How does state marijuana policy affect U.S. youth?

Medical marijuana laws, marijuana use and perceived harmfulness: 1991-2014

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Abstract

Aims: To test, among US students: 1) whether perceived harmfulness of marijuana has changed over time, 2) whether perceived harmfulness of marijuana changed post-passage of state medical marijuana laws (MML) compared with pre-passage; 3) whether perceived harmfulness of marijuana statistically mediates and/or modifies the relation between MML and marijuana use as a function of grade level.

Design: Cross-sectional nationally-representative surveys of U.S. students, conducted annually, 1991-2014, in the Monitoring The Future study.

Setting: Surveys conducted in schools in all coterminous states; 21 states passed MML between 1996-2014.

Participants: The sample included 1,134,734 adolescents in 8th, 10th, and 12th grades.

Measurements: State passage of MML; perceived harmfulness of marijuana use (perceiving great or moderate risk to health from smoking marijuana occasionally versus slight or no risk); and marijuana use (prior 30 days). Data were analyzed using time-varying multi-level regression modeling.

Findings: Perceived harmfulness of marijuana significantly decreased since 1991 (from an estimated 84.0% in 1991 to 53.8% in 2014, $p<0.01$), and, across time, perceived harmfulness was lower in states that passed MML (OR=0.86, 95% C.I. 0.75-0.97). In states with MML, perceived harmfulness of marijuana increased among 8th graders after MML passage (OR=1.21, 95% C.I. 1.08-1.36), while marijuana use decreased (OR=0.81, 95% C.I. 0.72-0.92). Results were null for other grades, and for all grades combined. Increases in perceived harmfulness among 8th graders after MML passage

was associated with ~33% of the decrease in use. When adolescents were stratified by perceived harmfulness, use in 8th graders decreased to a greater extent among those who perceived marijuana as harmful.

Conclusions: While perceived harmfulness of marijuana use appears to be decreasing nationally among adolescents in the United States, passage of medical marijuana laws (MML) is associated with increases in perceived harmfulness among young adolescents, and marijuana use has decreased among those who perceive marijuana to be harmful after passage of MML.

Introduction

Marijuana use policy is undergoing substantial changes worldwide to include provisions for medical use. In the United States, since 1996, 23 states have legalized medical use of marijuana in some form, and as of 2015, four states have also legalized recreational use for adults. These changes have stimulated substantial discussion about potential unintended consequences of the laws. In particular, commentators have posited that more permissive marijuana legislation may lead to greater marijuana use among adolescents,[1-6] an age group of particular concern because neurobiology develops rapidly during adolescence,[7-9] and heavy marijuana use during this critical period is posited to have long-lasting adverse effects.[10-12]

Studies show that in states with MMLs, adolescents and adults have higher rates of marijuana use than in other states.[13-15] However, most studies that compare adolescents surveyed in states pre- and post-MML passage show no post-MML increase,[16-19] save for a recent study demonstrating a potential increase in marijuana initiation.[20] Among adults, evidence is mixed for state-level MML effects across a variety of outcomes.[20-29] Large-scale pre-/post-comparisons of marijuana use while taking into account other secular changes and state-level differences face substantial methodological challenges, suggesting that a fruitful approach to understanding the link, or lack of one, between adolescent marijuana use and MML may be to investigate

mechanisms that might explain the relationship between MML and changes in marijuana use.

One suggested partial mechanism for an association between MML and marijuana use is through changes in the perception of marijuana use; MML passage has been postulated to decrease the perception of harm of marijuana use. If so, such changes in perceptions might set the stage for subsequent increases in use, since changes in attitudes can be short-term indicators of future behavior change.[30] Public perceptions of the harms associated with marijuana use have varied considerably over time[31,32] and such variations are consistently associated with changes in the prevalence of marijuana use.[30,33,34] Descriptively, data from the yearly U.S. national Monitoring the Future surveys indicate that perceived harmfulness of marijuana has declined among adolescents since 2007-2009,[35] but differences between states with and without MMLs in the perceived harm due to marijuana use have not been tested. In Colorado, following a number of policy changes in a state that had had MML for several years, the proportion of middle- and high school students perceiving marijuana to be a great harm decreased from 2011 to 2013, as did the prevalence of marijuana use.[36] In sum, examination of perceptions of the harmfulness of marijuana after passage of MML may provide insights into potential mechanisms through which MML may affect public health. Few studies have had sufficient data to address potential pre-post MML effects on perceptions of marijuana harmfulness, or how such perceptions mediate the relationship between MML and marijuana use.

