Journal of Safety Research 50 (2014) 35–52

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Changes in driver cannabinoid prevalence in 12 U.S. states after implementing medical marijuana laws

Scott V. Masten *, Gloriam Vanine Guenzburger

California Department of Motor Vehicles, Research and Development Branch, 2570 24th Street, MS H-126, Sacramento, CA 95818-2606, USA

ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form 18 December 2013
Accepted 19 March 2014
Available online 5 April 2014

Keywords:
Medical marijuana laws
Cannabinoids
Drugged driving
Prevalence
United States

ABSTRACT

Objective: To determine if cannabinoid prevalence increased among fatal-crash-involved drivers in 12 U.S. states after implementing medical marijuana laws. *Methods:* Time series analyses of 1992 to 2009 driver cannabinoid prevalence from the Fatality Analysis Reporting System. *Results:* Increased driver cannabinoid prevalence associated with implementing medical marijuana laws was detected in only three states: California, with a 2.1 percentage-point increase in the percentage of all fatal-crash-involved drivers who tested positive for cannabinoids (1.1% pre vs. 3.2% post) and a 5.7 percentage-point increase (1.8% vs. 7.5%) among fatally-injured drivers; Hawaii, with a 6.0 percentage-point increase (2.5 vs. 8.5) for all drivers and a 9.6 percentage-point increase (4.9% vs. 14.4%) among fatally-injured drivers; and Washington, with a 3.4 percentage-point increase (0.7% vs. 4.1%) for all drivers and a 4.6 percentage-point increase (1.1% vs. 5.7%) among fatally-injured drivers. Changes in prevalence were not associated with the ease of marijuana access afforded by the laws. *Discussion:* Increased prevalence of cannabinoids among drivers involved in fatal crashes was only detected in a minority of the states that implemented medical marijuana laws. The observed increases were one-time changes in the prevalence levels, rather than upward trends, suggesting that these laws may indeed provide marijuana access to a stable population of patients as intended, without increasing the numbers of new users over time. Although this study provides some insight into the potential impact of these laws on public safety, differences between states in drug testing practices and regularity, along with the fairly recent implementation of most medical marijuana laws, suggest that the long-term impact of these laws may not yet be known. *Practical applications:* It is recommended that nationwide standardization of drug testing procedures and criteria be considered to improve the consistency of testing both between and within jurisdictions.

1. Introduction

The first medical marijuana law in the United States was passed in 1996, allowing California physicians under state law to recommend the use of marijuana for symptom relief for patients with specified medical conditions. Eighteen other United States jurisdictions have subsequently passed medical marijuana laws (Table 1), which vary in degree of regulation, qualifying medical conditions, provisions for patient access to marijuana, and protections from legal or civil penalties (NORML, 2012; ProCon.org, 2012; The Marijuana Policy Project, 2011). Most laws provide both legal protections and means to legally access marijuana, but some, like Maryland's, provide some protection from criminal prosecution, but no routes to legally access marijuana.

Recent use of marijuana is associated with 2 to 6 times higher risk of crashing while driving a motor vehicle—depending on the dose—compared to driving unimpaired (Asbridge, Hayden, & Cartwright, 2012; Baldock, 2008; Bates & Blakely, 1999; Beirness, Simpson, & Williams, 2006; Li et al., 2012; Ramaekers, Berghaus, van Laar, & Drummer, 2004). From 1992 to 2009, about 20,000 drivers nationwide involved in fatal crashes tested positive for cannabinoids (National Highway Traffic Safety Administration [NHTSA], 2012). In some states, self-reported marijuana use among young adults was higher after implementation of medical marijuana laws (Anderson & Rees, 2011; U. S. Department of Health and Human Services, Substance Abuse and Mental Health Services Administration, Office of Applied Studies [DHHS], 2010), but whether cannabinoid use increased among motor vehicle drivers in medical marijuana states—a potential concern for traffic safety—is less clear (Cancer & Cancer, 2010; Johnson, Kelley-Baker, Voas, & Lacey, 2012; Lacey, Kelley-Baker, Romano, Brainard, & Ramirez, 2012; Lacey et al., 2009).

To address this question, we looked at changes in cannabinoid prevalence among drivers involved in fatal crashes from 1992 to 2009 in 12 states that passed medical marijuana laws, adjusting for changes in drug testing rates and national trend towards higher driver cannabinoid prevalence (NHTSA, 2010, 2012). A potential dose–response relationship was also explored between changes in cannabinoid prevalence in these states and ease of patient access to marijuana afforded by the laws.

* Corresponding author. Tel.: +1 916 657 6638; fax: +1 916 657 8589.
E-mail address: Scott.Masten@dmv.ca.gov (S.V. Masten).

http://dx.doi.org/10.1016/j.jsr.2014.03.009
0022-4375/

Table 1
19 U.S. jurisdictions with medical marijuana laws as of December 2012, dates of initial enactment or significant modification, and effective dates.

Jurisdiction	Initial enactment and significant modifications	Effective date
1. Alaska	Ballot Measure 8 (Nov 3, 1998)	Mar 4, 1999
	Senate Bill 94 (Jun 1, 1999)	Jun 2, 1999
2. Arizona	Ballot Proposition 203 (Nov 2, 2010)	Apr 14, 2011
3. California	Proposition 215 (Nov 5, 1996)	Nov 6, 1996
	Senate Bill 420 (Oct 12, 2003)	Jan 1, 2004
4. Colorado	Ballot Amendment 20 (Nov 7, 2000)	Jun 1, 2001
	House Bill 1284 & Senate Bill 109 (Jun 7, 2010)	Jul 1, 2010
5. Connecticut	House Bill 5389 (May 31, 2012)	Oct 1, 2012
6. Delaware	Senate Bill 17 (May 13, 2011)	Jul 1, 2011
7. District of Columbia	Amendment Act B18-622 (May 21, 2010)	Jul 27, 2010
	Emergency Amendment to Title 22 (Apr 14, 2011)	Apr 14, 2011
8. Hawaii	Senate Bill 862 (Jun 14, 2000)	Dec 28, 2000
9. Maine	Ballot Question 2 (Nov 2, 1999)	Dec 22, 1999
	Senate Bill 611 (Apr 2, 2002)	Jul 25, 2002
	Question 5/Legislative Document 1811 (Nov 3, 2009/Apr 9, 2010)	Dec 23, 2009
	Legislative Document 1296 (Jun 24, 2011)	Sep 22, 2011
10. Maryland	Senate Bill 502 (May 22, 2003)	Oct 1, 2003
	Senate Bill 308 (May 10, 2011)	Jun 1, 2011
11. Michigan	Proposal 1 (Nov 4, 2008)	Dec 4, 2008
	Administrative Regulations (Apr 4, 2009)	Apr 6, 2009
12. Montana	Initiative 148 (Nov 2, 2004)	Nov 2, 2004
	Senate Bill 423 (May 14, 2011)	Jul 1, 2011
13. Nevada	Ballot Question 9 (Nov 7, 2000)	Oct 1, 2001
	Assembly Bill 453/Assembly Bill 519 (Jun 15, 2001)	Oct 1, 2001
14. New Jersey	Senate Bill 119 (Jan 18, 2010)	Oct 1, 2010
	Administrative Regulations (Nov 23, 2011)	Dec 19, 2011
15. New Mexico	Senate Bill 523 (Apr 2, 2007)	Jul 1, 2007
	Administrative Regulations (Dec 1, 2008)	Dec 15, 2008
	Revised Administrative Regulations (Dec 15, 2010)	Dec 30, 2010
	Senate Bill 240 (Mar 5, 2012)	Jul 1, 2012
16. Oregon	Ballot Measure 67 (Nov 3, 1998)	Dec 3, 1998
	House Bill 3052 (Jul 21, 1999)	Jul 21, 1999
	Senate Bill 1085 (Sep 8, 2005)	Jan 1, 2006
17. Rhode Island	Senate Bill 0710 (Jan 3, 2006)	Jan 3, 2006
	Senate Bill 0791 (Jun 21, 2007)	Jun 21, 2007
	House Bill 5359 (Jun 16, 2009)	Jun 16, 2009
	House Bill 8172 (Jun 22, 2010)	Jun 22, 2010
	Senate Bill 2555/House Bill 7888 (May 22, 2012)	May 22, 2012
18. Vermont	Senate Bill 76/House Bill 645 (May 26, 2004)	Jul 1, 2004
	Senate Bill 00007 (May 30, 2007)	Jul 1, 2007
	Senate Bill 17 (Jun 2, 2011)	Jun 2, 2011
19. Washington	Initiative 692 (Nov 3, 1998)	Nov 3, 1998
	Senate Bill 6032/Administrative Regulations (May 8, 2007)	Jul 22, 2007/Nov 2, 2008
	Senate Bill 5798 (Apr 1, 2010)	Jun 10, 2010

Note. This information was compiled from ProCon.org (2012), NORML (2012), state legislative web sites, and correspondence with state personnel.

2. Methods

2.1. Data source and coding

We examined records of all drivers from the Fatality Analysis Reporting System for the period 1992 to 2009 (NHTSA, 2012). This database contains information on drivers, vehicles, and environmental conditions for all motor vehicle crashes in the United States that involve a death within 30 days of the incident. Drivers involved in fatal crashes were examined because this database contains detailed drug test results for drivers and no such database for nonfatal crashes exists in the United States. Drivers were classified as having been tested for drugs if one or more of the available drug result fields on their record indicated that they had tested either positive or negative for any drug besides alcohol (codes 1–10 and 98 for 1992; codes 100–996, 998 for 1993–2009), and positive for cannabinoids if at least one of the available drug result fields indicated that a cannabinoid or related metabolite was detected in their urine or blood (code 6 for 1992; codes 600–695 for 1993–2009), regardless of whether alcohol or other drugs were also detected. Drivers were also classified as to whether or not they were killed in the crashes. The percentages of drivers tested for drugs and the percentages who tested positive for cannabinoids were aggregated by state and calendar year. To allow for follow-up time, only the 14 states that enacted a medical marijuana law before 2010 (AK, CA, CO, HI, MD, ME, MI, MT, NM, NV, OR, RI, VT, and WA) were considered for potential inclusion as medical marijuana states. Changes in driver cannabinoid prevalence across time in the other 37 jurisdictions were used as a proxy for nationwide trends in driver cannabinoid use in the absence of medical marijuana laws. Because most medical marijuana states require proof of residency in order to qualify for their programs (NORML, 2012; ProCon.org, 2012), the control prevalence would be minimally biased due to patients who cross state borders to obtain medical marijuana.

2.2. Data analysis

The method used for determining whether there was a reliable change in driver cannabinoid prevalence after the enactment of medical marijuana laws in each state was Auto-Regressive Integrated Moving Average (ARIMA) interrupted time series analysis (Box & Jenkins, 1970; Box & Tiao, 1975). ARIMA analysis was used because it provides the most flexibility and power for modeling time series, allows for multiple and time-varying intervention points, and results in state-specific estimates of changes in driver cannabinoid prevalence associated with implementing the laws along with each subsequent modification of the laws (Yaffee & McGee, 2000). Through this method, the annual percentages of fatal-crash-involved drivers (both those who were killed and those who survived) who tested positive for cannabinoids in each

Table 2
Average percentages of fatal-crash-involved drivers and fatally-injured drivers tested for drugs in 14 U.S. states enacting medical marijuana laws before 2010 and 37 aggregated comparison jurisdictions that did not enact medical marijuana laws before 2010, 1992–2009.

