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State Medical Marijuana Laws and Adolescent Marijuana Use in The United States: 1991 – 2014

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Abstract

Background—Adolescent marijuana use is associated with adverse later-life consequences, so identifying factors underlying adolescent use is of substantial public health importance. The relationship of U.S. state medical marijuana laws (MML) to adolescent marijuana use has been controversial. Such laws could convey a message about marijuana acceptability that increases

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Contributors

DH, MW, KMK, MC, JS, POM, SG, and RLP designed the study, with MW taking particular responsibility for the statistical analysis plan, and KMK, JS and POM for use of the MTF datasets to address the research questions. DH was responsible for obtaining funds and preparing the first and final drafts of the manuscript. MW conducted analyses and supervised the work of TF in conducting 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 manuscript, and approved the final version.

Declaration of interests

The authors declare no conflicts of interest.

marijuana use soon after passage, even if implementation is delayed or the law narrowly limits use. We used 24 years of U.S. national data to examine the relationship between state MML and adolescent marijuana use.

Methods—Data came from 1,098,270 U.S. adolescents in 8th, 10th, and 12th grade in the national Monitoring the Future annual surveys conducted between 1991–2014. The main outcome was any marijuana use in the prior 30 days. Using multilevel regression modeling, we examined marijuana use in adolescents nested within states, including whether marijuana use was higher overall in states that ever passed a MML up to 2014, and whether the risk of use changed after state MML were passed. Individual-, school- and state-level covariates were controlled.

Findings—Overall, marijuana use was more prevalent in states that enacted MML up to 2014 than in other states (AOR=1.27, 95%CI=1.07–1.51). Pre- and post-MML risk did not differ in the full sample (AOR=0.92, 95%CI=0.82–1.04). A significant interaction ($p<0.001$) indicated differential post-MML risk by grade. In 8th graders, post-MML use decreased (AOR=0.73, 95%CI=0.63–0.84), while no significant change occurred in 10th or 12th graders. Results were generally robust across sensitivity analyses.

Interpretation—Previous evidence and this study show that MML passage does not result in increased adolescent marijuana use. However, overall, adolescent use is higher in states that ever enacted MML than in other states. State-level risk factors other than MML may contribute to both marijuana use and MML, warranting investigation. An observed 8th-grade post-MML decrease also merits further study.

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In the United States, adolescent marijuana use has increased since the mid-2000s[1,2]. Adolescent use of marijuana, particularly regular use, is associated with increased likelihood of deleterious consequences, including short-term impairments in memory, coordination and judgement, and longer-term risk of altered brain development, cognitive impairments, and addiction[3,4]. Therefore, identifying factors underlying adolescent use is of substantial importance. To affect prevalence nationally, factors must influence wide segments of the population. State medical marijuana laws (MML) have been proposed as one such factor[5–7]. Since 1996, 23 U.S. states and the District of Columbia passed MML, and other states are considering such laws. The specifics of state MML[8] differ, but they all have a common purpose: to legalize marijuana use for medical purposes. By conveying a message about acceptability or lack of negative health consequences, passage of state MML could affect youth perception of harms, leading to increased prevalence of marijuana use in the years immediately after passage, even with delayed implementation or narrow limits on use.

Whether MML passage is associated with increased adolescent marijuana use remains unclear. Some suggest that MML have no effect, or discourage use[9,10]. Others suggest that MML increase adolescent marijuana use through various mechanisms[5], e.g, sending a message that marijuana use is acceptable[6,7]. In one study, 55% of adolescents in pediatric practices in non-MML states thought MML passage would “make it easier for teens to start to smoke marijuana for fun”[11]. In 2013, 18.8% of high school seniors reported they would try marijuana or use it more often if it were legalized[12]. These findings suggest that MML could increase adolescent marijuana use.

Previously, we showed that adolescent[13] and adult[14] marijuana use was more prevalent in states with MML than in other states. However, limited time periods were examined, and the studies did not address whether higher prevalence preceded or followed MML passage[15,16]. A comparison of Colorado to non-MML states suggested that adolescent marijuana use increased post-MML[17]. Other studies (of four[18] and five states[19]; seven states total due to overlap) did not find increased adolescent marijuana use post-MML. However, sample sizes, states and years were limited, leaving questions about whether the lack of effect might be due to limited statistical power or the particular states studied. Examining a greater number of participants, years and states should more definitively establish whether MML passage predicts increased post-passage adolescent marijuana use.