Previously, using Monitoring the Future data, we reported that the passage of medical marijuana laws was not associated with post-MML increases in state-level adolescent marijuana use (results even suggested a post-MML *decline* in use among 8th grade students).[14] However, given the complex interplay between policies/laws, public attitudes, and drug use, we now examine the role that adolescent perception of the harmfulness of marijuana plays in the relationship between MML passage and subsequent changes in adolescent marijuana use. We utilized national Monitoring The Future (MTF) data from 1991 to 2014 to investigate the following: 1) whether perceived harmfulness of marijuana has changed over time, 2) whether perceived harmfulness of marijuana changed post-passage of state MML compared with pre-passage; 3) whether perceived harmfulness of marijuana partially statistically mediates and/or modifies the relation between MML and marijuana use among 8th grade students. Following our previous research,[14] we assess these associations both in the overall sample and by grade. Marijuana use and attitudes change substantially across stages of adolescent development,[37] and our previous findings indicate that MML passage is associated with decreased use among 8th grade students.

Methods

Sample. MTF studies include yearly cross-sectional surveys of 8th, 10th and 12th grade students, sampled to be nationally representative.[35] Approximately 400 schools are surveyed each year in the 48 coterminous U.S. states; students are assessed with self-administered questionnaires. We included data collected since 1991, the first year all three grades were included. The study employs a multi-stage random sampling design with school replacement upon refusal. Up to 350 students per grade are included; only one grade (8, 10 or 12) is surveyed per school. Schools typically participate for two years. Non-participating schools are replaced with others closely matched on geographic location, size, and urbanicity. Of all selection sample units, 95%-99% obtained one or more participating school in all study years; lack of a time trend in school participation rates[38] suggests limited influence of school nonresponse on trend data.

Approximately 15,000 students are included in the total sample per grade per year, totaling 1,134,734 students in the 48 states through 2014. Student response rates were 81%-91% for all years and grades. Most non-response was due to absenteeism; <1% refused. Consistency in data collection procedures was strictly maintained over the years. Parents and students received advance information about the study, including that participation was voluntary and responses anonymous (8th, 10th grade) or confidential (12th grade). Students completed questionnaires in classrooms or larger group administrations. After excluding students missing marijuana use or perceived harm, 973,089 (90.5%) remained for analysis: 363,539 8th graders (88.9%); 336,420 10th graders (90.8%) and 273,130 12th graders (92.2%). Small differences were found in

demographics comparing those with data to those with missing data, such that those with data were more likely to be: female, white versus non-white, younger age, and higher parental education.

Measures.

Past 30-day marijuana use. Our main marijuana use variable was a dichotomous use variable, consistent with pervious studies in time-trend analysis,[30,39] consisting of any marijuana use (vs. no use) within the prior 30 days. We also conducted sensitivity analyses using a graded response option (0, 1-2, 3-5, through a maximum of 40+ occasions of use). The validity of MTF substance reports is supported by low question non-response; the high proportion of participants reporting illicit drug use; strong evidence of construct validity; and methodological studies using objective validation methods.[38]

Perceived harm of marijuana use. Students are asked "How much do you think people risk harming themselves (physically or in other ways), if they smoke marijuana occasionally?" Response options included "No risk", "Slight risk", "Moderate risk", "Great risk", and "Can't say, drug unfamiliar". We dichotomized the item into those who perceived "Great risk" or "moderate risk" versus "No risk" or "Slight risk" ("can't say" was considered missing data), enabling us to model the prevalence of those who perceived marijuana to be harmful versus all others. We also conducted sensitivity analyses using

the item: “How much do you think people risk harming themselves if they smoke marijuana *regularly*, dichotomizing the variables similarly as great or moderate risk vs. all others.

Medical marijuana laws (MML). Two MML indicators were used. The first was a state-level binary variable indicating if a state ever passed a MML by 2014, regardless of the year it was passed. This variable was used to compare prevalence of marijuana use between adolescents living in states that ever passed a MML and in states that did not. The second was a time-varying state-level binary MML variable for each year (1991-2014) and state indicating whether the state had a MML during that year or not. This enabled us to examine adolescents within states prior to and after passage of a MML. Years in which states were considered to have passed MML are listed in Online Table 1. We also conducted sensitivity analyses by re-categorizing the MML variable according to whether the state medical marijuana law implicitly permitted dispensing via caregivers and amounts per patient, or explicitly acknowledged dispensaries as either permitted or not declared illegal (coding consistent with our previous publication on MMLs[14]); years are also listed in Online Table 1.

