**Title:**

Impact of Cannabis and Low Alcohol Concentration on Divided Attention Tasks during Driving in the National Advanced Driving Simulator

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**Data Availability Statement:**

The data that support the findings of this study are available from the corresponding author, [author initials], upon reasonable request.

**Structured Abstract:**

**Objective**: To assess performance during divided attention tasks while driving under the influence of cannabis with/without alcohol we analyzed three divided attention tasks following administration of placebo, cannabis and/or alcohol.

**Methods:** Healthy adult cannabis users participated in 6 sessions, receiving combinations of cannabis (placebo/low-THC/high-THC) and alcohol (placebo/active) in randomized order, separated by washout periods of ≥1 week. At 0.5 hours post-dosing participants performed simulator drives in the University of Iowa National Advanced Driving Simulator (NADS-1), a full vehicle cab simulator with a 360° horizontal field of view and motion base that provided realistic motion feedback. Drives contained repeated instances of three tasks: a side-mirror task (reaction to a triangle appearing in the side-mirrors), an artist-search task (select a specified artist from a navigable menu on the vehicle’s console), and a message-reading task (read aloud a message displayed on the console). Blood THC and BrAC were interpolated using individual power curves from samples collected approximately 0.17, 0.42, 1.4, and 2.3 hours post-dose. Driving measures during tasks were compared to equal-duration control periods occurring just prior to the task. Performance shifts, task completion, and lane departures were modeled relative to blood THC and breath alcohol concentration (BrAC) using mixed-effects regression models.

**Results:** Each 1 µg/L increase in blood THC predicted increased odds of failing to complete the artist-search task (OR: 1.05, CI: 1.00-1.11, p=0.046), increased odds of selecting at least one incorrect response (OR: 1.05, CI: 1.00-1.09, p=0.041), declines in speed during the side-mirror task (0.005 m/s, CI: 0.001-0.009, p=0.023), and longer lane departure durations during the side-mirror task (0.74% of task-period, CI: 0.12-1.36 p=0.020). BrAC (approximately 0.05%) was not associated with task performance, though each 0.01g/210 L increase predicted longer departure durations during the side-mirror task (1.41% of task-period, CI: 0.08-2.76, p=0.040), and increased standard deviation of lane position in the message-reading task (0.61 cm, CI: 0.14-1.08, p = 0.011).

**Conclusions:** With many states passing cannabis legislation, it is essential to explore the impacts of acute cannabis on various driving performance aspects, including divided attention. This research indicates divided attention is an area of concern following acute cannabis, raising safety concerns.

**Keywords**: Cannabis, THC, driving, alcohol, divided attention, Marijuana

**INTRODUCTION**

Alcohol and cannabis are the most common legal and illegal drugs detected in drivers worldwide. The detrimental effects of alcohol are well-documented and include: delayed reaction times, impaired visual function, and slower information processing. Alcohol slows breaking times, impairs drivers’ ability to maintain lane positions, and decreases the detection of potential hazards on the roadway (Martin et al. 2013). Recent meta-analyses showed blood alcohol concentration was associated with increased standard deviation of lane position and standard deviation of speed, two established measures of lateral and longitudinal control respectively (Irwin et al. 2017, Hartman et al. 2015, Hartman et al. 2016).

The effects of cannabis are less clear. The principal psychoactive compound found in cannabis, Δ9-tetrahydrocannabinol (THC), impairs executive function and decision making, decreases perceptual motor speed and accuracy, worsens concentration, and alters the activity of the brain networks involved in cognition (Ramaekers et al. 2009). Previous research observed that cannabis use increases lane weaving, decreases driving speed, and increases variability in headways and lane positioning (Anderson et. al 2010, Downey et al. 2013). While many studies linked blood THC concentration with increased crash risk and driver culpability, the degree to which cannabis use increases crash risk is less clear, with recent meta-analyses finding highly variable and sometimes contradictory results. Additionally, cannabis is frequently used in tandem with other drugs, complicating risk attribution. Li et al. (2013) and Asbridge et al. (2012) reported that marijuana was a significant contributor to fatal crash risk, regardless of the presence of alcohol or other drugs.

The present study examines the influence of cannabis, with and without alcohol, on the performance of drivers engaged in divided attention tasks, including tuning the radio or using navigation maps, as is increasingly common in modern driving. For non-impaired drivers, a recent meta-analysis found 80% of 350 identified studies reported detrimental effects of secondary divided attention task engagement on driving performance (Ferdinand et al. 2014). Given the established effects of cannabis and alcohol, there is reason to believe performance declines will be more pronounced in intoxicated drivers; however, we are unaware of existing research into this hypothesis. This work, which seeks to evaluate the relationship between THC, alcohol, and secondary tasks performed while driving, is part of a series of manuscripts evaluating cannabis and alcohol’s effects on driving with the NADS-1. Earlier publications evaluated the effects of cannabis and/or alcohol on lateral control (Hartman et al. 2015), and longitudinal control (Hartman et al. 2016).