We therefore examined the relationship between state MMLs and adolescent marijuana use using 24 years of survey data (1991 to 2014) from over one million adolescents in the 48 contiguous states, of which 21 passed MML by 2014 (Figure 1). Controlling for individual-, school- and state-level factors, we addressed two questions.

1. Were participants generally at higher risk for marijuana use in states that ever passed a MML by 2014 than in other states? This extends our prior work[13,18] by greatly increasing the number of years considered and controlling for potentially important state and individual covariates. The findings provide a context for the second question.

2. Were participants in states that passed MML at higher risk for marijuana use in the years immediately after MML passage than in those states before passage of MML?

We examined these questions in the full sample and by grade. Prevalence of marijuana use differs by grade[20], and thus risk factors could differ as well.

Methods

Since 1991, Monitoring The Future (MTF) conducted national annual cross-sectional surveys of 8th, 10th and 12th graders, collecting data via self-administered questionnaires in ~400 schools each year in the 48 contiguous U.S. states. The study employs a multi-stage random sampling design with replacement. Stages include geographic 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 on location, size, and urbanicity. Of all selection sample units, 95%–99% obtained one or more participating schools in all study years; lack of a time trend in school participation[21] indicates that school non-response does not affect trends. Each year, ~17,000 8th graders, ~16,000 10th graders, and ~15,000 12th graders were included, totaling 1,134,734 students through 2014. We analyzed all grades together, and also analyzed participants separately by grade. Excluding students 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%).

Student response rates were 81%–91% for virtually all years and grades (mean response rate, 1991–2013, 86.51%). Most non-response was due to absenteeism; <1% refused. Measures and data collection procedures remained consistent across years. Advance notice to parents and students about the study included that participation was voluntary and responses anonymous (8th, 10th grade) or confidential (12th grade). Students completed questionnaires in classrooms or larger group administrations. MTF representatives distributed and collected questionnaires using standardized procedures to maintain confidentiality.

Measures

Outcomes—The primary outcome was an individual-level binary variable: any marijuana use within the prior 30 days vs. none, reflecting definitions previously used in MTF time-trend analysis[22]. We also examined any marijuana use within the last 12 months, similarly dichotomized, in sensitivity analyses. Self-administered forms and data collection procedures are designed to maximize validity of substance use reporting. Validity of MTF substance reports is supported by low question non-response; high proportions consistently reporting illicit drug use; and strong construct validity[21].

Main exposures—Our primary exposure was state-level MML, indicated with two state-level variables. The first was a binary variable indicating if a state enacted a MML by 2014 regardless of the year enacted. This variable was used to compare risk for adolescent marijuana use in states that ever passed a MML to states that did not. The second was a binary variable for each year (1991–2014) and state (48 states) indicating whether the state had a MML that year or not, as determined through review of state policies by legal scholars, economists, and policy analysts at RAND Corporation[8]. The MML state/year variable was defined as the year the law was enacted (eTable 1). This variable enabled us to examine adolescents within states prior to and after MML enactment, in conjunction with adolescents in states that never enacted MML.

MML states with medical marijuana dispensaries may differ from other MML states on marijuana availability, public perceptions, and potency[23], so we explored an alternative definition of state MML[8], re-coding it as a three-level variable: no MML, MML without dispensaries, MML with dispensaries (the state MML implicitly permitted dispensing via caregivers and amounts per patient, or explicitly acknowledged dispensaries as either permitted or not declared illegal (eTable 1 shows years states were coded positive by this definition).

School- and state-level covariates—School-level control variables included number of students per grade within school; public vs. private; and urban/suburban (schools within Metropolitan Statistical Areas[24]) vs. rural. State-level control variables included proportion of each state's population male, white, aged 10–24, and aged >25 years without high school education. Census values from 1990, 2000 and 2010 were used for 1991–1995, 1996–2005, and 2006–2014, respectively.

