**Abstract (short)**

Alcohol and marijuana are the most common legal and illegal drugs detected in drivers worldwide. While there is a general consensus regarding the effects of alcohol on driving performance, the effects of marijuana remain relatively unknown. This study examines the effects of cannabis and alcohol on performance during secondary tasks performed while driving using a within-subject, placebo-controlled experiment conducted in advanced driving simulator. For cognitively demanding secondary tasks, higher blood THC concentrations were associated with lower rates of task completion, and higher rates of incorrect responses. However, changes in driving performance were limited to differential decreases in speed during task periods. Additionally, some previously established effects of alcohol were detected, though alcohol was not found to interact with THC, with each drug being found to have separate effects on different aspects of driving performance.

**1. Introduction**

Alcohol and cannabis are the most common legal and illegal drugs detected in drivers worldwide (Augsburger et al., 2005). The detrimental effects of alcohol are well-documented and include: delayed reaction times (Starmer 1989), impaired visual function (Grant 1974, Wallgren & Barry, 1970), and slower information processing (Brown, 1970). At blood concentrations as low as 0.03% steering errors and collision frequency rise, and as concentrations reach 0.05% drivers have an increased tendency to ignore rules and instructions (Ogden & Moskowitz, 2004). Alcohol has been shown to impair the ability of drivers to maintain lane positions, slows braking time, and also reduces the ability to detect potential hazards on the roadway (Liguori, 2009; Martin et al., 2013; Ogden & Moskowitz, 2004, Van Dyke & Fillmore, 2014). A recent meta-analysis by Irwin et al., (2017) reviewed 50 studies and found blood alcohol concentration to be associated with increases in standard deviation of lane position and standard deviation of speed.

The impact of cannabis on driving performance is less clear. The principal active compound in cannabis, 9-Tetrahydrocannabinol (THC), has been shown to impair executive function and decision making (Ramaekers et al., 2006), decrease perceptual motor speed and accuracy, and worsen concentration (Kurzthaler et al., 1999), and alter the activity of the brain networks involved in cognition (Battistella et al., 2013). Previous research has found cannabis increases lane weaving, decreases driving speed, and increases variability in headways and lane position (Anderson et al., 2010; Downey et al., 2013; Hartman and Huestis, 2013; Lenne et al., 2010). While many studies have linked blood THC concentration with increased crash risk and driver culpability (Asbridge et al., 2012; Drummer et al., 2004; Gjerde et al., 2011; Laumon et al., 2005; Li et al., 2012), the degree to which cannabis use increases crash risk is less clear, with recent meta-analyses finding highly variable, and at times contradictory, results (Romano et al., 2017). Cannabis is frequently used in tandem with other drugs, complicating risk attribution. Li et al. (2013) reported that marijuana was a significant contributor to fatal crash risk, regardless of the presence of alcohol or other drugs. However, Romano et al. (2014) found a non significant contribution of marijuana to crash risk after accounting for the presence of other drugs.

As of 2019, 33 U.S. states have legalized medical or recreational marijuana (cannabis), with several legalizations occurring in the last year. Colorado, which first legalized medical marijuana in 2000, has seen increases in driving under the influence of cannabis (DUIC) (Urfer et al., 2014), and motor vehicle fatalities involving cannabis positive drivers, while these rates have not changed in non-medical marijuana states (Salomonsen-Sautel et al., 2014). In Europe, Switzerland and others have adopted zero tolerance policies, prohibiting drivers from having any traces of drugs in their blood while driving (Steentoft et al., 2010). However, developing evidence based cannabis-driving legislation is challenging. Residual THC can be detected in the blood for up to a month among frequent users (Bergamaschi et al., 2013), and some research suggests driving-related psychomotor skills may be less impaired for regular THC users than for non-regular users following acute consumption (Marks and MacAvoy, 1989; Wright and Terry, 2002). Better understanding the relationships between cannabis consumption, blood THC concentrations, and various aspects of driving performance would lend clarity to policy determinations. Further, because cannabis and alcohol are frequently detected together (Legrand et al., 2013), it is necessary to investigate possible synergistic effects of the two drugs.