**METHODS**

**Participants**

Healthy individuals aged 21-55, with self-reported cannabis use ≥1x3/months but ≤3days/week over the past 3 months, were recruited. Eligibility criteria required all participants to be licensed drivers for ≥2 years, with valid unrestricted licenses, and self-reported driving ≥1300 miles in the past year. Exclusion criteria were a past or current clinically significant medical illness; history of clinically significant adverse events related to cannabis or alcohol or motion sickness; a ≥450 mL blood donation in the 2 weeks before drug administration; currently pregnant or nursing; an interest in drug abuse treatment within the past 60 days; currently taking drugs contraindicated with cannabis or alcohol or known to impact driving; need for non-standard driving equipment; or prior participation in a similar driving simulator study. The study was approved by the xxx IRB; all participants gave written informed consent before starting the study.

**Dosing**

Each participant attended 6 sessions, separated by washout periods ≥1 week, receiving different combinations of cannabis (placebo, low THC, high THC) and alcohol (placebo, active) in randomized order. Participants spent 10-16 h at the research clinic prior to treatment administration to avoid acute intoxication. Sessions began with the participant drinking either 90% grain alcohol in fruit juice until reaching 0.065% peak breath alcohol concentration (BrAC, Alco-Sensor FST, Intoximeters, St. Louis MO), or a placebo drink with an alcohol-swabbed rim. After drinking, participants inhaled 500 mg placebo (0.008±0.002% THC), low THC (2.9±0.14%), or high THC (6.7±0.05%) vaporized cannabis (NIDA Chemistry and Physiological Systems Research Branch) *ad libitum* over 10 minutes using a Volcano® desk-top vaporizer (Storz & Bickel, Tuttlingen, Germany) .

**Data Collection**

Simulated drives occurred 0.5-1.3 h after dosing in the University of Iowa National Advanced Driving Simulator (NADS-1), a full vehicle cab simulator with a 360° horizontal field of view and a motion base that provides realistic feedback. Following a short practice drive, participants embarked on a challenging 45 min main drive containing varied road segments and numerous programmed events. Event orders were randomized to minimize familiarity across the 6 sessions. During each drive, NADS-1 recorded a comprehensive record of driver inputs and vehicles states, which were processed and recorded as 60 Hz time-series data files.

Blood collection was performed 0.17, 0.42, 1.4, and 2.3 hours post-inhalation, and blood THC concentration was quantified by a previously-published method (Schwope et al. 2011) where 0.5 mL blood was protein precipitated with ice-cold acetonitrile, and supernatants diluted and solid-phase extracted. THC concentrations and BrAC were interpolated using individual power curves derived from these four measurements (Hartman et al. 2015), thereby providing estimated concentrations at every point during the drive.

**Secondary Tasks**

During each drive, participants were prompted to complete multiple instances of three different divided attention tasks.

The *side-mirror task* required participants to push a button whenever a red triangle appeared in one of their side-mirrors. If ignored, the triangle disappeared after 5 seconds, resulting in an incompletion for that instance of the task. Otherwise, the length of time the triangle was visible prior to completion was recorded. The side-mirror task occurred 14 times during each drive.

The *artist-search task* required participants to select the correct artist from a 3-page navigable touchscreen menu on the vehicle’s console, each page listing 12 artists. The task occurred 3 times during each drive, and participants had 10 seconds to provide a correct response before failing that instance of the task. Completion time and a count of incorrect selections were recorded.

The *message-reading task* required participants to read aloud a text message shown on the car’s display. Messages were designed to be of equal difficulty, containing an average of 18 words (min=15, max=24) and 111 characters (min=93, max=141). The task occurred 6 times in each drive, with each message displayed for 10 seconds.

**Statistical Analyses**

Data were analyzed separately for each divided attention task. Three different aspects of performance were evaluated while engaged in each task: changes in speed and lateral control; prevalence and duration of lane departures; and performance on the task itself.

We define the *task period* as the time interval beginning when a task first became available and ending when the task terminated (either due to completion or time-out). For evaluating changes in speed and lateral control, we paired each task period with an equal duration *control period* immediately prior to the task becoming available. Across the task and control periods, paired differences in standard deviation of lane position (SDLP), average speed (Speed), and standard deviation of speed (SDS) were then modeled in response to blood THC concentration, BrAC, and their possible interaction using mixed effects linear regression models.

For the second series of analyses, lane departures and departure durations were derived using the width of the NADS-1 vehicle chassis, the lane width of the roadway segment, and the position of vehicle’s center of mass within the lane. Departures were characterized using three nested categories of severity: *minor departures* – where any portion of the vehicle was out of lane, *major departures* – where ≥25% of the vehicle’s width was out of lane, and *extreme departures* – where ≥50% of the vehicle’s width was out of lane. Each category of departure during a task period was modeled in response to blood THC, BrAC, and their possible interaction using mixed effects logistic regression models. Among task periods where a departure was observed, the duration of the departure (defined as a fraction of the task period) was also modeled in response to blood THC, BrAC, and their possible interaction using mixed effects linear regression models.

Task performance was measured by successful task completion, prevalence of an incorrect response, and time taken to complete the task. Each of these outcomes were modeled in response to blood THC, BrAC, and their possible interaction. Due to the original secondary nature of performance on the message-reading task and high cost to manually code it, no completion or time data were available..

