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Impact of Medical Marijuana Laws on State-Level Marijuana Use by Age and Gender, 2004–2013

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Abstract In states that have passed medical marijuana laws (MMLs), marijuana use (MU) increased after MML enactment among people ages 26 and older, but not among ages 12–25. We examined whether the age-specific impact of MMLs on MU varied by gender. Data were obtained from the 2004–2013 restricted-use National Survey on Drug Use and Health, aggregated at the state level. The exposure was a time-varying indicator of state-level MML (0 = No Law, 1 = Before Law, 2 = After Law). Outcomes included past-month MU prevalence, daily MU prevalence among past-year users (i.e., 300+ days/year), and past-year marijuana use disorder (MUD) prevalence. Linear models tested the state-level MML effect on outcomes by age (12–17, 18–25, 26+) and gender. Models included a state-level random intercept and controlled for time- and state-level covariates. Past-month MU did not increase after enactment of MML in men or women ages 12–25. Among people 26+, past-month MU increased for men from 7.0% before to 8.7% after enactment (+ 1.7%, $p < 0.001$) and for women from 3.1% before to 4.3% after enactment (+ 1.1%, $p = 0.013$). Among users 26+, daily MU also increased after enactment in both genders (men 16.3 to 19.1%, + 2.8%, $p = 0.014$; women 9.2 to 12.7%, + 3.4%, $p = 0.003$). There were no statistically significant increases in past-year MUD prevalence for any age or gender group after MML enactment. Given the statistically significant increase in daily use among past-year users aged 26+ following enactment, education campaigns should focus on informing the public of the risks associated with regular marijuana use.

Keywords Medical marijuana laws · Cannabis · Gender · Marijuana use

Abbreviations

MML	Medical marijuana laws
MU	Marijuana use
MUD	Marijuana use disorder

Introduction

In 1996, California became the first state to legalize the medical use of marijuana. Over the following 20 years, more than half of the USA have passed medical marijuana laws (MMLs), with 28 states legalizing medical marijuana use (MU) as of November 2016 (ProCon.org 2016). With the recent legalization of recreational marijuana use in at least seven states and the District of Columbia, and the decriminalization of minor marijuana offenses in 21 states (National Conference of State Legislatures 2016), it is clear that public perception of marijuana use has changed, with Americans gradually becoming more accepting of MU, more in favor of marijuana legalization (Pew Research Center 2014), and less likely than in the past to view MU as a risky behavior (Compton et al. 2016; Pacek et al. 2015). This changing perception is reflected in

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trends of increasing MU. Adult marijuana use has increased from 9.9% in 2007 to 13.3% in 2014 (Compton et al. 2016). This upward trend in adult MU has been observed across epidemiological studies with statistically significant increases seen across varied adult subgroups between 2001–2002 and 2012–2013 (Hasin et al. 2015a).

Increases in marijuana use raise concerns regarding associated increases in heavy use of marijuana and marijuana use disorder (MUD). Some studies have shown an increase in the prevalence of MUD in recent years (Budney et al. 2007; Hasin et al. 2016), while others have found no change in MUD among adults since 2002 (Compton et al. 2016). Marijuana dependence is common among heavy users (Hall and Degenhardt 2009; Hasin et al. 2008; Volkow et al. 2014); it is estimated that 16.2 and 57.2% of daily marijuana users meet criteria for DSM-IV abuse and dependence diagnosis, respectively (Hasin et al. 2008). Further, habitual MU has been associated with respiratory issues (Hall and Degenhardt 2009; Tashkin et al. 2002; Tetrault et al. 2007); increased risk of psychosis and psychiatric disorders, particularly among those already more susceptible (Davis et al. 2013; Di Forti et al. 2015; Hall and Degenhardt 2009); and higher risk of unintentional injury (Gerberich et al. 2003; Grotenhermen et al. 2007; Hall 2009). Additionally, some researchers have posited that persistent MU may cause decreased cognitive function over time (Meier et al. 2012), and alter brain development among adolescents (Jager and Ramsey 2008; Volkow et al. 2014).