School- and state-level covariates. School-level control variables included number of students per grade within school; public vs. private school; and urban/suburban vs. rural (school located within a Metropolitan Statistical Area or not[40]). State-level control

variables included the proportion of the population in each state that was male, white, aged 10-24, and aged >25 years without high school education based on census data.

Individual covariates. These included age, gender, race/ethnicity (self-defined: White, Black, Hispanic, Asian, Mixed, Other), and highest parental education.

Statistical analysis. First, we modeled the prevalence of perceived harmfulness of marijuana use (great or moderate harm), by year, grade, and by state MML status using a multilevel logistic regression model with adolescents nested within states. The model included perceived harmfulness of marijuana use as the outcome, and the state-level MML predictors, individual-, school-, and state-level covariates and a piecewise cubic spline to smoothly control the nonlinear historical trend across 24 years (fixed at overall US distributions for prevalence estimates). Because states passed MML in different years, adjusted prevalence estimates for each year scaled the modeled pre-post change effect by the cumulative proportion of the US population exposed to MML in that particular year, following procedures detailed previously[14]). Not all states have MTF data available for every year and grade; the multilevel model addresses this by smoothing associations across missing years and grades with state-level random effects. Details of our modeling strategy as well as model code for SAS 9.4 can be found in an online supplement to this paper.

Second, we used the same multilevel logistic regression model with perceived harmfulness of marijuana use as the outcome to examine the odds of change in perception of harmfulness after passage of MML compared to prior to MML passage. We estimated the overall effect of living in a state that ever passes an MML, and a pre-post effect, i.e., a time-varying difference-in-difference estimate of the change in adolescent attitudes after the law was passed.

Third, we used a similar multilevel regression modeling, with past 30-day marijuana use as the outcome, to address whether the estimate of past-30 day marijuana use changed after passage of MML, controlling for perceived harmfulness of marijuana use. Baseline probabilities of marijuana use across time are provided in a previous publication of these data.[14] Proportion of the total effect of pre-post change on MML use statistically mediated by changes in perceived harm were also estimated on the log odds ratio scale, using the approach of Vanderweele.[41] Multiplicative interactions of perceived harmfulness by MML were tested, and estimates were generated by perceived harmfulness from the model with interaction terms included. Estimates of the association between MML and use by perceived harmfulness by state were also extracted.

Three sensitivity analyses were also conducted in selected analyses. First, we examined perceived harmfulness of “regular use” in place of the primary “occasional use” variable. Second, we examined an ordinal indicator of marijuana use in the past 30 days (number of occasions) in place of the any use vs. none variable. Third, we examined dispensary

effects using an alternative three-level MML definition: states with MML and implicit or explicit provision for marijuana dispensaries (as defined above); states with MML and no provision for dispensaries, and states with no MML.

Results

Figure 1 shows the prevalence of perceived harmfulness of marijuana use, by grade, stratified by state MML status. Overall, perceived harmfulness decreased across time, and was lower among those in MML states than in non-MML states, especially in 10th and 12th grade.

Were state-level MML associated with changes in adolescent perceived harmfulness of marijuana?

Pre- versus post-MML analyses indicated among 8th graders, perceived harmfulness significantly *increased* post-MML passage (OR=1.21, 95% C.I. 1.08-1.36); perceived harmfulness did not change significantly post-MML passage among 10th and 12th graders. Not shown, adolescents in states that ever pass an MML were less likely to perceive marijuana as harmful both overall (OR=0.86, 95% C.I. 0.75-0.97) and within each grade.

Did perceived harmfulness statistically mediate state-level MML effects on adolescent marijuana use?

The association between state-level MML and marijuana use, adjusted for perceived harmfulness, is shown in Table 2. Controlling for perceived harmfulness, MML passage was significantly associated with lower post-MML marijuana use among 8th graders (OR=0.81, 95% C.I. 0.72-0.92), but not among 10th and 12th graders (Table 2).

Marijuana use was higher (OR=1.21, 95% C.I. 1.06-1.39) and perceived harmfulness lower (OR=0.1131, 95% C.I. 0.1114-0.1148) in states that ever passed an MML versus states that did not in all grades combined, though there was no significant change in marijuana use after passage of MML in all grades combined.

The total association between pre-post change in the law and marijuana use among 8th graders was previously reported in these data as OR=0.73 (95% C.I. 0.63-0.84).[14] Hence, the proportion of this MML association on decreasing 8th grader use that was associated with changes in the perception that marijuana is harmful was 33% on the log odds scale (log(0.73)-log(0.81))/log(0.73).

Did state-level MMLs have a differential effect on adolescent marijuana use depending on its perceived harmfulness?

