Perceived effects of cannabis and changes in driving performance under the influence of cannabis

Thomas S. Burt, Timothy L. Brown, Rose Schmitt, Daniel McGehee, Gary Milavetz, Gary R. Gaffney & Chris Berka

View supplementary material ⬀

Published online: 29 Jun 2021.

Submit your article to this journal ⬀

Article views: 92

View related articles ⬀

View Crossmark data ⬀

Taylor & Francis
Taylor & Francis Group

Check for updates

Perceived effects of cannabis and changes in driving performance under the influence of cannabis

Thomas S. Burt[a] (iD), Timothy L. Brown[a] (iD), Rose Schmitt[a] (iD), Daniel McGehee[a] (iD), Gary Milavetz[b] (iD), Gary R. Gaffney[c] (iD), and Chris Berka[d] (iD)

[a]National Advanced Driving Simulator, University of Iowa, Iowa City, Iowa; [b]College of Pharmacy, University of Iowa, Iowa City, Iowa; [c]Department of Psychiatry, Carver College of Medicine, University of Iowa, Iowa City, Iowa; [d]Advanced Brain Monitoring, Carlsbad, California

ABSTRACT

Objective: Reports indicate that cannabis users will adapt their driving to compensate for the perceived drug effects of cannabis. This analysis examined the relationship between driver perceptions of their state contrasted with objective measures of their performance while operating a motor vehicle.

Methods: Data was collected from ten subjects in a study examining the effects of cannabis on driving performance. Driving performance was collected on the NADS quarter-cab miniSim, a limited field of view non-motion simulator, approximately two hours after cannabis inhalation. Driving measures of both lateral and longitudinal control were included in our analysis. Subjective measures of the effects of cannabis were collected at peak and prior to driving, using visual analog scales. Data were analyzed using the SAS GLM Select procedure with subjective effect, dosing condition (placebo vs 6.9% THC), and driving event as independent measures. The stepwise selection method was used.

Results: The analysis of each of the subjective effects showed significant differences between the placebo and the active cannabis dosed conditions. While we found variance in difference between group means, there was greater variability between subject values. We found that subjective measures were predictive of variance in driver inputs, such as steering frequency and steering reversal rate. Variance in SDLP and other driving performance measures, however, were predicted by dosing condition.

Conclusions: Overall, some of the effects perceived by the driver were better related to changes in driver inputs rather than the presence of cannabis itself. Changes in performance measures such as SDLP are better explained by dosing condition. Thus, driver's perceptions may result in changes to driving behavior that could mitigate the effect of cannabis. For both lateral and longitudinal control, an increasing perception of stimulation produced a positive effect on performance. Our results provide a better understanding of how different strains of cannabis, which produce different subjective experiences for users, could impact driving safety. Specifically, we found drug effects that produce more stimulation results in less impact on driving, while those that produce a more stoned or high feeling results in a greater negative effect on driving.

Introduction

The move toward cannabis legalization in the U.S. has accelerated over the past decade. In 2010, recreational cannabis was illegal throughout the U.S., and medical availability was limited. As of the time of writing, thirty-six states approved medical marijuana and fifteen states have decriminalized recreational use (National Conference of State Legislatures 2021). Furthermore, in 2020, the U.S. House of Representative passed HR 3884 to decriminalize cannabis (Marijuana Opportunity Reinvestment and Expungement Act of 2020 2020), although it failed to advance in the U.S. Senate. The continued move toward legalization raises concerns over potential unintended consequences for traffic

safety as there is a paucity of research documenting cannabis use and driver performance.

The widespread decriminalization of active cannabis has coincided with an increase in road users driving while under its influence. Between 2007 and 2014 the percentage of weekend nighttime drivers testing positive for cannabis increased from 8.6% to 12.6% (Berning et al. 2015). In a survey of Colorado cannabis users, 76% reported driving within two hours of cannabis use at least once during the past month and a full 47% reported doing so at least half of the days (Brooks-Russell et al. 2019).