State	Intervention year(s)	All fatal-crash-involved drivers				Fatally-injured drivers			
		$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$	$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$
Alaska	1999	39.5	26.7	−12.7	−32.2	46.4	29.0	−17.4	−37.6
California	1997, 2004	35.2	38.3	3.1	8.8	79.1	81.8	2.8	3.5
Colorado	2001	31.3	33.8	2.5	8.0	57.7	67.1	9.4	16.3
Hawaii	2001	41.8	59.8	18.0	43.1	91.9	90.7	−1.2	−1.3
Maine	2000, 2002	0.8	1.7	0.8	100.5	0.3	0.7	0.4	131.2
Maryland	2004	2.1	35.6	33.5	1566.2	5.2	78.4	73.1	1393.1
Michigan	2009	13.2	29.3	16.1	121.2	27.2	47.4	20.3	74.7
Montana	2005	44.8	70.0	25.2	56.2	54.8	78.9	24.1	44.0
Nevada	2002	16.1	41.2	25.0	155.1	28.1	65.6	37.4	133.0
New Mexico	2007, 2009	39.8	80.1	40.3	101.4	78.5	95.5	17.1	21.7
Oregon	1999, 2006	14.0	20.9	6.9	49.0	9.5	14.5	5.0	52.1
Rhode Island	2006, 2007, 2009	44.3	33.4	−10.9	−24.6	93.4	65.3	−28.1	−30.1
Vermont	2004, 2007	11.2	52.9	41.7	370.7	22.1	92.0	69.9	315.6
Washington	1999, 2007, 2009	24.4	43.8	19.4	79.4	52.5	82.7	30.2	57.5
Jurisdictions without medical marijuana laws	None[a]	17.5	25.1	7.6	43.6	31.0	40.6	9.6	30.9

Note. $\%_{Pre}$ = average annual percentage of drivers tested for drugs prior to initial medical marijuana law. $\%_{Post}$ = average annual percentage of drivers tested for drugs after initial medical marijuana law. Δ_{PP} = percentage-point difference in drug testing. $\Delta_{\%}$ = percentage change in drug testing relative to the pre-law time period. The percentage-point difference and percentage change estimates are not exact in some cases due to rounding.

[a] Because there is no 'intervention' date from which to compute pre–post values for the control states, for descriptive purposes these figures represent a comparison before and after the first medical marijuana law was implemented in California.

state were first statistically adjusted for any preexisting secular trends, autocorrelation, variations in the frequency of drug testing of drivers, and slowly upward trending marijuana use among drivers in non-medical marijuana states, prior to estimating any changes in prevalence associated with implementing medical marijuana laws or modifications to the laws. The annual percentages of fatal-crash-involved drivers in each state who were tested for drugs were used in the ARIMA analyses to adjust for variations in drug testing frequency over time, which fluctuate as a function of available funding and other factors (Liu, 2006). The annual driver marijuana prevalence among the 37 jurisdictions that did not implement medical marijuana laws prior to 2010 was used in the ARIMA analyses to model and remove the national upward trend in marijuana use, which could otherwise be mistaken for an intervention effect. Individual ARIMA models were run for each of the states that implemented medical marijuana laws and both step and gradual intervention models were tested for each (Yaffee & McGee, 2000). Because drivers who are killed in crashes tend to be drug tested more frequently and consistently than non-fatally-injured drivers (NHTSA, 2010), analyses were also conducted for only fatally-injured drivers (i.e., only drivers who were killed in the crashes).

Two of the 14 medical marijuana states (ME and MD) were excluded from the ARIMA analyses of cannabinoid prevalence because the driver drug testing levels in these states were exceedingly low, as described later. For the remaining 12 medical marijuana states for which ARIMA analyses were conducted, the 18-year study period provided from 5 to 17 years of pre-medical marijuana law data ($M = 10.4$ years), and 1 to 13 years of post-law data ($M = 7.6$ years). Though the statistical power for Michigan was satisfactory, the results should be considered preliminary because only 1 year of post-law data was available. Analysis of the statistical power for this study revealed that power was 80% or higher across the 12 included medical marijuana states and both outcome series (i.e., all fatal-crash-involved drivers and also only

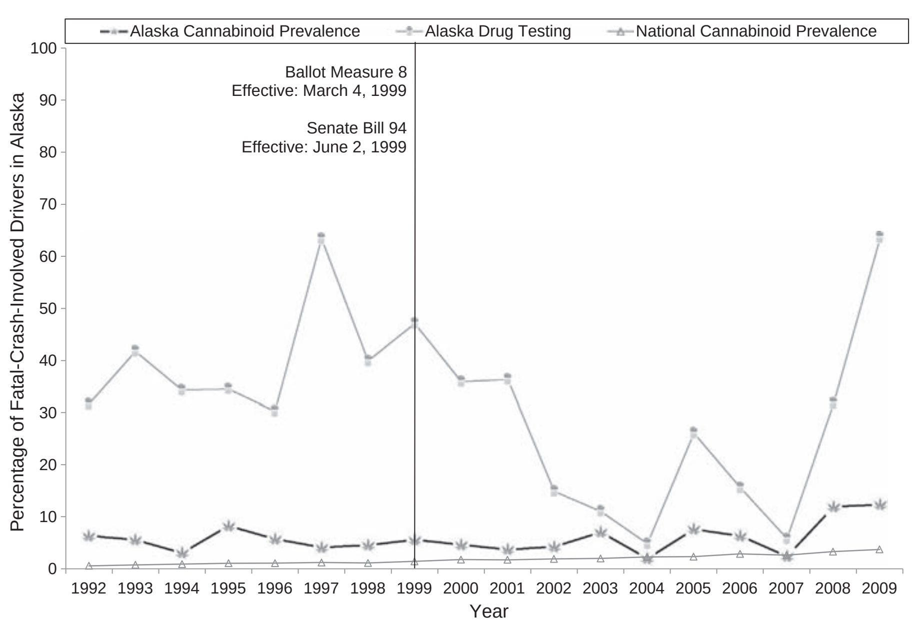

Fig. 1. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Alaska, 1992–2009.

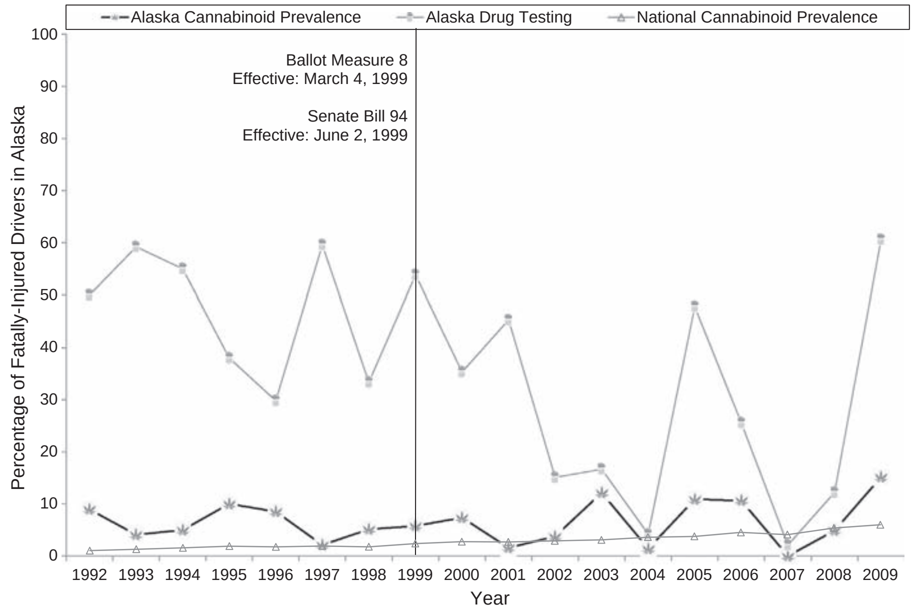

Fig. 2. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Alaska, 1992–2009.

fatally-injured drivers) for detecting a 15–83% change in driver cannabinoid prevalence. The analyses of all fatal-crash-involved drivers were generally more powerful than those of only fatally-injured drivers, with minimum detectable changes in driver cannabinoid prevalence of 15–25% for two states (AK and CA), 26–50% for five states (CO, HI, MT, OR, and RI), 51–75% for three states (MI, NV, and NM), and 76–81% for two states (VT and WA). While these minimum detectable percentage changes seem large at first blush, the pre-law driver cannabinoid prevalence levels were very low in all states, so even modest absolute changes of 1–3 percentage-points represent large percentage changes.

For the sake of brevity, the ARIMA model parameters (e.g., moving average terms) are not presented. All the final models had fairly simple non-seasonal ARIMA structures involving at most only a single first-order moving average or auto-regressive term. All auto-regressive and moving average terms in the final models were within the bounds of stationarity and invertibility, meaning that they had absolute values less than 1.0 and were mathematically stable (Yaffee & McGee, 2000). Joint estimation of model parameters and outlier effects was used during the analyses to reduce the impact of outliers (Chen & Liu, 1993). The final models were those that best represented the underlying prevalence of cannabinoids among the drivers in each state as determined by the best-fitting auto-correlation and partial-auto-correlation functions of the series residuals (Liu, 2006). The results of the ARIMA analyses provided state-by-state estimates of the percentage-point change in driver cannabinoid prevalence associated with implementation or modification of the medical marijuana laws, after adjustments to remove trend towards increased marijuana use in general and variation in driver

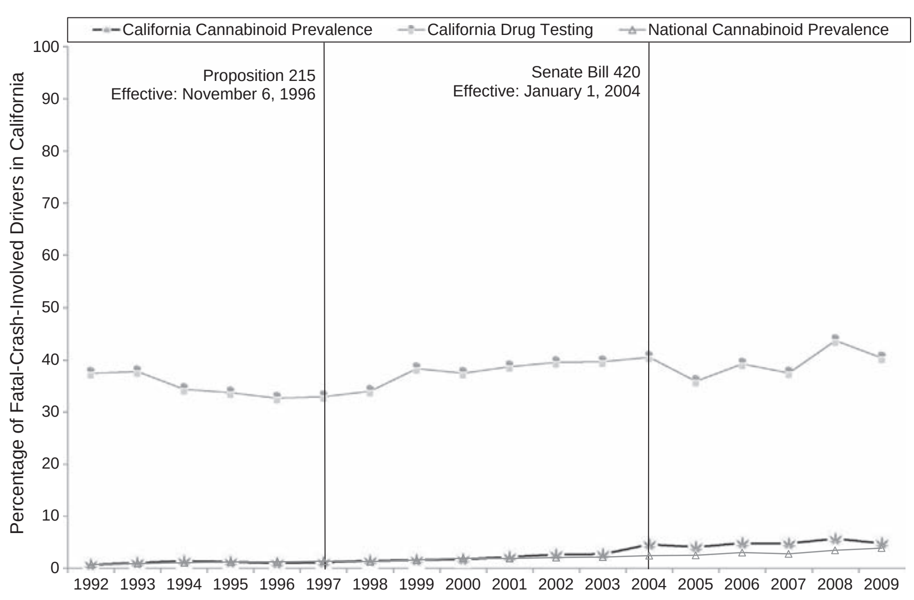

Fig. 3. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in California, 1992–2009.

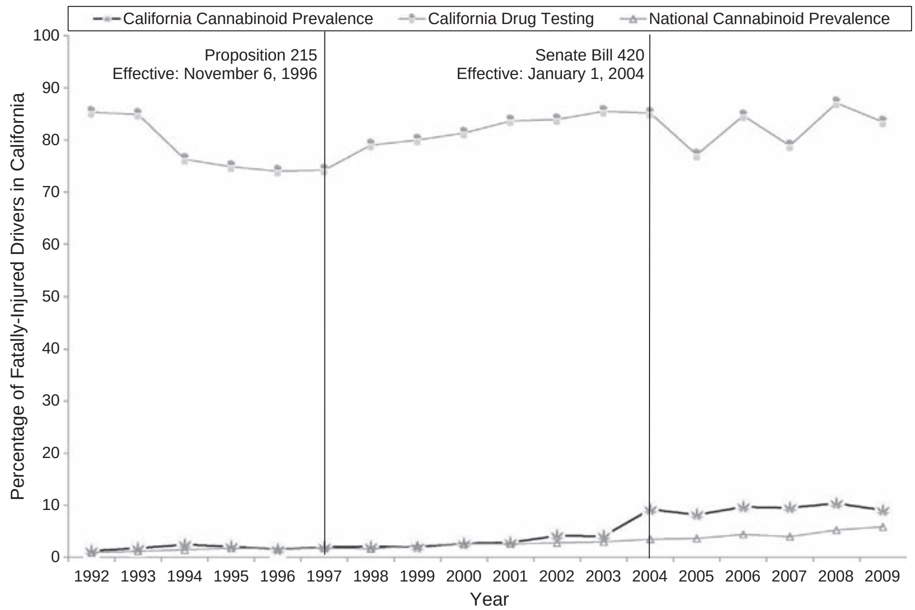

Fig. 4. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in California, 1992–2009.

drug testing regularity. Percentage change estimates relative to the pre-intervention series were also calculated for descriptive purposes.

