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Changes in undergraduates' marijuana, heavy alcohol and cigarette use following legalization of recreational marijuana use in Oregon

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ABSTRACT

Background and Aims Recreational marijuana legalization (RML) went into effect in Oregon in July 2015. RML is expected to influence marijuana use by adolescents and young adults in particular, and by those with a propensity for substance use. We sought to quantify changes in rates of marijuana use among college students in Oregon from pre- to post-RML relative to college students in other states across the same time period. **Design** Repeated cross-sectional survey data from the 2012–16 administrations of the Healthy Minds Study. **Setting** Seven 4-year universities in the United States. **Participants** There were 10 924 undergraduate participants. One large public Oregon university participated in 2014 and 2016 (n = 588 and 1115, respectively); six universities in US states where recreational marijuana use was illegal participated both in 2016 and at least once between 2012 and 2015. **Measurements** Self-reported marijuana use in the past 30 days (yes/no) was regressed on time (pre/post 2015), exposure to RML (i.e. Oregon students in 2016) and covariates using mixed-effects logistic regression. Moderation of RML effects by recent heavy alcohol use was examined. **Findings** Rates of marijuana use increased from pre- to post-2015 at six of the seven universities, a trend that was significant overall. Increases in rates of marijuana use were significantly greater in Oregon than in comparison institutions, but only among students reporting recent heavy alcohol use. **Conclusions** Rates of Oregon college students' marijuana use increased (relative to that of students in other states) following recreational marijuana legislation in 2015, but only for those who reported recent heavy use of alcohol. Such alcohol misuse may be a proxy for vulnerabilities to substance use or lack of prohibitions (e.g. cultural) against it.

Keywords Cannabis, cigarettes, early adulthood, heavy alcohol use, Oregon, recreational marijuana legalization.

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INTRODUCTION

More than half of Americans support the legalization of recreational marijuana use [1]. Supporters believe marijuana is relatively safe compared to other drugs, whereas opponents express concerns about harm to society and individuals, including health dangers and addiction concerns. Compared to research on alcohol and other drug use, there is indeed less evidence of harm from marijuana use [2,3], although there are negative health and educational consequences, particularly in cases of adolescent onset, or long-term, heavy use [4,5]. As such, there is great scientific and policy interest in understanding the public health effects of changes in marijuana laws.

Oregon voters passed a recreational marijuana legalization (RML) ballot measure in November, 2014. Recreational use became legal in July, 2015, and sales from retail dispensaries became legal and began in October, 2015. Frequency of use among marijuana users and numbers of new users are expected to have increased given lower prices, increased and safer access from legal sources, greater social approval of use and users, and the absence of criminal penalties that previously deterred consumption [6]. To date, however, there have been no studies of the impact of Oregon RML on rates of marijuana use.

RML is expected to have its greatest impact on use in adolescence and early adulthood, the developmental period in which marijuana experimentation, onset of patterned use and the establishment of chronic, problematic use

commonly occur [4,7]. During this period individual vulnerabilities and new contextual conditions (e.g. increased substance availability, peer modeling, decreased adult supervision, college culture of experimentation and use) interact to predict substance use patterns [8]. Thus, any significant changes in these contextual conditions may be especially impactful during early adulthood. RML is one such dramatic contextual change, as it may affect the availability of marijuana, norms about use and the negative consequences of consumption. Thus, the present study considers RML effects among college students, an important subgroup of young adults.

To date, few studies have examined RML impacts on marijuana use in any state or for any population, and most lack critical design elements—namely, pre-RML measures and non-RML state controls. In one exception, marijuana use rates among 8th and 10th graders in Washington state were found to increase significantly more following that state's RML when compared to same-age youth in 47 non-RML states; however, the pattern did not hold for youth from Colorado (another RML state) or for 12th-graders in either state [9]. Other research, also concerning adolescents, has suggested that attitudes and beliefs about marijuana use changed following RML in Washington and Colorado, but use itself did not [10,11]. Studies of young adults are needed, as the increasingly liberal attitudes and perceptions about marijuana use that are expressed in adolescence may become manifest in increased use during this next developmental period. Additionally, studies of the effects of Oregon's RML are needed, as Hunt & Miles [12] have noted that RML is actually a 'package' of laws that differ by state, and therefore may have different influences on residents.

Thus, we addressed these gaps in the research on how RML may have impacted a critical segment of the population. We used national survey data collected from college students from 2012 to 2016 to test the primary hypothesis that rates of marijuana use among Oregon college students increased more from before to after RML went into effect relative to students attending colleges in states without RML across the same period. To evaluate the specificity of any change, we repeated the analyses for heavy alcohol use and cigarette use.