This study examines the influence of cannabis, with and without alcohol, on driving performance while engaged in a secondary task. Secondary tasks, such as tuning the radio or using navigation maps, require divided attention and are commonplace in modern driving. For non-impaired drivers, a recent meta-analysis found 80% of 350 identified studies reported detrimental effects of secondary task engagement on driving performance (Ferdinand, A. et al., 2014). Given the established effects of cannabis and alcohol, there is reason to believe performance declines will be more pronounced for intoxicated drivers. This work evaluates the relationship between THC, alcohol, and secondary tasks, it is part of a series of manuscripts [from the NIDA simulator study?], and earlier publications have evaluated the effects of cannabis and alcohol on lateral control (Hartman et al., 2015), and longitudinal control (Hartman et al., 2016).

**2. Methods**

**2.1 Participants**

Healthy adults ages 21-55 years with self reported cannabis use ≥ 1x3/months but ≤ 3days/week over the past 3 months were recruited to participate in this Institutional Review Board (IRB) approved study. The inclusion criteria required participants to have been a licensed driver for ≥ 2 years, with a valid unrestricted license and a self-reported driving of ≥ 1300 miles in the past year. Exclusion criteria were a past or current clinically significant medical illness; a history of clinically significant adverse events related to cannabis or alcohol or motion sickness; a ≥ 450 mL blood donation in the 2 weeks predating the 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; a need for non-standard driving equipment; or prior participation in a similar driving simulator study.

**2.2 Treatment Protocol**

In 6 separate sessions each participant received combinations of cannabis (placebo/low/high) and alcohol (placebo/active). The ordering of cannabis-alcohol combinations was randomized, with sessions separated by washout periods ≥ 1 week. Participants spent 10-16h at the research clinic prior to treatment administration to avoid acute intoxication. Treatments began with the participant drinking 90% grain alcohol in fruit juice until reaching 0.065% peak breath alcohol concentration, or a placebo of fruit juice with an alcohol-swabbed rim designed to mimic the odor and taste of alcohol. After drinking, participants inhaled 500mg placebo (0.008±0.002% THC), low (2.9±0.14%), or high (6.7±0.05%) THC vaporized cannabis (NIDA Chemistry and Physiological Systems Research Branch) ad libitum over 10 minutes.

Blood collection was performed 0.17, 0.42, 1.4, and 2.3 hours post inhalation, and blood THC concentration was quantified using a previously-published method (Schwope et al., 2011) where 0.5mL blood was protein precipitated with ice-cold acetonitrile, and supernatants diluted and solid-phase extracted. THC and blood alcohol concentrations (BAC) were interpolated using individual power curves derived from these four measurements (Hartman et al., 2015; Jones, 2003).

**2.3 Data Collection**

Simulated drives took place 0.5-1.3 hours after the start of cannabis dosing in the University of Iowa National Advanced Driving Simulator (NADS-1), a Chevrolet Malibu sedan mounted in a dome that allows drivers to experience a 360° field of view, and uses a motion system that provides 400m2acceleration space, 300° rotation, and high-frequency motion (Lee et al., 2010). After a short practice drive, participants embarked on a challenging 45min main drive which included urban, rural, and interstate segments and numerous programmed events. Because each participant drove 6 times, 3 scenarios with differing event orders were used to minimize familiarity. During each drive NADS-1 recorded a comprehensive record of driver inputs and vehicle states.

**2.4 Secondary Tasks**

At various points during each drive participants needed to complete multiple occurrences of three types of secondary tasks - side-mirror, artist-search, and message-reading.

The side-mirror task required participants to push a response button whenever a red triangle appeared in one of their side mirrors. The triangle disappeared when the participant completed the task by pressing a response button, or after it was visible for 5 seconds. The side mirror task occurred a total of 14 times in each drive, with 5 instances in urban and interstate segments, and 4 instances in rural segments.

In the artist-search task participants were prompted by an audio trigger to select a specific artist on the car’s display from a navigable menu consisting of 3 pages, each listing 12 artists. The artist-search task occurred 3 times in each drive, taking place exclusively on the interstate segment. During each instance, participants had 10 seconds to complete the task before it timed-out.