2.3. Ease of medical marijuana access/degree of regulation rankings

To explore whether the changes in driver cannabinoid prevalence in the 12 medical marijuana states were associated in a dose–response manner with the ease of patient access to medical marijuana afforded by the laws, each state's medical marijuana law was scored for eight access/regulation dimensions: (a) protection from criminal charges/civil penalties, (b) qualifying conditions, (c) possession limits, (d) dispensary availability, (e) caregiver availability and protection, (f) home cultivation, (g) identification card requirements, and (h) out-of-state portability (The Marijuana Policy Project, 2011). Composite scores were created by summing across the eight dimensions and the states were ranked based on the composite scores as providing 1 (least) to 12 (most) means of patient access to marijuana. The percentage-point changes in driver cannabinoid prevalence resulting from the ARIMA models were plotted as a function of these ranks.

3. Results

3.1. Description of nationwide driver drug testing and cannabinoid prevalence

From 1992 to 2009, 1,000,864 drivers were involved in fatal crashes in the United States, of whom 452,144 were fatally-injured. Of these, 24.5% (n = 245,495) were tested for drugs. Drivers were more

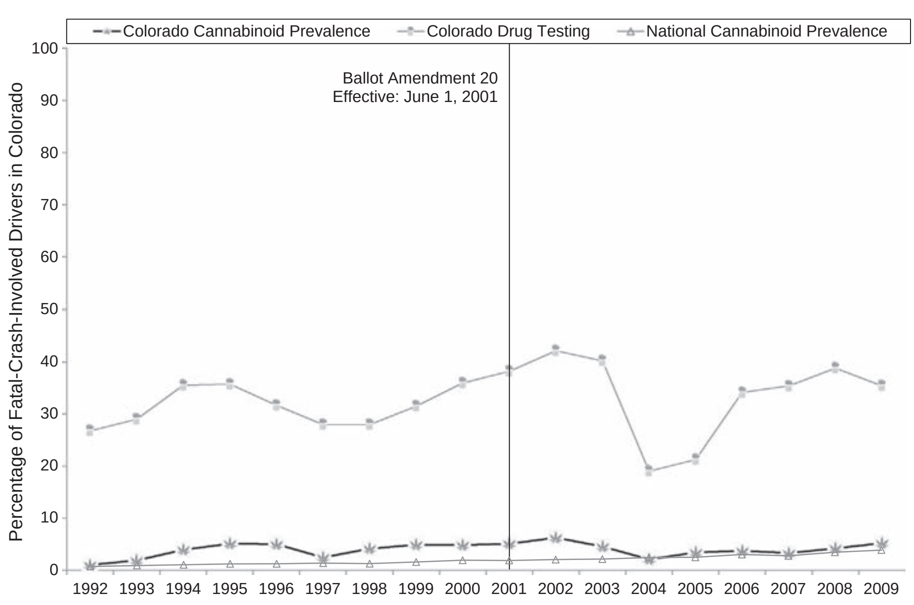

Fig. 5. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Colorado, 1992–2009.

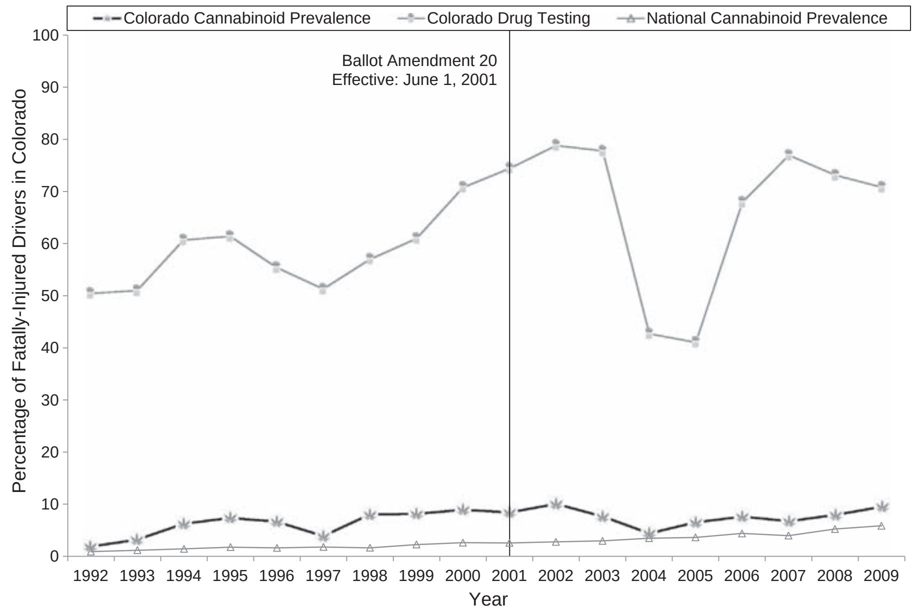

Fig. 6. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Colorado, 1992–2009.

frequently tested for drugs in medical marijuana states (30.3%) than in other jurisdictions (22.9%). About 2.0% (n = 19,977) of drivers were found to be positive for cannabinoids, with higher overall prevalence in medical marijuana states (2.7%) than the other jurisdictions (1.8%). Among fatally-injured drivers, 42.4% (n = 191,787) were tested for drugs; again testing was more frequent in the medical marijuana states (59.1%) than in other jurisdictions (38.1%). About 3.2% (n = 14,297) of the fatally-injured drivers were found to be positive for cannabinoids, with higher overall prevalence in the medical marijuana states (4.6%) than jurisdictions without medical marijuana laws (2.8%). These estimates of cannabinoid prevalence likely underestimate the actual prevalence among fatal-crash-involved drivers given that cannabinoid status is only known among the fraction of drivers who were tested.

3.2. Differences in driver drug testing rates

There was wide variation across states in the percentages of drivers tested for drugs both before and after the laws were implemented. In all but two medical marijuana states (AK and RI), the percentages of all fatal-crash-involved drivers tested for drugs were higher after the laws were implemented (Table 2), with increases ranging from 0.8 to 41.7 percentage-points. The percentages of fatally-injured drivers tested for drugs were higher following the laws in all but three of the medical marijuana states (AK, HI, and RI), with increases ranging from 0.4 to 73.1 percentage-points. Higher post-law percentages of drivers tested would be expected to bias the crude cannabinoid prevalence estimates towards higher values in the states that increased drug testing. Drug testing also

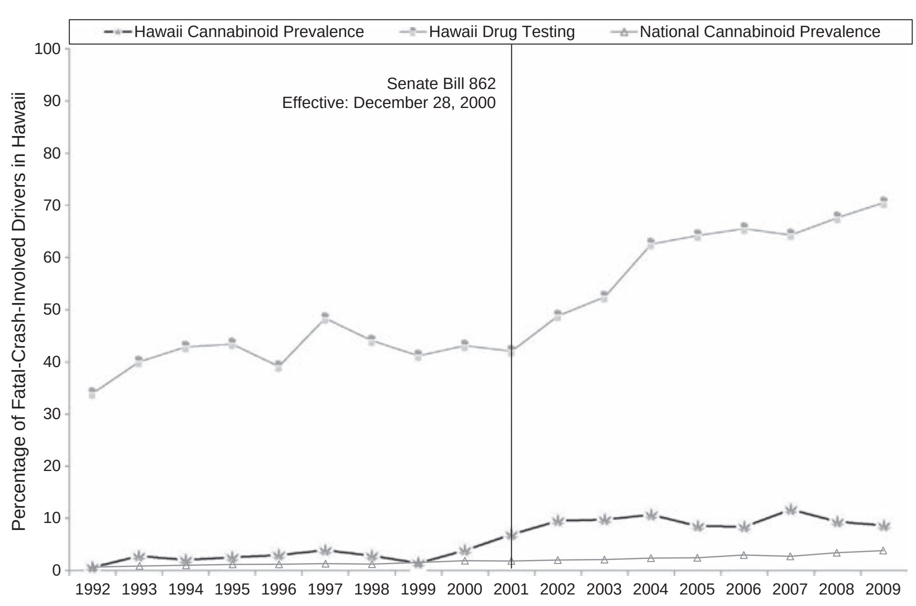

Fig. 7. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Hawaii, 1992–2009.

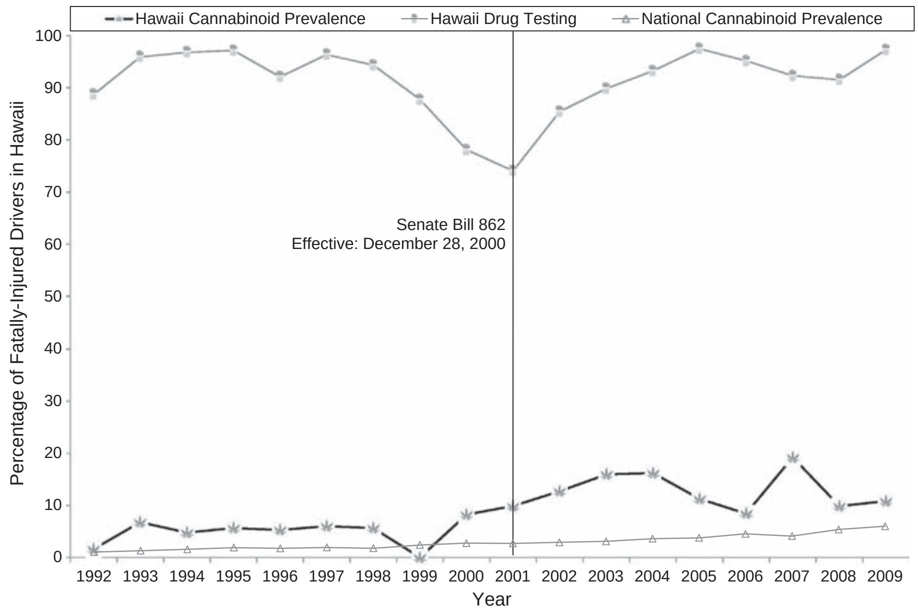

Fig. 8. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Hawaii, 1992–2009.

increased 7.6 percentage-points for all fatal-crash-involved drivers and 9.6 percentage-points among fatally-injured drivers in the aggregated non-medical marijuana states.

Note that the table presents differences between the pre-law and post-law testing percentages (i.e., percentage-point differences defined as $\%_{Post} - \%_{Pre}$ and labeled as Δ_{PP} in the table) and also the percentages that those differences represent compared to the pre-law testing levels (i.e., percentage change defined as $[(\%_{Post} - \%_{Pre}) / \%_{Pre}] \times 100$ and labeled as $\Delta_{\%}$ in the table). These estimates sometimes appear to be widely different, particularly in cases where the pre-law percentages were low and the post-law percentages were much higher. For example, in Maryland only 2.1% of fatal-crash-involved drivers were tested for drugs before the medical marijuana law was implemented, but 35.6% were tested subsequently. The percentage-point difference in testing was 33.5 ($35.6 - 2.1 = 33.5$). Because this was a large percentage-point increase in testing and the pre-law percentage was very low, this represents about a 1,566% increase ($[(35.6 - 2.1) / 2.1] \times 100$) in driver drug testing compared to the pre-law level.

The percentages of drivers tested before the laws were implemented were particularly low for Maine and Maryland, making any crash-based cannabinoid prevalence estimates in these states to be of questionable validity. While the frequency of drug testing was used as a covariate in the analyses of driver cannabinoid prevalence, the rates of testing in these states were so low as to make comparisons meaningless, so these states were excluded from the subsequent analyses of driver cannabinoid prevalence.