This increase in cannabis influenced driving does not come without a cost. A meta-analysis using PRISMA guidelines of nine studies over the past twenty years found that

CONTACT Thomas S. Burt ✉ thomas-burt@uiowa.edu National Advanced Driving Simulator, University of Iowa, 2401 Oakdale Blvd, Iowa City, IA 52242.
Associate Editor Kathy Stewart oversaw the review of this article.

they all came to the same conclusion: the cost is reduced (or compromised) road safety. Furthermore, that the risk of motor vehicle crashes increases two-fold after smoking marijuana (Li et al. 2012). Driving during acute cannabis intoxication impairs psychomotor functions along with a variety of critical driving-related skills (Lisdahl et al. 2014; Broyd et al. 2016; Newmeyer et al. 2017; Hartley et al. 2019). To illustrate and model cannabis impairment while driving, well documented and accepted performance measures can be used, such as standard deviation of lane position (SDLP), response time, divided-attention tasks, and critical-tracking tasks. A 2015 study examining cannabis effects on lateral driving control with and without alcohol found that driving with a blood THC concentration of $13.1 \mu g/L$ increased SDLP similar to the effects of a BrAC of 0.08—the legal limit in the United States (Hartman et al. 2015). This is not to say blood THC can provide a clear-cut prediction of driving performance; residual cannabis remains in the body for up to a month, even during abstinence (Bergamaschi et al. 2013).

Modeling cannabis-induced driving impairment becomes more complicated when trying to predict performance due to individual variances in response to the drug. However, a basic understanding of the pharmacokinetic profile of cannabis can help explain why people react differently. Delta-9-tetrahydrocannabinol (THC), one of over several hundred cannabinoids, is the primary psychoactive ingredient found in the cannabis genus of plant. The human endocannabinoid system is rich in cannabinoid receptors found throughout the body. CB1 receptors are found throughout the central nervous system and in regions of the brain that regulate memory, fear, and motor response, among others (National Academies of Sciences et al. 2017). Physiological impairment manifests in different regions of the brain, corresponding to endocannabinoid receptor locations. Variance in these regions of the brain account for up to 25% of individual variances in subjective response to cannabis, while the other 75% is attributed to environmental factors (Lyons et al. 1997). While this knowledge helps explain why people react differently, it does not explain how these differences impair driving performance.

Subjective perceptions may hold a clue in explaining these manifestations. Prior research that analyzed subjective effects following acute administration of cannabis in a controlled setting, has shown that blood THC levels are a statistically significant predictor of subjective perceptions and objective measures of driving performance; however the investigations found a significant variance in concentration-effect curves (Schwope et al. 2012; Hartman et al. 2016). The value of subjective perceptions in modeling driving performance, therefore, may provide insight into individual, subjective variances in drug response and by extension variance in driving performance. Some research has shown the effects of cannabis impairment persist for hours after use. Furthermore, research has shown subjective effects to be more persistent than blood THC levels (Schwope et al. 2012). To date no research has examined subjective perceptions to predict variance in measures of driving performance. This analysis will evaluate if cannabis administration affects critical subjective perceptions of state; furthermore, the study will analyze how cannabis interacting with perceived state predict changes in objective measures of driving performance.

Methods

Data were collected from ten subjects in a within-subjects study examining the effects of cannabis on driving performance and brain activity. All participants were occasional users with a minimum frequency of once every three months but no more than three times per week. More detail on subject demographics can be found under Supplemental Material. The study consisted of three sessions: a screening session and two data collection/dosing sessions. The first session began with informed consent, followed by a urinalysis drug screen, a pregnancy screen (if female), a physical examination (including an interview, a questionnaire to detect sleep apnea, heart rate, blood pressure, and ECG via Kardia Mobile), and a psychiatric examination. Subjects were then asked to complete a brief (5–8 min) drive in the simulator followed by a wellness questionnaire to screen out those subjects at risk for simulator sickness. Participation was ended if any of the exclusion criteria were met (e.g., active pregnancy, eating disorders, psychiatric disorders).