In the message reading task participants were prompted by an audio trigger to read aloud a message shown on the car’s display. Messages were designed to be of equal difficulty and contained an average of 18 words (min=15, max =24) and 111 characters (min = 93, max = 141). The task occurred 6 times in each drive, twice during urban, interstate, and rural segments, and each message was displayed for 10 seconds.

**2.5 Statistical Analysis**

Secondary tasks were analyzed separately, these analyses included an evaluation of baseline driving characteristics, shift in driving performance while engaged in the task, and performance on the task itself. For each instance of each task, the *task period*, which began when the task first became available and ended when the task terminated (either due to completion or time-out) was paired with a *control period*, which was the same duration as the task period and occurred immediately prior to the task becoming available. Control periods were used to evaluate baseline driving characteristics, which included 2 measures of lateral control - standard deviation of lane deviation (SDLD) (Gawron & Ranney, 1988; Ramaekers, Robbe, & O'Hanlon, 2000) and the number of lane departures - as well as mean speed (Speed), a measure of cautiousness, and standard deviation of speed (SDS)(Arnedt, Wilde, Munt, & MacLean, 2001; Gawron & Ranney, 1988), a measure of longitudinal control. Performance shift was measured by change in SDLD, lane departures, Speed, and SDS across paired task and control periods. For the artist-search and side-mirror task, performance shift analyses included only task and control periods where the task had been completed; however, for the message-reading task completion was not measured, and all task-control periods were analyzed for performance shift. Task performance on the artist-search and side-mirror tasks was measured by successful task completion, prevalence of incorrect responses, and time taken to complete the task.

The effects of blood THC, BAC, and their possible interaction, were modeled using mixed effects regression models, which included subject specific random intercepts and adjusted for additional covariates specific to the outcome and task. For numeric dependent measures, a Gaussian distribution and identity link function were used, while for binary measures these models used a binomial distribution and logit link. Each model considered related factors specific to the task and outcome, including the road segment where the task occurred, the visit and event number, initial speed (for lateral control outcomes), and the page number of the correct response in the artist-search task, a factor related to task difficulty. Final models were selected based upon the Akaike Information Criterion, or AIC (Akaike, 1974). AIC was also used to gauge whether non-linear effects of THC/BAC, or an interaction term between THC and BAC warranted inclusion in each model. From each model we report coefficient estimates, standard errors, test statistics, and Wald p-values. All models were fit using maximum likelihood estimation using the lme4 package (Bates et al., 2015) in R version 3.5.1.

**3. Results**

**3.1 Participants**

Nineteen healthy adults (13 men, ages 21-37 years, 74% white) completed in the study. The majority consumed cannabis ≥2x/month, but ≤3days/week, and reported their most recent use as less than one week prior to admission. Self-reported driving experience ranged from 6-23 years, and all participants reported driving ≥1x/week. The first visit of one participant (#123) was excluded from side-mirror task analyses due to a 0% task completion rate on that drive, and the high-THC/placebo drive for another participant (#21) did not have data for the message-reading task. Otherwise each participant had at least one recorded event for each task, and 94.8%, 98.3% and 99.1% of all drives had complete data for every instance of the side-mirror, artist-search, and message-reading tasks respectively.

[FIGURE 1 ABOUT HERE, see end of doc]

**3.2 Dosing**

Figure 1 displays estimated blood THC concentrations during the first occurrence of the side-mirror task, demonstrating the substantial variability in blood THC by dosing condition. Several subjects had higher blood THC on the low-THC condition than they did on high-THC condition, presenting a barrier to conducting a meaningful statistical analysis using assigned treatment groups. Based upon these results, blood THC concentration, rather than treatment group, was used as the explanatory variable of interest in each of our statistical models.

[TABLE 1, 2, 3 ABOUT HERE, see end of doc]

**3.3 Secondary Tasks**

Descriptive results for each secondary task by dosing condition are presented in Tables 1, 2, and 3. For the side-mirror task we observed high overall completion rates, with the highest rates on rural gravel road segments (97.9%), and the lowest on urban segments (89.4%). Most participants who completed the task did so quickly, with average completion times of 1.87, 1.90, and 1.70 seconds for urban, instate, and rural segments. Completion rates for the artist-search task were lower, overall only 61.8% of task instances were completed, the task also took participants longer to complete, with an average completion time of 5.89 seconds. Speed, SDLP, and SDS varied considerably by road segment, highlighting the need to control for location when modeling performance in tasks which spanned multiple locations.