We then considered whether there was evidence that the association between MMLs and marijuana use differs depending on whether the individual adolescent perceived marijuana use to be harmful (Table 3). The interaction of law effect by perceived harmfulness was statistically significant for 8th graders (Online Table 2, p=0.046), indicating that perceived harmfulness of marijuana significantly modified the relationship between MML passage and 8th grade marijuana use.

As shown in Table 3, among those who perceived marijuana use to be harmful, marijuana use decreased post-MML (OR=0.76, 95% C.I. 0.66, 0.87); among those who did not perceive marijuana to be harmful, marijuana use marijuana use also decreased post-MML (OR=0.84, 95% C.I. 0.73-0.95), but the effect of MML passage was stronger among those who perceive marijuana use to be harmful. Online Figure 1 shows the state-by-state effects, which demonstrated some variability across state, though results are generally consistent with those in the pooled state analysis.

Sensitivity analyses

First (Online Table 3), we examined perceived harmfulness of *regular* (rather than occasional) use. In this analysis, MML passage was associated with lower likelihood of marijuana use only among 8th graders who perceive marijuana use to be harmful (OR=0.76, 95% C.I. 0.65, 0.88).

Second (Online Table 4), we examined marijuana use as an ordinal (rather than dichotomous) outcome. Among those who perceive marijuana use to be harmful, MML passage remained associated with decreases in occasions of marijuana use in 8th graders (p=0.008).

Third (Online Table 5), we used the three-level MML indicator that took dispensaries into account in place of the binary MML measure. Among 8th graders who perceive marijuana use to be harmful, marijuana use decreased both in states with an implicit or explicit dispensary allowance (OR=0.80, 95% C.I. 0.66-0.99) and among those in states without such an allowance (OR=0.77, 95% C.I. 0.63-0.95).

Discussion

Since 1991, perceived harmfulness of marijuana use has decreased among U.S. adolescents. However, among 8th grade students, in states with MML compared to those without, perceived harmfulness *increased* after MML were passed, a result contrary to the overall national time trend. These findings indicate that in a national landscape of decreasing perceived harmfulness, young adolescents in states that pass MML have a lower overall decrease in perceived harmfulness than adolescents in states without MML. Given that perceived harmfulness of marijuana is strongly associated with less use of marijuana, this indicates that over time, young adolescents in MML states could be expected to be less likely to use marijuana than adolescents in those states pre-

passage. In fact, the findings are consistent with perceived harmfulness explaining approximately one-third of the *decrease* in marijuana use among 8th graders previously observed in these data after passage of MML,[14] though perceived harmfulness may be an indicator of overall changes in national perceptions regarding marijuana use. Further, the association between state-level MML passage and decreased marijuana use in 8th grade was stronger among those who perceive marijuana to be harmful to health. These associations were robust to multiple sensitivity analyses.

State-level MML associations with marijuana use and perceived harmfulness were found among 8th graders, but not 10th or 12th graders, therefore constituting a robust age effect. After passage of medical marijuana laws, these young adolescents (for whom attitudes may be malleable compared to older adolescents who have already formed opinions) may decide that marijuana is something for use by individuals who are sick, which would make marijuana use seem less appealing as a fun or recreational activity. Also, within-state media coverage of potential harms associated with marijuana use may increase around the time that MML are passed, potentially influencing the post-MML opinion of young adolescents. This could have a greater effect on 8th graders, who are generally not yet in high school and therefore have more limited exposure to recreational marijuana use[35] than on 10th and 12th grade high school students. In addition, parents may be attuned to messages their younger teens hear and provide more counter-marijuana messages to them than to older teens. To our knowledge, public health education, conversations, and controversies around MML passage have not targeted

young adolescents, suggesting that policy and funding at a state level do not explain these findings; rather, we speculate that the mechanisms underlying these results arise from developmental differences in the way that marijuana use is perceived and used among young adolescents. Further investigation of age differences in the adolescent understanding of peer and media marijuana messages is an important future direction indicated by this research.

We note that approximately one third of the decrease in marijuana use after passage of MML among 8th grade students is associated with the change in attitudes towards marijuana. Thus, our results suggest that young adolescents in MML states are increasingly perceiving marijuana to be a risk to health, and that this perception at least in part mediates the decreasing marijuana use among adolescents in these states compared with non-MML states. However, we also note that perceived harmfulness may be indicative of other attitudes and/or unmeasured factors associated national trends in marijuana use; given that we observe an association between MML passage and reduced prevalence of marijuana use even among 8th grade students who do not perceive marijuana to be harmful, this suggests that additional pathways through which MML may affect adolescent use are operative. As noted above, these pathways may include more general attitudinal changes about the uses of marijuana (e.g. as a medication, not as a recreational drug), though we do not have data at this time to test such pathways. On this point, we note that two thirds of this decrease is unexplained, suggesting that the diverse mechanisms including motivations for use, parental attitudes,

availability, and peer and school influences should also be investigated, to the extent that they correlate with MML passage. To the extent that these factors also correlate with perceived harmfulness, further analyses may be able to tease apart more specific mechanisms.