Next, we explored three potential moderators of RML effects on marijuana use. First, we tested[1] whether RML effects on marijuana use were stronger among students who reported heavy alcohol use compared to those who did not. Heavy alcohol use is a common behavior among college students and may be a useful proxy for multiple general substance use propensity factors (e.g. individual vulnerabilities; involvement in social contexts that support use; fewer religious or health beliefs that inhibit use [13]) that affect sensitivity to the law change. Secondly, we predicted that RML effects would be more pronounced among students in their first year of college (versus later years), a period of transition and potentially greater sensitivity to the increased availability and decreased prohibitions against substances [8,13]. Finally, given that adults cannot purchase legally or use marijuana recreationally in Oregon until age 21 years, we expected RML effects would be stronger for students who were 'of age' than for minors (under 21).[2] All hypotheses were tested in models that controlled for secular trends towards increased marijuana use [14], as well as individual vulnerability (e.g. depressive symptoms; other substance use), demographic (e.g. gender; race/ethnicity) and contextual (e.g. Greek system involvement; relationship status) factors that could vary by institution and be associated with substance use patterns [13–17].

METHOD

Participants

Data were drawn from the 2012–16 administrations of the Healthy Minds Study (HMS; healthymindsnetwork.org), a national survey study of college students' mental health and wellbeing that includes measures of substance use. HMS is led by researchers at the University of Michigan and was implemented using Qualtrics survey software. Participating institutions generated a random sample of enrolled students (e.g. via the registrar's master list of students), which the researchers used for survey recruitment. Sampled students were invited via email to participate in an online survey. The study was approved by the University of Michigan Institutional Review Board.

For our analyses, we selected data from the only seven 4-year institutions that participated in HMS both prior to (2012–15 academic years) and after (i.e. 2016) the legalization of recreational marijuana in Oregon (1 July 2015), and that collected data on the key covariates. The sample included data from one large public institution in Oregon, and six comparison institutions located in states around the country where recreational marijuana use was illegal to Spring 2016. We limited the analytical sample to undergraduates and students aged 18–26 years (n = 10 924).

Data collection lasted approximately 1 month, and institutions varied in terms of the timing of the administration (beginning mid-January to mid-April). Participation rates ranged from 16 to 47.1% (mean participation rates = 31.2 and 26.3% pre- and post-RML, respectively). The Oregon university chose an option offered by HMS to oversample several groups (e.g. veterans, athletes,

[1]This was not an a priori hypothesis. See Limitations.

[2]Although year in college and age are correlated, these time-related factors are separable, and the hypotheses are not contradictory.

racial/ethnic minority students) in 2016. Follow-up analyses that adjusted for this oversampling, whether by statistical mean, sample weighting or by excluding oversampled subgroups, yielded nearly identical results and identical conclusions.

Measures

Substance use variables

We analysed three outcome variables: 30-day marijuana use, 30-day cigarette use and frequency of heavy alcohol use during the past 2 weeks. For marijuana and cigarette use, participants identified from a list all the substances they had (1) or had not (0) used in the past 30 days. For frequency of heavy alcohol use, participants indicated the number of occasions they had four (female), five (male) or four or five (transgender/other gender) drinks in a row during the past 2 weeks; response options of 0, 1, 2, 3–5, 6–9 and 10 or more times were recoded to 0, 1, 2 and 3 or more times. In 2016 participants first indicated whether or not they had used any alcohol in the past 2 weeks; those who answered no were recoded as '0' for recent heavy alcohol use.

Recreational marijuana legalization (RML)

We created one variable ('post versus pre') indicating survey participation after (1) or prior to (0) July 2015, when RML occurred in Oregon. A second variable was created to indicate whether (1) or not (0) participants attended an institution in Oregon after 2015 to represent effects of exposure to RML.