[TABLE 4 ABOUT HERE, see end of doc]

**3.4 Performance on Secondary Tasks**

Model results for secondary task performance are presented in Table 4. For the artist search task, each 1% increase in THC concentration led to 9% increased odds of failing to complete the task (p = 0.046). Additionally, blood THC was a significant predictor of incorrect responses, each 1% increase in THC concentration led to 10% increased odds of selecting an incorrect artist (p = 0.041). For the side mirror task, THC was not significantly associated with task completion. BAC was not significantly associated with any measure of task completion.

[TABLE 5 ABOUT HERE, see end of doc]

**3.5 Baseline Driving Performance**

Baseline driving performance model results are presented in Table 5. For the side mirror task BAC was associated with significantly higher SDLD (p = 0.041), Speed (p = 0.007), and SDS (p = 0.049). For the artist search task, BAC (p = 0.010) and THC (p = 0.010) was significantly associated with lower Speed. There was no statistically significant effects of THC or BAC on driving behavior detected for message reading tasks.

[TABLE 6 ABOUT HERE, see end of doc]

**3.6 Driving Performance during Secondary Tasks**

Model results for shift in driving performance are presented in Table 6. For the message reading and artist search tasks participants tended to decrease speed, on average slowing by 2.3 mph (p < 0.001) and 1.4 mph (p = 0.45) for each respective task. For the message reading task THC was inversely related with this slowdown, with each 1% increase THC lessening the decrease in speed by 0.04 mph (p = 0.026). Conversely for the side mirror task unimpaired participants tended not to decrease their speed (p = 0.910), but THC was a significant predictor of decrease in speed, with decreases of 0.01 mph for each 1% increase in THC (p = 0.020).

[TABLE 7 ABOUT HERE, see end of doc]

Across all 3 tasks, a total of 11 lane departures occurred during control or task periods. These departures are documented in Table 7. All departures took place during task periods, with 6 occurring during the artist-search task, 4 during the message-reading task, and 1 during side-mirror task. There were too few departures to use the statistical models as described in Sec 2.5; however, 10 of the 11 departures occurred under non-placebo cannabis dosing conditions. Applying a simple two-sided binomial test to these events yields a p-value of 0.113.

No changes in SDLD or SDS were detected for unimpaired participants during any of the secondary tasks, and THC was not associated with shifts in either measure. BAC was associated with a significant increase in SDLD (p = 0.011) during the message reading task, but had no detectable effect on change in SDLD or SDS for the other two tasks.

**4. 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 using a highly realistic driving simulator. Higher blood THC concentrations were associated with worsened task performance and completion rates, similar effects were not found for BAC. During task periods, participants tended to decrease their speed relative to pre-task control periods, with blood THC being associated with the magnitude of speed change for the message-reading and side-mirror tasks. Higher BAC was associated with worse lane keeping as measured by SDLD during the side-mirror task, while no detectable effect of THC on lane keeping was found for any of the three tasks. Too few lane departures occurred to reach any statistically sound conclusions.

Higher blood THC predicted lower rates of completion and increased the likelihood of providing an incorrect selection on the artist search task, but THC was not associated with completion of the side-mirror task. This may be explained by the different complexities of each task. The side-mirror task requires attentiveness, but is straightforward to complete once the driver notices the triangle icon. In contrast, the artist-search requires the driver to interact with the console display and make a precise selection, likely resulting in a greater cognitive demand and leading to more divided attention. These differences suggest that our findings are consistent with prior research which has shown detrimental effects of cannabis on performance for tasks requiring substantial divided attention. Additionally, lower completion rates might be explained by drivers impaired by THC actively choosing not to attempt the task and instead concentrating on their driving performance.

On average drivers decrease their speed during secondary task periods. For the side mirror task, higher concentrations of THC amplified this slowdown, with higher blood THC predicting larger decreases in speed. This finding might suggest more time being spent processing the task, as decreases in speed are positively correlated with the amount of time spent on a task; however, we did not find a statistically significant relationship between completion time and THC.