Our understanding of the relationship between marijuana legal policy and marijuana use has been outpaced by the rapidity of the legal changes that have occurred, particularly over the last 10 years. To our knowledge, four main data sources have been used to examine the impact of medical marijuana laws on marijuana use: the National Household Survey on Drug Use and Health,[13,16,20] the Youth Risk Behavior Surveillance Survey,[17-19] the National Longitudinal Study of Youth,[19,42] and Monitoring the Future.[14] Other data sources have also examined outcomes such as treatment admissions and traffic fatalities.[19,22,27] Almost all studies have found little evidence of a change in adolescent marijuana use in states that passed MML. However, some studies have suggested positive associations when examining initiation[20] or when examining specific aspects of the laws rather than a broad comparison of any versus no MML.[42] Our results did not find any overall positive effect of dispensaries. However, medical marijuana laws differ substantially in legal provisions across states,[43] thus careful continued attention to these variations across states are critical. Further, MML passage is ongoing within the context of other marijuana legislation, including decriminalization and legalization of recreational use for adults, and marijuana policy is ongoing within a broader context of shifting economic conditions in the US and other substance use policy and taxation,

which may also affect drug use. Continuing studies are needed to examine the effects of each of these policies and dynamic economic conditions conjointly

Study limitations are noted. The MTF was not originally designed to be representative of specific U.S. states. Thus, the number of schools included in each state in each year varies, and adolescents in the schools were not selected to be representative of the state overall. However, data are drawn from a very large sample across diverse geographic areas in the 48 coterminous U.S. states, and thus the study is population-based. Further, additional specific variations in MML were not considered here, including permission for home cultivation, possession, and the illnesses approved; all merit examination in future studies. Timing of passage and implementation of laws as well as *de facto* operations change by state and across time,[2,42,43] so determining the effects of laws already passed on future rates of marijuana use will require continued surveillance. Our mediation strategy provides an assessment of the overall proportion of the association between MML passage and marijuana use in 8th grade that is associated with changes in attitudes, but causal interpretation should be cautioned given that perceived harmfulness may be associated with other attitudes and/or unmeasured environmental factors, thus our estimates for the proportion mediated by perceived harmfulness specifically may be an overestimate. Moreover, given that there is an interaction between attitudes and MML passage in association with marijuana use, the total proportion mediated by perceived harmfulness indicates an average effect across heterogeneous strata of MML associations. Further, adolescents reported on their

attitude towards marijuana use and their use of marijuana at the same time, thus the longitudinal association between a change in attitude and a subsequent change is use cannot be disentangled; further analysis in longitudinal designs, should such data become available, would aid in more rigorously teasing apart the timing of attitude formation and changes in behavior. Additionally, our results cannot be generalized to adults, among whom rates of marijuana use access to medical marijuana differ.

In conclusion, the present study documents changed perception of the harmfulness of marijuana overall among adolescents since 1991, and further, differing directions of change among the youngest adolescents after state-level MML passage. The grade-specific effects are consistent with previous finding on use.[14] This change in perception for 8th graders partially mediates the association between MML passage and a decrease in marijuana use. Because marijuana use during early adolescence predicts long-term adverse consequences,[10,11] gaining a better understanding of the relationship between laws, perceived harmfulness and use among the youngest adolescents is a critical research priority. As American marijuana legal policy regarding the manufacture, sale, possession, and use of marijuana continues to change, continued epidemiological surveillance is critical to monitor potential effect of the laws.

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Table 1. Association between MML passage and change in perceived harmfulness[+] towards marijuana use, Monitoring the Future (1991-2014)

	Post Medical marijuana law passage	Pre Medical marijuana law passage	Odds ratio (95% CI)
Pre-post change, all grades	69.6%	68.9%	1.03 (0.93 - 1.15)
Pre-post change, 8th grade	78.9%	75.5%	1.21 (1.08 - 1.36)**
Pre-post change, 10th grade	64.1%	66.1%	0.93 (0.83 - 1.04)
Pre-post change, 12th grade	56.7%	57.2%	0.99 (0.89 - 1.11)

Notes: The "Pre-post change" is a pre-post test, it indicates the estimated change in adolescent attitudes after an MML is passed (in the states that passed MML from 1991 through 2014), OR > 1 indicates an increase in perceived harmfulness occurs after a law is passed as compared to before.

