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Sex Differences in the Effects of Marijuana on Simulated Driving Performance[†]

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Abstract

In the United States, one in six teenagers has driven under the influence of marijuana. Driving under the influence of marijuana and alcohol is equally prevalent, despite the fact that marijuana use is less common than alcohol use. Much of the research examining the effects of marijuana on driving performance was conducted in the 1970s and led to equivocal findings. During that time, few studies included women and driving simulators were rudimentary. Further, the potency of marijuana commonly used recreationally has increased. This study examined sex differences in the acute effects of marijuana on driving performance using a realistic, validated driving simulator. Eighty-five subjects (n = 50 males, 35 females) participated in this between-subjects, double-blind, placebo controlled study. In addition to an uneventful, baseline segment of driving, participants were challenged with collision avoidance and distracted driving scenarios. Under the influence of marijuana, participants decreased their speed and failed to show expected practice effects during a distracted drive. No differences were found during the baseline driving segment or collision avoidance scenarios. No differences attributable to sex were observed. This study enhances the current literature by identifying distracted driving and the integration of prior experience as particularly problematic under the influence of marijuana.

Keywords

acute effects; cannabis; cognition; driving; marijuana

Despite its illegal status, marijuana (*Cannabis sativa*) is commonly used in the United States. Over one-fourth of individuals aged 18 to 25 reported using marijuana in the previous year (US DHHS 2007) and approximately 50% of users smoke marijuana while driving or drive under its influence (Johnson & White 1989). Subjective and behavioral effects of marijuana begin within minutes and last at least two hours (Curran et al. 2002; Barnett, Licko & Thompson 1985). The common effects include euphoria,

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depersonalization, altered time sense, lethargy, and drowsiness (Hollister 1986). Studies examining the effects of acute marijuana use on driving in both simulated and on-road settings have shown that acute marijuana use negatively impacts a driver's ability to successfully complete driving tasks. The impacts are subtle, however, and not always replicated in studies (Ronen et al. 2008; Menetrey et al. 2005; Ogden & Moskowitz 2004; Lamers & Ramaekers 2001; NHTSA 2000, [1999]; Ramaekers, Robbe & O'Hanlon 2000; Sexton et al. 2000; Robbe & O'Hanlon 1999; Liguori, Gatto & Robinson 1998; Berghaus, Scheer & Schmidt 1995; Peck et al. 1986; Smiley, Noy & Tostowaryk 1986; Moskowitz 1985; Stein et al. 1983; Sutton 1983; Attwood et al. 1981; Casswell 1977; Hansteen et al. 1976; Moskowitz, Hulbert & McGlothlin 1976; Klonoff 1974; Kielholz et al. 1973; Rafaelsen, Bech & Rafaelsen 1973; Retterstol 1973; Gostomzyk, Gewecke & Eisele 1971; Kalant & Crancer 1969).

Since the inception of the National Institutes of Health's policy mandating the inclusion of women in clinical research studies (Wetherington 2007), sex differences have been found for drugs such as alcohol, cocaine, and nicotine (Wiren et al. 2006; Fallon et al. 2005; Mann et al. 2005; Daurignac et al. 2001; Shiffman & Paton 1999). Little work has been performed exploring sex differences in the effects of marijuana. Despite strong theoretical evidence of sex differences (for a review, see Anderson et al. Submitted), a meta-analysis of driving and marijuana found fewer than 25% of studies included women in their analyses (Berghaus, Scheer & Schmidt 1995).

Because driving deficits due to marijuana have been difficult to replicate and so few women have been included in such studies, we hypothesized that driving impairment following marijuana use may be a sex-specific vulnerability. This study examined a large sample of occasional marijuana users of both sexes (n = 50 males, 35 females) in a between-subjects, double-blinded placebo control study of simulated driving performance using a realistic off-road driving simulator. The driving paradigm is well validated to identify impaired driving in neurological conditions such as Alzheimer's and Parkinson's diseases (Uc et al. 2006; Rizzo, Jermeland & Severson 2002). It evaluates a variety of paradigms such as speed and steering control and variability, avoidance of obstacles, decision making, and distraction. Specifically, we hypothesized that women would show an increased variability in steering and speed control while under the influence of marijuana, and that this difference would not be evident in men.