Individual covariates—Age, gender, race/ethnicity (White, Black, Hispanic, Asian, Mixed, Other), grade (when combining grades), and socioeconomic status (highest parental education: high school not completed; high school graduate/equivalent; some college; four-year college degree or higher.

Statistical analysis—Multilevel logistic regression modeling of adolescents nested within states was used to address (1) whether marijuana use was higher overall in states that passed a MML at any point between 1991 and 2014 than in other states; and (2) whether the risk of marijuana use changed after passage of MML compared to the risk prior to passage, controlling for the contemporaneous risk of use overall in other states. The nonlinear historical trend in marijuana use across the 24 years was controlled using a piecewise cubic spline. Individual-, school-, and state-level covariates were controlled (see online supplemental material for the model and SAS Proc GLIMMIX code). A single multilevel model was fit to the entire MTF dataset that simultaneously addressed both research questions through specification of the two primary predictors: (1) a dichotomous indicator of whether a state passed MML any time between 1991–2014, coded 1 for all individuals in the states with MML before 2014, regardless of year passed, and 0 for all others; and (2) a time-varying indicator coded 0 for individuals in states in years prior to MML (including those in states with no MML before 2014) and 1 for individuals in states in years when and after MML passed. The time-varying indicator provides a difference-in-difference estimator of change in risk due to MML where the contrast is between the average within-state change in risk of use pre- vs. post-MML passage, compared to the aggregated contemporaneous average change in risk of use in states that do not pass MML. Adjusted odds ratios (AOR) and 95% confidence intervals (CI) for the two MML effects are presented, as are state-specific pre- vs. post-MML log-odds ratio estimates for the 21 states that passed laws. Adjusted prevalence estimates aggregated for MML and non-MML states for each year were derived from the multilevel logistic model and plotted. Not all states have MTF data available for every year and grade; the multilevel model addresses this by smoothing effects across missing years and grades with state-level random effects (allowing the effects of covariates, e.g., race, to vary by state). The multilevel model was fit combining 8th, 10th and 12th grades, and then re-fit to examine grade-specific effects, using an interaction between grade and the primary MML predictors. Estimation and testing of the state-level predictors using the multilevel model did not require inclusion of sampling weights, as the model directly incorporated all individual- and school-level variables related to the sampling design[25]. Multiple imputation at the individual level was used to handle missing covariate data (range: 2.98% [age] to 8.05% [parent education]). Proc MI (SAS 9.3) was used to impute ten datasets. All model estimates and standard errors were aggregated across these ten imputed datasets using Rubin's Rule[26], which incorporates uncertainty due to imputation.

Sensitivity analyses—Five sets of sensitivity analyses ascertained robustness of the findings. (1) To examine frequency of past-month use, an ordered categorical outcome (0, 1–2, 3–5, 6–9, 10–19, 20–39, 40+ occasions), was modeled with cumulative odds. (2) The time-varying MML indicator was re-coded as positive three different ways: (a) starting the following year if MML was passed after July; (b) one or (c) two years after the law was passed to allow for delayed effect. (3) The three-level dispensary variable replaced the binary MML indicator. (4) Past-year use replaced past-month use. (5) To ensure that no state unduly influenced results, the multilevel model was re-fit 48 times, removing one state each time. Sensitivity analyses utilized a model that combined effects across grades, and a model with grade by MML interaction to identify grade-specific effects.

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

Results

Marijuana use in the prior 30 days was more prevalent in states that passed MML between 1991–2014 than in those that did not (AOR=1.27, CI=1.07–1.51). This did not differ by grade (Table 1) (interaction of grade and state MML status, p=0.33). This effect, aggregating across years prior to and after passing MML, indicates that overall, MML states had higher prevalence of marijuana use even before passing MML (Figure 2).