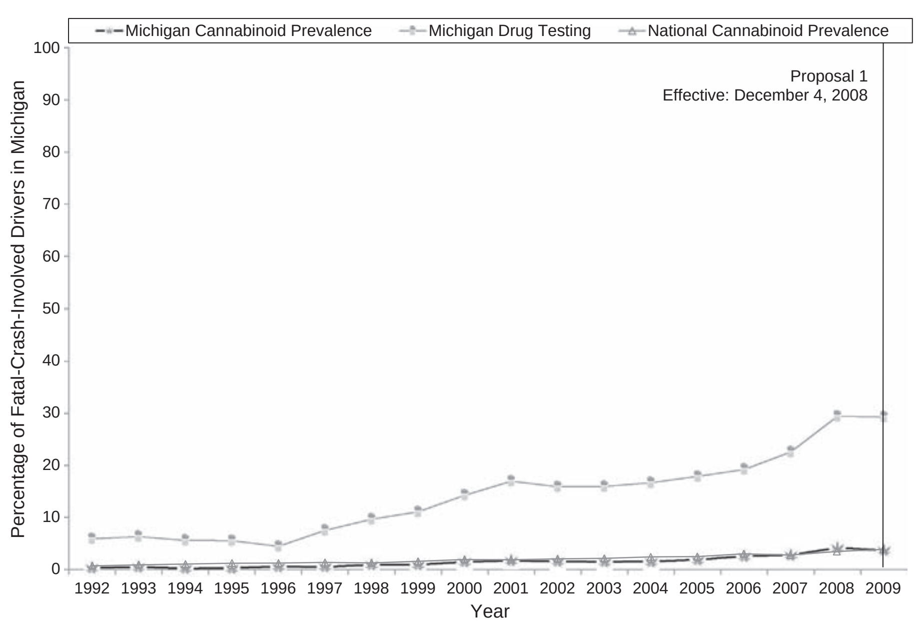

Fig. 9. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Michigan, 1992–2009.

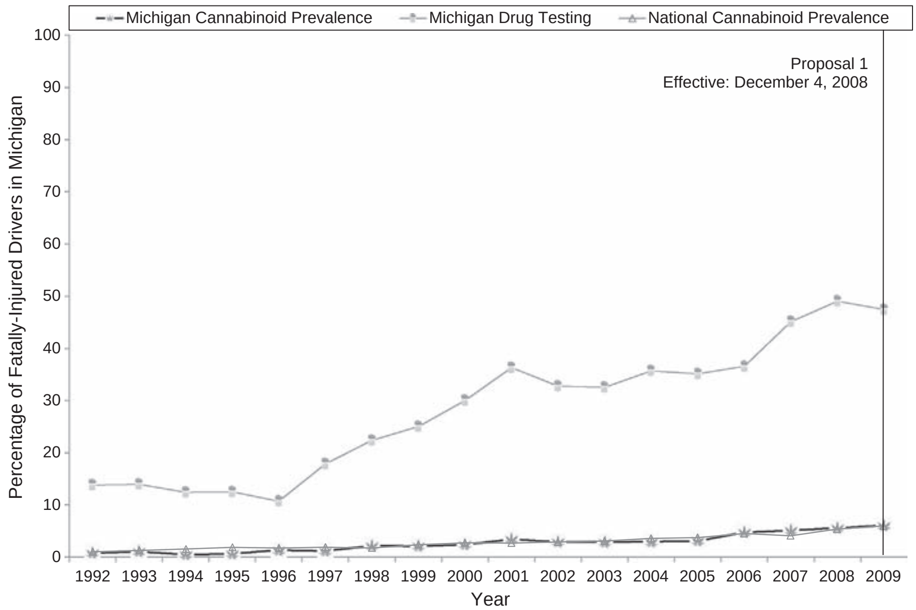

Fig. 10. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Michigan, 1992–2009.

3.3. Analyses of changes in driver cannabinoid prevalence after medical marijuana laws

The crude, or unadjusted, annual 1992–2009 cannabinoid prevalence estimates in each of the 12 included medical marijuana states among all fatal-crash-involved drivers and separately for only fatally-injured drivers are shown in Figs. 1–24. The series labeled "Cannabinoid Prevalence" in the figures shows the cannabinoid prevalence among the drivers (the percentage of all drivers found to be positive for cannabinoids). The vertical lines in the figures indicate the initial implementation date of the medical marijuana law in each state and any significant modifications to the law that were used as intervention points in the time series models. Also shown in the figures are the corresponding annual percentages of drivers in each state who were tested for drugs, which are labeled as "Drug Testing" in the figures, and the cannabinoid prevalence of drivers in the aggregated jurisdictions that did not implement medical marijuana laws before 2010, which is labeled "National Cannabinoid Prevalence" in the figures.

The crude average prevalence of cannabinoids among all fatal-crash-involved drivers was higher in all but 1 of the 12 medical marijuana states (NM) after their medical marijuana laws were implemented (Table 3), with increases ranging from 0.5 to 8.2 percentage-points.

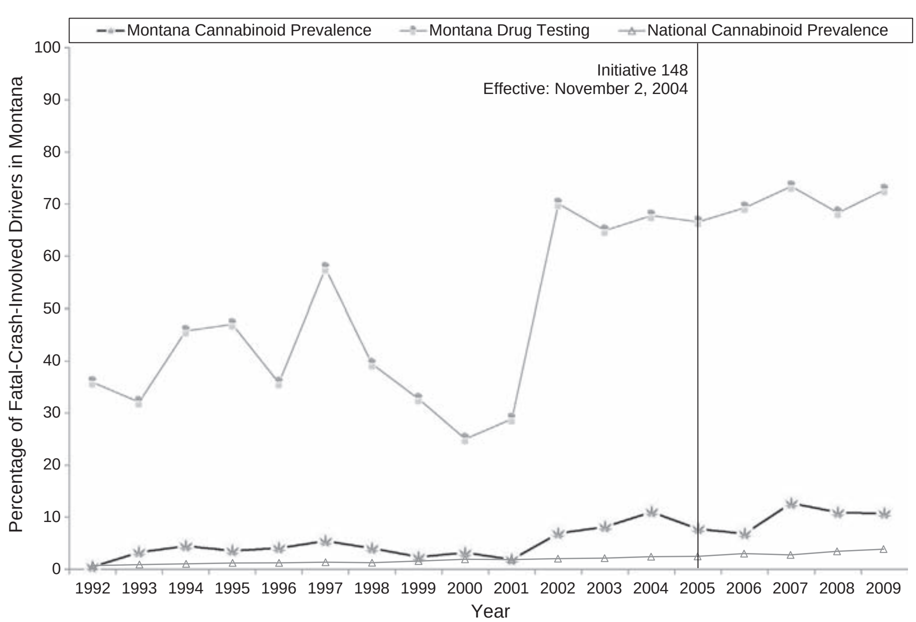

Fig. 11. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Montana, 1992–2009.

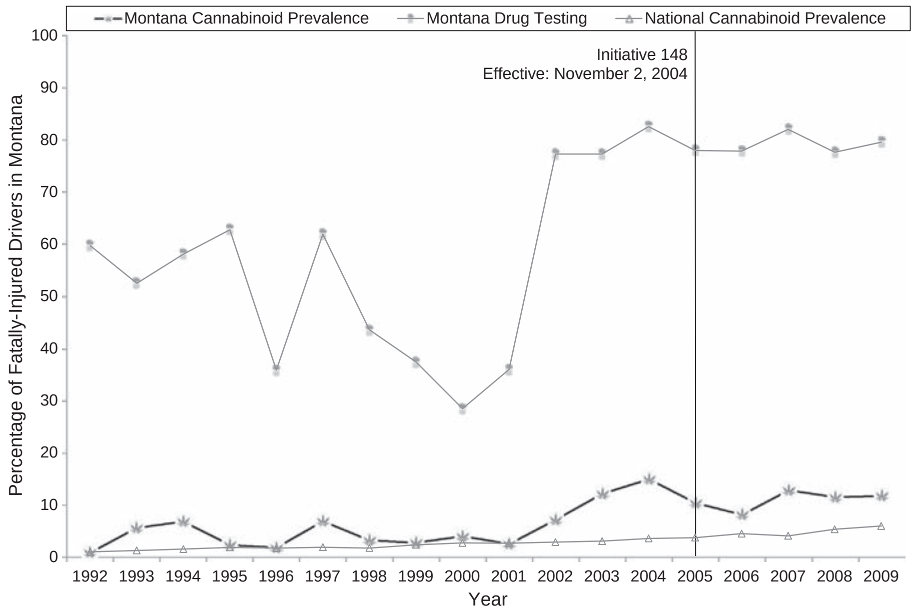

Fig. 12. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Montana, 1992–2009.

The results were similar among only fatally-injured drivers with increases ranging from 0.4 to 15.1 percentage-points in all but two of the states (NM and OR). After adjusting for both driver drug testing frequency in each state and national trend in driver cannabinoid prevalence among states without medical marijuana laws (Table 4), the implementation of medical marijuana laws was found to be reliably associated with increased cannabinoid prevalence in only three states (CA, HI, WA). The increases in all three states were stable step increases, meaning that the prevalence increased to a new level in these states and remained relatively flat subsequent (see Figs. 3 and 4 for California, 7 and 8 for Hawaii, and 23 and 24 for Washington).

Interestingly, the initial implementation of the California medical marijuana law in 1996 was not reliably associated with a change in driver cannabinoid prevalence. However, after the medical marijuana law was operationalized by the California Legislature under Senate Bill 420 in 2004, cannabinoid prevalence increased 2.1 percentage-points (95% confidence interval [CI], 1.4–2.9) among all fatal-crash-involved drivers and 5.7 percentage-points (CI, 4.3–7.0) among fatally-injured drivers. Relative to the time period before the California law was implemented, these seemingly small percentage-point increases correspond to subsequent cannabinoid prevalence being about 196% higher among all fatal-crash-involved drivers and 315% higher among fatally-injured drivers in California.

Taking into account changes in drug testing frequency and trend in national driver cannabinoid prevalence, cannabinoid prevalence in Hawaii increased 6.0 percentage-points (CI, 4.4–7.6) among all fatal-crash-involved drivers and 9.6 percentage-points (CI, 5.0–14.1)

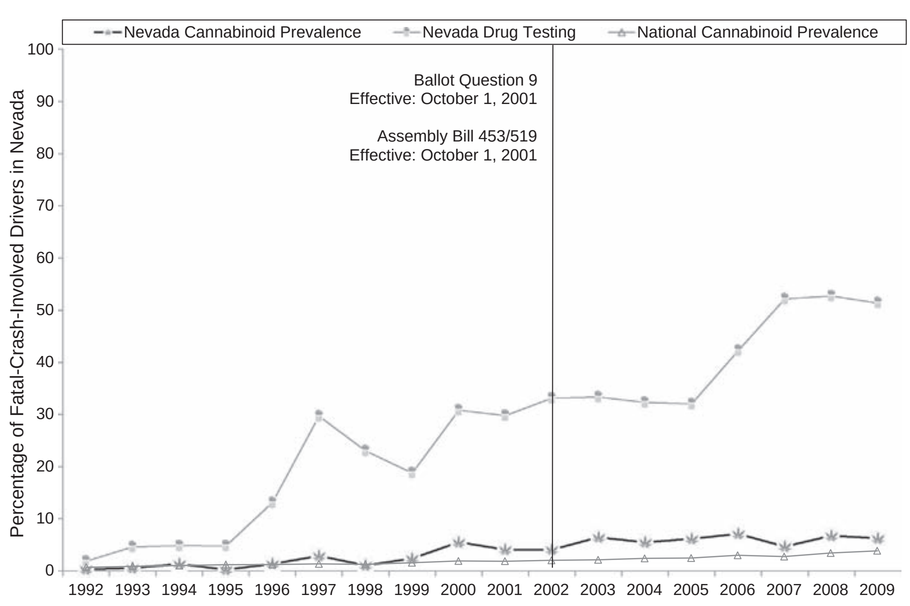

Fig. 13. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Nevada, 1992–2009.