For the message-reading task higher concentrations of THC predicted smaller decreases in speed. These results might be explained by the fact that NADS-1 does not record participant audio, so we have no completion data for the message reading task. Because the cognitive demands of the message-reading task are similar to those of the artist-search task it is possible that participants impaired by THC were less likely to attempt the task. Participants not engaging in a task have no reason to slow down, so the observed relationship between THC and speed in the message reading task might be an artifact of impaired drivers choosing not to attempt the task.

The short duration of task periods makes it difficult to detect differences in driving behavior. The side mirror task, although short in nature, had the longest combined duration as it occurred 14 times during each simulated drive. Despite BAC having a well-established relationship with baseline driving performance, we only detected significant BAC effects during control periods of the side mirror task for SDLD and SDS, likely due to the longer combined duration of this task. Additionally, the only significant performance shift attributable to alcohol was in the message reading task, which had the second longest duration, and was more cognitively demanding than the side-mirror task. Future research in this area might require more occurrences of each task, or tasks which are longer in duration.

**4.1 Limitations**

Because cannabis was inhaled ad libitum, several participants in the low-THC condition had higher levels of blood THC than participants in the high-THC condition. Additionally, while the study population was restricted to occasional smokers and took measures to preclude prior intoxication, some participants had detectable blood THC under placebo conditions. A homogeneous study population is important because frequent marijuana smokers display some tolerance to acute marijuana intoxication effects (Ramaekers et al., 2011); however, tolerance does not fully compensate for all the effects (Downey et al., 2013). The variable relationship between dosing condition and blood THC, combined with subject-specific cannabis tolerance makes it difficult to uniformly quantify the relationship between blood THC and driving performance. Nevertheless, there is a considerable interest in tolerance differences between occasional and frequent users as medical and recreational cannabis become more commonplace (Ramaekers et al., 2009; Toennes SW et al., 2008; Wright and Terry, 2002).

Possible bias may have been introduced due to participants knowing that their driving performance was under observation constant observation by researchers and altering their behavior accordingly. In addition, while the study used placebo conditions, it is probable that some participants were aware of their 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 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).