The advent of MMLs has been proposed as one potential cause of the increased prevalence of MU. The majority of studies examining the MML-MU relationship have restricted their analysis to adolescent age groups; there is now a general consensus that MMLs have not affected rates of use in adolescents (Anderson et al. 2015; Choo et al. 2014; Hasin et al. 2015b; Lynne-Landsman et al. 2013; Wall et al. 2016). One of these studies actually found evidence of a decrease in MU after enactment of MMLs in those under 17 (Anderson et al. 2015). Studies on adult populations are less common and have produced mixed results. In analyses of both youth and adult populations, Harper and colleagues found no statistically significant changes in MU following the enactment of MMLs (Harper et al. 2012), whereas Martins and colleagues found an increase in use among those aged 26+ but no change in use among those aged 12–17 and 18–25 (Martins et al. 2016). Wen and colleagues found an increase in use among those aged 21+ (Wen et al. 2015). Although all three studies relied on the same data source (National Survey on Drug Use and Health), Martins et al. and Wen et al. used individual-level (rather than state-level) data and controlled for individual-level covariates. Both were also published more recently, so analyses were based on more MML states as well as more post-MML years of observation, possibly explaining the discrepancy in findings with earlier work.

There are fewer studies examining the effect of MMLs on youth and adult daily MU. One study found no effect of MMLs on daily MU in youth and an increase in daily use among adults aged 21+ (Wen et al. 2015), consistent with findings of any MU. Research examining the impact of MMLs on MUD is also somewhat limited. A study by Cerdá et al. (2012) did not directly assess the impact of MMLs on MUD, but reported that MUD rates were higher in states with MMLs as compared to states without MMLs. The only study to our knowledge directly assessing the impact of MMLs on abuse/dependence suggests that marijuana abuse/dependence has increased among adults 21 and older only when testing for 1-year lagged effects of MMLs, but not among individuals under 21 (Wen et al. 2015). No study, to date, has examined the impact of MMLs on abuse/dependence separately for adolescents (those aged 12–17) and young adults (18–25).

Despite some public health concern regarding increased use of marijuana associated with MMLs, enactment of MMLs has been associated with some positive outcomes. MMLs have been linked to decreased opioid use (Bachhuber et al. 2014; Kim et al. 2016; Powell et al. 2015) and decreased alcohol consumption (Anderson et al. 2013), with the later subsequently tied to decreased rates of traffic injury fatalities at the state level (Anderson et al. 2013; Santaella-Tenorio et al. 2017). The potential impacts of MMLs on changes in MU, both positive and negative, highlight the public health importance in understanding the factors that influence trends in MU.

One important consideration when analyzing the effects of MMLs is that MU is not uniform across population subgroups. Overall prevalences of MU and MUD differ by age and gender, with consistently higher rates among men and emerging adults ages 18–25 (Copeland and Swift 2009; Hasin et al. 2015a; Substance Abuse and Mental Health Services Administration 2014). A recent study (Carliner et al. 2017) found that the gender gap in MU prevalence among adults has widened since 2007. Carliner et al. (2017) reported that this widening of the gender gap occurred primarily due to increased prevalence among men in the lowest income level (+ 6.2%) from 2007 to 2014. It is therefore important to consider these demographic factors when examining the effects of MMLs on MU. To date, only one study has examined gender as a possible modifying variable of the relationship between MMLs and MU. This study was restricted to youth and found no evidence of a gender difference (Anderson et al. 2015). To our knowledge, no other study has examined gender differences in the association between MMLs and the prevalence of marijuana use, frequency of use, and marijuana abuse/dependence in adult populations.

We aimed to address these gaps in the literature. Therefore, we explored whether the impact of state-level MMLs on past-month MU prevalence, daily MU prevalence, and past-year MUD prevalence varies by age (12–17, 18–25, 26+) and

gender in the US household population from 2004 to 2013. We hypothesized that MMLs would have the greatest influence on marijuana use and disorder among the largest user group, 18–25-year-old men. Building the evidence base in this area will help public health professionals to better understand which age/sex groups, if any, may be most affected by MMLs.

