not permitting dispensaries, and a medical marijuana law permitting dispensaries. The latter category was defined as implicitly permitting dispensing via caregivers and amounts per patient, or explicit acknowledgment of dispensaries as either permitted or not declared illegal (p 1 of the appendix shows the years that states were coded positive by this definition).

	Adjusted prevalence		Adjusted odds ratio (95% CI)	p value
	Medical marijuana law passed by 2014	Medical marijuana law not passed by 2014		
Combined grades	15·87%	13·27%	1·27 (1·07–1·51)	0·0057
8th grade	7·22%	6·95%	1·18 (0·98–1·44)	0·0871
10th grade	18·02%	15·04%	1·23 (1·01–1·49)	0·0352
12th grade	22·36%	17·83%	1·35 (1·11–1·63)	0·0024

Table shows marijuana use in the previous 30 days. Modal ages of students: 8th grade 13–14 years; 10th grade 15–16 years; 12th grade 17–18 years. Adjusted prevalences encompassing years 1991 to 2014 were derived from the multilevel model, with distributions of covariates fixed at grade-specific overall US distributions averaged across all 24 years. The model controlled for sex, age, race, education of parents, class size, whether educated at an urban or rural school, public or private school, and state-aggregated percentage who were male, percentage who were white, percentage with no high school education, and percentage aged 11–24 years. The model also included a state random intercept, and state-specific cubic spline polynomials to control for trend with a knot at the years 1998 and 2006. See appendix p 4 for absolute numbers.

Table 1: **Adolescent use of marijuana in the 48 US contiguous states between 1991 and 2014**

School-level control variables included the number of students per grade within school; public versus private school; and urban or suburban (ie, within metropolitan statistical areas)[27] versus rural schools. State-level control variables included the proportion of each state's population who were male, white, aged 10–24 years, and older than 25 years without high-school education. We used US census values from 1990, 2000, and 2010 for survey years 1991–95, 1996–2005, and 2006–14, respectively.

Individual covariates included age, gender, ethnic origin (white, black, Hispanic, Asian, mixed, and other), grade (when combining grades), and socioeconomic status (highest parental education categorised as high school not completed, high-school graduate or equivalent, some university education, or a 4-year university degree or higher).

Statistical analysis

We conducted multilevel logistic regression modelling of adolescents nested within states to address whether marijuana use was higher overall in states that passed a medical marijuana law at any point between 1991 and 2014 than in other states; and whether the risk of marijuana use changed after a medical marijuana law was passed compared with the risk before the law passed, controlling for the contemporaneous risk of use overall in other states (appendix pp 6 and 7). For these analyses, we used SAS Proc Glimmix code (version 9.4). We controlled for the non-linear historical trend in marijuana use across the 24 years with a piece-wise cubic spline. Covariates at an individual, school, and state level were controlled (appendix pp 6 and 7). We fitted a single multilevel model to the entire study dataset that simultaneously addressed both research questions through specification of the two primary predictors: a dichotomous indicator of whether a state passed a medical marijuana law any time between 1991 and 2014, coded 1 for all individuals in the states with a law before 2014 (irrespective of year passed) and 0 for all others; and a time-varying indicator coded 0 for individuals in states in the years before a medical marijuana law passed (including states with no medical marijuana laws before 2014) and 1 for individuals in states in the years during and after the law passed). The time-varying indicator provides a difference-in-difference estimator of change in risk due to marijuana laws in which the contrast is between the average within-state change in risk of use before versus after the law passed, compared with the aggregated contemporaneous average change in risk of use in states that do not pass such a law. We first fitted the multilevel model combining 8th, 10th, and 12th grades, and then refitted the model including and testing an interaction with grade to obtain grade-specific medical marijuana law effects. The latter was done because the prevalence of marijuana use differs by grade, and thus risk factors could differ as well.

We present adjusted odds ratios (ORs) and 95% CIs for the combined and grade-specific effects, and state-specific log OR estimates (pre-law *vs* post-law) for the 21 states that passed such laws. We derived adjusted prevalence estimates aggregated for the states with and without medical marijuana laws for each year from the multilevel logistic model, aggregating across years and also plotted by year. State-specific log OR estimates in the post-passage years compared with the pre-passage years are presented for the 21 states that passed laws.