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 secular trends in all states with knots at the years 1998 and 2006.

[+] Based on survey question: "How much do you think people risk harming themselves (physically or in other ways) if they smoke marijuana occasionally?" Response options were dichotomized into "Great risk" and "Moderate risk" versus "slight risk", and "no risk".

†p<0.10; *p<0.05, **p<0.01

Table 2. Association between MML passage and adolescent marijuana use, adjusted for adolescent's perceptions of the perceived harmfulness[+] of marijuana (1992[++]-2014)

	Odds ratio (95% CI)
Pre-post change, all grades	0.95 (0.86 - 1.04)
Pre-post change, 8th grade	0.81 (0.72 - 0.92)**
Pre-post change, 10th grade	1.00 (0.89 - 1.12)
Pre-post change, 12th grade	1.00 (0.89 - 1.12)
Living in a state that ever passes an MML versus never, all grades	1.21 (1.06 - 1.39) **
Living in a state that ever passes an MML versus never, 8th grade	1.16 (0.99 - 1.35) †
Living in a state that ever passes an MML versus never, 10th grade	1.20 (1.03 - 1.39)
Living in a state that ever passes an MML versus never, 12th grade	1.26 (1.08 - 1.46)**
Perceives marijuana use to be harmful versus not, all grades	0.11 (0.11 - 0.11) **
Perceives marijuana use to be harmful versus not, 8th grade	0.11 (0.11 - 0.12)**
Perceives marijuana use to be harmful versus not, 10th grade	0.11 (0.11 - 0.11)**
Perceives marijuana use to be harmful versus not, 12th grade	0.12 (0.11 - 0.12)**

Notes: "Living in a state that ever passes an MML versus never" is not a pre-post test. It indicates the odds of marijuana use among adolescents in states that ever pass an MML at any point from 1992 through 2014 compared to those in states that never pass a law over the same time period. The "Pre-post change" is a pre-post test, it indicates the estimated change in adolescent marijuana use after an MML is passed.

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 one knot at the year 2000.

[+] Based on survey question: “How much do you think people risk harming themselves (physically or in other ways) if they smoke marijuana occasionally?” Response options were dichotomized into “Great risk” and “Moderate risk” versus “slight risk”, and “no risk”.

[++]Effects were estimated from 1992-2014 as models including 1991 data did not converge

†p<0.10, *p<0.05, **p<0.01

Table 3. Association between MML passage and adolescent marijuana use, stratified by adolescent’s perceptions of the perceived harmfulness** of marijuana

	Odds ratio	**Confidence interval**
Among those who perceive marijuana use to be harmful:		
Pre-post change, all grades	0.90	(0.82-0.99)*
Pre-post change, 8th grade	0.76	(0.66-0.87)**
Pre-post change, 10th grade	1.00	(0.89-1.14)
Pre-post change, 12th grade	0.97	(0.85-1.10)
Living in a state that ever passes an MML versus never, all grades	1.25	(1.09-1.42)*
Living in a state that ever passes an MML versus never, 8th grade	1.18	(1.01-1.38)*
Living in a state that ever passes an MML versus never, 10th grade	1.20	(1.03-1.40)*
Living in a state that ever passes an MML versus never, 12th grade	1.36	(1.17-1.60)**
Among those who do not perceive marijuana use to be harmful:		
Pre-post change, all grades	0.95	(0.87-1.04)
Pre-post change, 8th grade	0.84	(0.73-0.95)*

Pre-post change, 10th grade	1.00	(0.89-1.12)
Pre-post change, 12th grade	1.01	(0.91-1.13)
Living in a state that ever passes an MML versus never, all grades	1.18	(1.04-1.34)*
Living in a state that ever passes an MML versus never, 8th grade	1.14	(0.97-1.33)†
Living in a state that ever passes an MML versus never, 10th grade	1.19	(1.02-1.38)*
Living in a state that ever passes an MML versus never, 12th grade	1.21	(1.04-1.41)*

Table 3. Association between MML passage and adolescent marijuana use, stratified by adolescent's perceptions of the perceived harmfulness** of marijuana (continued)

Notes: "Living in a state that ever passes an MML versus never" is not a pre-post test. It indicates the odds of marijuana use among adolescents in states that ever pass an MML at any point from 1991 through 2014 compared to those in states that never pass a law over the same time period. The "Pre-post change" is a pre-post test, it indicates the estimated change in adolescent attitudes after an MML is passed.