Demographic and other covariates

Age was dichotomized to represent legal (i.e. 21 and over) drinking and marijuana use age (1) or minor (0). Sex was coded female (referent), male or transgender/other. Race/ethnicity included six mutually exclusive categories: white (referent), Asian, black/African American, Hispanic, multi-racial and other race/ethnicity. The international (1) and domestic (0) student variable was coded dichotomously. Year in school was dichotomized to represent first-year (1) or other-year student (0). Distributions of residence codes permitted recoding into the following three categories: on-campus/university housing (referent), Greek (e.g. fraternity) and other/off-campus housing. The relationship status variable was coded single (referent), in a relationship, married or other. Distributions on sexual orientation permitted recoding to the following five categories: heterosexual (referent), bisexual, gay/lesbian/queer, questioning or other. The survey included two screening instruments for psychological dysfunction: the Patient Health Questionnaire-9 (PHQ-9) for clinical depression [18] and the Generalized Anxiety Disorder-7 assessment (GAD-7) for anxiety [19]. For each of these, we used a dichotomous variable indicating the presence (1) or absence (0) of a positive screen (score ≥ 10). Participants' scores on the Psychological Well-Being Scale [20] were used as a measure of positive psychological adjustment. We also included survey administration period and enrollment size as institution-level covariates in the analyses, given that the small number of institutions other institution-level covariates were redundant (e.g. all large schools were public) or uniquely identifying (e.g. some geographic regions contained only one institution). Survey administration periods were classified into three categories: January–February, February–March and March–May (referent). Given limited variance, the enrollment sizes of the institutions were dichotomized to 'small' or 'large' schools ($> 20\,000$ students; referent group),

Statistical analysis

Data were weighted by the HMS team using institution-specific administrative data on the gender/sex, race/ethnicity, academic level and grade point averages of the student samples to minimize biases introduced by oversampling and differences in participation rates by student demographic characteristics. Additional details concerning the construction of non-response weights are available in prior HMS reports [21].

For the first stage of analysis, we analyzed data for each school separately. Survey weight-adjusted prevalence of the three outcomes variables (30-day marijuana use, 30-day cigarette use and heavy alcohol use) was calculated for each school, stratified by pre/post-RML time-points. Then, multivariate logistic regression analysis was conducted for each school separately to investigate whether there was a time effect (pre/post-RML) on the three outcome variables adjusting for demographics and other covariates. For analysis of each outcome variable, the other two outcomes were included as covariates in the model to control for other substance use. Higher estimates of the time effect in the Oregon school compared to non-Oregon schools would support an RML effect.

In the second stage of analysis, we directly tested the impact of RML in Oregon by creating a combined data set for all schools and years in a mixed-effects logistic regression model of the following general form:

$$y_{ist} = m(\beta_0 + \beta_1 RML_{st} + \beta_2 PrePost_{st} + X\beta_3 + \alpha_s + \alpha_{st} + \varepsilon_{ist}),$$

where i denotes an individual, s denotes the institution and t denotes the year; y_{ist} represents the substance use outcomes for each participant; RML_{st} is the indicator for the implementation of RML in institution s during year t and $PrePost_{st}$ is the indicator for the survey administration pre- and post-RML in Oregon, which captures the time

effect (or secular trend). Two schools participated at two pre-RML time-points. There were no statistical differences in marijuana use rates at the two time-points adjusting for covariates. We chose the most recent pre-RML time-points prior for these two school to minimize within-school sample differences. X is a design matrix for individual- and institution-level covariates. The terms α_s and α_{st} are random intercepts per each unique institution and each institution in each survey administration year, respectively, which account for possible correlations among the students in the same institution and in the same institution within the same year; $m(\cdot)$ is the function that relates the outcome variable to independent variables. In this model, the primary statistical inference was on the indicator variable for RML exposure; under the null hypothesis of no RML effect, we expect the odds ratio (OR) associated with this variable to be 1. Interaction terms were added to the above model to evaluate whether the effect of RML differed significantly across different strata of the moderator variables (e.g. heavy alcohol use). When heavy alcohol use was modeled as an outcome variable, ordinal logistic regression was used with cumulative logit link function.

All analyses were performed using SAS Studio (release 3.5; build date: 3 February 2016). An alpha level of 0.05 was used in all statistical tests.

RESULTS

Descriptive statistics

Descriptive statistics for analytical variables are summarized in Table 1, stratified by the pre/post-2015 time-points for the Oregon school, non-Oregon schools and combined data. There was a trend towards increasing rates of 30-day marijuana use in all but one participating school (see Supporting information, Fig. S1). Overall, 30-day marijuana use rates increased from 21.7 to 23.8% ($P = 0.03$). These data also suggest heterogeneity in marijuana prevalence among different schools (lowest prevalence: 16.7%; highest prevalence: 31.9%). In the combined data trends over time indicated decreasing rates of 30-day cigarette use (from 12.9 to 8.6%, $P < 0.0001$; see Supporting information, Fig. S2) and any heavy alcohol use (from 55.4 to 47.9%, $P = 0.005$; Supporting information, Fig. S3).