Estimation and testing of the state-level predictors with the multilevel model did not require inclusion of sampling weights, because the model directly incorporated all individual-level and school-level variables related to the sampling design.[28] Within the Monitoring the Future study, not all states had data available for every year and grade; the multilevel model addresses this difficulty by smoothing effects across missing years and grades with state-level random effects (allowing for the effects of covariates—eg, ethnic origin—to vary by state). We used multiple imputation (Proc MI, SAS version 9.4) at the individual level to handle missing covariate data (range 2·98% [age] to 8·05% [parental education]; appendix pp 2, 6).

We conducted five sets of sensitivity analyses to determine the robustness of the findings. First, the binary marijuana use variable was replaced with an ordered categorical outcome indicating frequency of past-month use (0, 1–2, 3–5, 6–9, 10–19, 20–39, or 40+ occasions), modelled with cumulative odds. Second, the time-varying variable indicating medical marijuana law was re-coded as positive in three different ways to allow for delayed effects (lag) between passage of the law and changes in population behaviour: recoding the state–year variable positive starting the year following passage

if the medical marijuana law was passed after July; recoding the variable as positive in the year following passage for all states with medical marijuana laws; recoding the variable as positive 2 years following passage for all states with medical marijuana laws (appendix p 7). Third, we replaced the binary state–year law variable with the three-level dispensary variable. Fourth, we replaced use in the past month with use in the past year. Fifth, to ensure that no state unduly influenced the results, the multilevel model was refitted 48 times, removing one state each time. Sensitivity analyses used a model that combined effects across grades, and a model with grade-by-law interaction to identify grade-specific effects.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

By 2014, 21 of the 48 contiguous states had passed a medical marijuana law (figure 1, appendix p 1). Across the 21 states, the mean number of years since the law was passed was 6·76 (SD 6·06), and the median number of years was 4·0 (see appendix, p 7 for more detail). Between 1991 and 2014, the Monitoring the Future study surveyed a total of 1 134 734 (408 942 in 8th grade, 370 449 in 10th grade, and 355 343 in 12th grade). After we excluded students who were missing marijuana data, 1 098 270 (96·8%) remained for analysis: 396 310 8th graders (96·9%), 361 400 10th graders (97·6%), and 340 560 12th graders (95·8%). Of all selection sample units, 95–99% obtained one or more participating schools in all study years. Previous studies have shown no time trend in school participation.[29] Student response rates were 81–91% for almost all years and grades (mean response rates for 1991–2013). Most non-responses were because of absenteeism; less than 1% of students declined participation in the survey when asked in the school to complete the questionnaire.

Marijuana use in the previous 30 days was more prevalent in states that passed a medical marijuana law between 1991 and 2014 than in those that had not (adjusted prevalence 15·87% *vs* 13·27%; adjusted OR 1·27, 95% CI 1·07–1·51, p=0·0057). This finding did not differ by grade (table 1; interaction of grade and state medical marijuana law status, p=0·33). This effect, aggregated across years before and after passage of marijuana laws, suggests that, overall, states with a medical marijuana law had an increased prevalence of marijuana use even before the law was passed (figure 2).

Aggregating across grade, the risk of marijuana use did not significantly change after passage of a medical marijuana law (adjusted prevalence 16·25% pre-law *vs* 15·45% post-law; adjusted OR 0·92, 95% CI 0·82–1·04, p=0·185). The interaction between grade and risk before and after the law passed was significant (p=0·001), suggesting differential results by grade (table 2). Among 8th graders, marijuana use decreased significantly after passage of medical marijuana laws (table 2), but no significant change was found before versus after passage in 10th or 12th graders (table 2). Substantial state-to-state variability was found for pre- passage versus post-passage risk of adolescent marijuana use (figure 3). States also varied in whether the effects of medical marijuana laws differed significantly by grade.