Methods

Subjects

A total of eighty-five (85) occasional marijuana smokers [n = 50 males, 35 females; 18 to 31 years of age; mean age = 20.5 years (SD 2.7)] were recruited from the Iowa City, Iowa area through word of mouth, fliers, and local newspaper advertisements from 2004-2006. Attempts were made to recruit equal numbers of men and women, however, fewer women expressed interest in participating in the study. Ads were placed specifically recruiting women and participants were encouraged to inform their female friends of the need for participants. A brief phone screen was performed. Participants were required to be occasional users of marijuana, defined as those who reported their current marijuana use as at least once per month but no more frequently than ten times per month. Drug-naïve participants were not recruited due to ethical issues. Participants were excluded if they met criteria for current or past alcohol dependence or reported use of the following drugs more than five times or within the prior three months: methamphetamine, cocaine, opiates, Ecstasy, mushrooms, sleeping pills, or any injected or inhaled drug of abuse. They were also excluded if they reported a current neurological or psychiatric diagnosis or history of traumatic brain injury, significant medical problems such as diabetes, heart disease, or

respiratory disorders, or if they were taking prescription medications other than birth control or acne medication. Specifically, any participants taking stimulants, antidepressants or anti-anxiety medications were excluded. Finally, they were required to have normal or corrected to normal vision as verified during baseline testing.

The study had a between-subject, double-blinded, placebo-controlled design. Qualifying participants were asked to abstain from marijuana use for one week prior to the visit to minimize the impact of residual drug effects on performance. This study was approved by the University of Iowa Institutional Review Board and informed consent was obtained prior to participation in the study. See Figure 1 for a flow of the study and average time for each section. A urine drug screen (TRIAGE Drugs of Abuse Panel Kit) was administered to all participants to test for THC and six other drugs of abuse (phencyclidine, benzodiazepines, cocaine, amphetamines, opiates, and barbiturates). Participants were excluded if any drugs other than THC were detected in their urine. Positive THC tests were found in 14% of the females and 32% of the male participants. One male participant was excluded from the study for having a positive result for cocaine. Female participants were also required to have a negative urine pregnancy test prior to participation in the study; no participants were excluded due to pregnancy.

Baseline measures of vision, heart rate, blood pressure, height, and weight were obtained. Visual assessment of far letter acuity was obtained in each eye using the Early Treatment for Diabetic Retinopathy Study chart (Ferris et al. 1982). Near letter acuity was assessed for each eye with a Snellen Eye Chart. Contrast sensitivity was assessed in each eye using the Pelli-Robson chart (Pelli, Robson & Wilkins 1988). Previous research has found letter acuity and contrast sensitivity to be unaltered following marijuana smoking, thus they were assessed only prior to smoking (Adams et al. 1975). No participants were excluded due to letter acuity or contrast sensitivity. Baseline cognitive assessment included Matrix Reasoning from the Wechsler Adult Intelligence Scale – III (Wechsler 1997) and the American National Adult Reading Test (ANART) (Grober & Sliwinski 1991), both of which were used to compute estimated intelligence scores.

Additional assessments were completed to establish criteria that participants had to meet prior to discharge from the study site after smoking marijuana. This assessment checked participants' orientation to time, date, and location. It evaluated the presence of paranoia, delusions, and hallucinations. Measures of subjective “highness” were also obtained. For this, participants were asked to evaluate how “high” they felt on a zero to ten scale with zero being no effect and ten being the highest they have ever felt after smoking marijuana. Participants completed this highness scale at baseline (time = -10 minutes), immediately after smoking (time = 0 minutes), immediately after completing the simulated drive (time = ~30 minutes), immediately after neuropsychological testing (time = ~90 minutes) and prior to study discharge (time = ~120 minutes). Heart rate was evaluated at similar time points to provide an objective measure of marijuana's effect. To address potential confounds of fatigue or sleepiness, all participants completed the Stanford Sleepiness Scale (Hoddes et al. 1973) at similar time points to the highness scale and heart rate measures. Participants were not told the criteria for study discharge: a subjective “highness” rating of 3 or less. Heart rate was utilized as a secondary, objective measure of highness and was required to be within ten beats of baseline. This discharge criterion was chosen based on standards previously utilized in our laboratory.

Smoking Session

After completion of baseline testing, participants were escorted to the General Clinical Research Center (GCRC) “Environmental Chamber,” a stainless steel cage with controlled airflow venting to the outside of the hospital. The experimenter sat outside the chamber and

communicated with the participant through a glass partition and a two-way intercom system. Participants were informed they would be receiving “one of two possible doses of marijuana.” The cigarettes, provided by the National Institute of Drug Abuse, were administered in a within-sex randomized, double-blinded placebo controlled design and contained either approximately 0% delta-9-tetrahydrocannabinol (THC) (placebo) or 2.9% delta-9-THC (active) doses of marijuana. Both active and placebo cigarettes were 85 mm length and 25 mm in circumference. The average weight was 0.790 grams equating to approximately 0 mg THC in the placebo condition (because it was marijuana with the THC removed, trace amounts may still be present) and 22.9 mg THC in the active cigarette.