Aggregating across grade, risk of marijuana use did not change after MML passage (AOR=0.92, CI=0.82–1.04). The grade by pre-post MML interaction was significant (p=0.001), indicating differential results by grade (Table 2). Among 8th graders, marijuana use *decreased* significantly post-MML passage (AOR=0.73, CI=0.63–0.84); 8th-grade adjusted prevalence in MML states decreased from 8.14% pre-MML to 6.05% post-MML (Table 2). No significant pre-post MML change was found in 10th or 12th graders (Table 2). Substantial state-to-state variability was found for pre-post MML differences (Figure 3). States also varied in whether MML effects differed significantly by grade.

Sensitivity analyses did not meaningfully affect results (eTable 2). (1) Modeling frequency of past-month use, the overall pre-post MML effect remained non-significant (p=0.26), and a pre-post decrease was found for 8th (p<0.0001) but not 10th or 12th graders. (2) Re-coding MML year to one year post-passage in states that passed MML after July, the overall pre-post MML effect remained non-significant (p=.20), with a post-MML decrease in 8th (p<0.0001), but not 10th or 12th graders. Re-coding MML year to one year post-passage for all MML states, the overall pre-post MML effect remained non-significant (p=.36), and was significant in 8th (p<0.0001), but not 10th or 12th graders. Re-coding MML year to two years post-passage, the overall pre-post MML effect was non-significant (p=.29), with a post-MML decrease in 8th graders (p=0.015), a post-MML increase in 10th graders (p=0.028) and no difference for 12th graders. (3) No pre-post MML effect was found overall whether MML states did not (p=.24) or did (p=.65) have dispensaries. In 8th graders, the pre-post decrease was significant whether the MML did not (p<0.01) or did (p<0.01) allow for dispensaries, and non-significant in 10th and 12th graders. (4) Modeling past-year marijuana use, the overall pre-post MML effect was non-significant (p=.36), with a decrease in 8th (p<0.001) but not 10th or 12th graders. (5) Re-running 48 models with interaction by grade, removing one state at a time, results were all significant for 8th graders (AOR=0.69–0.75) but not 10th or 12th graders.

Discussion

We examined whether adolescent marijuana use was greater in states that eventually passed MML, and whether adolescent marijuana use increased after passage of state MML. Compared to 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 ever enacted MML up to 2014 had higher rates of adolescent marijuana use than other states. However, importantly, the pre-post analyses did not indicate that adolescent marijuana use increased post-MML. These findings, consistent with earlier studies[7,18,19], provide the strongest empirical evidence yet that MML do not account for increased rates of U.S. adolescent marijuana use.

Whether MML increased availability through diversion, or changed adolescent approval of marijuana is unknown. Regardless, our findings suggest that these factors did not operate sufficiently to increase adolescent marijuana use. However, because adolescent norms could affect risk of later adult marijuana use, and because national trends in marijuana use may yield different results in the future, MML influences on adolescent attitudes towards the acceptability and riskiness of marijuana use (available in the MTF dataset) warrant further investigation.

Compared to states that never passed MML by 2014, adolescent marijuana use overall was higher in states that ever passed MML, a difference particularly notable in the 12th graders. Since this difference did not occur post-MML, these states may differ from others on common factors yet to be identified, e.g., norms regarding marijuana use[22] or marijuana availability. Investigation of these is warranted.

The post-MML decrease in marijuana use among 8th graders was unexpected but robust. One explanation is that 10th and 12th graders had already formed attitudes towards marijuana and hence were unaffected by MML passage, while 8th graders had more modifiable attitudes and beliefs about marijuana, becoming less likely to see marijuana as recreational after states authorized medical use. Unlike 10th and 12th graders, 8th graders show little evidence of an increase in use since 2005 (Figure 3). Perhaps MML passage and increasingly positive public attitudes focused parental vigilance and counter-efforts against use in the youngest adolescents. These and other explanations should be investigated.

Until 2011, no states permitted recreational marijuana use, but four states (Colorado, Washington, Alaska, Oregon) and the District of Columbia have now passed laws permitting adult recreational use. Concerns exist that at least to some extent, efforts to legalize medical marijuana are actually concealed efforts to eventually legalize recreational use[27,28]. Since we examined laws governing medical use, this report does not address the debate over legal recreational use. Research on the relationship between legalized recreational marijuana and adolescent marijuana use is important; such relationships cannot be inferred from the present study.