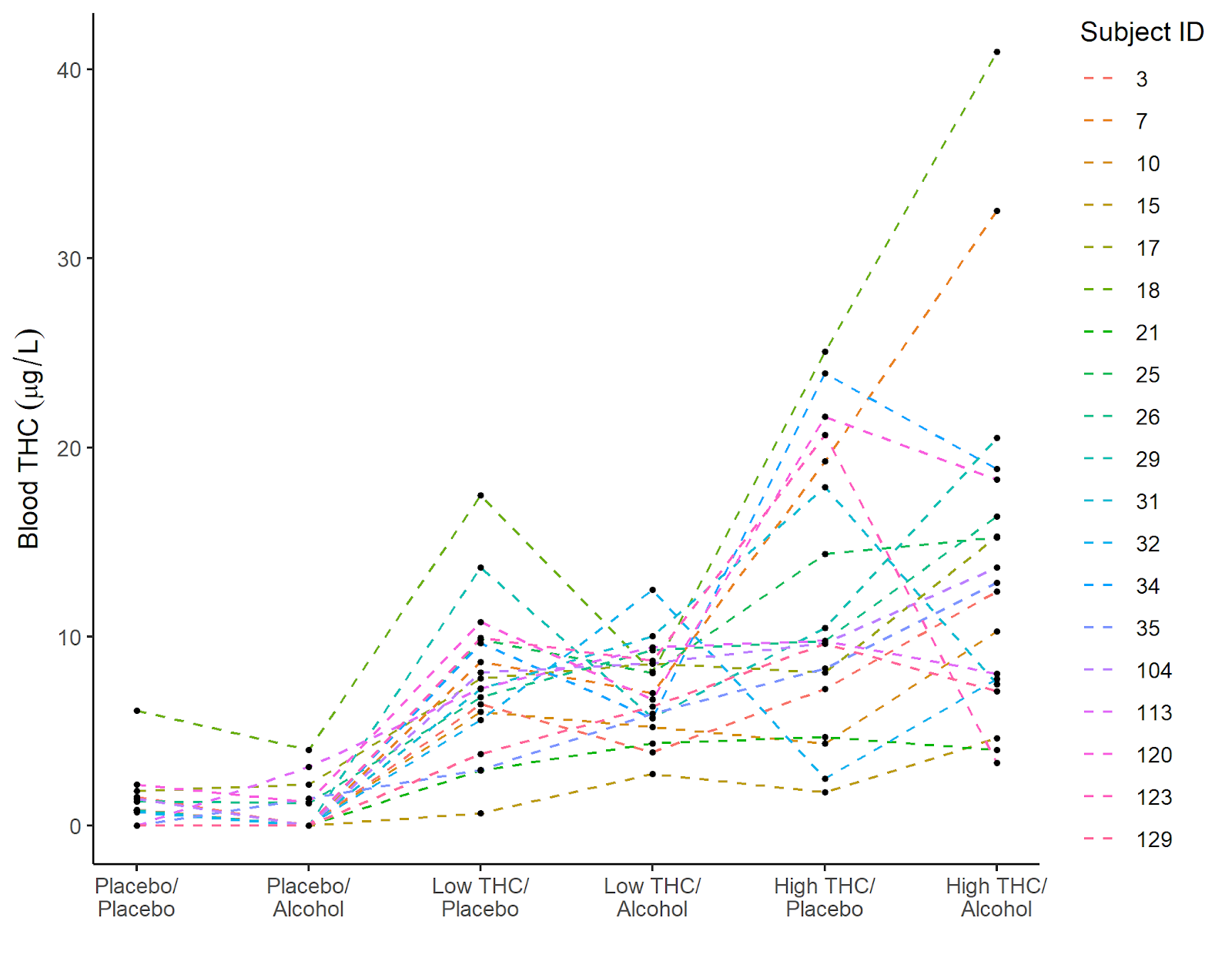
A final potential drawback in this study, as well as many other cannabis related studies, is that the potency of the cannabis administered is lower than is typically consumed by smokers (Ramaekers et al., (2006). Ramaekers et al. (2006) used cannabis containing 13% THC, a potency higher than what can be legally obtained for the research in the US. The US National Institute of Drug Abuse provides marijuana cigarettes which contain about 4% of THC (approximately 15-20mg THC). However, since the introduction of indoor hydroponic cultivation techniques the mean THC content of marijuana in the US and EU has risen from 5% to 10%, and concentrations up to 40% have been observed in hash oil (ElSohly, 2016; King et al, 2004, 2005).

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**Figures and Tables**

**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**: 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 | Total |
| Urban | THC | 0.92 | 0.71 | 7.94 | 7.20 | 12.1 | 14.0 | 7.24 |
| BAC | 0 | 0.059 | 0 | 0.052 | 0 | 0.048 | 0.026 |
| % complete | 88.3 | 89.7 | 95.1 | 87.1 | 88.9 | 86.9 | 89.4 |
| Time (sec) | 1.85 | 1.91 | 1.74 | 2.02 | 1.91 | 1.81 | 1.87 |
| SDLD | 0.149 | 0.105 | 0.134 | 0.162 | 0.118 | 0.142 | 0.135 |
| Speed | 28.5 | 29.3 | 29.5 | 29.5 | 27.6 | 28.3 | 28.8 |
| SDS | 0.190 | 0.255 | 0.248 | 0.302 | 0.281 | 0.227 | 0.251 |
| Interstate | THC | 0.888 | 0.638 | 6.07 | 5.62 | 9.36 | 10.5 | 5.574 |
| BAC | 0 | 0.057 | 0 | 0.052 | 0 | 0.049 | 0.026 |
| % complete | 95.5 | 94.7 | 97.9 | 97.9 | 92.6 | 98.0 | 96.1 |
| Time (sec) | 1.99 | 1.95 | 1.89 | 2.04 | 2.02 | 1.91 | 1.97 |
| SDLD | 0.448 | 0.58 | 0.475 | 0.51 | 0.646 | 0.626 | 0.548 |
| Speed | 63.4 | 65.0 | 64.8 | 62.6 | 61.7 | 61.9 | 63.2 |
| SDS | 0.253 | 0.282 | 0.247 | 0.344 | 0.291 | 0.312 | 0.289 |
| Rural | THC | 0.885 | 0.600 | 5.01 | 4.57 | 7.30 | 8.69 | 4.529 |
| BAC | 0 | 0.054 | 0 | 0.051 | 0 | 0.049 | 0.026 |
| % complete | 100 | 100 | 95.9 | 94.5 | 97.2 | 100 | 97.9 |
| Time (sec) | 1.73 | 1.65 | 1.67 | 1.76 | 1.75 | 1.67 | 1.70 |
| SDLD | 0.190 | 0.249 | 0.211 | 0.213 | 0.183 | 0.247 | 0.217 |
| Speed | 50.1 | 53.0 | 49.8 | 52.1 | 47.9 | 50.3 | 50.5 |
| SDS | 0.205 | 0.267 | 0.257 | 0.265 | 0.241 | 0.254 | 0.249 |