All models included subject-specific random intercepts and were fit using maximum likelihood via the lme4 package (Bates et al. 2015) in R version 3.5.1 (R Core Team. 2018). For quantitative dependent measures, the Gaussian distribution and identity link function were used; for binary measures, the binomial distribution and logit link were employed. Performance shift and task performance models each included covariates that adjusted for task-specific difficulty factors, such as page number in the artist-search task or message length in the message-reading task, as well as road segment. Lane departure models included covariates that adjusted for speed and initial lane position at the onset of the task period. For each model, the Akaike Information Criterion (AIC) was used to determine whether an interaction between THC and BrAC warranted inclusion in the model. For each analysis, we report model coefficients for the estimated effects of THC, BrAC, and their interaction (if selected), as well 95% Wald confidence intervals and p-values.

**RESULTS**

**Participants**

Fifty-five healthy adults enrolled, of whom nineteen (13 men, ages 21-37 years, 74% white) completed the study. Of those who completed the study, sixteen reported consuming cannabis ≥2x/month, but ≤3days/week, and three reported consuming cannabis ≤1x/month. Fifteen reported their most recent use as less than one week prior to admission (mean=12.5, median=4.0, stdev=27.9). Self-reported driving experience ranged from 6-23 years (mean=10, median=10, stdev=4), and all participants reported driving ≥1x/week. The first visit of one participant (#18) was excluded from analyses on the side-mirror task due to completing 0 of 14 task instances on that drive. The high-THC/placebo drive for participant (#7) did not have data for the message-reading task and was also excluded. Otherwise all participants had at least one recorded event for each task, and 94.8%, 98.3% and 99.1% of the programmed instances of the side-mirror, artist-search, and message-reading tasks, respectively, were included in our analyses.

**Dosing**

Blood THC concentration showed high variability by dosing condition (Fig. 1). Several subjects had greater blood THC concentrations on the low-THC condition than on the high-THC condition, prompting our decision to base our statistical analyses on blood THC concentration, rather than assigned THC dose group.

**Secondary Tasks**

Completion rates varied considerably by task (p<0.001), with higher completion rates for the side-mirror task (93.3 %) and lower completion rates for the artist-search task (61.8%). Average completion times were 1.85 seconds for the side-mirror task and 5.89 seconds for the artist-search. Summaries of participants’ Speed, SDLP, and SDS during task periods in response to dosing condition can be found in Tables A1-A3 in the appendix.

**Task Performance**

A summary of task performance models can be found in Table 1. For the artist-search task, each 1 µg/mL increase in THC concentration led to 5.4% increased odds of failing to complete the task (OR CI: 1.01-1.11, p=0.046). Additionally, blood THC was a significant predictor of incorrect responses; each 1 µg/L increase in THC concentration led to 4.7% increased odds of selecting an incorrect artist (OR CI: 1.00-1.09, p=0.041). THC concentration was associated with significantly longer time spent on the artist-search task (0.05sec per 1 µg/mL increase, CI: 0.00-0.10, p=0.041), but there was no such association when considering only completed instances of the task. Neither THC concentration nor BrAC were significantly associated with completion times for the side-mirror task.

**Changes in Driving Performance**

A summary of modeling results for changes in driving performance across paired task and control periods is presented in Table 2. AIC did not select an interaction between THC and BrAC for any model/outcome.

During the message-reading task participants tended to decrease speed, slowing on average by 1.02 m/s (CI: 0.59-1.45, p<0.001), relative to control periods. THC concentration was inversely related to the degree of slowdown, with each 1 µg/L increase in blood THC concentration lessening the decrease in speed by 0.02 m/s (CI: 0.00-0.04, p=0.026). In contrast, for the side-mirror task, each 1 µg/L increase in THC concentration predicted a 0.005 m/s (CI: 0.001-0.009, p=0.020) decrease in speed. BrAC was not associated with speed in any of the 3 tasks.

Blood THC was not associated with changes in SDLP or SDS in any of the 3 tasks. BrAC was associated with a significant increase in SDLP (0.613 cm per 0.01 g/210 L BrAC) during the message-reading task (CIL 0.143-1.084, p=0.011), but had no detectable effects on change in SDLP or SDS in the other two tasks.

**Lane Departures**

In general, lane departures of all severity types were more common during task periods and less common in the placebo-placebo dosing condition, but were not systematically different among the active dosing conditions (Appendix Table A4). Extreme departures were rare, occurring in only 12 of the 5250 task/control periods, primarily during task periods (8 of 12), and exclusively in dosing conditions with active THC, with 3 in the low THC/placebo condition, 2 in the low THC/alcohol condition, and 7 in the high THC/alcohol conditions.

After adjusting for driver speed and initial lane position, blood THC and BrAC were not significant predictors of lane departures of any severity in any of the 3 tasks (Table 3). However, for the artist-search task THC was associated with significantly increased duration of minor departures (p=0.02, Table 4), with each 1 µg/L increase predicting an additional 0.74% of the task period to be out of lane (CI: 0.12-1.36). BrAC was associated with longer durations (1.41% of the period per 0.01 g/210 L increase) of minor departures in the side-mirror task (CI: 0.08-2.76, p=0.040), but shorter durations (1.19% of the period per 0.01 g/210 L increase) of minor departures in the message-reading task (CI: 0.34-2.04, p=0.006). AIC did not select an interaction between THC and BrAC for any model/outcome.