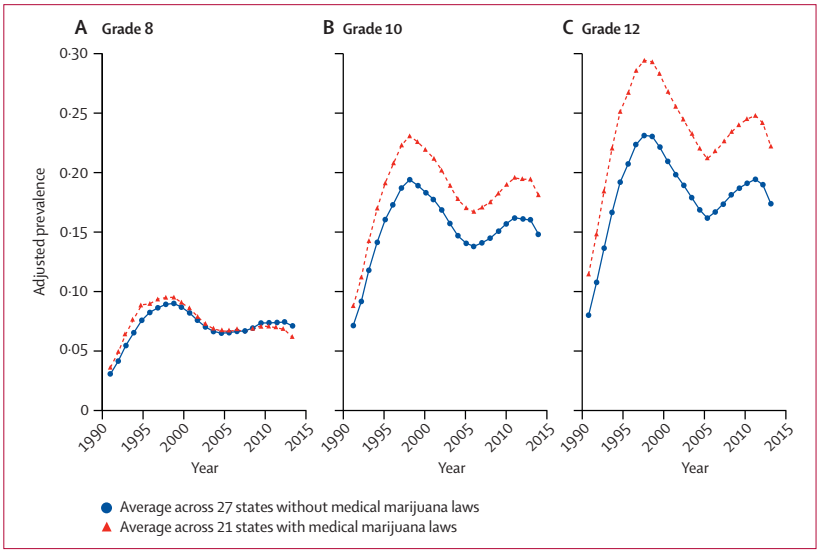

Figure 2: **Adjusted prevalence of US adolescent marijuana use* by year (1991–2014), school grade, and whether states had medical marijuana laws**

*Marijuana use refers to use in the previous 30 days. Modal ages of students: 8th grade 13–14 years; 10th grade 15–16 years; 12th grade 17–18 years. Adjusted prevalence estimates are derived from the multilevel model, fit to all 24 years of Monitoring the Future data from the 48 contiguous US states, with individual, school, and state-level covariates fixed at the age-specific overall US distributions each year. The 21 states with medical marijuana laws passed them in varying years, thus the yearly prevalence estimates for these states are aggregated irrespective of whether the state had passed a law yet.

	Adjusted prevalence		Adjusted odds ratio (95% CI)	p value
	Before law passed	After law passed		
Combined grades	16·25%	15·45%	0·92 (0·82–1·04)	0·185
8th grade	8·14%	6·05%	0·73 (0·63–0·84)	<0·0001
10th grade	17·94%	18·27%	1·02 (0·90–1·17)	0·738
12th grade	22·68%	22·02%	0·96 (0·84–1·10)	0·581

Table shows marijuana use in the previous 30 days. Modal ages of students: 8th grade 13–14 years; 10th grade 15–16 years; 12th grade 17–18 years. Adjusted prevalences derived from the multilevel model that also includes states that did not pass medical marijuana laws to control for historical trends. Distributions of covariates were fixed at grade-specific overall US distributions averaged over varying numbers of years before and after the law was passed, depending on when the change in law occurred. See appendix p 5 for absolute numbers.

Table 2: **Adolescent use of marijuana before and after passage of medical marijuana in the 21 US contiguous states that passed medical marijuana laws up to 2014**