**Table 2**: 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 | Total |
| THC | 0.832 | 0.650 | 6.00 | 5.60 | 9.31 | 10.8 | 5.535 |
| BAC | 0 | 0.057 | 0 | 0.052 | 0 | 0.048 | 0.026 |
| % complete | 66.7 | 71.4 | 64.3 | 49.1 | 57.9 | 61.4 | 61.8 |
| % incorrect | 15.8 | 17.9 | 32.1 | 26.3 | 15.8 | 12.3 | 20.0 |
| time (sec) | 6.18 | 5.43 | 6.14 | 5.78 | 5.31 | 6.30 | 5.86 |
| SDLD | 0.761 | 0.851 | 0.877 | 0.810 | 0.652 | 0.781 | 0.791 |
| Speed | 66.6 | 64.9 | 67.1 | 61.9 | 62.1 | 61.0 | 64.1 |
| SDS | 0.453 | 0.709 | 0.706 | 0.609 | 0.572 | 0.765 | 0.637 |

**Table 3**: 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 | Total |
| Urban | Avg THC | 0.877 | 0.692 | 7.66 | 7.21 | 12.5 | 14.2 | 7.138 |
| Avg BAC | 0 | 0.059 | 0 | 0.052 | 0 | 0.048 | 0.027 |
| SDLD | 0.565 | 0.635 | 0.676 | 0.568 | 0.496 | 0.777 | 0.620 |
| Speed | 27.7 | 29.3 | 29.2 | 28.9 | 27.9 | 28.6 | 28.616 |
| SDS | 0.917 | 0.844 | 0.940 | 0.961 | 0.817 | 0.931 | 0.9025 |
| Interstate | Avg THC | 0.855 | 0.656 | 6.05 | 5.60 | 9.22 | 10.8 | 5.481 |
| Avg BAC | 0 | 0.057 | 0 | 0.051 | 0 | 0.049 | 0.027 |
| SDLD | 1.04 | 1.06 | 1.05 | 1.07 | 0.842 | 1 | 1.011 |
| Speed | 65.3 | 64.5 | 66.1 | 61.2 | 63.4 | 62.2 | 63.767 |
| SDS | 0.855 | 1.28 | 1.06 | 0.996 | 1.02 | 1.11 | 1.0566 |
| Rural | Avg THC | 0.782 | 0.573 | 4.91 | 4.59 | 8.09 | 8.78 | 4.5969 |
| Avg BAC | 0 | 0.054 | 0 | 0.516 | 0 | 0.048 | 0.026 |
| SDLD | 0.765 | 1.03 | 0.797 | 0.844 | 0.848 | 1.01 | 0.881 |
| Speed | 48.2 | 49.6 | 49.2 | 47.2 | 44.1 | 49.9 | 48.067 |
| SDS | 1.14 | 1.23 | 1.16 | 0.890 | 1.18 | 1.37 | 1.1602 |

**Table 4**: Models used to analyze performance on secondary tasks including coefficient estimates, odds ratios (OR) and p-values. GLMM indicates generalized linear mixed models using a binomial response, logit link, and subject specific random intercepts; GLM indicates ordinary logistic regression; LMM indicates linear mixed models with a Gaussian response, identity link, and subject specific random intercepts. Completion data for the message reading task was not available. AIC did not select an interaction between BAC and THC.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Task | Outcome | Model | BAC | | THC | |
| β, OR | p-value | β, OR | p-value |
| Artist | Completion | GLMM | -1.209, 0.299 | 0.802 | -0.052,  0.949 | 0.046 \* |
| Incorrect | GLM | -0.890, 0.411 | 0.858 | 0.04607, 1.047 | 0.041 \* |
| Side Mirror | Completion | GLMM | 1.496, 4.466 | 0.730 | 0.020, 1.020 | 0.385 |
| Time | LMM | -3.324 | 0.882 | -0.223 | 0.052 . |