Methods

Study Sample

Ten years of annual cross-sectional survey data were obtained from the National Survey on Drug Use and Health (NSDUH) restricted use data portal (individual level data) 2004–2013 and were aggregated at the state level for each gender-by-age group. Since 2004 (the first year in which restricted-access NSDUH data were made available), cross-sectional data on more than 17,500 youth (12–17 years old), 17,500 young adults (18–25 years old), and 18,800 adults 26 and older have been collected yearly (Substance Abuse and Mental Health Data Archive 2017). The NSDUH was designed to produce estimates of drug and alcohol use prevalence, as well as drug use patterns and their consequences, in the general US non-institutionalized population aged 12 and older. The annual cross-sectional surveys employed a 50-state design with an independent multistage area probability sample for each state and the District of Columbia. Importantly, the survey design allowed for computation of estimates that are representative of each state in all 50 states plus the District of Columbia. Younger age groups (ages 12–17 and 18–25) were oversampled. Each state's sample was approximately equally distributed among three major age categories: 12–17, 18–25, and 26 years or older. Design-based weights adjusted for non-response and post-stratify to the known total US population aged 12 and older. Professional field interviewers collected information using computer-assisted interviewing methods, including audio computer-assisted self-interviewing that had built-in skip logic and consistency checks. Audio computer-assisted self-interviewing provided respondents with a highly private and confidential means of responding to sensitive questions, increasing the level of honest reporting of illegal drug use and other sensitive behaviors (Morral et al. 2003). Survey screening response rates vary from 84 to 91%, and interview response rates vary from 72 to 77% for survey years 2004–2013. The reliability and validity of the NSDUH measures has been documented elsewhere (Harrison et al. 2007; Hunter et al. 2005; Piper et al. 2006).

Measures

Primary Exposure: State-Level Medical Marijuana Law Our primary exposure was state-level MMLs, parameterized as a time-varying three-level variable indicating whether the state had enacted a MML in a particular year or not, as determined through review of state policies by legal scholars, economists, and policy analysts at RAND Corporation (Pacula et al. 2014) (Table 1). States without MML by 2014 were coded as "never" states for all years in our data (2004–2013). States enacting MML were coded as "before" for the years in which they had not yet enacted a MML, and as "after" for the year in which they enacted a MML and also all years after enactment. The 11 states that passed MMLs prior to or during 2004 were coded as "after" on this variable for all years from 2004 to 2013. This strategy enabled us to examine changes in MU prevalence after enactment of a MML, while controlling for contemporaneous trends in states that have yet to enact a MML. More specifically, while our interest is in change in MU prevalence from before to after MMLs, the inclusion of never-MML states in modeling MU helped control for secular trends in MU independent of MMLs.

Outcome 1: State-Level Past-Month MU Prevalence Individuals were asked whether or not they had used marijuana in the past month. These individual-level responses were then aggregated into state-level annual prevalences for each gender-by-age group.

Outcome 2: State-Level Daily MU Prevalence—Measured Among Past-Year Users NSDUH participants were asked: "We want to know how many days you've used marijuana or hashish during the past 12 months. What would be the easiest way for you to tell us how many days you've used it?" Participants could choose from the following three options: (1) average number of days per week, (2) average number of days per month, or (3) total number of days in the past 12 months. Then participants were asked about frequency of use according to their previous answer: e.g., "On how many days in the past 12 months did you use marijuana or hashish?" Participants' responses were dichotomized as "having used marijuana < 300 days" vs. "300 or more days" in the past 12 months; 300 or more days of MU indicated daily MU. These individual-level responses were then aggregated into state-level annual prevalences for each gender-by-age group.

Outcome 3: State-Level Past-Year MUD (DSM-IV Abuse or Dependence) Prevalence If individuals met criteria for the Diagnostic and Statistical Manual of Mental Disorders IV (American Psychiatric Association 2000) marijuana abuse or dependence in the past year, they were coded as yes for this variable; otherwise no. These individual-level responses were then aggregated into state-level annual prevalences for each gender-by-age group.