Study limitations are noted. Additional variations in state MML were not examined (e.g., amount of marijuana permitted, approved illnesses), but merit later investigation. Marijuana use was self-reported, a shortcoming of large-scale surveys. However, data were collected in confidential circumstances, and methodological studies support validity[21]. MTF does not include adolescents out of school; these should also be studied. MTF was not designed to make state-level estimates. However, state-of-the-art statistical procedures produced these estimates. Some states had short post-MML periods, limiting detection of longer-term effects in those states. Analyses should be repeated when more years of data accumulate. Finally, results may not generalize to states that are considering but have not passed MML. These states have lower rates of marijuana use than states with MML, so results may differ. Analyses should be repeated if more states pass MML.

Study strengths are also noted. This study had a sample of over one million adolescents from 48 states, and 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 methodological issues as alternative explanations of study findings, as did the sophisticated statistical methods and control for important state, school and individual covariates. In a large set of sensitivity analyses (54 models in all), only one model suggested a different result, supporting the robustness of the findings.

In conclusion, this study found no evidence for an increase in adolescent marijuana use after passage of state MML. Whether access to a substance for medical purposes should be determined by legislation rather than biomedical research and FDA review is debatable[27]. However, concerns that increased adolescent marijuana use is an unintended consequence of state MML appear unfounded. Given the potential for harm from early use[29–37], other factors influencing wide segments of the population must be investigated.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Panel

Systematic Review

If passage of a state MML conveyed a public message to adolescents that marijuana use was acceptable or lacked adverse consequences, passage of MML could increase adolescent marijuana use quickly, even if a particular MML was implemented slowly or had provisions narrowly restricting use. To identify studies relevant to this issue, Pubmed was searched for the term, "medical marijuana". As of April 6, 2015, 449 articles were published, the first in 1978, and all of the rest since 1994. The vast majority of articles were opinion pieces about the pros and cons of medical marijuana use, either regarding its medicinal benefits, or implications for society. To be considered relevant to the present study, papers reviewed were limited to those reporting empirical findings that were based on general population surveys with state-based samples, that had marijuana use as an outcome, and that compared states with and without MML, or states pre- and post-passage of MML. We found two papers showing overall higher rates of marijuana use in MML states, one in adults[14] and the other in adolescents[13] with one replication of the adolescent result[15]. Comparison of Colorado to non-MML states found suggestive but inconclusive evidence that adolescent marijuana use increased post-MML passage. Two studies of seven states comparing pre- and post-MML adolescent marijuana use[18,19] did not find post-MML increases. However, limitations in the number of states examined, number of years, and sample sizes left unclear whether the lack of pre-post MML differences were real or due to methodological limitations. Given the importance of addressing potential effects of MML on adolescent marijuana use, a more definitive study was needed that could encompass a larger sample, a greater number of states, and a greater number of years. In this context, we conducted the present study, which included data from annual national surveys spanning 24 years (1991–2014) on 1,098,270 adolescents in 48 U.S. states.

Interpretation

The present study provides two pieces of definitive evidence regarding MML and adolescent marijuana use. First, across all survey years, overall adolescent marijuana use was higher in U.S. states that had ever passed medical marijuana laws, with the higher rates present before the laws were passed as well as after. This suggests that state-level factors other than MML influence adolescent marijuana use, which are important to identify to inform public health policy. Second, our comprehensive study showed no evidence for an increase in adolescent marijuana use in the year of passage of a state MML, or in the first or second year after passage. In fact, we found a decline in post-MML use among the youngest adolescents in the study. These results were consistent across multiple sensitivity analyses that considered a different definition of the marijuana outcome variable, that removed one state at a time from the sample to determine if one state was unduly influencing the overall results (none did), or whether a state MML provided for dispensaries. Because both human studies and animal models show that early adolescent marijuana use increases the risk for important adverse consequences in adulthood, identifying large-scale societal factors that increase the risk for early use is crucial. Our study contributes to the literature by suggesting that the debate over the role of MML in adolescent marijuana use should cease, and that resources should be applied to identifying the factors that do affect risk.