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 one knot at the year 2000.

** Based on survey question: "How much do you think people risk harming themselves (physically or in other ways) if they smoke marijuana occasionally?" Response options were dichotomized into "Great risk" and "Moderate risk" versus "slight risk", and "no risk".

†p<0.10; *p<0.05, **p<0.01

References

1. Wilkinson ST. Medical and recreational marijuana: commentary and review of the literature. *Missouri medicine.* 2013;110(6):524-528.
2. Pacula RL, Sevigny EL. Marijuana liberalization policies: why we can't learn much from policy still in motion. *Journal of policy analysis and management : [the journal of the Association for Public Policy Analysis and Management].* 2014;33(1):212-221.
3. Svrakic DM, Lustman PJ, Mallya A, Lynn TA, Finney R, Svrakic NM. Legalization, decriminalization & medicinal use of cannabis: a scientific and public health perspective. *Missouri medicine.* 2012;109(2):90-98.
4. Gorman DM, Charles Huber J, Jr. Do medical cannabis laws encourage cannabis use? *The International journal on drug policy.* 2007;18(3):160-167.
5. Khatapoush S, Hallfors D. "Sending the wrong message": did medical marijuana legalization in California change attitudes about and use of marijuana? *J Drug Issues.* 2004;34:751-770.
6. Ammerman S, Ryan S, Adelman WP, Committee On Substance Abuse TCOA, Committee On Substance Abuse The Committee On A. The impact of marijuana policies on youth: clinical, research, and legal update. *Pediatrics.* 2015;135(3):e769-785.
7. Casey B, Jones RM, Somerville LH. Braking and Accelerating of the Adolescent Brain. *Journal of research on adolescence : the official journal of the Society for Research on Adolescence.* 2011;21(1):21-33.
8. Steinberg L. Risk Taking in Adolescence: New Perspectives From Brain and Behavioral Science. *Current Directions in Psychological Science.* 2007;16(2):55-59.
9. Thompson PM, Vidal C, Giedd JN, et al. Mapping adolescent brain change reveals dynamic wave of accelerated gray matter loss in very early-onset schizophrenia. *Proceedings of the National Academy of Sciences of the United States of America.* 2001;98(20):11650-11655.
10. Hall W. What has research over the past two decades revealed about the adverse health effects of recreational cannabis use? *Addiction.* 2015;110(1):19-35.
11. Filbey FM, Aslan S, Calhoun VD, et al. Long-term effects of marijuana use on the brain. *Proc Natl Acad Sci U S A.* 2014;111(47):16913-16918.
12. Volkow ND, Compton WM, Weiss SR. Adverse health effects of marijuana use. *The New England journal of medicine.* 2014;371(9):879.
13. Wall MM, Poh E, Cerda M, Keyes KM, Galea S, Hasin DS. Adolescent marijuana use from 2002 to 2008: higher in states with medical marijuana laws, cause still unclear. *Annals of epidemiology.* 2011;21(9):714-716.
14. Hasin DS, Wall M, Keyes KM, et al. Medical marijuana laws and adolescent marijuana use in the USA from 1991 to 2014: results from annual, repeated cross-sectional surveys. *Lancet Psychiatry.* 2015;2(7):601-608.
15. Stolzenberg L, D'Alessio SJ, Dariano D. The effect of medical cannabis laws on juvenile cannabis use. *The International journal on drug policy.* 2015.