Dosing sessions were separated by a minimum of four days to accommodate drug washout. Sessions began with verification of continued eligibility (urinalysis screening, intake questionnaire) followed by a baseline blood sample. An EEG device was applied, and EEG data collected using the B-Alert X-24 system (Advanced Brain Monitoring, Inc, Carlsbad, CA), but is not discussed as part of this manuscript. After application of the device, dosing began. After dosing, subjects completed subjective assessments before proceeding to a computerized neurocognitive testbed (results not discussed as part of this manuscript). After the testbed, a blood sample was collected, subjective assessments were completed, and the subject completed a simulated drive. The simulated drive consisted of three different environments: interstate, urban, and rural. A final blood sample was collected after the drive. Table 1 provides more detail regarding the protocol for a dosing session (active cannabis or placebo).

As part of dosing, subjects were administered 500 mg of either placebo (0.009% THC) or active (6.7% THC) cannabis, counterbalanced by session across subjects, using a Volcano© Digit Vaporizer. The cannabis was inhaled ad

Table 1. Timeline of protocol for one dosing session. Every participant completed this protocol twice, once for each dosing condition (active cannabis and placebo).

Time (min)	Event
−70	Blood Draw
0	Dose
20	VAS/Likert
105	Blood Draw, *VAS/Likert*
120	Simulator Drive
170	Blood Draw

Note. The VAS response used in our analysis is boldened and italicized.

libitum over a 10-min period. The subjects were then given a 30-min resting period. Subjective measures of the effects of cannabis were collected at peak blood THC levels and prior to driving. These included visual analog scales (VAS), administered on paper, using a scale of 0 to 100 for good drug effect, high, stoned, stimulated, sedated, anxious, and restless. The VAS categories are based on prior research in psychomotor and subjective effects of cannabis (Schwope et al. 2012; Hartman et al. 2016). Anchors for the scales were "Not at All" and "Most Ever."

After subjects completed the second set of VAS (approximately two hours after cannabis inhalation), they were escorted to the NADS miniSim™ research driving simulator (Supplemental Figure 2). The miniSim is a PC-based research driving simulator with a quarter-cab and three 48" 1080p LED Active Backlit LCD displays that provide a forward field of view of 141.4° horizontal x 27.5° vertical at a 48" viewing distance. The simulator includes a real vehicle seat, steering wheel with column gear selector, and pedals with an active steering loader with DC motor/microprocessor control. The sound system includes a 2.1-channel sound system with a vibration transducer under the seat and an audio amplifier with external controls. A 22" LCD display provides the operators with a GUI interface to start and stop the simulation and choose scenarios. Driving parameters such as lane position and speed were sampled at a rate of 60 Hz. Driving measures evaluated were measures of lateral control and measures of longitudinal control.

Data were analyzed using the SAS GLM Select procedure with subjective effect prior to driving, dosing condition (placebo vs. 6.9% THC), subject identifier, and driving event as independent measures. No interactive effects were included. The SAS GLM Select procedure was repeated for each dependent measure. Dependent variables included four measures of lateral control and four measures of longitudinal control. Driving measures of lateral control included standard deviation of lane position (SDLP), steering frequency, steering reversal rate, and lane departures per minute. Driving measures of longitudinal control included speed relative to speed limit, accelerator pedal hold, and accelerator pedal reversal rate. The stepwise selection method was used.

Results

The following sections detail the relationship between cannabis use, subjective perception, and objective measures of driving performance (see Tables 2 and 3 for a summary view of cannabis dose, subjective effects, and their respective effects on objective measures).