RML effects on marijuana use (overall sample)

In school-specific logistic regression models for 30-day marijuana use, the Oregon school exhibited the largest time effect (pre/post-2015) with OR = 1.99 ($P = 0.0002$). In all other schools, the time effect ranged from 1.12 to 1.97 (Fig. 1). In the analysis of combined data, the positive association between RML and 30-day marijuana use was not statistically significant (OR = 1.21, $P = 0.48$) in the presence of a significant time effect (OR = 1.42, $P = 0.0026$), indicating an increasing secular trend of marijuana use.

The interactions of RML with first-year status and legal drinking/using age were not significant. However, we observed a significant interaction between RML and heavy alcohol use ($P < 0.0001$). To simplify interpretation, and given that the effect of RML on marijuana use was similar in three different categories of heavy alcohol use (compared to no heavy alcohol use), we created a dichotomous variable indicating either no heavy alcohol use (0) or any use of heavy alcohol (1) and re-fitted the model that included the interaction term between RML and this new variable; again, it was significant ($P < 0.0001$). Table 2 summarizes these results, as well as the joint effects of multiple covariates on 30-day marijuana use.

Higher rates of marijuana use were also associated with cigarette use, male gender, living in Greek and off-campus housing, identifying as bisexual, questioning or other sexual orientation and attending a private, smaller enrollment institution, and lower rates were found for Asian students, international students and for the earlier survey administration periods. There were no effects of relationship status, psychological dysfunction or wellbeing.

RML effects on marijuana use (stratified by recent heavy alcohol use)

To probe the interaction involving heavy alcohol use we conducted a stratified analysis to assess the effects of RML in two subsamples. Among the students with heavy alcohol use ($n = 5996$; 54.9% of the sample), there were significant effects of RML (OR = 1.73, $P = 0.0076$) and post- versus pre-2015 time (OR = 1.40, $P < 0.0001$). That is, when the analysis was restricted to students with any heavy alcohol use, students who were exposed to RML (i.e. students in the Oregon school in 2016) had 73% increased odds of marijuana use compared to students who were unexposed to RML while accounting for overall (cross-school) increasing secular trends in use (i.e. post- versus pre-2015), effects of individual- and institution-level covariates, and potential correlation among students within each institution. The significant time effect indicates that there was a general secular trend of increasing marijuana use over time, which is also evidenced from school-specific OR > 1 in all schools; the significant RML effect in the same model represents an 'additional' effect that increases the odds of marijuana use due to the RML in the presence of the current secular trend. Among students with no heavy alcohol use ($n = 4928$), the effect of time was significant (OR = 1.53, $P = 0.0004$), but RML was not (OR = 1.11, $P = 0.50$). The adjusted effects of RML and post- versus pre-2015 are summarized in

Table 1 Descriptive statistics for variables (survey weight adjusted) pre- and post-recreational marijuana legalization (RML).

	Oregon school		*Non-RML schools*		*Combined data*	
	Pre-RML	*Post-RML*	*Pre-RML*	*Post-RML*	*Pre-RML*	*Post-RML*
n	588	1115	4011	5210	4599	6325
30-day marijuana use (%) (% missing)	21.4 (0.9)	25.7 (14.9)	21.8 (3.3)	23.4 (13.8)	21.7 (3.0)	23.8 (14.0)
30-day cigarette use (%) (% missing)	12.4(0.9)	9.4 (11.5)	13.0 (3.5)	8.4 (10.6)	12.9 (3.2)	8.6 (10.8)
Heavy alcohol use past 2 weeks (%)						
(% missing)	(0)	(11.8)	(3.1)	(10.8)	(2.7)	(11.0)
None	55.4	65.4	42.6	49.1	44.6	52.1
Once	16.5	13.1	17.3	15.0	17.1	14.7
Twice	13.8	11.2	15.2	15.3	15.0	14.6
More than 3 times	14.2	10.3	24.9	20.5	23.3	18.7
Sex (%)						
Female	49.3	46.0	56.3	53.3	55.3	51.9
Male	50.6	52.1	43.4	45.4	44.5	46.7
Trans/other	0.1	1.9	0.2	1.3	0.2	1.4
Sexual orientation (%)						
Heterosexual	94.1	85.5	89.2	86.5	89.9	86.3
Bisexual	2.9	6.5	3.6	5.2	3.5	5.5
G/L/Q	1.6	2.3	4.0	3.7	3.7	3.4
Questioning	0.7	2.7	1.5	2.2	1.4	2.3
Other	0.8	3.0	1.6	2.4	1.5	2.5
Ethnicity (%)						
White	68.3	58.0	68.2	62.7	68.2	61.8
Asian	14.1	16.5	12.4	16.8	12.7	16.7
Black	0.7	2.3	3.7	4.2	3.2	3.9
Hispanic	4.5	7.0	3.8	5.9	3.9	6.1
Multi-racial	8.3	8.1	8.6	6.1	8.5	6.4
Others	4.2	8.1	3.4	4.3	3.5	5.0
Residential type (%)						
University housing	21.6	32.0	64.6	62.8	58.3	57.0
Greek housing	5.7	3.4	3.0	2.7	3.4	2.8
Off-campus	72.7	64.6	32.4	34.5	38.3	40.2
Relationship status (%)						
In a relationship	42.6	36.7	35.0	33.6	36.1	34.2
Married	3.3	3.8	0.8	0.9	1.2	1.4
Other	0.0	0.6	0.2	0.7	0.1	0.7
Single	54.1	58.9	64.0	64.8	62.5	63.7
International student (%)	9.7	16.7	8.2	8.7	8.4	10.2
Legal age (%)	50.8	41.8	36.6	37.4	38.7	38.2
First year in school (%)	21.3	30.1	25.2	24.9	24.6	25.8
Any depression	18.4	20.1	15.6	12.6	16.1	14.0
Any anxiety	14.4	24.3	13.6	17.6	13.7	18.8
Positive adjust. [mean (SD)]	47.03	42.86	46.71	44.78	46.76	44.42
	(0.302)	(0.302)	(0.138)	(0.131)	(0.126)	(0.121)