**DISCUSSION**

This study evaluated the effects of cannabis and alcohol on performance during three different secondary tasks using a placebo-controlled, within-subject experiment conducted with a highly realistic driving simulator. Our results are consistent with existing literature supporting decreased capacity to multi-task under the influence of cannabis. We found higher blood THC concentrations predicted lower odds of completing an artist-search task, increased odds of providing an incorrect response, longer times spent on the task, and slower recoveries from minor lane departures. Although these effects were not detected with the side-mirror and message-reading tasks, during the side-mirror task participants compensated by slightly decreasing speed.

Task complexity played a noticeable role in the manifestation of THC-related effects. Declines in task completion were prominent in the cognitively demanding artist-search task, but were not observed in the less demanding side-mirror task. This finding aligns with prior research showing greater detrimental effects of cannabis in tasks requiring substantial divided attention (Hartman et al. 2013, Lenné et. al. 2010, Anderson et al. 2010). Alternatively, these lower completion rates might also be attributable to intoxicated drivers actively choosing not to attempt the task and instead concentrating on their driving performance in recognition of their impairment.

While the prevalence of lane departures during task segments were not significantly associated with THC or BrAC concentrations, we did find evidence that THC was associated with longer departure durations during the artist-search task. This indicates either slower recoveries from departures, or decreased awareness of the vehicle’s lane position while engaged in divided-attention tasks. It bears consideration that the magnitude of BrAC effect on lane departure duration in secondary tasks was substantially higher per g/210 L (approximately equivalent to g/dL [%] blood alcohol concentration) than blood THC per µg/L. However, THC concentrations also vary considerably more and over shorter periods than alcohol during normal use, changing rapidly within a short duration after inhalation (Hartman et al. 2016). Distracted driving alone is shown to have severe detrimental effects on driving performance (Caird et al. 2014); adding the effects of intoxication to this raises significant safety concerns for both the driver and other vehicles on the roadway.

We observed a tendency for participants to decrease speed even without cannabis and alcohol when engaged in a secondary message-reading task; however, we also found evidence that THC may be associated with minor speed decreases during the side-mirror task. While this finding seems to be contradicted by results for the message-reading task, the incongruity is likely due to the absence of completion data for the message-reading task. Because we could not filter out non-attempts, individuals who ignored the task — thus having no reason to slow down—had data mixed in with those who actively engaged in the task. This might also explain the low magnitudes of change in speed (-0.01 mph and +0.04 mph per µg/L THC for side-mirror and artist-search, respectively) and the unexpected finding of higher BrAC predicting shorter lane departure durations during the message-reading task. It is also possible that the message-reading task requires more overall attention than detecting lights (side-mirror task) or even skimming for a certain value (artist-search)—resulting in less overall attention paid to the primary driving task and thus less attempt to compensate for intoxication through decreased speed.

No effect on SDLP or SDS was observed for any variable, with the exception of BrAC predicting increased SDLP during the message-reading task. While contrary to our hypothesis, the lack of effects on SDS was consistent with our findings from the overall drive (Hartman et al 2016). However, given our results from the full drive (Hartman et al 2015) we expected to observe both THC and BrAC effects on SDLP. This inconsistency is likely explained by the fact that the short durations of the events result in less stable measures (LaVelle et al. 2019).

Also noteworthy is that the effects of THC and BrAC were not found to be synergistic in any of our analyses. This is consistent with our previous findings from this study on lateral control (Hartman et. al 2015). Because cannabis was inhaled *ad libitum*, several participants in the low-THC condition had higher blood THC concentrations than participants in the high-THC condition. This is due to participants titrating their dose to their preferred level of drug high and tachycardia, as demonstrated multiple times (Hartman et al 2015). The availability of blood THC concentrations is a strength of the study, enabling analysis by the active THC blood concentration rather than by dose, as many older studies did.

**Limitations**

The short duration of task periods in this study, while more realistic, made it difficult to detect differences in driving behavior. Despite BrAC having a well-established relationship to driving performance, the only significant performance shift attributable to alcohol in this study was in the message-reading task. This task had the second-longest duration, and was arguably the most cognitively demanding. Future research in this area might require more occurrences of each task, or tasks which are longer in duration.

While the study population was restricted to occasional to moderate smokers and took measures to preclude prior intoxication, some participants had low detectable blood THC concentrations under placebo conditions from previously self-administered cannabis. Another limitation is that concentrations at time-points within the drive were estimated by individual modeling (rather than directly measured) via interpolation from collection times pre- and post-drive, since continuous blood collection during driving was not feasible and would be prohibitively disruptive to the driving and secondary tasks.

Possible bias may have been introduced by participants recognizing that their driving performance was under observation and altering their behavior accordingly. In addition, while the study used placebo conditions, it is probable that some participants were aware of dosing conditions due to their prior familiarity with cannabis and alcohol. Such awareness of study conditions may have led drivers to exhibit greater caution or focus, particularly given the vested interest some participants might have in demonstrating that cannabis does not impair driving performance. This notion is at least partially supported by survey data, which shows public attitudes towards driving under the influence of cannabis are less negative than attitudes towards driving under the influence of alcohol (McCarthy et al. 2007).