Subjective effects of cannabis use

The SAS TTEST procedure performed on each of the predrive VAS responses showed statistically significant differences between the placebo and cannabis dosed conditions. As shown in Table 1, perceived restlessness showed the least average change from cannabis use increasing at 18.7 points on the hundred-point VAS, whereas perceived stoned increased the most at 42.9 points. While there was variance in the difference between placebo and cannabis-dosed means with a range of approximately 24, this paled in comparison to the differences between subjects which at its greatest was 71. Additionally, the VAS constructs were not uniformly affected between subjects. Figure 1 illustrates the difference in how two subjects were affected by the use of cannabis. One of the subjects had a relatively low good drug effect but a large impact on anxious and sedated, whereas the other subject had a large good drug effect, high, stoned, stimulated, and much smaller ratings on the other scales (see Supplemental Figure 1 for a visualization of all subjects, highlighting individual differences in response).

Driver inputs

Steering frequency was affected by perceived good drug effect with variation by driving environment and subject, but not by dosing condition alone (F = 17.91, $p < 0.0001$).

Table 2. VAS responses mean (min,max) across dosing conditions, difference in dosing conditions, and paired t-test values.

	Placebo	Cannabis	Cannabis-Placebo
Anxious	2.32 (0,4)	24.08 (4,58)	21.9 (2,58), t = 3.89, p = 0.0037
Good Drug Effect	5.52 (0,26)	45.81 (8,74)	39.5 (8,74), t = 5.69, p = 0.0003
High	2.45 (0,17)	41.09 (0,74)	37.9 (−1,67), t = 4.59, p = 0.0013
Restless	11.45 (0,62)	29.89 (0,66)	18.7 (−4,46), t = 3.29, p = 0.0093
Sedated	11.86 (0,50)	49.38 (6,78)	35.3 (3,74), t = 5.74, p = 0.0003
Stimulated	13.14 (0,60)	44.31 (0,74)	31.4 (−4,69), t = 4.67, p = 0.0012
Stoned	1.73 (0,6)	45.84 (6,74)	42.9 (6,74), t = 5.36, p = 0.0005

Table 3. VAS responses, presence of cannabis, and their effects on objective measures.

	Anxious	*Cannabis*	Good Drug Effect	High	Restless	Sedated	Stimulated	Stoned
Steering frequency			↑					
Steering reversal rate			↑					
Accelerator hold per minute							↓	
Accelerator reversal rate				↑				↓
SDLP	↑							
Lane departures per minute	↑							
Average speed relative to speed limit							↓	
Standard deviation of speed relative to speed limit	↑							
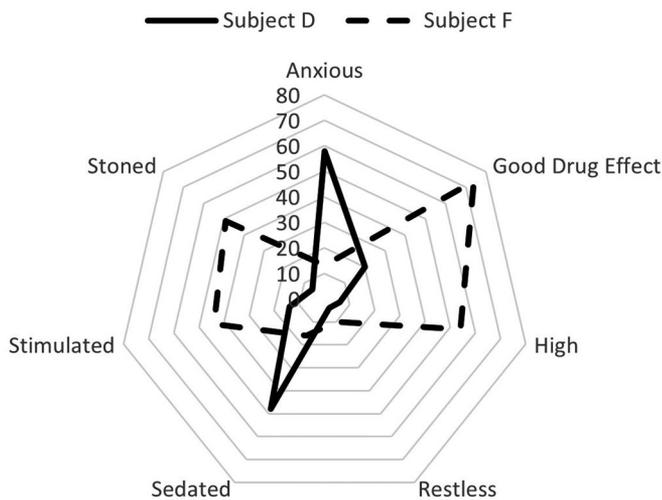
Figure 1. VAS responses for two exemplar subjects demonstrating individual differences in perception, calculated differences between active cannabis and placebo conditions.

Subject perception of good drug effect was positively associated with steering frequency, which increased by 0.004 Hz per unit increase (t = 4.85, $p < 0.0001$). For the average scale difference of 40 points this represents an increase of 0.16 Hz. Steering frequency varied between subjects, with the highest average being 0.62 Hz greater than the lowest.

Steering reversal rate, the average reversal rate in a six second window per minute, was affected by perceived good drug effect with variation by driving environment and subject, but not by dosing condition alone (F = 10.17, $p < 0.0001$). Subject perception of good drug effect was positively associated with steering reversal rate, which increased by 0.03 for every unit increase (t = 3.20, $p = 0.0018$). For the average scale difference of 40 points this translates to a 1.2. Steering reversal rate varied between subjects with the highest average being 5.15 greater than the lowest.