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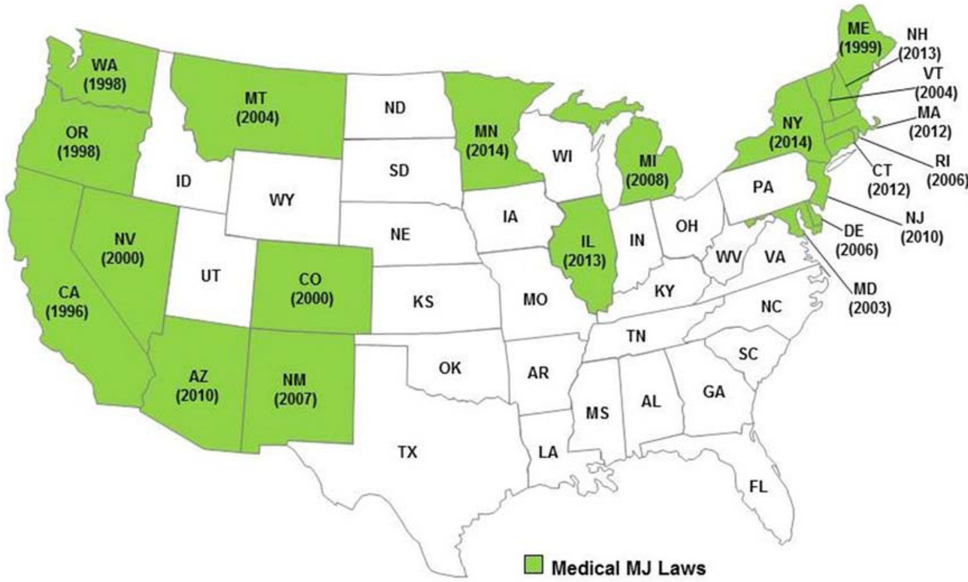

Figure 1.

Medical Marijuana Laws and Years of Passage in the 48 contiguous U.S. States

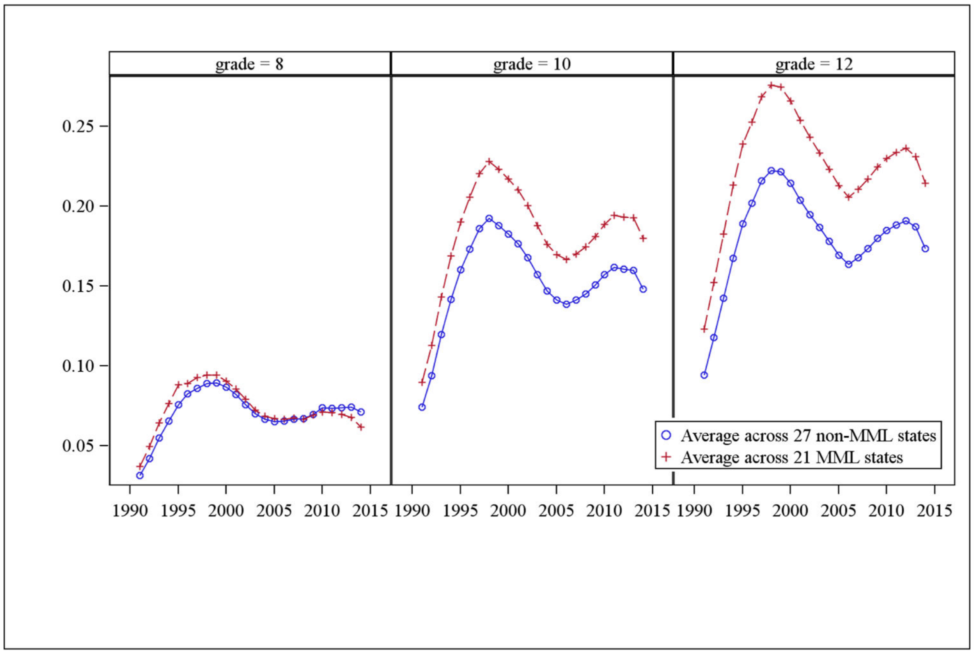

Figure 2.