SD = standard deviation; G/L/Q = gay/lesbian/queer.

Table 3 for each subsample; of note, the pattern of covariate effects was the same in the two subsamples.

Moderation of RML effects on marijuana use (stratified by recent heavy alcohol use)

In the two subsamples stratified by heavy alcohol use, we explored further the possibility of interaction between RML and legal age and first year status. First, in the subsample of students with any heavy alcohol use, the effect of RML on the odds of marijuana use was 2.31 times higher among minors compared to students aged 21 and older ($P < 0.0001$). Secondly, among students with no recent heavy alcohol use, the effect of RML on the odds of marijuana use was 1.76 times higher for those in their first year compared to those in later years ($P = 0.0005$). Follow-up analyses confirmed these interaction effects involving first-year status and legal age were not a product of

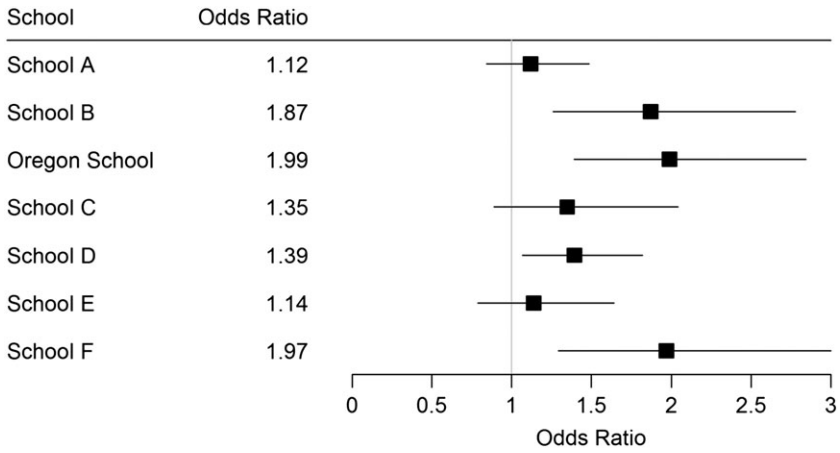

Figure 1 Forest plot of adjusted time effect [pre/post-recreational marijuana legalization (RML)] on marijuana use across participating schools. Each model was adjusted for other substance use, first year status, legal age, sex, race, residential type, relationship status, sexual orientation, international student status, depression, anxiety, positive adjustment, enrollment size of the institution and survey administration time-points

multi-collinearity. Additionally, although we did not hypothesize originally that these moderator effects would emerge only in stratified analyses, the significance levels do not suggest the patterns are attributable to chance.

RML effects on cigarette and heavy alcohol use

For the two secondary outcome variables, RML effects were not significant in combined data analyses (Table 4; full models in the Supporting information). In these models there were significant time effects indicating decreased cigarette use ($P = 0.0002$), but not heavy alcohol use ($P = 0.1291$) from pre- to post-2015.