Accelerator pedal hold per minute was affected by perceived stimulation, with variations by driving environment (F = 9.12, $p < 0.0001$). Subject perception of stimulation was negatively associated with accelerator pedal holds, which decreased by 0.09 per unit increase (t = −2.14, $p = 0.0347$). For the observed 31-point difference between conditions this represents a decrease of 2.79. The variation by driving environment does not provide a consistent pattern.

Accelerator reversal rate was affected by perceived feelings of high and stoned, with variations by subject (F = 7.57, $p < 0.0001$). Perceived high was positively associated with accelerator reversal rate, which increased by 0.16 per unit increase (t = 3.15, $p = 0.0021$). For the average scale difference of 38 points this produces a rise of 6.08. Perceived feelings of stoned was negatively associated with accelerator reversal rate, which decreased by 0.11 per unit increase (t = −2.36, $p = 0.0198$). For the average scale difference of 43 points produces a decrease by 4.73. Accelerator reversal rate varied by subject with the highest average being 14.47 greater than the lowest.

Measures of vehicle control

SDLP was affected by the use of active cannabis with variation by driving environment and subject but not impacted by any of the subjective measures (F = 24.03, $p < 0.0001$). On average across events, the use of active cannabis produced a 7.3 cm increase in SDLP compared to the placebo condition (t = 6.26, $p < 0.0001$). Variability in lane keeping was greater at higher speeds and on roadways with more curvature. Ability to maintain a consistent lane position also varied greatly across subjects with a difference of approximately 26 cm average SDLP between the subject with the most precise lane keeping and the subject with the least precise lane keeping.

Lane departures per minute were affected by the use of active cannabis with variation by driving environment and subject but not impacted by any of the subjective measures (F = 8.70, $p < 0.0001$). The use of active cannabis on average produced an increase of 0.30 lane departures per minute (t = 2.30, $p = 0.023$). Driving environments with higher speeds and more curvature resulted in more frequent lane departures. Frequency of departing the lane varied by subject with a mean of 0.73 and a standard deviation of 1.19 for active cannabis dosed drives.

Average speed relative to the speed limit was affected by perceived stimulation with variations by driving environment but not by dosing condition alone (F = 7.30, $p < 0.0001$). Subject perception of level of stimulation decreased average speed by 0.05 mph (0.08 kph), per every unit increase (t = −3.22, $p = 0.0017$). For an average scale difference of 31 this represents a decrease of 1.55 mph (2.5 kph). Driving environments with higher speed limits tended to produce higher speeds relative to the speed limit, while increased curvature on the road tended to produce lower average speeds relative to the speed limit.

Standard deviation of speed relative to speed limit was affected by the use of active cannabis with variation by driving environment (F = 23.43, $p < 0.0001$). The use of active cannabis produced an increased variability in speed of 0.6 mph compared to the placebo condition (t = 2.56, $p = 0.0117$). The variation by driving environment does not provide a consistent pattern.

Discussion

The aim of this analysis was to determine how a driver's perceptions of the effect of cannabis explains individual variability in driving performance beyond acute use of active cannabis. When looking at the subjective measures, variation in average effects between subjective scales was small in comparison to differences within each of the scales between individuals. Additionally, the results revealed a lack of uniformity from the same dose across subjects in terms of which subjective effects were observed, confirming that an identical dose of cannabis produces a different experience for different individuals.

Differences in driving performance as they relate to the use of cannabis and the resultant subjective effects, do not produce a uniform pattern across variables that explained

the changes in driving performance. Of note, was that some dependent measures were predicted by changes in perceived state, whereas others were predicted by dose. Contrary to our expectations, in no cases did both dose and perceived state predict performance. The results of our analysis indicate that differences in perception of the effect of cannabis are observed in changes in driving inputs such as accelerator holds and speed choice.