State-Level Covariates State-level control variables included proportion of each state's population that was male, White

Table 1 Year of enactment of MML across 23 states which have passed MML up to and including 2014[a]

State	Year MML was enacted	Years Observed "Before"	Years Observed "After"
California	1996	0	10
Oregon	1998	0	10
Washington	1998	0	10
Alaska	1998	0	10
Maine	1999	0	10
Hawaii	2000	0	10
Colorado	2000	0	10
Nevada	2000	0	10
Maryland	2003	0	10
Montana	2004	0	10
Vermont	2004	0	10
Rhode Island	2006	2	8
New Mexico	2007	3	7
Michigan	2008	4	6
Arizona	2010	6	4
New Jersey	2010	6	4
Delaware	2011	7	3
Connecticut	2012	8	2
Massachusetts	2012	8	2
Illinois	2013	9	1
New Hampshire	2013	9	1
Minnesota	2014	10	0
New York	2014	10	0

MML medical marijuana law

[a] States in the shaded box are those enacting MML during 2005–2013 (i.e., with pre- and post-MML data)

non-Hispanic, aged 10–24, and with at least high school education in the population aged > 25 years, as well as state unemployment rate and median household income. Values from the 2000 Census were used for years 2004–2005, while values form the 2010 Census were used for years 2006–2013.

Statistical Methods

State-level yearly proportions of MU outcomes were calculated using Taylor series linearization estimation methods (Stata "svy" commands) in order to account for the NSDUH complex survey design (Chromy and Abeyasekera 2005). All proportions were separately calculated for men and women in each of the age subgroups (12–17, 18–25, and 26 and older). The District of Columbia was excluded from all analyses since it is not a state and may behave differentially than US states.

For descriptive purposes, the prevalence of each MU outcome was calculated for each year, 2004–2013, by averaging NSDUH-weighted state-level prevalence estimates across three MML groups (according to whether MML states had pre/post-MML NSDUH data): (1) states without MMLs by 2014; (2) states having pre/post-MML data during the study period, i.e., those enacting laws from 2005 to 2013 (RI, NM, MI, AZ, NJ, DE, CT, MA, IL, NH); and (3) states with only post-MML data, i.e., states enacting MMLs before or during 2004 (CA, OR, WA, AK, ME, CO, NV, HI, MD, MT, VT). Summaries were stratified by gender and by the three age groups: 12–17, 18–25, and 26 + .

Multilevel linear regressions were used to model the association between MMLs and state-level MU outcomes. Separate models were fit for each outcome with a primary state-level predictor indicating MML status by year: never passed (non-MML), before MML enactment, or after MML enactment. All models controlled for historical trends in MU across the 2004–2013 years using a piecewise cubic spline function (de Boor 1978) of year with a knot at 2008.

Piecewise cubic splines are extremely flexible and therefore able to adequately capture the non-linear trend in MU over time; 2008 was chosen as a knot after exploratory data analyses that showed a decrease/constant trend in marijuana use until 2008 and then an increase in use 2008 and later. Further, these historical trends were allowed to vary by age group by the inclusion of age group by time interaction terms. Finally, the models also controlled for state-level covariates and included a random state-level intercept to account for the repeated measures of each state over time (see supplementary appendix for the model and SAS Proc MIXED code). The estimated variance of the random state intercept was statistically significant in all models, supporting its need to be included to control for clustering of responses at the state level. Models were stratified by age in three categories (12–17, 18–25, 26+) and gender (men, women).

The fitted multilevel linear regression models were then used to estimate the MU outcome prevalences for each type of state (never, before, after MML) and age/gender subgroup by setting all other covariates (time- and state-level covariates) in the model to their overall means. Adjusted prevalence differences (i.e., risk differences) for "After vs. Before" contrasts were also computed for each age-gender subgroup. SAS 9.4 was used for the regression analyses.

Results

Past-Month MU Prevalence

Past-month prevalence of MU during the 2004–2013 period was higher among individuals aged 18–25 compared with those ages 12–17 and those 26 or older, and among men, regardless of state MML status. Further, within each age/gender subgroup, prevalence of past-month MU was higher in states that had ever enacted an MML than in states that had not yet enacted an MML as of 2014, regardless of year of enactment (Fig. 1a).