DISCUSSION

Oregon college students' rates of marijuana use increased significantly from before to after implementation of state legalization of recreational marijuana use. Such rates also increased significantly across the same period among students attending college in non-RML states, underscoring the importance of using comparison conditions. Of central interest here, increases in rates of 30-day marijuana use were stronger among Oregon than non-RML state students, but only within the subpopulation (approximately 55%) of students who reported recent heavy alcohol use. Thus, the findings support the interpretation that RML accounted for this change, and that RML effects may depend upon individual and contextual factors. Of note, there was substantial heterogeneity between colleges in terms of level and change over time in use rates, and there were robust associations between marijuana use and a number of covariates. For these reasons, the RML effect on marijuana use was identified only in adjusted models, and was not obvious in simple unadjusted rates (i.e. gross percentages). Clearly, state legalization of recreational marijuana does not occur in a vacuum, and researchers will need to account for recent secular trends in substance use and myriad individual and local contextual conditions that govern use.

Consistent with this notion we examined three moderators of RML effects. First, as noted, RML effects on marijuana use were significant only among students who reported recent heavy alcohol use. We view this moderator as a proxy for unmeasured student characteristics, rather than alcohol or intoxication *per se*. Students' heavy drinking—a common behavior associated with college culture—is influenced by many psychological (e.g. sensation-seeking, expectancies), cultural (e.g. religious prohibitions, parental modeling and norms) and social-contextual (e.g. partying; social withdrawal) factors [13], many of which may be substance abuse propensities that generalize beyond alcohol abuse. That is, students who already use alcohol may be more open to using other substances if the social conditions (such as those secondary to RML) facilitate it. Similarly, some students' reasons for abstaining from heavy alcohol use also may cause them to refrain from marijuana, regardless of its legal status. Further research is needed that measures mechanisms of sensitivity to RML effects directly.

Secondly, we expected that as students who were aged 21 or older were able to purchase and use marijuana legally in Oregon they would be more responsive to RML effects. Results supported the opposite conclusion. On average, older students showed lower rates of marijuana use than minors, and RML effects did not depend upon legal status. Furthermore, in the stratified model there was evidence that, among heavy alcohol users, RML had a stronger effect on marijuana use for minors than for those over the age of 21. Of note, given that these Oregon minors had consumed alcohol illegally, perhaps it is not surprising that they were similarly undeterred from underage use of

Table 2 Logistic regression results for 30-day marijuana use in combined data.

	Beta	*Standard error*	*T statistic*	*Odds ratio*	*95% Lower limit*	*95% Upper limit*	*P*
RML	0.15	0.11	1.34	1.16	0.93	1.46	0.1818
Post- versus pre-2015	0.36	0.10	3.53	1.43	1.17	1.74	0.0004
30-day cigarette use	1.61	0.10	15.52	5.02	4.09	6.15	< 0.0001
Any heavy alcohol use	1.52	0.09	16.60	4.55	3.81	5.45	< 0.0001
RML × (any heavy alcohol use)	0.44	0.10	4.48	1.55	1.28	1.88	< 0.0001
First year	0.04	0.13	0.31	1.04	0.80	1.35	0.7581
Legal age	−0.29	0.06	−4.62	0.75	0.66	0.85	< 0.0001
Sex (male versus female)	0.46	0.06	8.33	1.59	1.42	1.77	< 0.0001
Sex (trans/other versus females	0.04	0.29	0.14	1.04	0.59	1.85	0.889
Race (Asian versus white)	−0.46	0.16	−2.89	0.63	0.47	0.86	0.0038
Race (black versus white)	0.28	0.21	1.35	1.32	0.88	1.98	0.1767
Race (Hispanic versus white)	−0.18	0.13	−1.43	0.83	0.65	1.07	0.1514
Race (multi versus white)	0.01	0.08	0.16	1.01	0.86	1.19	0.8725
Race (other versus white)	0.19	0.15	1.25	1.21	0.90	1.62	0.2095
Residential (Greek versus university)	0.66	0.17	3.94	1.94	1.40	2.70	< 0.0001
Residential (off-campus versus university)	0.50	0.09	5.36	1.65	1.38	1.99	< 0.0001
Relationship (in a relationship versus single)	−0.10	0.08	−1.30	0.91	0.78	1.05	0.1936
Relationship (married versus single)	−0.30	0.20	−1.51	0.74	0.50	1.09	0.1301
Relationship (other versus single)	0.06	0.62	0.10	1.06	0.32	3.58	0.9214
Sexual (bisexual versus heterosexual)	0.49	0.07	6.71	1.63	1.41	1.88	< 0.0001
Sexual (G/L/Q versus heterosexual)	0.14	0.19	0.74	1.15	0.80	1.66	0.4595
Sexual (questioning versus heterosexual)	0.64	0.16	3.96	1.90	1.38	2.60	< 0.0001
Sexual (other versus heterosexual)	0.56	0.15	3.71	1.75	1.30	2.34	0.0002
International student	−1.03	0.18	−5.83	0.36	0.25	0.51	<0.0001
Any depression	0.03	0.12	0.27	1.03	0.81	1.32	0.7899
Any anxiety	0.02	0.07	0.30	1.02	0.89	1.16	0.7658
Positive adjustment	−0.01	0.01	−1.71	0.99	0.97	1.00	0.0878
Enrollment size (small versus large)	0.56	0.08	6.91	1.75	1.50	2.06	< 0.0001
Survey period (January–February)	−0.61	0.23	−2.61	0.54	0.34	0.86	0.009
Survey period (February–March)	−0.09	0.10	−0.99	0.91	0.75	1.10	0.3211