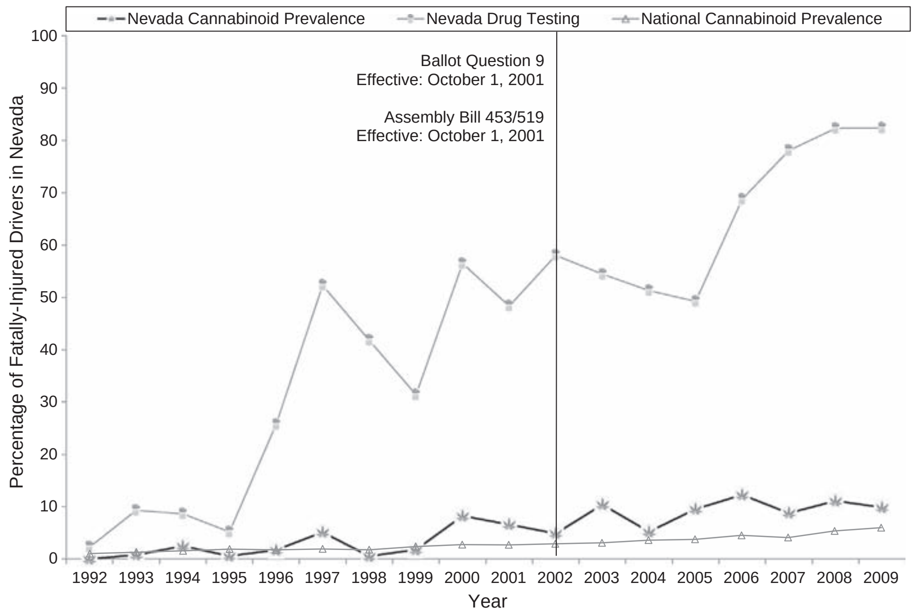

Fig. 14. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Nevada, 1992–2009.

among fatally-injured drivers after the medical marijuana law was implemented in 2001. Relative to the time period before the Hawaii law was implemented, these percentage-point increases correspond to subsequent cannabinoid prevalence being about 235% higher among all fatal-crash-involved drivers and 196% higher among fatally-injured drivers in Hawaii.

After the implementation of the Washington medical marijuana law in 1999, and again taking both confounders into account, driver cannabinoid prevalence increased 3.4 percentage-points (CI, 1.4–5.3) among all fatal-crash-involved drivers and 4.6 percentage-points (CI, 0.5–8.7) among fatally-injured drivers. Relative to the time period before the Washington law was implemented these percentage-point increases correspond to subsequent cannabinoid prevalence being more than four times as high among all fatal-crash-involved drivers as well as fatally-injured drivers in Washington.

3.4. Relation to ease of medical marijuana access/degree of regulation rankings

To explore whether any post-law changes in driver cannabinoid prevalence in the 12 medical marijuana states were associated in a dose–response manner with the ease of patient access to medical marijuana afforded by the laws, the estimates from the time series models were plotted for all fatal-crash-involved drivers (Fig. 25) and fatally-injured drivers (Fig. 26) as a function of the state ease of access/degree of regulation rankings. If increases in driver cannabinoid prevalence were positively associated with weaker regulation by the states, more protections for patients, and overall easier patient access to marijuana, then it would be expected that the higher percentage-point increase estimates would tend to cluster near the right side of the figures. However, no relation between the

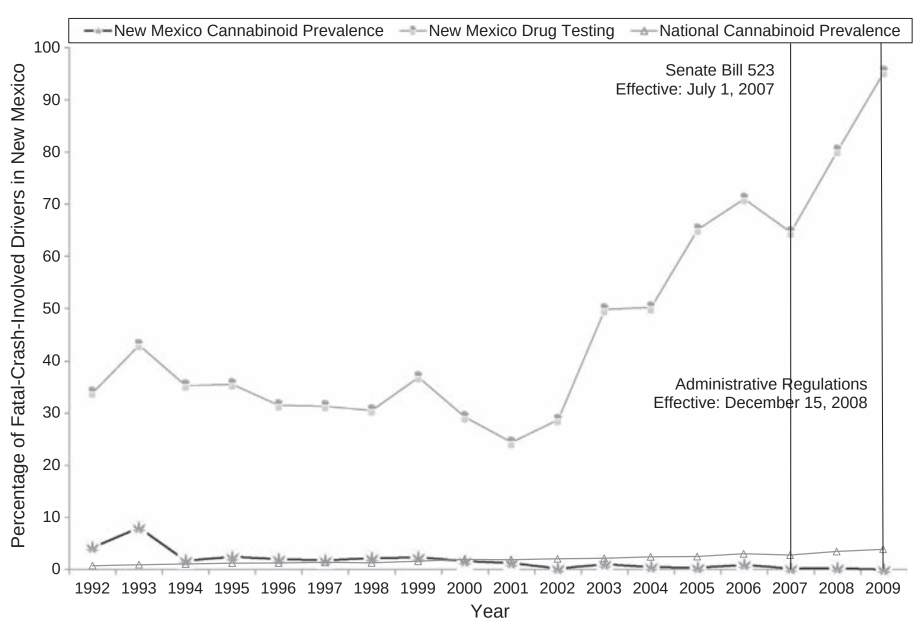

Fig. 15. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in New Mexico, 1992–2009.

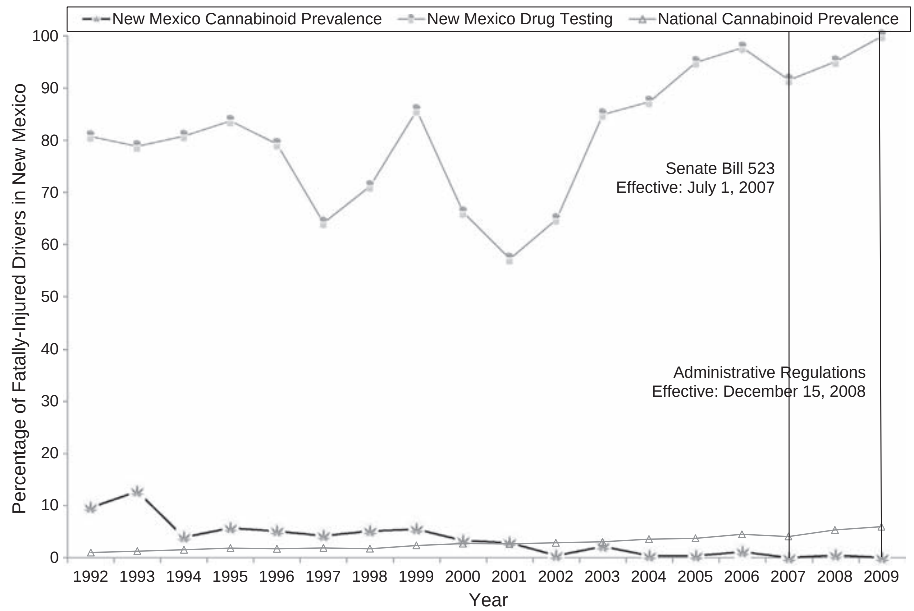

Fig. 16. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in New Mexico, 1992–2009.

post-law cannabinoid prevalence change estimates and the ease of access rankings is apparent in the figures.

4. Discussion

4.1. General discussion of findings

After adjustments were made for both driver drug testing frequency in each state and national trend in driver cannabinoid prevalence, the implementation of medical marijuana laws was found to be reliably associated with increased cannabinoid prevalence in only 3 of the 12 states: California, Hawaii, and Washington. The increases in all three states were step increases, meaning that the prevalence increased to a new level in these states and remained relatively flat for long time intervals subsequent: 6 years in California, 9 years in Hawaii, and 10 years in Washington. The increases in cannabinoid prevalence found in these states are certainly concerning if they resulted from driver marijuana use being a causal factor in the fatal crashes. Making this causal determination was not the intent of the present study; it requires a different study design. However, finding that all three states experienced step increases in cannabinoid prevalence, rather than upward trends, suggests that the medical marijuana laws in these states may have indeed provided marijuana access to a stable population of patients as intended, without increasing the numbers of new users over time (Johnson et al., 2012). Alternatively, medical marijuana laws may increase the numbers of users, but they are less likely to drive, less likely to be involved in a fatal crash, or both. The findings are consistent with recent evidence from oral fluid results taken from roadside samples of California drivers indicating that cannabinoid prevalence was relatively stable between 2010 and 2012 (Lacey et al., 2012).

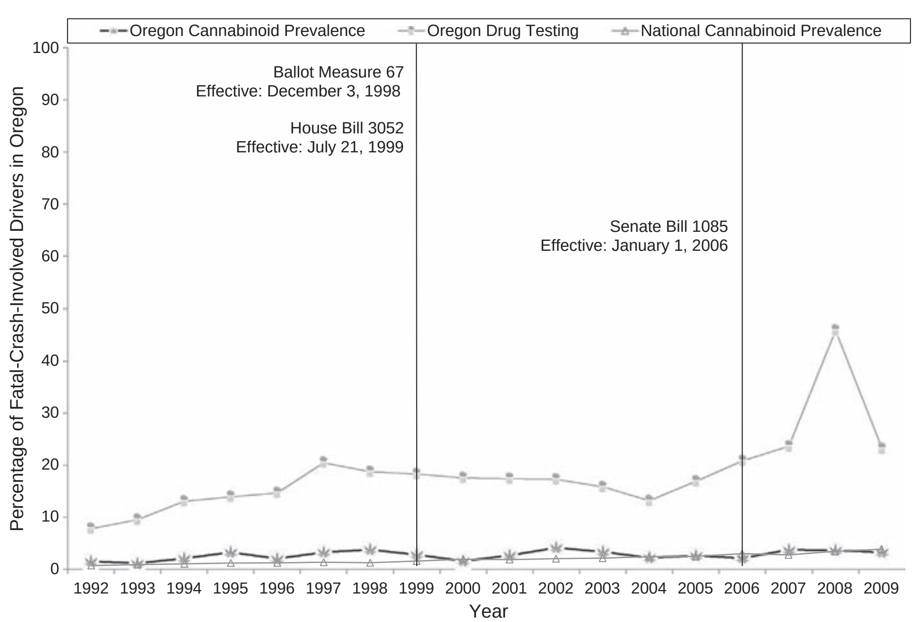

Fig. 17. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Oregon, 1992–2009.

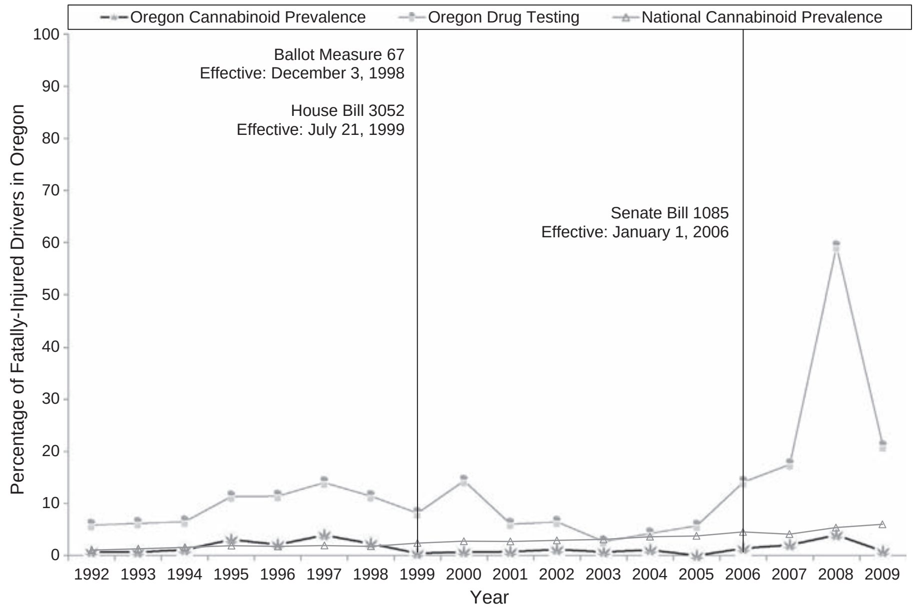

Fig. 18. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Oregon, 1992–2009.