Cigarettes were stored in a locked refrigerator in the hospital pharmacy prior to use to retain their potency. Approximately twenty-four hours before use, the cigarette was removed from storage and humidified with a saline solution. Cigarettes were administered via a paced smoking paradigm, according to procedures routinely utilized by our laboratory (Block, Farinpour & Braverman 1992). During this paced smoking paradigm participants were instructed to inhale for three seconds, hold their breath for five seconds, and were then given twenty-seven seconds between inhalations to rest. The experimenter timed the protocol and instructed the participants for each puff. Participants were asked to continue this inhalation procedure until the cigarette was consumed. The number of puffs and the time taken to finish the cigarette were recorded. To ensure subject safety, heart rate was monitored during the smoking paradigm and smoking was discontinued if the heart rate exceeded 150 beats per minute. One person was instructed to stop smoking due to a high heart rate; however, he chose to complete the remaining cigarette puff. Several participants expressed concern about the size of the marijuana cigarette. They were encouraged to consume the entire cigarette but reminded they could discontinue from a section of the study if they began to feel uncomfortable. One male and eight females chose to discontinue smoking before completing the entire cigarette. Behavioral data were collected on these participants but they were not used in the final analyses.

Driving Assessment

After the smoking session, participants were taken to the Simulator for Interdisciplinary Research in Ergonomics and Neurosciences (SIREN) where driving performance was assessed. (A more detailed description of the simulator can be found in Rizzo, McGehee & Jermeland 2000.) Briefly, the simulator consists of a 150-degree forward and 50-degree rear field of views. The simulation was constructed with Drive Safety Technologies (Salt Lake City, Utah) software and included independent scenario vehicles that exhibited naturalistic behaviors. Three-dimensional audio output included engine noise, wind, tire squeal, and Doppler effects of passing vehicles. Both digital and video data streams were recorded to allow inspection of artifacts and review of driver safety errors including behavior in the moments preceding a crash.

Each subject drove for approximately fifteen minutes on a simulated rural two-lane highway with a speed limit of 55 miles per hour and interactive traffic, resembling a drive on the roads surrounding Iowa City. Prior to beginning the experiment, each driver was familiarized with the SIREN simulator. Participants were given approximately one minute of driving to adjust to the vehicle's handling (0.62 miles). Microphones within the car allowed the operator to monitor onboard activity, answer questions as needed, and start and stop the simulation on demand. The test portion of the simulation consisted of “events” associated with potential crashes interspersed with uneventful highway segments. The events were chosen to evaluate performance in a realistic setting while taxing cognitive skills known to be affected by acute marijuana use. A baseline section of driving lasting 60 seconds was collected following the multitasking event. Because participants drove at

varying speeds, the actual time between events varied; distances between events are provided. The events were as follows:

Multitasking—For this event we tested the effects of a secondary (distracter) task which has the potential to divide a driver's attention from the road and thereby degrade driving performance. The driver was familiarized with and completed the task during baseline cognitive testing, prior to smoking. For this task, participants were administered the Paced Auditory Serial-Addition Test [PASAT (Sherman, Strauss & Spellacy 1997)] with a 2.4 second inter-stimulus interval. The distracter task lasted 110 seconds and occurred during an otherwise uneventful segment of the drive. Behavioral performance and effects of the task on driver performance were assessed to provide an index of multitasking (divided attention) during driving (Rizzo et al. 2005 b). Scores obtained during the predriving baseline were also compared with scores obtained during the drive. The dependent measures were the difference in number of math errors made while driving compared to a nondriving baseline, mean and standard deviation of the speed, and mean and standard deviation of the steering wheel position.

Go/No-Go—For this event, the driver approached a traffic light that changed from green to yellow. The onset of the yellow light was controlled to manipulate the appropriate response (i.e., stop when there is adequate time to do so versus proceed because there is inadequate opportunity to stop safely). This task aimed to assess executive function (decision making) and attention to traffic signs. The dependent measure was safe driving through the yellow light (i.e., no hesitation in making a decision and clearing the intersection while the light was still yellow).

Response to emergency vehicle—After 500 feet of uneventful driving, subjects came upon a police car pulled off on the right-hand side of the road. This task assessed attention (noticing the vehicles), perception of time and distance to contact, and decision making (whether to veer into the left lane or slow down while passing the patrol car) (Rizzo et al. 2005a). The dependent measures were mean speed, steering position, time to reaction and type of reaction.