Post- versus pre-2015 indicates survey participation prior to (0) or after (1) July 2015, when recreational marijuana legalization (RML) occurred in Oregon. RML indicates whether (1) or not (0) participants attended an institution in Oregon after 2015 (i.e. students who were exposed to RML) to represent the RML effects. G/L/Q = gay/lesbian/queer.

Table 3 Adjusted effects of RML and time on marijuana use in stratified analyses.

Subsample	*Variable*	*Beta*	*Standard error*	*T statistic*	*Odds ratio*	*95% Lower limit*	*95% Upper limit*	*P*
Among students with no heavy alcohol use (n = 4928)	RML	0.10	0.15	0.68	1.11	0.82	1.49	0.4964
	Post- versus pre-2015	0.42	0.12	3.52	1.53	1.21	1.93	0.0004
Among students with any heavy alcohol use (n = 5996)	RML	0.55	0.20	2.67	1.73	1.16	2.57	0.0076
	Post- versus pre-2015	0.34	0.10	3.30	1.40	1.15	1.71	0.001

Post- versus pre-2015 indicates survey participation prior to (0) or after (1) July 2015, when recreational marijuana legalization (RML) occurred in Oregon. RML indicates whether (1) or not (0) participants attended an institution in Oregon after 2015 (*i.e.* students who were exposed to RML) to represent the RML effects. Reported are the estimated effects of RML and post- versus pre- time-points, adjusted for cigarette use, first year status, legal age, sex, race, residential type, relationship status, sexual orientation, international student status, depression, anxiety, positive adjustment, enrollment size of the institution and survey administration time-points among students with no heavy alcohol use (top) and students with any heavy alcohol use (bottom).

marijuana. Nevertheless, one would expect their older peers to be able to more easily procure marijuana following RML, and for such increased access to influence use.

Thirdly, we predicted that first-year students might be more prone to RML effects, as they are new to the college experience, and may participate at higher rates in

Table 4 Summary of adjusted RML and time (pre/post) effects for secondary outcome variables.

Outcome	*Variable*	*Beta*	*Standard error*	*T statistic*	*Odds ratio*	*95% Lower limit*	*95% Upper limit*	*P*
30-day cigarette use	RML	−0.23	0.15	−1.47	0.80	0.59	1.08	0.1405
	Post- versus pre-2015	−0.65	0.18	−3.67	0.52	0.37	0.74	0.0002
Heavy alcohol use (ordinal)	RML	−0.38	0.20	−1.93	0.68	0.46	1.01	0.0531
	Post- versus pre-2015	−0.17	0.11	−1.52	0.85	0.68	1.05	0.1291

Post- versus pre-2015 indicates survey participation prior to (0) or after (1) July 2015, when recreational marijuana legalization (RML) occurred in Oregon. RML indicates whether (1) or not (0) participants attended an institution in Oregon after 2015 (i.e. students who were exposed to RML) to represent the RML effects. Reported are the estimated effects of RML and post- versus pre- time-points, adjusted for other substance use, first year status, legal age, sex, race, residential type, relationship status, sexual orientation, international student status, depression, anxiety, positive adjustment, enrollment size of the institution and survey administration time-points.

gatherings where substance use is prevalent and experiment with some substances for the first time [8,22]. Again, we did not find evidence overall for this prediction. Rather, we found support only in stratified models, among those who denied heavy alcohol use. Perhaps some first-year students choose not to drink heavily for reasons that do not extend to and preclude use of other substances. Such students may be sensitive to the opportunities afforded by RML. Future research may replicate and explain this unexpected pattern.