**Table 5**: Models used to analyze baseline driving performance including coefficient estimates and p-values. All models were linear mixed models with a Gaussian response, identity link, and subject specific random intercepts. AIC did not select an interaction between BAC and THC.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Task | Outcome | BAC | | THC | |
|  | p-value |  | p-value |
| Side Mirror | SDLD | 0.625 | 0.041 \* | -0.000 | 0.651 |
| Speed | 16.289 | 0.007 \*\* | -0.085 | 0.340 |
| SDS | 0.559 | 0.049 \* | -0.000 | 0.997 |
| Artist | SDLD | 2.266 | 0.089 | 0.000 | 0.889 |
| Speed | -35.763 | 0.010 \* | -0.198 | 0.010 \* |
| SDS | 0.225 | 0.875 | -0.006 | 0.415 |
| Message | SDLD | -0.244 | 0.698 | 0.000 | 0.979 |
| Speed | 2.972 | 0.773 | -0.102 | 0.056 . |
| SDS | 0.878 | 0.267 | 0.001 | 0.802 |

**Table 6**: Models used to analyze baseline driving performance including intercepts, coefficient estimates, and p-values. LMM indicates linear mixed models with a Gaussian response, identity link, and subject specific random intercepts. LM indicates ordinary least squares regression. AIC did not select an interaction between BAC and THC.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Task | y | Model | Intercept | | BAC | | THC | |
|  | p-value |  | p-value |  | p-value |
| Side Mirror | Δ SDLD | LMM | 0.004 | 0.910 | -0.222 | 0.648 | -0.000 | 0.996 |
| Δ Speed | LMM | -0.016 | 0.908 | 1.407 | 0.178 | -0.011 | 0.023 \* |
| Δ SDS | LMM | 0.004 | 0.806 | -0.085 | 0.743 | 0.000 | 0.533 |
| Artist | Δ SDLD | LM | -0.088 | 0.872 | -0.562 | 0.772 | -0.013 | 0.206 |
| Δ Speed | LM | -1.432 | 0.455 | 4.287 | 0.529 | -0.000 | 0.999 |
| Δ SDS | LM | -0.261 | 0.548 | -0.622 | 0.688 | 0.007 | 0.383 |
| Message | Δ SDLD | LMM | -0.137 | 0.168 | 2.012 | 0.011 \* | -0.000 | 0.959 |
| Δ Speed | LMM | -2.278 | <0.001\*\*\* | -2.506 | 0.515 | 0.042 | 0.026 \* |
| Δ SDS | LMM | 0.011 | 0.917 | -0.718 | 0.599 | 0.009 | 0.186 |

**Table 7**: Lane departures by secondary task.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Task | Participant ID | Dose | Period | THC | BAC | Lane Departure  (% of Period) |
| Artist | 15 | Low/  Alcohol | Task | 2.12 | 0.032 | 9.60 |
| 21 | High/  Placebo | Task | 3.79 | 0 | 28.36 |
| 34 | Placebo/  Placebo | Task | 0 | 0 | 13.66 |
| 35 | Low/  Placebo | Task | 2.50 | 0 | 17.41 |
| 129 | High/  Alcohol | Task | 5.47 | 0.041 | 17.63 |
| 129 | High/  Alcohol | Task | 5.47 | 0.041 | 23.58 |
| Side Mirror | 129 | High/  Alcohol | Task | 4.53 | 0.041 | 48.54 |
| Message Reading | 21 | High/  Alcohol | Task | 2.17 | 0.061 | 29.67 |
| 25 | Low/  Placebo | Task | 7.90 | 0 | 2.33 |
| 31 | High/  Alcohol | Task | 5.68 | 0.042 | 6.17 |
| 129 | High/  Alcohol | Task | 4.52 | 0.032 | 17.83 |