**Conclusion**

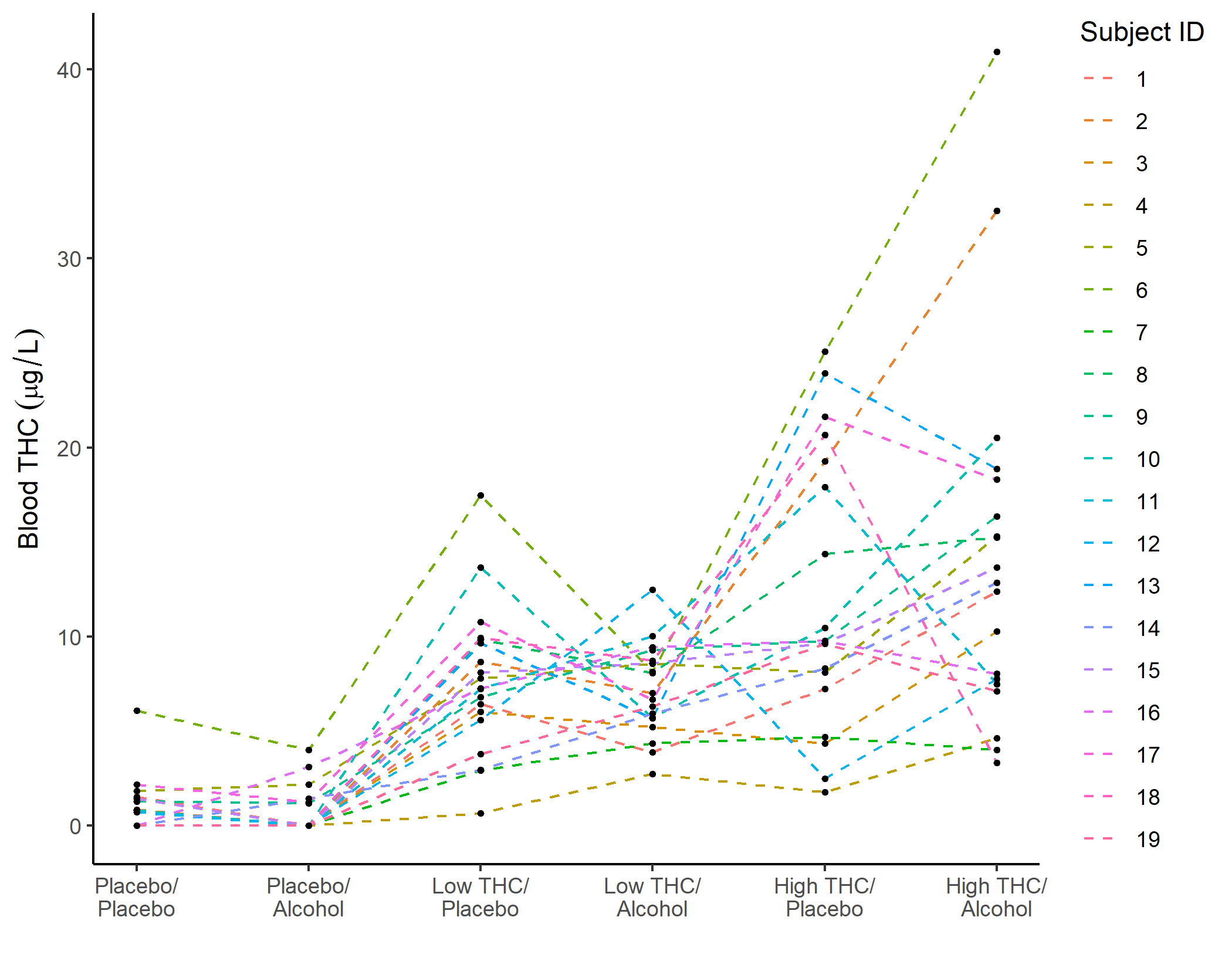
Due to THC’s effect on higher cognitive performance, evaluating divided-attention tasks such as these in drivers with cannabis impairment is important—especially given the current high prevalence of cellular phones and other driving distractions. Our research suggests that divided attention is an area of concern following acute cannabis, particularly for complex tasks and more research is needed to understand the effects across the spectrum of divided attention while driving including in longer distraction engagements. This raises significant safety concerns, exemplified by increased durations of lane departures during an artist-search task. As cannabis legalization increases across the US, additional research on THC’s impact on driving performance is essential.

**ACKNOWLEDGMENTS AND DISCLOSURES**

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**FIGURES AND TABLES**

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**Figure 1.** Estimated blood THC concentrations by administered cannabis and alcohol doses during the first occurrence of the side-mirror task for each of the 19 participants.