Regression modeling showed that there was not a statistically significant increase in past-month MU after enactment of MMLs in men or women aged 12–17 or 18–25 (Table 2 (A)). However, among people 26+, the increase in past month MU was statistically significant for both men and women. Among men 26+, past-month prevalence was 7.0% before and 8.7% after MML enactment (+1.7 percentage points, $p < 0.001$). Among women, past-month MU prevalence was 3.1% before and 4.3% after (+ 1.1 percentage points, $p = 0.013$).

Past-Year Daily MU Prevalence

Prevalence of daily MU among past-year marijuana users during the 2004–2013 period was generally higher among individuals aged 18–25 compared with those ages 12–17 and those 26 or older and among men regardless of MML status (Fig. 1b). Across most of the age/gender subgroups, there were no major differences in the prevalence of daily MU in the past year across states with and without MML. One exception was men ages 18–25, among whom daily MU was higher in states with MMLs enacted before or during 2004 compared to other states, specifically after 2009 (Fig. 1b).

Regression modeling showed no statistically significant change in daily MU prevalence among ages 12–17 for either gender after enactment of MMLs (Table 2 (B)). In individuals aged 18–25, the increase in daily MU after MML enactment was statistically significant among men only (+ 2.4 percentage points, $p = 0.047$), but not among women (+ 0.8 percentage points, $p = 0.490$) (Table 2 (B)). In individuals aged 26+, the increase in daily MU among people who reported MU was statistically significant for both genders following MML enactment (men + 2.8 percentage points, $p = 0.014$; women + 3.4 percentage points, $p = 0.003$). Among men 26+, daily MU prevalence was 16.3% before enactment and 19.1% after enactment; among women 26+, 9.2% before and 12.7% after MML enactment.

Past-Year Marijuana Use Disorder Prevalence

Prevalence of past-year MUD during the 2004–2013 period was generally higher among individuals aged 18–25 compared with those ages 12–17 and those 26 or older and among men regardless of state MML status. Among both men and women ages 12–17 and 18–25, states with MMLs had higher prevalences of past-year MUD compared with states without MMLs (Fig. 1c).

Regression modeling showed no statistically significant change in past-year MUD prevalence after enactment of MMLs for any of the age-gender subgroups (Table 2 (C)).

Discussion

In this study, we examined gender differences in the age-specific effects of MMLs on three MU outcomes (i.e., past month MU, daily MU among users in the past year, and MUD in the past year), using 10 years of state-aggregated estimates derived from a nationally representative sample of non-institutionalized individuals in the USA. We found no evidence of an effect of MML enactment in any MU outcome for both men and women aged 12–17. Among people aged 18–25, MML enactment had no effect on past-month MU, but the increase in daily MU among users was statistically significant only among men following MML enactment. Notably, more than one in five young men ages 18–25 living in MML states who used marijuana were reporting daily marijuana in the past year. Lastly, among people ages 26+, the increase in both past-month MU and daily MU among users was