Reliable increases in driver cannabinoid prevalence were not detected in the other nine included states that implemented medical marijuana laws before 2010. In some cases this may be due to lower statistical power related to fewer observations over time in some states, and hence large year-to-year variability in cannabinoid prevalence and testing (e.g., AK). Testing higher percentages of drivers for drugs was associated with increased prevalence, and drug testing tended to be higher in many states coinciding with the implementation of medical marijuana laws. Hence, the increases in the crude prevalence estimates in several states were apparently the result of confounding due to increased testing of drivers after the laws were implemented (i.e., ascertainment bias). While changes over time in the frequency of driver drug testing were adjusted within each state, the low levels of testing before and after the laws in some states (e.g., OR), dramatic fluctuations in testing often corresponding with implementation of the laws (e.g., VT), and erratic testing over time in other states (e.g., AK and NV) may have made it difficult to detect changes in prevalence in these states. Nonetheless, some of the states had relatively high levels of testing during the study time period (e.g., CO and NM), yet no increase in prevalence was detected. Given that only 1 year of post-law data were available for Michigan, the finding of no increase in cannabinoid prevalence in this state should be considered preliminary.

Why increased driver cannabinoid prevalence was detected in California, Hawaii, and Washington, but not in other medical marijuana states, is not known. Marijuana use in general among adults tends to be higher in jurisdictions with medical marijuana laws (Anderson & Rees,

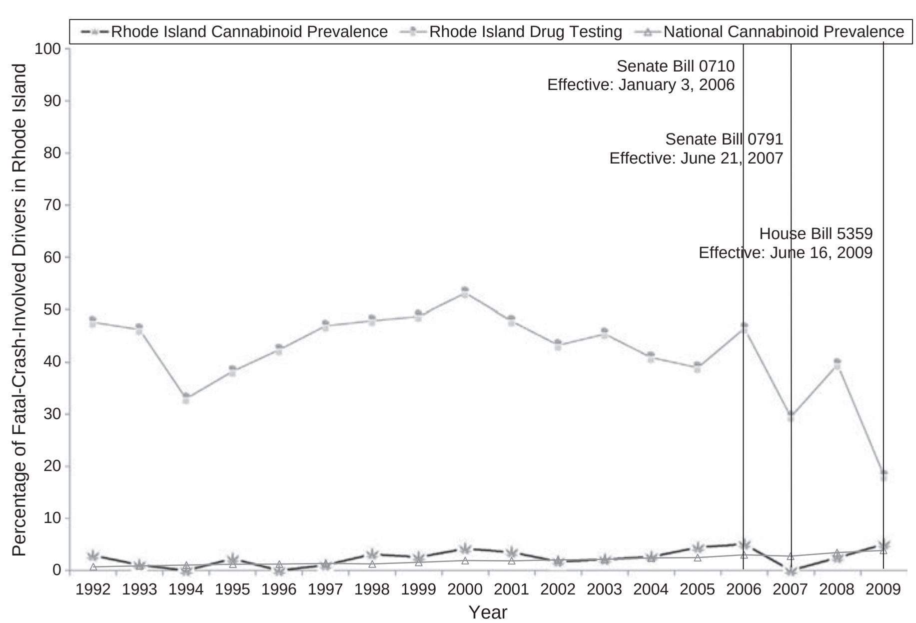

Fig. 19. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Rhode Island, 1992–2009.

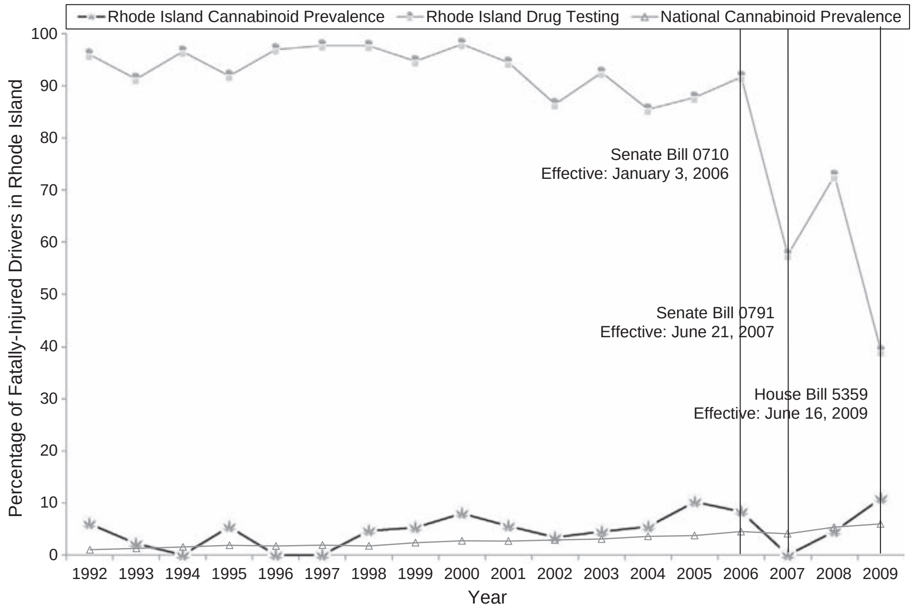

Fig. 20. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Rhode Island, 1992–2009.

2011; DHHS, 2010). However, it is unclear whether the laws actually lead to more marijuana use or whether the higher prevalence and passage of medical marijuana laws are both a reflection of more accepting norms regarding marijuana use in those jurisdictions (Cerdá, Wall, Keyes, Galea, & Hasin, 2012). Self-reported adult marijuana use was high in Washington, California, and Hawaii relative to other jurisdictions both before and after their medical marijuana laws were enacted; as of 2009 (the latest available data) they ranked 11th to 13th highest in adult marijuana use out of all 51 United States jurisdictions (DHHS, 2010). However, adult marijuana use in these three states is not particularly elevated compared to other medical marijuana states; they rank 8th to 10th highest in adult marijuana use out of the 14 states that implemented medical marijuana laws before 2010. Between 2002 and 2009 young adult marijuana use increased slightly in California, but no reliable increases occurred for any age groups in Hawaii or Washington (DHHS, 2010). If higher marijuana use in general was driving the step changes found among drivers in these three states it would be expected to be mirrored in these general prevalence estimates. With the possible exception of California, this does not appear to be the case.

One factor that was specifically explored to explain the differences between states in post-law cannabinoid prevalence was the degree of regulation and/or ease of access to medical marijuana afforded by the different laws. While the California medical marijuana law was ranked as providing the easiest access to marijuana and strongest protections for patients from criminal charges/civil penalties, the Hawaii and Washington laws were not ranked exceptionally high on these factors. In fact, no relation between the post-law cannabinoid prevalence

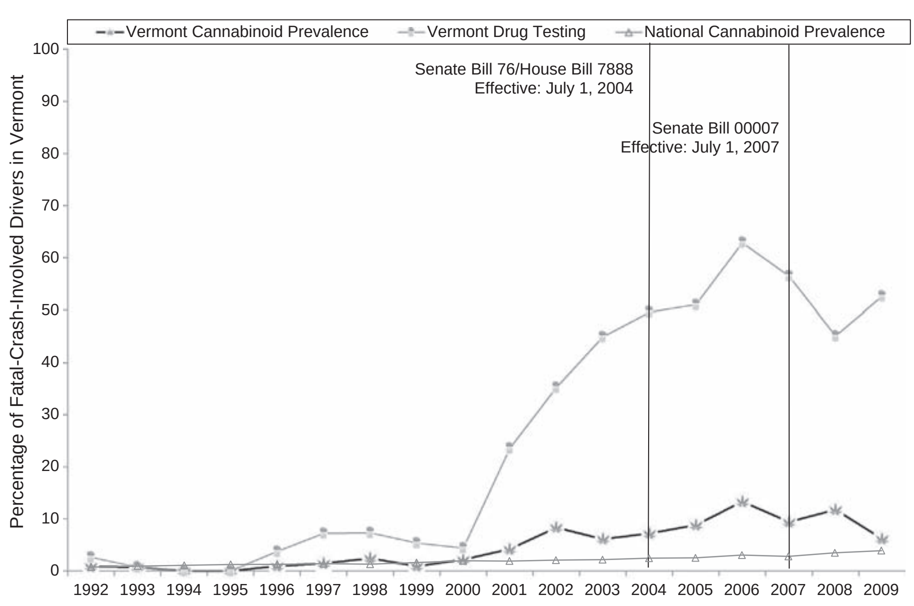

Fig. 21. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Vermont, 1992–2009.

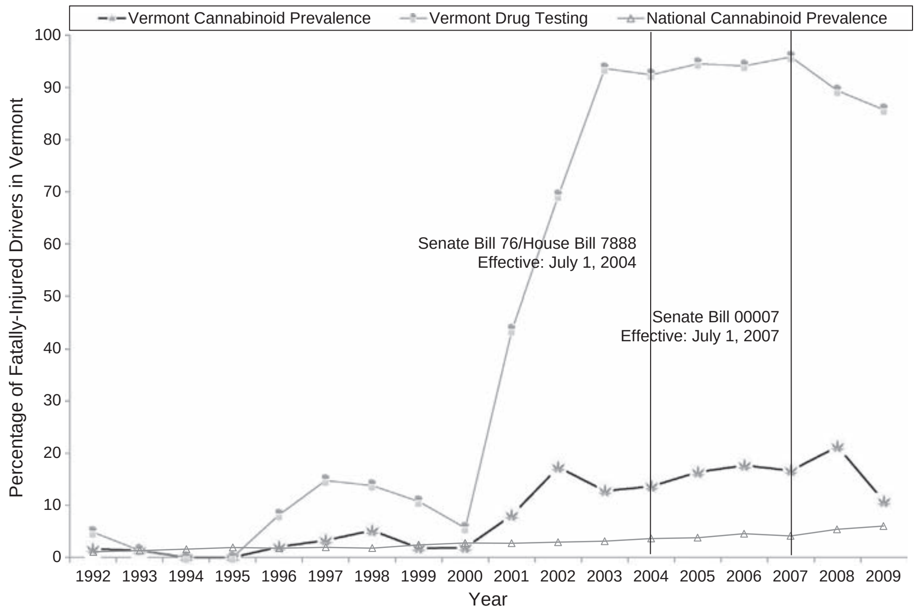

Fig. 22. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Vermont, 1992–2009.

change estimates and the ease of marijuana access rankings was apparent across the 12 states. Although the scoring criteria used to create these ranks were based on factors deemed important by marijuana legalization advocates (The Marijuana Policy Project, 2011), and the weighting scheme was created based on responses from medical marijuana patients, the ranks may not have been valid reflections of the intended construct. Alternatively, ease of access to marijuana afforded by the laws may simply not be related to changes in cannabinoid prevalence among drivers involved in fatal crashes.

Perhaps the abundant supplies of marijuana grown in California, Hawaii, and Washington account for why these states had detectable increases in driver cannabinoid prevalence when other medical marijuana states did not. These three states are in the top five marijuana crop states in terms of both total numbers of plants and pounds of marijuana produced overall, each with annual yields estimated to be worth over 1 billion dollars (Gettman, 2006). However, they are not in the top five in terms of general adult marijuana use (DHHS, 2010), suggesting that a lot of the marijuana produced in these states is exported to other jurisdictions (Weisheit, 2011). Nonetheless, it may be the case that ample supplies of marijuana better explain why driver cannabinoid prevalence increased in these three states than the ease of availability afforded by their medical marijuana laws.

