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How does state marijuana policy affect US 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; and (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 US 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 and 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** The perceived harmfulness of marijuana has decreased significantly 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 [odds ratio (OR) = 0.86, 95% confidence interval (CI) = 0.75–0.97]. In states with MML, perceived harmfulness of marijuana increased among 8th graders after MML passage (OR = 1.21, 95% CI = 1.08–1.36), while marijuana use decreased (OR = 0.81, 95% CI = 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, the 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.

Keywords Adolescents, attitudes, laws, marijuana, medical marijuana, Monitoring the Future.

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INTRODUCTION

Marijuana use policy is undergoing substantial changes world-wide 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 medical marijuana laws (MML), 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, as 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 associated consistently with changes in the prevalence of marijuana use [30,33,34]. Descriptively, data from the yearly US national Monitoring the Future (MTF) surveys indicate that perceived harmfulness of marijuana has declined among adolescents since 2007–09 [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 MTF 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 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; and (3) whether perceived harmfulness of marijuana partially mediates and/or modifies statistically 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 US states; students are assessed with self-administered questionnaires. We included data collected since 1991, the first year in which 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 participate typically for 2 years. Non-participating schools are replaced with others matched closely 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 non-response 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 to 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 maintained strictly 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 previous studies in time-trend analysis [30–39], consisting of any marijuana use (versus no use) within the prior 30 days. We also conducted sensitivity analyses using a graded response option (0, 1–2, 3–5, to 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 versus 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 or not the state had a MML during that year. 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 the Supporting information, Table S1. A total of 21 states passed MML between 1996 and 2014. We also conducted sensitivity analyses by re-categorizing the MML variable according to whether the state medical marijuana law implicitly permitted dispensing via care-givers 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 Supporting information, Table S1.

School- and state-level covariates

School-level control variables included number of students per grade within school; public versus private school; and urban/suburban versus rural (school located or not within a Metropolitan Statistical Area [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 state MML status using a multi-level 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 non-linear 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 multi-level 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 version 9.4 can be found in the Supporting information to this paper.

Secondly, we used the same multi-level 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.

Thirdly, we used a similar multi-level 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]. The proportion of the total effect of pre–post change on MML use mediated statistically 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. Secondly, we examined an ordinal indicator of marijuana use in the past 30 days (number of occasions) in place of the any use versus none variable. Thirdly, 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 (from an estimated 84.0% in 1991 to 53.8% in 2014, $P < 0.01$), and was lower among those in MML states than in non-MML states, especially in 10th and 12th grade [odds ratio (OR) = 0.86, 95% confidence interval (CI) = 0.75–0.97].

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

As shown in Table 1, pre- versus post-MML analyses indicated among 8th graders, perceived harmfulness increased post-MML passage significantly [odds ratio (OR) = 1.21, 95% confidence interval (CI) = 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% CI = 0.75–0.97) and within each grade.

Did perceived harmfulness mediate state-level MML effects statistically 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 associated significantly with lower post-MML marijuana use among 8th graders (OR = 0.81, 95% CI = 0.72–0.92), but not among 10th and 12th graders (Table 2).

Marijuana use was higher (OR = 1.21, 95% CI = 1.06–1.39) and perceived harmfulness lower (OR = 0.1131, 95% CI = 0.1114–0.1148) in states that ever passed an MML versus states that did not in all grades