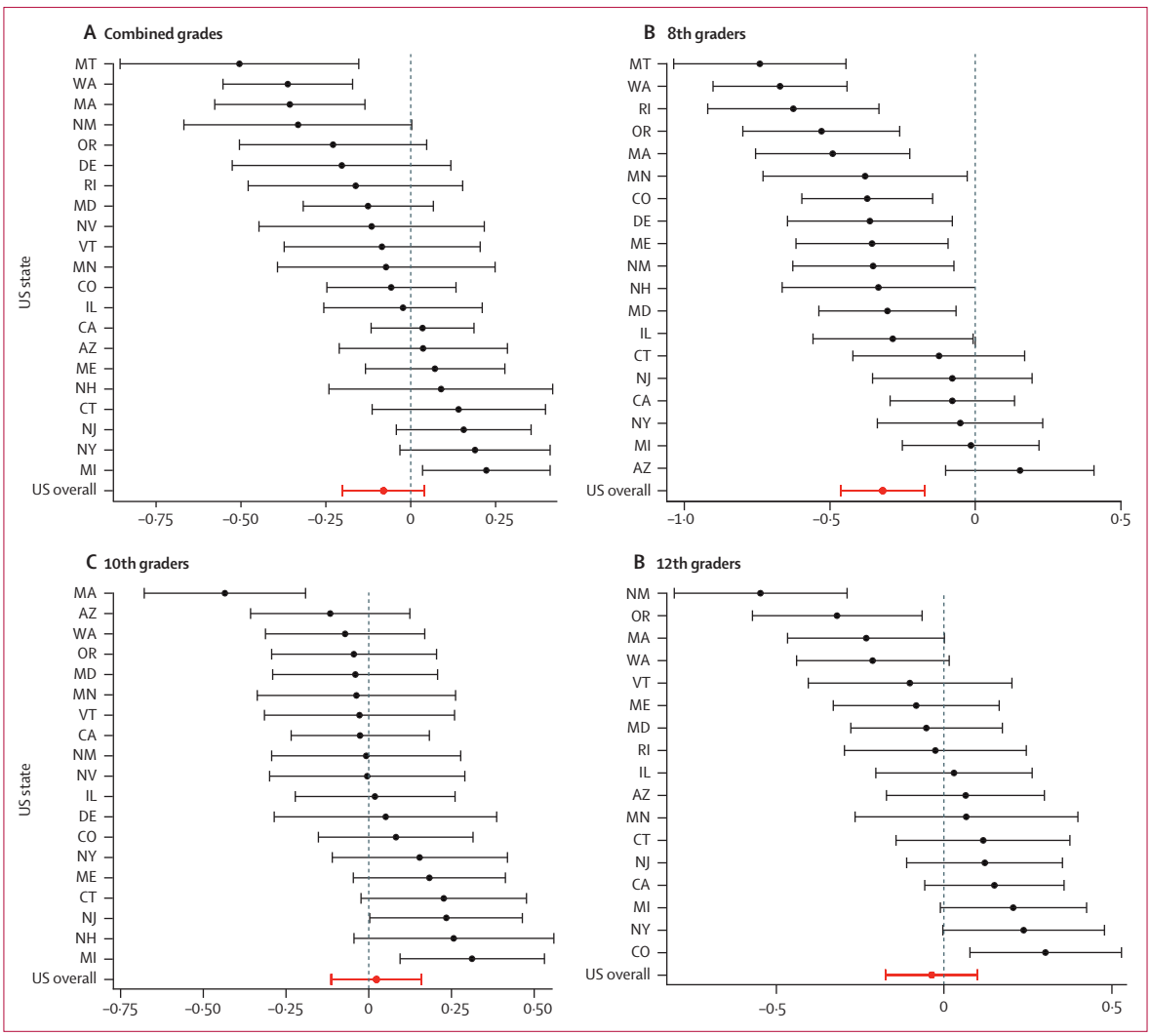

***Figure 3*: State-specific risk of adolescent marijuana use before versus after passage of state medical marijuana laws**

Modal ages of students: 8th grade 13–14 years; 10th grade 15–16 years; 12th grade 17–18 years. Figure shows log odds ratio (95% CI) for marijuana use in the previous 30 days. Values >0 indicate increased log odds ratios of the last month of marijuana use in the post-passage year compared with the pre-passage years; values <0 indicate a decrease. Post-passage includes the year in which the medical marijuana law was passed. State estimates for each grade are not shown when a state did not have pre-passage or post-passage data from the Monitoring the Future study within that grade. For 8th graders, NV did not have pre-law data and VT did not have any data for this grade. For 10th graders, MT did not have pre-law data and RI did not have any data for this age group. For 12th graders DE, MT, and NV did not have pre-law data and NH did not have post-law data.

Sensitivity analyses did not meaningfully affect results (appendix p 3). Modelling frequency of use in the previous 30 days, the overall effect of medical marijuana laws on adolescent use before versus after passage of the law remained non-significant, although (as for the overall results), use was significantly reduced in 8th but not 10th or 12th graders. Recoding the year of passage to model delayed effects did not change the findings for adolescents overall, nor did our re-analyses that incorporated dispensary information or use of marijuana in the previous year. Finally, rerunning 48 models with interaction by grade, removing one state at a time, results were all significant for 8th graders (adjusted OR 0·69–0·75) but not for 10th or 12th graders (data available on request).

Discussion

In this analysis of repeated annual, cross-sectional survey data we examined whether adolescent use of marijuana was greater in US states that eventually passed medical marijuana laws, and whether adolescent marijuana use increased in these states after passage of such laws. Compared with previous reports, we used data from a much larger sample, and included many more states (48) and years (24). Controlling for important covariates, states that had ever enacted a medical marijuana law up to 2014 had higher prevelance of adolescent marijuana use than did other states. However, importantly, the analyses of use pre-law versus post-law did not indicate that adolescent marijuana use increased after passage of

medical marijuana laws. To our knowledge, these findings, consistent with those from earlier studies,[10,21,22] provide the strongest empirical evidence yet that medical marijuana laws do not account for increased use of marijuana in US adolescents.