4.2. Study limitations

There are several limitations of this study besides the inconsistent and sometimes meager drug testing of drivers in some states. The estimates are based on fatal crashes, which are only a small subset of all crashes. The causes of fatal crashes differ from less serious crashes; for example, fatal crashes are more likely to involve risky behaviors such

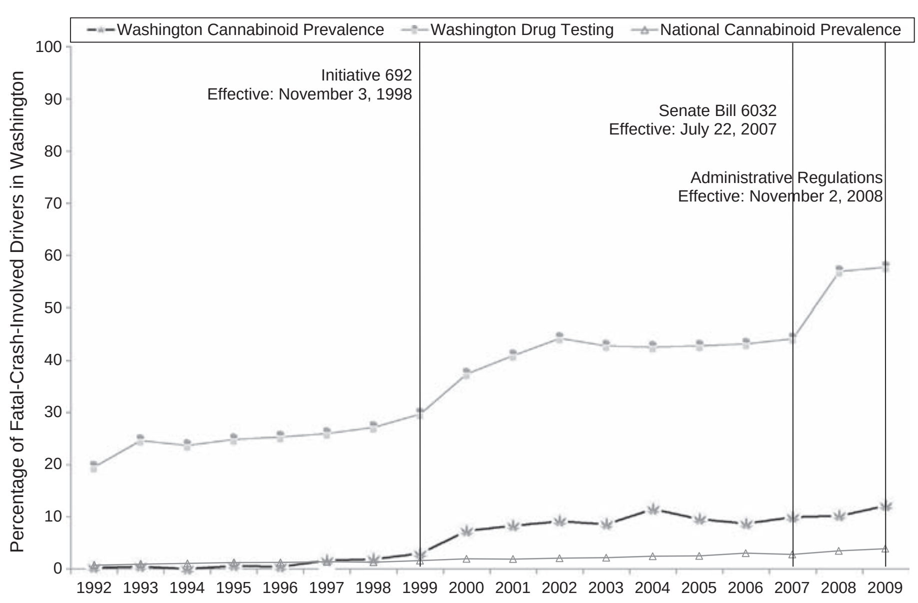

Fig. 23. Cannabinoid prevalence and percentage drug tested among fatal-crash-involved drivers in Washington, 1992–2009.

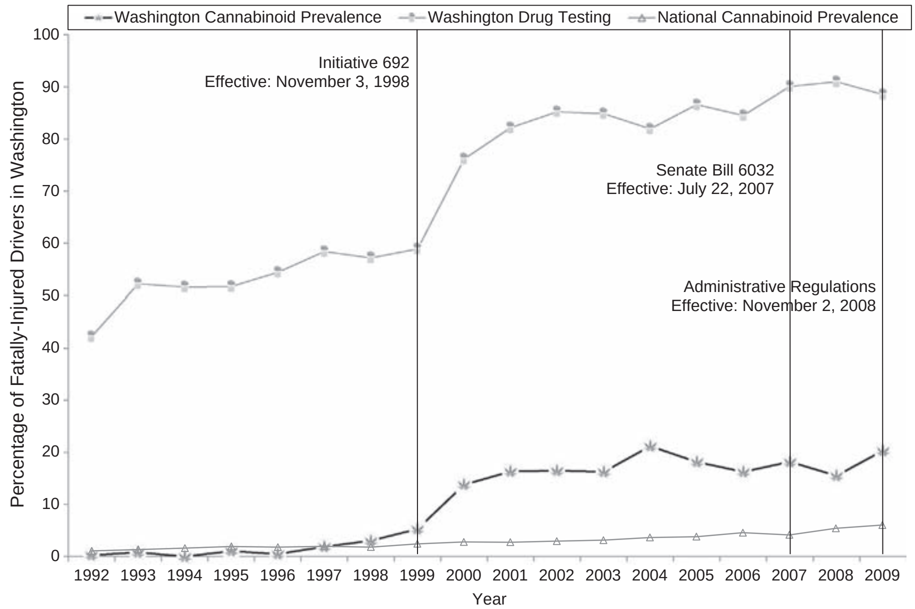

Fig. 24. Cannabinoid prevalence and percentage drug tested among fatally-injured drivers in Washington, 1992–2009.

as driver alcohol use or excessive speeding (Lam, 2003). Consequently, the cannabinoid prevalence estimates likely do not reflect prevalence among drivers in general. It would have been desirable to include less severe crashes, but unfortunately no national database of less severe crashes exists that contains detailed information about drug testing results. While drivers involved in these less-severe crashes also do not necessarily represent drivers in general, it seems likely that they are more similar than those in fatal crashes. Still, changes in cannabinoid prevalence among fatal crashes likely reflect some underlying change in prevalence among drivers in general.

The drug test results reported in FARS are poorly documented and there are likely variations both across and within jurisdictions in drug testing standards and procedures, such as different concentration thresholds for deeming results to be positive (Huestis, 2002; NHTSA, 2010). Some laboratories may not even routinely test for cannabinoids, or they may have only routinely begun such testing after medical marijuana laws were implemented. There are also differences among state laws concerning implied consent and other aspects of drug testing when crashes occur (Office of National Drug Control Policy, 2011). Some laboratories may not report tests with negative results and drivers with unavailable test results may be systematically biased in a positive or a negative direction (NHTSA, 2010). The factors that increase the likelihood of drivers being tested for drugs are also not known. Tested drivers may not be representative of all fatal-crash-involved drivers, especially in the states that test a minority of their drivers, and prevalence estimates based on such drivers may be higher or lower than that among drivers in general.

It is evident that higher percentages of drivers were tested for drugs in most of the medical marijuana states after their laws were passed, which is why drug testing levels were used as a covariate in the analyses. However, it is also possible that better attention to testing and coding details—including more consistent testing practices and improved

Table 3
Crude average percentages of fatal-crash-involved drivers and fatally-injured drivers with positive cannabinoid test results, crude percentage-point differences, and crude percentage changes in 12 United States jurisdictions enacting medical marijuana laws before 2010 and 37 aggregated comparison jurisdictions that did not enact medical marijuana laws before 2010, 1992–2009.

State	Intervention year(s)	All fatal-crash-involved drivers				Fatally-injured drivers			
		$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$	$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$
Alaska	1999	5.5	6.3	0.8	14.3	6.3	6.7	0.4	6.9
California	1997, 2004	1.1	3.3	2.2	200.3	1.8	5.8	4.0	223.3
Colorado	2001	3.7	4.2	0.5	13.9	6.1	7.7	1.6	26.5
Hawaii	2001	2.5	9.3	6.7	264.5	4.9	12.7	7.8	160.4
Michigan	2009	1.4	3.7	2.3	165.7	2.5	6.0	3.5	140.0
Montana	2005	4.5	9.8	5.3	116.6	5.5	11.0	5.5	99.0
Nevada	2002	2.0	5.9	3.9	197.0	2.8	9.0	6.2	223.9
New Mexico	2007, 2009	2.0	0.1	−1.9	−93.0	4.2	0.2	−4.0	−96.1
Oregon	1999, 2006	2.5	2.9	0.5	19.8	2.0	1.2	−0.8	−40.9
Rhode Island	2006, 2007, 2009	2.2	3.1	0.9	40.2	4.3	5.9	1.6	37.2
Vermont	2004, 2007	2.3	9.5	7.1	303.2	4.6	16.1	11.4	248.6
Washington	1999, 2007, 2009	0.7	8.9	8.2	1102.9	1.1	16.2	15.1	1421.1
Jurisdictions without medical marijuana laws	None[a]	0.9	2.2	1.3	148.6	1.4	3.3	1.9	142.0

Note. The table figures are not adjusted for trend, seasonality, or autocorrelation. $\%_{Pre}$ = average annual cannabinoid prevalence prior to initial medical marijuana law. $\%_{Post}$ = average annual cannabinoid prevalence after initial medical marijuana law. Δ_{PP} = crude percentage point difference in cannabinoid prevalence. $\Delta_{\%}$ = crude percentage change in cannabinoid prevalence relative to the pre-law time period. The percentage-point difference and percentage change estimates are not exact in some cases due to rounding.

[a] Because there is no 'intervention' date from which to compute pre-post values for the control states, for descriptive purposes these figures represent a comparison before and after the first medical marijuana law was implemented in California.

Table 4
ARIMA results for fatal-crash-involved drivers and fatally-injured drivers with positive cannabinoid test results showing adjusted percentage-point differences and percentage changes in 12 United States jurisdictions enacting medical marijuana laws before 2010, 1992–2009.

State	All fatal-crash-involved drivers			Fatally-injured drivers		
	Δ_{PPadj}	95% CI	$\Delta_{\%adj}$	Δ_{PPadj}	95% CI	$\Delta_{\%adj}$
Alaska	−2.2	−5.5, 1.1	−39.2	−1.5	−6.9, 3.9	−24.0
California	2.1*	1.4, 2.9	195.8	5.7*	4.3, 7.0	315.2
Colorado	−0.2	−1.7, 1.3	−4.8	−0.5	−2.6, 1.6	−8.4
Hawaii	6.0*	4.4, 7.6	235.3	9.6*	5.0, 14.1	195.8
Michigan	−0.1	−0.6, 0.4	−8.0	0.4	−0.6, 1.4	14.6
Montana	−0.6	−3.1, 1.9	−13.3	−1.4	−4.0, 1.1	−25.9
Nevada	1.2	−0.3, 2.6	58.8	2.0	−0.6, 4.7	73.4
New Mexico	0.1	−2.0, 2.2	3.0	1.6	−1.8, 5.0	37.9
Oregon	0.1	−1.0, 1.2	3.3	−1.2*	−2.3, −0.0	−59.8
Rhode Island	−2.5	−6.4, 1.3	−112.0	−4.6	−9.8, 0.7	−105.6
Vermont	0.0	−2.7, 2.8	1.7	−1.0	−4.9, 3.0	−21.0
Washington	3.4*	1.4, 5.3	454.9	4.6*	0.5, 8.7	432.4

Note. Δ_{PPadj} = percentage-point difference in annual cannabinoid prevalence subsequent to the medical marijuana law implementation adjusted for changes in drug testing and national cannabinoid prevalence. 95% CI = 95% confidence interval for the adjusted percentage-point difference. $\Delta_{\%adj}$ = adjusted percentage change in annual cannabinoid prevalence relative to the pre-law period. All estimates are based on sudden-permanent ARIMA models. The percentage-point difference and percentage change estimates are not exact in some cases due to rounding.

* $p < .05$, two-tailed from adjusted ARIMA model.

coding on crash reports—could have also occurred after the medical marijuana laws were passed. If so, this would be expected to result in higher cannabinoid detection among those tested and would have biased the results towards finding increased cannabinoid prevalence after the laws were passed.

While there are many unknowns about the reliability and validity of drug test results in FARS, they represent the only national source for data on drugged driving, and hence have been used by other researchers to estimate the prevalence of various drugs among United States drivers (NHTSA, 2010; Office of National Drug Control Policy, 2011). Nonetheless, testing-related factors that changed over time within states could bias the prevalence estimates, and therefore the conclusions based on changes in those estimates (National Transportation Safety Board, 2012). The extent to which changes occurred and the impact of any resulting bias are unknown. If there was no such bias in reality, changes in prevalence based on fatal crashes are a reasonable proxy to determine whether relatively recent (within a few weeks) marijuana use among drivers changed after medical marijuana laws were implemented, though positive results do not necessarily imply that the driver was impaired or that marijuana was a causal factor in the crashes. Further, the magnitude of the prevalence estimates should not be taken to be representative of all crashes or all drivers in these states.