Next, specificity analyses indicated that RML was not associated significantly with deviations from the trends towards decreased heavy alcohol and cigarette use observed during this period across colleges. Although non-significant effects must be interpreted with caution, these findings are not consistent with the facilitation or gateway hypothesis, that by increasing marijuana use, RML will encourage other substance use [23]. However, such a hypothesis requires additional attention in other populations, for other substances and for other substance-related outcomes. For example, in one study of MML binge drinking rates were found to be higher among adolescents and adults in MML than in non-MML states [24].

The lack of effect of RML on these other outcomes also is inconsistent with the opposing substitution hypothesis—that RML-related increases in marijuana use will lead to decreases in alcohol use and cigarette smoking [23]. Again, further studies are needed, as there are good reasons to expect substitution. Marijuana has different intoxicative and after-effects (e.g. no hang-over) than alcohol, is perceived as non-addictive, and among adolescents in Washington (an RML state), favorable ratings and perceptions of community favorability are increasing and perceptions of harm are decreasing [11]. Given that RML removes salient barriers to marijuana use (e.g. negative legal consequences; cost) individuals who prefer the effects and social contexts of marijuana use to those associated with heavy alcohol and cigarette use may show substitution. It is possible that the effects of RML we noted among first-year students who denied heavy alcohol use reflect substitution effects; within-subjects designs would be better suited to testing this hypothesis. Substitution effects have scarcely been examined, although some studies of MML may be relevant. For example, consistent with substitution, one study found a decreased rate of alcohol-related traffic fatalities in the year following state MML [25]. Given the heavy toll that binge drinking and tobacco take on individuals and society (e.g. traffic deaths; sexual assault; cancer) marijuana substitution effects could indicate a net health benefit of RML [26], and require further consideration.

This study had some limitations. First, participants' honesty when reporting marijuana use may have been influenced by the legal status of use. Thus, it is not possible to discern changes in actual use from changes in reported use; offsetting this concern, RML effects were detected in students who reported another illegal behavior (alcohol use as a minor). Secondly, generalizability from this convenience sample of institutions may be limited in several ways. Specifically, given the heterogeneity in use rates across non-RML state institutions, heterogeneity across universities within Oregon is also likely—thus, findings may not generalize to young adults attending other colleges in Oregon. Similarly, the reference group may not be representative of institutions in non-RML states. Also, the effects of RML in Oregon may differ from the effects of similar laws in other RML states. Thirdly, the variable timing of the assessments across institutions may limit the extent to which the effects of the national dialogue regarding RML were controlled. Fourthly, the Oregon sample may have differed from the non-RML state sample in potentially important ways that the models may not have controlled fully. Fifthly, use of any alcohol (not just heavy use) across a wider time-frame (not just past 2 weeks) may have been a more valid proxy variable for these tests of moderation. Sixth, despite our use of a multiple cross-sectional design, non-response weights and numerous covariates, we

cannot rule out whether sampling differences or true institutional population changes from year to year accounted for some observed effects. Our inability to control for additional state (e.g. MML) and institutional covariates is a further limitation. A seventh limitation is that the question of moderation of RML effects by heavy alcohol use was not an a priori hypothesis. The authors identified the effect after mistakenly limiting the analytical sample to alcohol users following a recoding error. The question is justified theoretically, and the effects do not appear to be attributable to chance; nevertheless, the analysis should be viewed as exploratory and in need of replication. Finally, we did not have information about participants' medical marijuana use.

In conclusion, quantifying changes in health behaviors in important segments of the Oregon population following RML is an important first step in developing evidence-based, effective health policy. Oregon students' increased rates of marijuana use were part of a broader trend towards increased rates of marijuana across the examined institutions from 2012 to 2016. Oregon students' marijuana use rates increased even more than that of their peers at schools in non-RML states, but only among heavy alcohol users. Future studies of RML should examine additional outcomes, following the lead of medical marijuana legalization research that has documented increased rates of abuse, dependence, treatment-seeking and marijuana-positive traffic fatalities [24,27,28]. RML researchers should also consider positive and negative effects of RML on rates of marijuana- and alcohol-related harms of special relevance to young adults (e.g. sexual assault, health-risking sexual behavior, violence, academic failure). Proper comparison groups, particularly in combination with a within-subjects design, are needed to advance understanding. There are multiple natural experiments with RML under way across the United States; it is time to examine the preliminary results.

Declaration of interests

None.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1 Logistic regression results for 30-day cigarette use in combined data.
Table S2 Ordinal logistic regression results for heavy alcohol use in combined data.
Figure S1 Survey weight-adjusted prevalence trends for 30-day marijuana use.
Figure S2 Survey weight-adjusted prevalence trends for 30-day cigarette use.
Figure S3 survey weight-adjusted prevalence trends for heavy alcohol use by response categories.