16. Harper S, Strumpf EC, Kaufman JS. Do medical marijuana laws increase marijuana use? Replication study and extension. *Annals of epidemiology.* 2012;22(3):207-212.
17. Choo EK, Benz M, Zaller N, Warren O, Rising KL, McConnell KJ. The impact of state medical marijuana legislation on adolescent marijuana use. *The Journal of adolescent health : official publication of the Society for Adolescent Medicine.* 2014;55(2):160-166.
18. Lynne-Landsman SD, Livingston MD, Wagenaar AC. Effects of state medical marijuana laws on adolescent marijuana use. *American journal of public health.* 2013;103(8):1500-1506.
19. Anderson DM, Hansen B, Rees DI. Medical Marijuana Laws and Teen Marijuana Use. *American Law and Economics Review.* 2015;ePub April 24, 2015.
20. Wen H, Hockenberry JM, Cummings JR. The effect of medical marijuana laws on adolescent and adult use of marijuana, alcohol, and other substances. *J Health Econ.* 2015;42:64-80.
21. Masten SV, Guenzburger GV. Changes in driver cannabinoid prevalence in 12 U.S. states after implementing medical marijuana laws. *Journal of safety research.* 2014;50:35-52.
22. Salomonsen-Sautel S, Min SJ, Sakai JT, Thurstone C, Hopfer C. Trends in fatal motor vehicle crashes before and after marijuana commercialization in Colorado. *Drug and alcohol dependence.* 2014;140:137-144.
23. Johnson MB, Kelley-Baker T, Voas RB, Lacey JH. The prevalence of cannabis-involved driving in California. *Drug and alcohol dependence.* 2012;123(1-3):105-109.
24. Brady JE, Li G. Trends in alcohol and other drugs detected in fatally injured drivers in the United States, 1999-2010. *American journal of epidemiology.* 2014;179(6):692-699.
25. Chu YW. The effects of medical marijuana laws on illegal marijuana use. *Journal of health economics.* 2014;38:43-61.
26. Morris RG, TenEyck M, Barnes JC, Kovandzic TV. The effect of medical marijuana laws on crime: evidence from state panel data, 1990-2006. *PloS one.* 2014;9(3):e92816.
27. Anderson DM, Hanson B, Rees DI. Medical marijuana laws, traffice fatalities and alcohol consumption. *Journal of Law and Economics.* 2013;56:333-369.
28. Anderson DM, Rees DI, Sabia JJ. Medical marijuana laws and suicides by gender and age. *American journal of public health.* 2014;104(12):2369-2376.
29. Bachhuber MA, Saloner B, Cunningham CO, Barry CL. Medical cannabis laws and opioid analgesic overdose mortality in the United States, 1999-2010. *JAMA internal medicine.* 2014;174(10):1668-1673.
30. Keyes KM, Schulenberg JE, O'Malley PM, et al. The social norms of birth cohorts and adolescent marijuana use in the United States, 1976-2007. *Addiction.* 2011;106(10):1790-1800.
31. Musto DF. Marihuana and the Federal Bureau of Narcotics. *American Disease*. New York: Oxford University Press; 1999.
32. Musto DF. The Marihuana Tax Act of 1937. *Archives of general psychiatry.* 1972;26(2):101-108.

33. Bachman JG, Johnson LD, O'Malley PM. Explaining recent increases in students' marijuana use: impacts of perceived risks and disapproval, 1976 through 1996. *American journal of public health.* 1998;88(6):887-892.
34. Johnston LD, Bachman JG, O'Malley PM. Highlights from Student Drug Use in America, 1975-1980. *(DHHS Publication No. (ADM) 81-1066) Washington, D.C.: National Institute on Drug Abuse.* 1981.
35. Miech RA, Johnson LD, O'Malley PM, Bachman JG, Schulenberg JE. Monitoring the Future national survey results on drug use, 1975-2014: Volume I, Secondary school students. *Ann Arbor: Institute for Social Research, The University of Michigan.* 2015.
36. Ghosh TS, Van Dyke M, Maffey A, Whitley E, Erpelding D, Wolk L. Medical marijuana's public health lessons--implications for retail marijuana in Colorado. *The New England journal of medicine.* 2015;372(11):991-993.
37. Johnston LD, O'Malley PM, Miech RA, Bachman JG, Schulenberg JE. Monitoring the Future national survey results on drug use: 1975-2014: Overview, key findings on adolescent drug use. . *Ann Arbor: Institute for Social Research, The University of Michigan.* 2015.
38. Johnston LD, O'Malley PM, Bachman JG, Schulenberg JE. *Monitoring the Future national survey results on drug use, 1975–2010: Volume I, Secondary school students.* Ann Arbor, MI: Institute for Social Research, The University of Michigan; 2011.
39. Kepple NJ, Freisthler B. Exploring the ecological association between crime and medical marijuana dispensaries. *Journal of studies on alcohol and drugs.* 2012;73(4):523-530.
40. United States Census Bureau. Metropolitan and micropolitan statistical areas main. https://www.census.gov/population/metro/. Accessed April 15, 2014.
41. Vanderweele TJ, Vansteelandt S. Odds ratios for mediation analysis for a dichotomous outcome. *American journal of epidemiology.* 2010;172(12):1339-1348.
42. Pacula RL, Powell D, Heaton P, Sevigny EL. Assessing the effects of medical marijuana laws on marijuana use: the devil is in the details. *Journal of policy analysis and management : [the journal of the Association for Public Policy Analysis and Management].* 2015;34(1):7-31.
43. Pacula RL, Hunt P, Boustead A. Words Can Be Deceiving: A Review of Variation Among Legally Effective Medical Marijuana Laws in the United States. *Journal of drug policy analysis.* 2014;7(1):1-19.