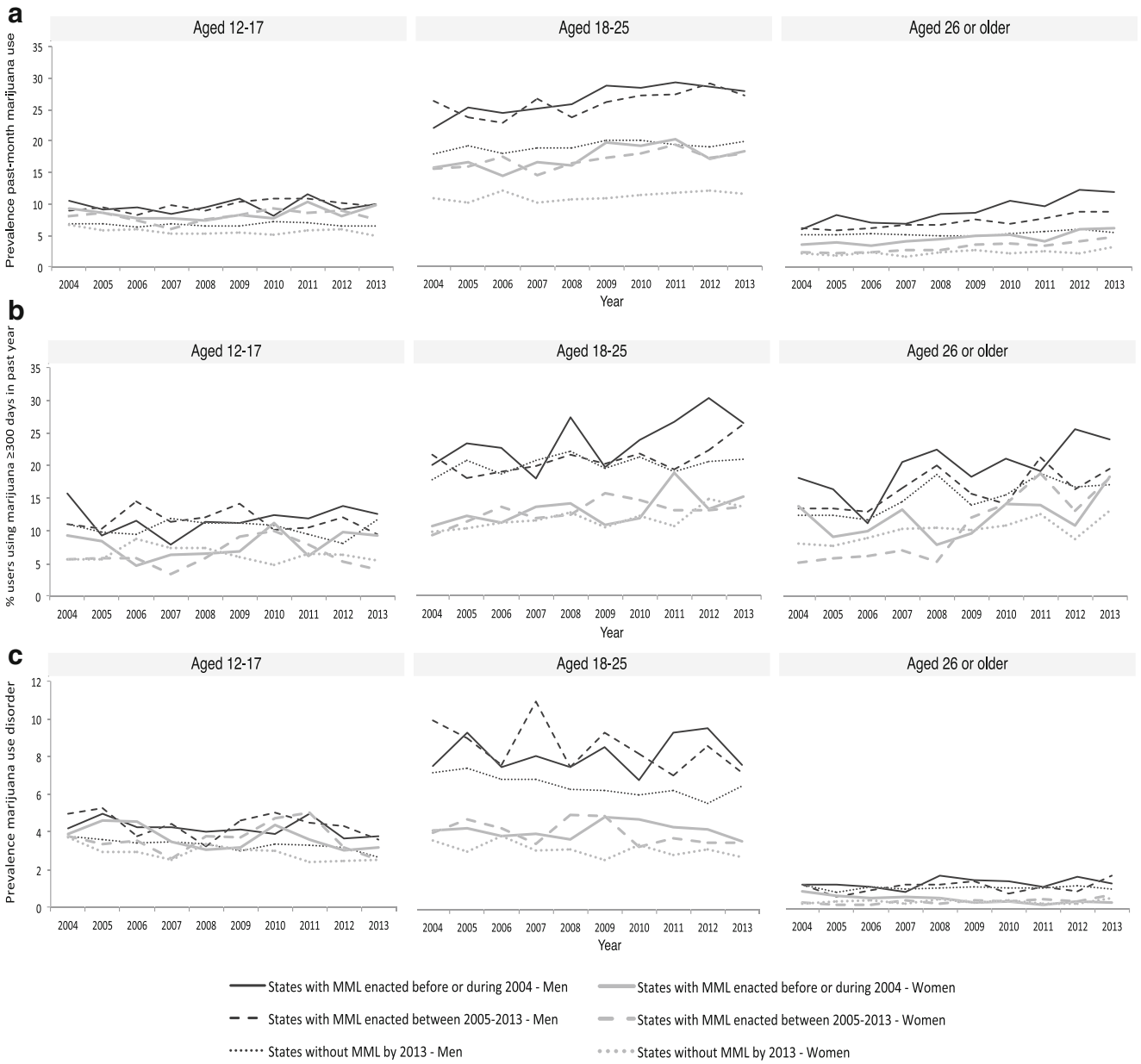

Fig. 1 Observed marijuana-related outcomes over time stratified by age, gender, and state MML status (**a** past-month marijuana use; **b** frequency of daily marijuana use among past-year users; **c** prevalence of marijuana use disorder)

statistically significant for both genders after enactment of MML. There was no significant change in MUD after enactment of MMLs for any of the age/gender subgroups.

Consistent with past research (Anderson et al. 2015; Choo et al. 2014; Hasin et al. 2015b; Lynne-Landsman et al. 2013; Wall et al. 2016), there did not appear to be an impact of MMLs in the adolescent subgroup on any of the three MU outcomes. The current study extends these previous findings by showing no gender differences in this age group in change in past-month MU, daily MU, or MUD related to MML. Males in this age group consistently show higher prevalence of MU outcomes relative to females, and enactment of state MMLs does not appear yet to affect these patterns of MU. Due to developmental concerns, MMLs are explicitly designed to restrict access to youth. As such, the lack of change in MU outcomes among youth could reflect MMLs being implemented as intended. Thus, to date, MMLs have not affected prevalence of MU, daily MU, or MUD in this age group.