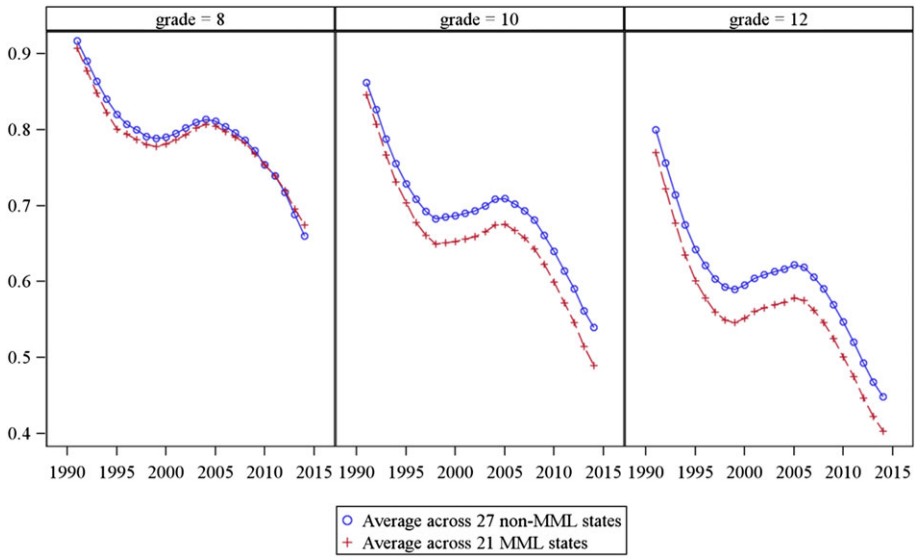

Figure 1 Yearly estimate[a] of perceived harmfulness[b] of marijuana use, by grade and medical marijuana laws (MML) passage, Monitoring the Future (1991–2014). [a]Model-based estimates of prevalence of perceived harmfulness were obtained using a multi-level logistic regression model with perceived harmfulness of marijuana use as the outcome including the state-level MML predictors, individual-, school- and state-level covariates in addition to a piecewise cubic spline to smoothly control the non-linear historical trend across 24 years (fixed at overall US distributions for prevalence estimates). 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 years. The model also included a state random intercept, and state-specific cubic spline polynomials to control for trend with knots at the years 1998 and 2006. [b]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'

Table 1 Association between medical marijuana laws (MML) passage and change in perceived harmfulness[a] 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)

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 to 2014), odds ratio (OR) > 1 indicates an increase in perceived harmfulness occurs after a law is passed 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 and % population aged 11–24 years. 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 years 1998 and 2006. [a]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'. **$P < 0.01$.

Table 2 Association between medical marijuana laws (MML) passage and adolescent marijuana use, adjusted for adolescent's perceptions of the perceived harmfulness[a] of marijuana (1992[b]–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)**

'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 to 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 and % population aged 11–24 years. The model also included a state random intercept and state-specific cubic spline polynomials to control for trend with one knot at year 2000. **$P < 0.01$; ***$P < 0.10$. [a]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'. [b]Effects were estimated from 1992 to 2014, as models including 1991 data did not converge. CI = confidence interval.

combined, although 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 reported previously in these data as OR = 0.73 (95% CI = 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 (Supporting information, Table S2, $P = 0.046$), indicating that perceived harmfulness of marijuana modified significantly 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% CI = 0.66, 0.87); among those who did not perceive marijuana to be harmful, marijuana use also decreased post-MML (OR = 0.84, 95% CI = 0.73–0.95), but the effect of MML passage was stronger among those who perceive marijuana use to be harmful. Supporting information, Figure S1 shows the state-by-state effects, which demonstrated some variability

Table 3 Association between medical marijuana laws (MML) passage and adolescent marijuana use, stratified by adolescent's perceptions of the perceived harmfulness[a] 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)*

'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 to 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 and % population aged 11–24 years. The model also included a state random intercept and state-specific cubic spline polynomials to control for trend with one knot at year 2000. *$P < 0.05$; **$P < 0.01$; ***$P < 0.10$. [a]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'.

across state, although results are generally consistent with those in the pooled state analysis.

SENSITIVITY ANALYSES

First (Supporting information, Table S3), 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% CI = 0.65, 0.88).

Secondly (Supporting information, Table S4), 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 ($P = 0.008$).

Thirdly (Supporting information, Table S5), 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% CI = 0.66–0.99) and among those in states without such an allowance (OR = 0.77, 95% CI = 0.63–0.95).

DISCUSSION

Since 1991, perceived harmfulness of marijuana use has decreased among US 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 associated strongly 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 observed previously in these data after passage of MML [14], although 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), although 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 during 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 MTF [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 is 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 United States 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 designed originally to be representative of specific US 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 US 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 teasing apart the timing of attitude formation and changes in behavior more rigorously. 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 findings 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.

Declaration of interests

None.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Figure S1 US overall and state-specific estimates of the association between medical marijuana laws (MML) passage and marijuana use stratified by perceived harmfulness of marijuana.

Table S1 Years in which states were analyzed as passing medical marijuana laws (MML) laws and years in which state medical marijuana law implicitly permitted dispensing via care-givers and amounts per patient, or explicitly acknowledged dispensaries as either permitted or not declared illegal.

Table S2 Interactions between perceived harmfulness** of marijuana use and pre–post medical marijuana laws (MML) on MJ use, 1993*–2014.

Table S3 Association between medical marijuana laws (MML) passage and adolescent marijuana use, stratified by adolescent's perceptions of the perceived harmfulness of regular* marijuana use (1992–2014**).

Table S4 Association between medical marijuana laws (MML) passage and adolescent marijuana use, stratified by adolescent's perceptions of the perceived harmfulness* of marijuana, using an ordinal definition** of the number of occasions of marijuana use as the outcome.

Table S5 Association between medical marijuana laws (MML) with dispensary provision and adolescent marijuana use, stratified by adolescent's perceptions of the perceived harmfulness* of marijuana.