**Table 1**: Results from models used to analyze performance on secondary tasks performed while driving, including coefficient estimates, odds ratios (OR), 95% confidence intervals, and p-values.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Task | Outcome | Model | BrAC (0.01 g/210 L) | | Blood THC concentration (µg/L) | |
| β, OR | p-value | β, OR | p-value |
| Artist-search | Completion | GLMM | -0.012,  0.988 (0.900, 1.086) | 0.802 | **-0.052,**  **0.949 (0.902, 0.999)** | **0.046 \*** |
| Incorrect | GLMM | -0.009,  0.991 (0.898, 1.092) | 0.858 | **0.046,**  **1.047 (1.000, 1.094)** | **0.041 \*** |
| Time (engaged), sec | LMM | -0.018 (-0.111, 0.074) | 0.697 | **0.049 (0.002, 0.096)** | **0.041 \*** |
| Time (completed), sec | LMM | 0.001 (-0.073, 0.087) | 0.864 | 0.000 (-0.041, 0.043) | 0.967 |
| Side-mirror | Completion | GLMM | 0.030,  1.030 (0.952, 1.113) | 0.461 | 0.020,  1.020 (0.980, 1.063) | 0.327 |
| Time (completed), sec | LMM | -0.003 (-0.014, 0.008) | 0.595 | -0.003 (-0.009, 0.002) | 0.250 |
| \*Denotes statistical significance at p<0.05.  BrAC: breath alcohol concentration; THC: Δ9-tetrahydrocannabinol;  GLMM indicates generalized linear mixed models using a binomial response, logit link, and subject-specific random intercepts; LMM indicates linear mixed models with a Gaussian response, identity link, and subject-specific random intercepts. AIC did not select an interaction between BrAC and THC for any outcomes. | | | | | | |



**Table 2**: Results of models used to analyze baseline driving performance, including fixed-effect intercepts, coefficient estimates, 95% confidence intervals, and p-values.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Task | Outcome | Intercept (fixed effect) | | BrAC (0.01 g/210 L) | | THC (µg/L) | |
| β (95% CI) | p-value | β (95% CI) | p-value | β (95% CI) | p-value |
| Side-Mirror | Δ SDLP (cm) | 0.128  (-2.090, 2.346) | 0.910 | -0.068  (-0.358, 0.223) | 0.648 | 0.000  (-0.138, 0.137) | 0.996 |
| Δ Speed (m/s) | -0.007  (-0.127, 0.113) | 0.908 | 0.007  (-0.002, 0.016) | 0.143 | **-0.005**  **(-0.009, -0.001)** | **0.020 \*** |
| Δ SDS (m/s) | 0.027  (-0.014, 0.069) | 0.200 | -0.113  (-0.620, 0.394) | 0.664 | 0.001  (-0.001, 0.004) | 0.417 |
| Artist-Search | Δ SDLP (cm) | -2.687  (-35.390, 30.015) | 0.872 | -0.171  (-1.334, 0.991) | 0.772 | -0.389  (-0.993, 0.215) | 0.206 |
| Δ Speed (m/s) | -0.640  (-2.326, 1.045) | 0.455 | 0.019  (-0.041, 0.079) | 0.529 | -0.000  (-0.031, 0.031) | 0.999 |
| Δ SDS (m/s) | -0.117  (-0.500, 0.266) | 0.548 | -0.003  (-0.016, 0.011) | 0.688 | 0.003  (-0.004, 0.010) | 0.383 |
| Message-Reading | Δ SDLP (cm) | -4.184  (-10.126, 1.758) | 0.168 | **0.613**  **(0.143, 1.084)** | **0.011 \*** | -0.006  (-0.236, 0.224) | 0.959 |
| Δ Speed (m/s) | **-1.019**  **(-1.450, -0.588)** | **<0.001\*\*\*** | -0.011  (0.045, 0.022) | 0.515 | **0.019**  **(0.002, 0.036)** | **0.026 \*** |
| Δ SDS (m/s) | 0.005  (-0.088, 0.098) | 0.917 | -0.003  (-0.015, 0.009) | 0.599 | 0.004  (-0.002, 0.010) | 0.186 |
| \*Denotes statistical significance at p<0.05.  BrAC: breath alcohol concentration; THC: Δ9-tetrahydrocannabinol;  AIC did not select an interaction between BrAC and THC for any outcomes. | | | | | | | |

**Table 3:** Results from models used to analyze the prevalence of lane departures during task periods, including coefficient estimates, odds ratios (OR), 95% confidence intervals, and p-values.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Task | Outcome | BrAC (0.01 g/210 L) | | THC (µg/L) | |
| β, OR (95% CI) | p-value | β, OR (95% CI) | p-value |
| Side- Mirror | Minor departures | -0.015,  0.985  (0.925, 1.048) | 0.632 | -0.003,  0.997  (0.961, 1.033) | 0.851 |
| Major departures | -9.723,  0.985  (0.810, 1.014) | 0.089 | -0.016  0.907  (0.920, 1.047) | 0.637 |
| Severe departures | 0.197,  1.218  (0.580, 3.43) | 0.600 | -0.004,  0.996  (0.520, 1.270) | 0.982 |
| Artist-Search | Minor departures | 0.024,  1.025  (0.914, 1.149) | 0.673 | 0.003,  1.003  (0.945, 1.059) | 0.924 |
| Major departures | -0.002,  0.998  (0.816, 1.210) | 0.981 | -0.051,  0.950  (0.841, 1.057) | 0.375 |
| Severe departures | 0.192,  1.212  (0.661, 2.221) | 0.534 | 0.030,  1.030  (0.733, 1.448) | 0.864 |
| Message-Reading | Minor departures | 0.012,  1.012  (0.941, 1.088) | 0.748 | -0.003,  0.996  (0.962, 1.031) | 0.826 |
| Major departures | -0.002,  0.998  (0.905, 1.100) | 0.963 | 0.003,  1.003  (0.954, 1.054) | 0.904 |
| Severe departures | 0.108,  1.114  (0.773, 1.151) | 0.549 | -0.009,  0.992  (0.782, 1.151) | 0.929 |
| \*Denotes statistical significance at p<0.05.  BrAC: breath alcohol concentration; THC: Δ9-tetrahydrocannabinol;  r | | | | | |