In the 18–25-year-old age group, no changes in past month MU were found, but a statistically significant increase in daily MU among male users was found after MML enactment. Further research is necessary to understand this finding; however, it could be related to the fact that marijuana use is associated with lower educational achievement (Fergusson et al. 2003; Lynskey and Hall 2000; Pacek et al. 2015). More women than men pursue

Table 2 Model-based estimates of marijuana use outcomes of interest

		Prevalence before MML[b]	Prevalence after MML[b]	Change in prevalence (after-before)	Change 95% lower	Change 95% upper	*p* value (after-before)
(A) Estimates of past-month marijuana use prevalence by MML status							
Age 12–17	Men	9.1	9.8	0.7	− 0.2	1.7	0.125
	Women	7.9	8.4	0.6	− 0.3	1.5	0.219
Age 18–25	Men	25.7	26.5	0.8	− 0.2	1.9	0.120
	Women	16.9	17.1	0.3	− 0.8	1.3	0.586
Age 26+	Men	7.0	8.7	1.7	0.8	2.6	0.000
	Women	3.1	4.3	1.1	0.2	2.0	0.013
(B) Estimates of daily marijuana use prevalence among past-year marijuana users by MML status							
Age 12–17	Men	12.3	11.6	− 0.7	− 2.9	1.4	0.505
	Women	6.8	7.4	0.6	− 1.5	2.8	0.559
Age 18–25	Men	21.0	23.5	2.4	0.0	4.8	0.047
	Women	12.7	13.5	0.8	− 1.5	3.2	0.490
Age 26+	Men	16.3	19.1	2.8	0.6	5.1	0.014
	Women	9.2	12.7	3.4	1.2	5.7	0.003
(C) Estimates of past-year marijuana use disorder[a] prevalence by MML status							
Age 12–17	Men	4.0	4.4	0.4	− 0.2	0.9	0.177
	Women	3.6	3.7	0.1	− 0.4	0.6	0.714
Age 18–25	Men	8.8	8.4	− 0.4	− 1.0	0.1	0.124
	Women	4.2	4.2	0.0	− 0.5	0.6	0.983
Age 26+	Men	1.1	1.4	0.4	− 0.1	0.8	0.113
	Women	0.4	0.6	0.2	− 0.2	0.6	0.374

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[a] Based on DSM-IV marijuana abuse and/or marijuana dependence

[b] Estimates for prevalence for before and after MML were obtained from the regression model for each age/gender subgroup by setting all other covariates (time- and state-level covariates) in the model to their overall means

higher education in this age group, and there are also more women than men with bachelor's degree among those 25+ (Ryan and Bauman 2016). Further, women historically perceive more risk in using marijuana than men (Pacek et al. 2015; Thornton et al. 2013). Another possibility is that the impact of MMLs on availability of marijuana disproportionally affects men in this age group, potentially as a substitute for alcohol (Reiman 2009). Finally, there is the possibility that more men than women in this age group are the ones using marijuana for medical purposes or to substitute marijuana for opioid use (Scavone et al. 2013). Studies of medical marijuana patients tend to find that the vast majority are men (Reinarman et al. 2011); however, there is recent evidence showing that sex differences in medical marijuana program participation may be decreasing over time (Fairman 2016).

Results indicated that among people ages 26+, the increase in both past-month MU prevalence and daily use of marijuana among users after the enactment of an MML was statistically significant for both men and women. Further, among people ages 26+, the impact of MMLs on MU outcomes appears to be consistent for men and women. These results extend previous findings examining an adult population (Martins et al. 2016; Wen et al. 2015), highlighting that the observed increases are not gender specific. Even though men had up to twice the prevalence of MU outcomes compared to women in this age group, we found that MMLs were associated with similar prevalence increases in past-month and daily MU in both genders ages 26+. This contrasts with recent findings of a widening gender gap in secular use trends (Carliner et al. 2017), independent of MML status. Indeed, the increases in daily MU following MML enactment were larger in magnitude among women 26+ than among males in this age group, indicating that women should not be excluded from public health programming that focuses on marijuana.