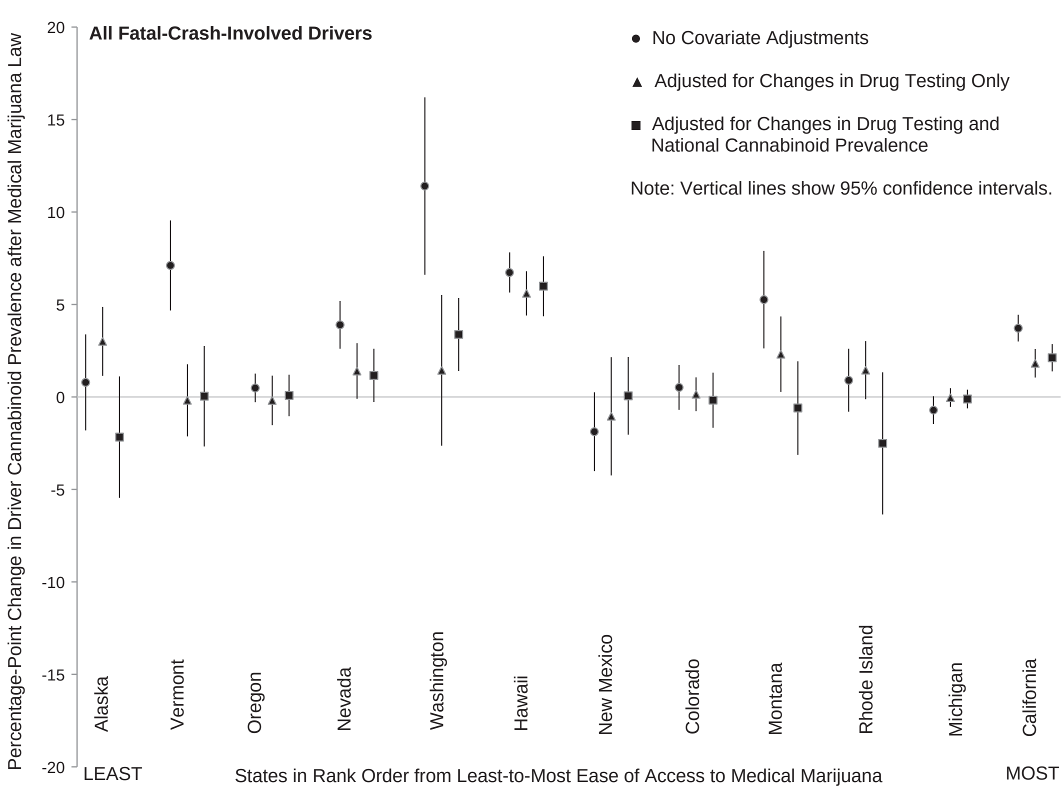

Fig. 25. Percentage-point change in cannabinoid prevalence among fatal-crash-involved drivers after medical marijuana law implementation by state rank order of least-to-most access to medical marijuana provided by the law, 1992–2009.

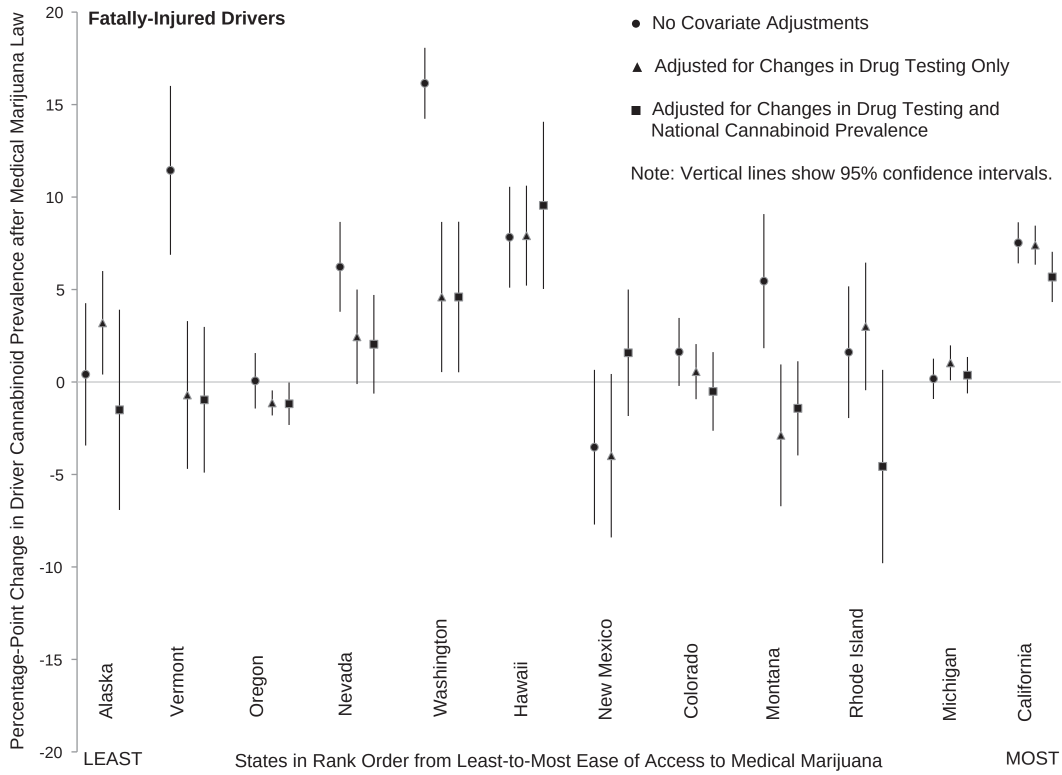

Fig. 26. Percentage-point change in cannabinoid prevalence among fatally-injured drivers after medical marijuana law implementation by state rank order of least-to-most access to medical marijuana provided by the law, 1992–2009.

5. Conclusions and implications

Increased prevalence of cannabinoids among drivers involved in fatal crashes was only detected in a minority of the states that implemented medical marijuana laws. The observed increases were one-time changes in the prevalence levels, rather than upward trends, suggesting that these laws result in stable increases in driver marijuana prevalence. The reasons that changes in prevalence were detected in some states but not in others are unknown, but one factor may be differences between states in drug testing practices and regularity. It is recommended that nationwide standardization of drug testing procedures and criteria be considered to improve the consistency of testing both between and within jurisdictions, which concurs with a recommendation made by The National Transportation Safety Board (2012). Ease of patient access to marijuana was not found to be related to changes in post-law cannabinoid prevalence.

Acknowledgment

This study was funded by the National Highway Traffic Safety Administration through a grant administered by the California Office of Traffic Safety (Grant 20738). The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the State of California or the National Highway Traffic Safety Administration.

References

Anderson, D. M., & Rees, D. I. (2011). *Medical marijuana laws, traffic fatalities, and alcohol consumption (Discussion Paper 6112)*. Bonn, Germany: Institute for the Study of Labor (IZA) (http://ftp.iza.org/dp6112.pdf. Accessed November 23, 2012).

Asbridge, M., Hayden, J. A., & Cartwright, J. L. (2012). Acute cannabis consumption and motor vehicle collision risk: Systematic review of observational studies and meta-analysis. *BMJ*, *344*(e536), 1–9.

Baldock, M. (2008). Cannabis and the risk of crash involvement. *Flinders Journal of Law Reform*, *10*(3), 795–814.

Bates, M. N., & Blakely, T. A. (1999). Role of cannabis in motor vehicle crashes. *Epidemiologic Reviews*, *21*(2), 222–232.

Beirness, D. J., Simpson, H. M., & Williams, A. F. (2006). Role of cannabis and benzodiazepines in motor vehicle crashes. *Transportation Research Circular*, *E-C096*, 12–21.

Box, G. E. P., & Jenkins, G. M. (1970). *Time series analysis: Forecasting and control*. San Francisco, CA: Holden Day.

Box, G. E. P., & Tiao, G. C. (1975). Intervention analysis with applications to econometric and environmental problems. *Journal of the American Statistical Association*, *70*, 70–79.

Cerdá, M., Wall, M., Keyes, K. M., Galea, S., & Hasin, D. (2012). Medical marijuana laws in 50 states: Investigating the relationship between state legalization of medical marijuana and marijuana use, abuse and dependence. *Drug and Alcohol Dependence*, *120*, 22–27.

Chen, C., & Liu, L. -M. (1993). Joint estimation of model parameters and outlier effects in time series. *Journal of the American Statistical Association*, *88*, 284–297.

Crancer, A., & Crancer, A. (2010). The involvement of marijuana in California fatal motor vehicle crashes 1998–2008. http://druggeddriving.org/pdfs/CAMJStudyJune2010.pdf (Accessed April 23, 2012)

Gettman, J. (2006). Marijuana production in the United States. *The Bulletin of Cannabis Reform*, *36*(2), 1–28.

Huestis, M. A. (2002). Cannabis (marijuana) — Effects on human behavior and performance. *Forensic Science Review*, *14*(2), 15–60.

Johnson, M. J., Kelley-Baker, T., Voas, R. B., & Lacey, J. H. (2012). The prevalence of cannabis-involved driving in California. *Drug and Alcohol Dependence*, *123*, 105–109.

Lacey, J. H., et al. (2009). *2007 National Roadside Survey of Alcohol and Drug Use by Drivers: Drug results (DOT HS 811 249)*. Washington, DC: National Highway Traffic Safety Administration.

Lacey, J. H., Kelley-Baker, T., Romano, E., Brainard, K., & Ramirez, A. (2012). *Results of the 2012 California Roadside Survey of Nighttime Weekend Drivers' Alcohol and Drug Use*. Calverton, MD: Pacific Institute for Research and Evaluation.

Lam, L. T. (2003). Factors associated with young drivers' car crash injury: Comparisons among learner, provisional, and full licensees. *Accident Analysis and Prevention*, *35*(6), 913–920.

Li, M. -C., Brady, J. E., DiMaggio, C., Lusardi, A. R., Tzong, K. Y., & Li, G. (2012). Marijuana use and motor vehicle crashes. *Epidemiologic Reviews*, *34*(1), 65–72.

Liu, L. (2006). *Time series analysis and forecasting* (2nd ed.). Villa Park, IL: Scientific Computing Associates Corp.

National Highway Traffic Safety Administration [NHTSA] (2010). *Drug involvement of fatally injured drivers (DOT HS-811-415)*. Washington, DC: United States Department of Transportation.

National Highway Traffic Safety Administration [NHTSA] (2012). *Fatality analysis reporting system*. Washington DC: United States Department of Transportation (ftp://ftp.nhtsa.dot.gov/FARS. Accessed May 5, 2012).

National Transportation Safety Board (2012). *Safety recommendation (H-12-32 and H-12-33)*. Washington, DC: Author (http://www.ntsb.gov/doclib/recletters/2012/H-12-032-033.pdf. Accessed October 29, 2012).

NORML (2012). State laws. http://norml.org/laws (Accessed January 1, 2013)

Office of National Drug Control Policy (2012). *Drug testing and drug-involved driving of fatally-injured drivers in the United States: 2005–2009.* Washington, DC: Author (http://www.whitehouse.gov/sites/default/files/ondcp/issues-content/fars_report_october_2011.pdf. Accessed October 29, 2012).

ProCon.org (2012). 18 legal medical marijuana states and DC: Laws, fees, and possession limits. http://medicalmarijuana.procon.org (Accessed January 1, 2013)

Ramaekers, J. G., Berghaus, G., van Laar, M., & Drummer, O. H. (2004). Dose related risk of motor vehicle crashes after cannabis use. *Drug and Alcohol Dependence*, *73*, 109–119.

The Marijuana Policy Project (2011). The sixteen states and one federal district with effective medical marijuana laws. http://www.mpp.org/assets/pdfs/library/Medical-Marijuana-Grid.pdf (Accessed January 1, 2013)

U. S. Department of Health and Human Services, Substance Abuse and Mental Health Services Administration, Office of Applied Studies (2010). *National Survey on Drug Use and Health, Appendix D: Comparison of the 2002–2003 and 2008–2009 model-based estimates.* Washington, DC: Author (http://www.oas.samhsa.gov/2k9state/AppD.pdf. Accessed November 12, 2012).

Weisheit, R. A. (2011). Cannabis cultivation in the United States. pp. 145–61. In G. Potter, & T. Decorte (Eds.), *World Wide Weed: The globalisation and localisation of cannabis cultivation.* Surry, United Kingdom: Ashgate Publishers.

Yaffee, R. A., & McGee, M. (2000). *An introduction to time series analysis and forecasting: With applications of SAS and SPSS.* New York: Academic Press.

Scott Vincent Masten is a research manager of the DUI Unit in the Research and Development Branch of the California Department of Motor Vehicles. He earned his PhD in Epidemiology from the University of North Carolina, Chapel Hill, where he worked as a traffic safety researcher at the University of North Carolina Highway Safety Research Center. His recent work includes studies on how graduated driver licensing laws affect licensing and crashes of older teens, increasing motorcycle licensure among improperly licensed owners, and an evaluation of mandatory ignition interlock devices for DUI offenders in four California counties. He also tirelessly pursues his lifelong goals of starting a band and finding the best taqueria in California.

Vanine Guenzburger is an applied traffic safety researcher in the DUI Unit of the Research and Development Branch of the California Department of Motor Vehicles. She received her MA degree in psychology from California State University, Sacramento. She recently completed a study of the difference between jail sentences and actual jail times served by DUI offenders, and is currently working on a study of the association of marijuana use and risky driving.