**Table 4:** Results from models used to analyze the duration of lane departures during task periods, including coefficient estimates, 95% confidence intervals, and p-values.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Task | Outcome | BrAC (0.01 g/210 L) | | THC (µg/L) | |
| β (95% CI) | p-value | β (95% CI) | p-value |
| Side-Mirror | Minor (percent of task out of lane) | **1.416**  **(0.076, 2.756)** | **0.040 \*** | 0.09  (-0.725,  0.899) | 0.834 |
| Major (percent of task out of lane) | 0.586  (-1.059, 2.231) | 0.487 | -0.26  (-1.284, 0.766) | 0.622 |
| Artist-Search | Minor (percent of task out of lane) | 0.468  (-1.025, 1.962) | 0.533 | **0.74**  **(0.118, 1.360)** | **0.020 \*** |
| Major (percent of task out of lane) | -0.729  (-2.921, 1.463) | 0.500 | -0.200  (-1.200, 0.801) | 0.685 |
| Message-Reading | Minor (percent of task out of lane) | **-1.193**  **(-2.043, -0.344)** | **0.006 \*** | -0.16  (-0.592, 0.262) | 0.451 |
| Major (percent of task out of lane) | 0.057  (-1.307, 1.421) | 0.935 | -0.10  (-0.936, 0.739) | 0.819 |
| \*Denotes statistical significance at p<0.05.  BrAC: breath alcohol concentration; THC: Δ9-tetrahydrocannabinol;  All models used a Gaussian response, identity link, adjusted for speed and initial lane position, and included subject-specific random intercepts. AIC did not select an interaction between BrAC and THC for any outcomes. There were not enough extreme lane departures to estimate model coefficients. | | | | | |

**APPENDIX**

**Table A1**: Average measures of driving and task performance for the side-mirror task by drive segment and dosing level.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Segment |  | Placebo/  Placebo | Placebo/  Alcohol | Low/  Placebo | Low/  Alcohol | High/  Placebo | High/  Alcohol |
| Urban | Blood THC (µg/L) | 0.9 | 0.7 | 7.9 | 7.2 | 12.1 | 14.0 |
| BrAC (g/210 L) | 0 | 0.059 | 0 | 0.052 | 0 | 0.048 |
| % complete | 88.3 | 89.7 | 95.1 | 87.1 | 88.9 | 86.9 |
| Time (sec) | 1.85 | 1.91 | 1.74 | 2.02 | 1.91 | 1.81 |
| SDLP (cm) | 4.57 | 3.05 | 3.96 | 4.88 | 3.66 | 4.27 |
| Speed (m/s) | 12.74 | 13.10 | 13.19 | 13.19 | 12.34 | 12.65 |
| SDS (m/s) | 0.08 | 0.12 | 0.11 | 0.13 | 0.13 | 0.10 |
| Interstate | Blood THC (µg/L) | 0.9 | 0.6 | 6.1 | 5.6 | 9.4 | 10.5 |
| BrAC (g/210 L) | 0 | 0.057 | 0 | 0.052 | 0 | 0.049 |
| % complete | 95.5 | 94.7 | 97.9 | 97.9 | 92.6 | 98.0 |
| Time (sec) | 1.99 | 1.95 | 1.89 | 2.04 | 2.02 | 1.91 |
| SDLP(cm) | 13.72 | 17.68 | 14.63 | 15.54 | 19.81 | 19.20 |
| Speed (m/s) | 28.34 | 29.06 | 28.97 | 27.98 | 27.58 | 27.67 |
| SDS (miles/h) | 0.11 | 0.13 | 0.11 | 0.15 | 0.13 | 0.14 |
| Rural | Blood THC (µg/L) | 0.9 | 0.6 | 5.0 | 4.6 | 7.3 | 8.7 |
| BrAC (g/210 L) | 0 | 0.054 | 0 | 0.051 | 0 | 0.049 |
| % complete | 100 | 100 | 95.9 | 94.5 | 97.2 | 100 |
| Time (sec) | 1.73 | 1.65 | 1.67 | 1.76 | 1.75 | 1.67 |
| SDLP (cm) | 5.79 | 7.62 | 6.40 | 6.40 | 5.49 | 7.62 |
| Speed (m/s) | 22.40 | 23.69 | 22.26 | 23.29 | 21.41 | 22.49 |
| SDS (m/s) | 0.09 | 0.12 | 0.12 | 0.12 | 0.11 | 0.11 |
| Abbreviations: THC, Δ9-tetrahydrocannabinol; BrAC, breath alcohol concentration; SDLD, standard deviation of lateral position; SDS, standard deviation of speed. | | | | | | | |