Adjusted prevalence[a] of last-month adolescent marijuana use by year (1991–2014), school grade (8, 10, 12[th]), and U.S. state MML status

[a]Adjusted prevalence estimates are derived from the multilevel model described in the methods section, fit to all 24 years of MTF data (1.13 million records) in the 48 contiguous U.S. states, with individual, school, and state level covariates fixed at the grade-specific overall U.S. distribution each year. Note that the 21 MML states passed their laws in varying years; thus, the yearly prevalence estimates for MML states are aggregated regardless of whether the state had passed a law yet.

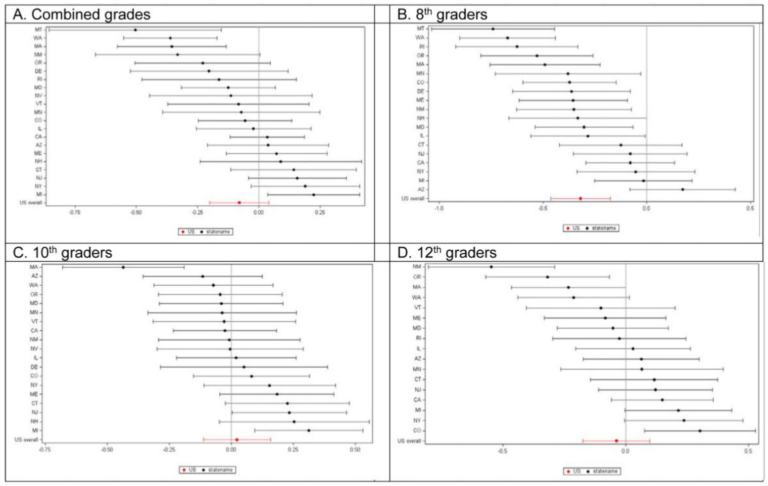

Figure 3.

Plotted log odds ratios for adolescent marijuana use pre vs. post passage of MML[a]

[a]Post-passage includes the year in which the law was passed. Values > 0 indicate increased log odds ratios of past month marijuana use post-MML compared to pre, values < 0 indicate a decrease. Error bars represent 95% confidence intervals for each state-specific estimate. State estimates for each grade are not shown when a state did not have pre or post MTF data available within that grade (for 8th grade, NV does not have pre MML data and VT does not have any 8th grade data. For 10th grade, MT does not have pre MML data and RI does not have any 10th grade data. For 12th grade, DE, MT and NV do not have pre MML data, and NH does not have post MML data).

Table 1

Adolescent marijuana use in the 48 U.S. contiguous states, by MML[1] passed between 1991–2014

	Adjusted Prevalence[2] 1991–2014					
Grade	**MML in 2014 or earlier**		**AOR**	**95% CI**		**p-value**
	Yes	**No**				
Combined	15.87	13.27	1.27	1.07	1.51	0.0057
8th	7.22	6.95	1.18	0.98	1.44	0.0871
10th	18.02	15.04	1.23	1.01	1.49	0.0352
12th	22.36	17.83	1.35	1.11	1.63	0.0024

[1] MML = state law permitting marijuana to be used legally for medical purposes

[2] Adjusted prevalences derived from the multilevel model with distributions of covariates fixed at grade-specific overall U.S. distributions averaged across all 24 years. Model controlled for gender, age, race, parent education, class size, urban/rural, public/private, state-aggregated % male, % white, % with no high school education, % population aged 11–24. 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.

Table 2

Adolescent marijuana use before and after MML passage in the 21 U.S. contiguous states that passed laws up to 2014

	Adjusted Prevalence in states with MML*					
	Pre MML %	**Post MML %**	**AOR**	**95% CI**		**p-value**
Combined	16.25	15.45	0.92	0.82	1.04	0.185
8th	8.14	6.05	0.73	0.63	0.84	<0.0001
10th	17.94	18.27	1.02	0.90	1.17	0.738
12th	22.68	22.02	0.96	0.84	1.10	0.581

* Adjusted prevalences derived from the multilevel model also including non-MML states to control for historical trend, with distributions of covariates fixed at grade-specific overall U.S. distributions averaged over varying number of years pre- and post MML depending on when law change occurred.