Increases in monthly and daily MU in those aged 26 and older, but not in those younger, could be in part due to increased availability of medical marijuana to treat medical conditions in individuals registered in medical marijuana programs, the majority of whom are adults 30 and older (Fairman 2016). However, it could be also due to the increases in the diversion of medical marijuana to individuals using it for recreational purposes (Grotenhermen et al. 2007; Nussbaum et al. 2015). The role of marijuana availability on

marijuana use patterns (e.g., relaxing norms and changing attitudes towards marijuana use) is not yet clear. Increased perceived availability of marijuana could also be contributing to increases in marijuana use among adults after MML enactment (Martins et al. 2016).

Our study found no corresponding increase in MUD after MML, even in age/gender subgroups reporting increases in past-month and daily MU. This is consistent with findings reported by Wen et al. (2015), who did not find a statistically significant increase in MUD after MML enactment (it is important to note that a significant increase was observed in models using 1-year lags for MMLs only in those 21 or older) (Wen et al. 2015). Because most states in our sample more recently passed MML, it is possible that not enough time has elapsed to observe meaningful and significant changes in MUD across age-gender subgroups following increases in daily MU that resulted from MML enactment. Moreover, there is likely no linear association between MU and MUD; instead, MUD is influenced by several factors including frequency of use (days in past year, number of times used per day), potency and quality of marijuana, reasons for use, and other social and mental health factors (van der Pol et al. 2013). Given the impact that MUD may have on individuals, families, and society, the prevalence of MUD should continue to be monitored regularly as other MU-related measures change across age-gender subgroups.

Limitations of the current study are noted. The NSDUH currently has state-level data only for years 2004–2013, and therefore, we were unable to examine the before and after effects of MML in states enacting these laws before 2004 or after 2013. It is possible that different effects could have been observed in these earlier state-years. Nonetheless, a major strength of the present study is its use of a large nationally representative sample, allowing for generalization of findings to the US non-institutionalized population across all 50 states. Further, during this time period, NSDUH did not differentiate between the use of marijuana for recreational and medicinal purposes. It is therefore possible that the observed increase in marijuana use for those aged 26+ could be a result of marijuana use for medical purposes. However, reported estimates of medicinal MU have been quite low, so it is unlikely that the full effect can be explained by medicinal use only (Lin et al. 2016). Future years of NSDUH will collect this information; as such state-level data becomes available, these distinctions between recreational and medical MU should be addressed. In addition, enactment of MMLs could affect individual reporting of MU outcomes if individuals are more likely to report legalized behaviors. However, the NSDUH survey uses ACASI technology to encourage reporting of these behaviors directly to a computer rather than via an in-person interviewer, reducing the potential for self-report bias. Further, increases over time in self-reported MU are consistent with other studies also showing increases over time in marijuana-related outcomes that did not rely on self-report, supporting the validity of the present findings (Hasin and Grant 2016). Lastly, there is variation across provisions included in different states' MMLs (Pacula and Sevigny 2014; Williams et al. 2017; Wen et al. 2015); some aspects, such as allowances on home cultivation or dispensaries, might have a role in changes in several health outcome indicators. In addition, eight states have now legalized recreational marijuana, which may also have an impact on MU outcomes over time. Our analyses did not account for such variability, due to concerns regarding having sufficient power to detect differences across the subgroups of interest. As more states enact MMLs and more post-MML years of data are available, future research should examine how elements of MMLs, legalization of recreational marijuana, and other local aspects contribute to changes in MU outcomes.

In conclusion, this study found an association between MML enactment and increased past-month and daily MU among men and women 26 and older. Consistent with past studies, prevalence of MU outcomes was generally unaffected by changes in MMLs among those under age 26. Further, the impact of gender on the MMLs and marijuana use outcomes association appears to be limited, with the exception of daily MU in those aged 18–25, increasing more among males than females following MML enactment. Daily marijuana use among males 18–25 may raise developmental concerns in the context of ongoing brain maturation. As MU becomes more prevalent, monitoring state-wide trends in MU by age and gender is important for public health planning. In particular, efforts to prevent and limit injury that may be associated with specific activities, such as driving, may be needed as daily MU increases among adults. Downstream effects, either positive or negative, of a growing proportion of the adult population reporting daily MU in states with MMLs warrants further attention.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent is not applicable as this was considered non-human subject research by Columbia University's IRB.

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