**Table A2**: Average measures of driving and task performance for the artist-search task by dosing level. All instances of the artist-search task took place on the interstate.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Placebo/  Placebo | Placebo/  Alcohol | Low/  Placebo | Low/  Alcohol | High/  Placebo | High/  Alcohol |
| Blood THC (µg/L) | 0.8 | 0.6 | 6.0 | 5.6 | 9.3 | 10.8 |
| BrAC (g/210 L) | 0 | 0.057 | 0 | 0.052 | 0 | 0.048 |
| % complete | 66.7 | 71.4 | 64.3 | 49.1 | 57.9 | 61.4 |
| % incorrect | 15.8 | 17.9 | 32.1 | 26.3 | 15.8 | 12.3 |
| time (sec) | 6.18 | 5.43 | 6.14 | 5.78 | 5.31 | 6.30 |
| SDLP (cm) | 23.16 | 25.91 | 26.82 | 24.69 | 19.81 | 23.77 |
| Speed (m/s) | 29.77 | 29.01 | 30.00 | 27.67 | 27.76 | 27.27 |
| SDS (m/s) | 0.20 | 0.32 | 0.32 | 0.27 | 0.26 | 0.34 |
| Abbreviations: THC, Δ9-tetrahydrocannabinol; BrAC, breath alcohol concentration; SDLP, standard deviation of lateral position; SDS, standard deviation of speed. | | | | | | |

**Table A3**: Average measures of driving and task performance for the message-reading task by drive segment and dosing level.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Segment |  | Placebo/  Placebo | Placebo/  Alcohol | Low/  Placebo | Low/  Alcohol | High/  Placebo | High/  Alcohol |
| Urban | Blood THC (µg/L) | 0.9 | 0.7 | 7.7 | 7.2 | 12.5 | 14.2 |
| BrAC (g/210 L) | 0 | 0.059 | 0 | 0.052 | 0 | 0.048 |
| SDLP (cm) | 17.22 | 19.35 | 20.60 | 17.31 | 15.12 | 23.68 |
| Speed (m/s) | 12.38 | 13.10 | 13.05 | 12.92 | 12.47 | 12.78 |
| SDS (m/s) | 0.41 | 0.38 | 0.42 | 0.43 | 0.37 | 0.42 |
| Interstate | Blood THC (µg/L) | 0.855 | 0.656 | 6.05 | 5.60 | 9.22 | 10.8 |
| BrAC (g/210 L) | 0 | 0.057 | 0 | 0.051 | 0 | 0.049 |
| SDLP (cm) | 31.70 | 32.31 | 32.00 | 32.61 | 25.66 | 30.48 |
| Speed (m/s) | 29.19 | 28.83 | 29.55 | 27.36 | 28.34 | 27.81 |
| SDS (m/s) | 0.38 | 0.57 | 0.47 | 0.45 | 0.46 | 0.50 |
| Rural | Blood THC (µg/L) | 0.782 | 0.573 | 4.91 | 4.59 | 8.09 | 8.78 |
| BrAC (g/210 L) | 0 | 0.054 | 0 | 0.516 | 0 | 0.048 |
| SDLP (cm) | 23.32 | 31.39 | 24.30 | 25.73 | 25.85 | 30.78 |
| Speed (m/s) | 21.55 | 22.17 | 21.99 | 21.10 | 19.71 | 22.31 |
| SDS (m/s) | 0.51 | 0.55 | 0.52 | 0.40 | 0.53 | 0.61 |
| Abbreviations: THC, Δ9-tetrahydrocannabinol; BrAC, breath alcohol concentration; SDLP, standard deviation of lateral position; SDS, standard deviation of speed. | | | | | | | |

**Table A4:** The prevalence of lane departures of each severity category by assigned dosing condition across all task instances.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Control Periods | | | | Task Periods | | | |
|  | None | Minor | Major | Extreme | None | Minor | Major | Extreme |
| Placebo/  Placebo | 370 | 49 | 28 | 0 | 341 | 78 | 38 | 0 |
| Placebo/  Alcohol | 359 | 66 | 31 | 0 | 328 | 97 | 40 | 0 |
| Low/  Placebo | 382 | 52 | 23 | 1 | 345 | 89 | 52 | 2 |
| Low/  Alcohol | 360 | 57 | 28 | 1 | 333 | 84 | 40 | 1 |
| High/  Placebo | 356 | 55 | 28 | 0 | 337 | 74 | 41 | 0 |
| High/  Alcohol | 359 | 65 | 22 | 2 | 338 | 86 | 36 | 5 |
| Lane departure categories are nested and are determined by the extent to which the vehicle is out of lane. Minor departures indicate any portion of the vehicle is out of lane, major departures indicate at least 25% of the vehicle chassis width is out of lane, and extreme departures indicate at least 50% of the vehicle chassis width is out of lane. | | | | | | | | |

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