Whether medical marijuana laws increase availability through diversion, or change adolescent approval of marijuana, is unknown. Irrespective of this point, our findings suggest that medical marijuana laws did not influence these factors sufficiently to raise adolescent marijuana use. However, because adolescent norms could affect risk of later adult marijuana use, and because national trends in marijuana use might yield different results in the future, the effects that these laws could have on adolescent attitudes towards the acceptability and riskiness of marijuana use (also assessed in the Monitoring the Future study) warrant further investigation.

Compared with states that had never passed a medical marijuana law by 2014, adolescent marijuana use overall was higher in states that had passed such a law, a difference particularly noticeable in 12th graders. Because this difference did not occur after the law was passed, these states might differ from the others on common factors yet to be identified (eg, norms surrounding marijuana use[25] or marijuana availability). Investigation of these factors is warranted.

The post-law decrease in marijuana use among 8th graders was unexpected but robust across main and sensitivity analyses (appendix p 3). One explanation for this finding is that 10th and 12th graders had already formed attitudes towards marijuana and hence were not influenced by medical marijuana laws, but the younger 8th graders had more modifiable attitudes and beliefs about marijuana, and were less likely to view marijuana as recreational after states authorised its use for medical purposes. Unlike 10th and 12th graders, 8th graders show little evidence of an increase in use since 2005 (figure 3). Also, perhaps the passage of medical marijuana laws and increasingly positive public attitudes towards marijuana have focused parental vigilance and counter-efforts against use in the youngest adolescents. These and other explanations should be investigated.

Until 2011, no states allowed recreational marijuana use, but four states (Colorado, Washington, Alaska, and Oregon) and the District of Columbia have now passed laws permitting adult recreational use. Concerns exist that, at least to some extent, efforts to legalise medical marijuana are actually concealed efforts to eventually legalise recreational use.[30,31] Because we examined only laws governing medical use, this report does not address the debate about legal recreational use. Research into the relationship between legalisation of recreational marijuana and adolescent marijuana use is important, but such associations cannot be inferred from the present study.

Our study has several limitations. We did not examine additional variations in state medical marijuana laws (eg, the amount of marijuana permitted, or approved illnesses), but they merit future investigation. Marijuana use was self-reported, which is a shortcoming of large-scale surveys. However, data were collected in confidential circumstances, and findings from methodological studies support the validity of this method in the Monitoring the Future study.[29] The survey did not include adolescents who were temporarily absent from or do not attend school; this population should also be studied. Also, some states had only short periods after passage of medical marijuana laws, which limited the detection of longer-term effects in those states. Thus, analyses should be repeated after more years of data have accumulated. Finally, results might not be generalisable to states that are considering but have not passed medical marijuana laws. These states have lower prevalences of marijuana use than do states with these laws, so the effect of medical marijuana laws on adolescent use in these states could differ. Analyses should be repeated if more states pass medical marijuana laws.

However, our study also has notable strengths. We analysed a sample of more than 1 million adolescents from 48 US states, with the most comprehensive time span yet in terms of years examined. Consistency in measures, data collection methods over time, and consistently excellent response rates ruled out many issues with the methods as alternative explanations of study findings, as did the sophisticated statistical methods that we used along with controls for important state, school, and individual covariates. In a large set of 54 sensitivity analyses, only one model suggested a different result, lending support to the robustness of our findings. Self-administered forms and data collection procedures were designed to maximise the validity of substance-use reporting. The validity of our report is supported by low quantities of non-responses, high proportions of students consistently reporting illicit drug use, and strong construct validity. The absence of a time trend in school participation suggests that school non-response did not affect trends.

In conclusion, the results of this study showed no evidence for an increase in adolescent marijuana use after passage of state laws permitting use of marijuana for medical purposes. Whether access to a substance for medical purposes should be determined by legislation rather than biomedical research and regulatory review is debatable.[30] However, concerns that increased adolescent marijuana use is an unintended effect of state medical marijuana laws seem unfounded. In view of the potential for harm from early use,[3–5,32–35] other factors influencing wide segments of the population need to be investigated.

Contributors

DSH, MW, KMK, MC, JS, PMO'M, SG, and RLP designed the study. MW took particular responsibility for the statistical analysis plan, and KMK, JS, and PMO'M for use of datasets from Monitoring the Future study to address the research questions. DSH was responsible for obtaining funds and prepared the first and final drafts of the report.

MW did the analyses and supervised the work of TF in doing the analyses. RLP provided definitions of medical marijuana laws and their variations as determined by herself and her group of experts at RAND. All authors contributed to subsequent versions of the report, and approved the final version.

Declaration of interests

We declare no competing interests.

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