The acute use of cannabis was associated with increases in continuous control measures of SDLP, lane departures per minute, and standard deviation of speed relative to speed limit. These drug-induced increases are indicative of degraded performance and are in line with prior research showing that the use of cannabis can impair the ability of a driver to maintain control of the vehicle. We found these performance measures were not affected by differences in how individuals perceived the effects of cannabis on them, which points to the possibility that impairment in continuous vehicle control may be a more robust and potentially impervious to perceived individual differences. This would counter the argument, at least for continuous control, that cannabis impairment can be predicted based on the subjective impact on the individual.

Of the subjective measures of cannabis effects as reflected on the VAS, only good drug effect, high, stimulated, and stoned show predictive value. Good drug effect impacted measures of steering input, being positively related to both steering frequency and steering reversal rate. Perception of high increased accelerator reversal rate while stoned decreased the same measure. Stimulation decreased accelerator hold per minute and average speed relative to the speed limit. Unlike the dependent measures affected by cannabis dose alone, driving performance is better explained by how the individual perceives the effects of active cannabis for driver inputs rather than outcomes with the possible exception of average speed. Taken in combination with measures of continuous control, this supports the concept that driver mitigation efforts reported in the literature (Brooks-Russell et al. 2019) may be tied more to how the driver perceives the cannabis is affecting them, rather than the actual impairment. Thus, compensatory behaviors may not be effective as observed by the degradation in continuous control.

More broadly, these results provide a better understanding of how different cannabis products that produce different subjective experiences for users could differentially impact driving safety. Specifically, those that produce a more stimulating effect may have less impact on driving due to causing the driver to be more cautious as observed by slower speeds relative to the speed limit. Other products that produce a more sedated, stoned, or high feeling may have a greater negative effect on driving as observed by the degradation in continuous control.

Limitations

There are several limitations that may impact the interpretation of the results. Our sample size for this analysis was limited to ten participants, which may limit the generalizability of our results to the broader population. Additionally, this dataset did not have a complete sample of blood levels with THC levels available, and as such we were not able to include it in our analysis, which prevents us from relating subjective highs to objective differences in blood THC concentrations. We were unable to capture blood draws from some participants due to difficult draws, collapsing veins, etc. leading to missed samples. Lastly, with vaporized administration at two hours post dose, blood THC levels are relatively low, despite persistent detriments in performance (Hartman et al. 2016). It is worth noting, however, blood levels are not clearly correlated to effects in the brain as it is with alcohol levels in the blood or breath.

Research needs

This analysis points to the need for more research to better understand the complex interactions between the subjective perception of a cannabis high and the performance decrements that relate to impaired driving. The following areas warrant additional consideration:

- Investigations into why the individual variance in VAS responses was much greater than the difference in means between condition, which could have a pharmacological cause.
- Future research into what regions of the brain account for perceived and physiological effects (such as EEG), and to what extent these differences are occurring; This could better explain individual variations.
- As this research focused on only a limited subset of possible driving performance measures and general driving environments without significant crash risk, future research that looks at a larger range of scenarios and measures would shed more light onto the relationship between cannabis use, subjective perceptions, and driving performance.

Data availability statement

The data that support the findings of this study are available from Timothy Brown [TLB], upon reasonable request.

ORCID

Thomas S. Burt http://orcid.org/0000-0002-2895-3941
Timothy L. Brown http://orcid.org/0000-0001-7530-9801
Rose Schmitt http://orcid.org/0000-0002-8712-975X
Daniel McGehee http://orcid.org/0000-0002-7019-3317
Gary Milavetz http://orcid.org/0000-0002-3822-1285
Gary R. Gaffney http://orcid.org/0000-0003-1842-7902
Chris Berka http://orcid.org/0000-0003-1566-2907

References

Bergamaschi MM, Karschner EL, Goodwin RS, Scheidweiler KB, Hirvonen J, Queiroz RHC, Huestis MA. 2013. Impact of prolonged cannabinoid excretion in chronic daily cannabis smokers' blood on per se drugged driving laws. Clin Chem. 59(3):519–526. doi:10.1373/clinchem.2012.195503

Berning A, Compton R, Wochinger K. 2015. Results of the 2013-2014 national roadside survey of alcohol and drug use by drivers (DOT HS 812 118). https://www.nhtsa.gov/behavioral-research/2013-14-national-roadside-study-alcohol-and-drug-use-drivers.

Brooks-Russell A, Brown T, Rapp-Olsson AM, Friedman K, Kosnett M. 2019. Driving after cannabis use and compensatory driving behaviors among current cannabis users in Colorado. Traffic Inj Prev. 20(sup2):S199–S201. doi:10.1080/15389588.2019.1665424

Broyd SJ, van Hell HH, Beale C, Yücel M, Solowij N. 2016. Acute and chronic effects of cannabinoids on human cognition—a systematic review. Biol Psychiatry. 79(7):557–567. doi:10.1016/j.biopsych.2015.12.002

Hartley S, Simon N, Larabi A, Vaugier I, Barbot F, Quera-Salva M-A, Alvarez JC. 2019. Effect of smoked cannabis on vigilance and accident risk using simulated driving in occasional and chronic users and the pharmacokinetic–pharmacodynamic relationship. Clin Chem. 65(5):684–693. doi:10.1373/clinchem.2018.299727

Hartman RL, Brown TL, Milavetz G, Spurgin A, Gorelick DA, Gaffney G, Huestis MA. 2016. Controlled vaporized cannabis, with and without alcohol: subjective effects and oral fluid-blood cannabinoid relationships. Drug Test Anal. 8(7):690–701. doi:10.1002/dta.1839

Hartman RL, Brown TL, Milavetz G, Spurgin A, Pierce RS, Gorelick DA, Huestis MA. 2015. Cannabis effects on driving lateral control with and without alcohol. Drug Alcohol Depend. 154:25–37. doi:10.1016/j.drugalcdep.2015.06.015

Li M-C, Brady JE, DiMaggio CJ, Lusardi AR, Tzong KY, Li G. 2012. Marijuana use and motor vehicle crashes. Epidemiol Rev. 34(1):65–72. doi:10.1093/epirev/mxr017

Lisdahl KM, Wright NE, Kirchner-Medina C, Maple KE, Shollenbarger S. 2014. Considering cannabis: the effects of regular cannabis use on neurocognition in adolescents and young adults. Curr Addict Rep. 1(2):144–156. doi:10.1007/s40429-014-0019-6

Lyons MJ, Toomey R, Meyer JM, Green AI, Eisen SA, Goldberg J, Tsuang MT. 1997. How do genes influence marijuana use? The role of subjective effects. Addiction. 92(4):409–417. doi:10.1111/j.1360-0443.1997.tb03372.x

Marijuana Opportunity Reinvestment and Expungement Act of 2020. 2020, 116th Congress

National Academies of Sciences, E., & Medicine. 2017. The health effects of cannabis and cannabinoids: the current state of evidence and recommendations for research. Washington (DC): The National Academies Press.

National Conference of State Legislatures. 2021. State Medical Marijuan Laws. http://www.ncsl.org/research/health/state-medical-marijuana-laws.aspx.

Newmeyer MN, Swortwood MJ, Taylor ME, Abulseoud OA, Woodward TH, Huestis MA. 2017. Evaluation of divided attention psychophysical task performance and effects on pupil sizes following smoked, vaporized and oral cannabis administration. J Appl Toxicol. 37(8):922–932. doi:10.1002/jat.3440

Schwope DM, Bosker WM, Ramaekers JG, Gorelick DA, Huestis MA. 2012. Psychomotor performance, subjective and physiological effects and whole blood Δ9-tetrahydrocannabinol concentrations in heavy, chronic cannabis smokers following acute smoked cannabis. J Anal Toxicol. 36(6):405–412. doi:10.1093/jat/bks044