Dog incursion avoidance—After 200 feet of further uneventful driving, a dog appeared from behind a bush near a farmhouse. The animal proceeded directly across the road. Participants had very little time (4.4 seconds) to formulate a plan in an attempt to avoid hitting the dog (e.g., brake, steer, or do nothing). The dependent measures were speed at first contact and avoidance tactic. Safe avoidance was defined as the ability to stop or steer clear of the obstacle while maintaining control of the vehicle. Unsafe avoidance involved hitting the obstacle or veering into a ditch.

Intersection incursion avoidance—After another short segment of uneventful driving, the driver approached a final intersection with a vehicle stopped at the intersection on the subject's right side. Approach by the subject to within 4.1 seconds of the intersection triggered this second vehicle to illegally enter the intersection. The dependent measures were speed at first contact and avoidance tactic.

Immediately following the simulated drive, participants were asked to complete a questionnaire evaluating the presence of Simulator Adaptation Syndrome symptoms, a collection of uncomfortable symptoms similar to motion sickness associated with virtual environments (Rizzo et al. 2003). Following completion of the driving simulator task, approximately 30 minutes after completion of smoking, participants took part in standardized “off-road” neuropsychological tests aimed at cognitive functions essential to driving. Analyses of these tests are beyond the scope of this paper. Vital signs were recorded

as were sleepiness and highness. Following the cognitive assessment, participants returned to the General Clinical Research Center for further monitoring. Baseline orientation measures (date, time, and location) and presence of psychosis were again assessed. Vital signs were again recorded as were sleepiness and highness. Participants were provided a meal and asked to remain at the research center for further monitoring. Upon meeting criteria for discharge, participants were provided with a voucher for cab fare and returned home. For their safety, they were asked to remain at home and specifically not to drive for the remainder of the day.

Statistical Analyses

A two group (groups: placebo and active THC) by two sex (sex: male and female) analysis of variance (ANOVA) was conducted on demographic variables including age, education, estimated intelligence, prior driving and video game experience, and the Dula Dangerous Driving Index (DDDI) (Dula 2003). These tests were all conducted prior to the smoking session. A similar 2 × 2 ANOVA was used to evaluate the presence of simulator adaptation syndrome variables: headache, eyestrain, nervousness, boredom, sleepiness, dizziness, light-headedness, increased body temperature, nausea and motivation. Repeated measures analyses of variance were used to evaluate the effects of marijuana versus placebo smoking on subjective highness, heart rate, and Stanford Sleepiness Scale scores. Baseline measures of driver performance were calculated for the uneventful segment of the drive and included the means and standard deviations of speed and degrees of steering. The means and standard deviations of speed and steering were calculated and analyzed for the PASAT, emergency response vehicle, and eventful driving segments. The dog and intersection incursions were evaluated for the percentage of participants colliding, the speed at which the participant collided with the object, and the tactic used in an attempt to avoid the crash. All analyses were conducted with a 2 × 2 multivariate analysis of variance (MANOVA) using the two doses (placebo and active marijuana) and two sexes (male and female). A mixed model repeated measures ANOVA was used to examine PASAT performance with the within-subject factors being time of test (time: pre and post smoking) and between subjects factors being dose (placebo and active marijuana) and sex (male and female).

Results

As can be seen in Table 1, baseline testing showed no significant between-group differences in age or estimated intelligence. Despite attempts to match groups based on age, education and prior driving experience, women had an additional year of education ($F = 9.1$, $p = < 0.01$) and driving experience ($F = 6.2$, $p = 0.02$) compared to men. Although not statistically different, the increased age in women likely accounted for these differences ($F = 3.7$, $p = 0.06$). All analyses were conducted with the entire group of participants that completed the cigarettes and an age matched subsample; results did not differ. Not surprisingly, men weighed significantly more ($F = 9.3$, $p < 0.01$), reported consuming more alcoholic beverages per week ($F = 4.0$, $p = 0.05$) and spent more time playing video games ($F = 3.8$, $p = 0.05$) than women. Using the Dula Dangerous Driver Index, men rated themselves as having a more risky driving style in everyday life than women ($F = 4.5$, $p = 0.04$).

A sex difference was evident in the number of participants willing to complete the entire cigarette; 96% of men completed the active cigarette, while only 55.6% of the women did so; all males completed the placebo cigarette while one woman (5.9%) did not complete the placebo cigarette. Twenty-five percent of men and twenty percent of the women who received and completed the active marijuana cigarette reported a highness rating of 5 or less. Although no significant differences in highness or heart rate were found for those who completed the cigarette versus those who did not, behavioral findings were attenuated by inclusion of all participants. While this did eliminate more women than men, only results

from participants who completed the entire cigarette (n = 73) are reported in the remaining analyses.

As expected, highness ratings increased immediately after smoking the active cigarette and declined throughout the test session. Immediately following smoking, both male and female participants who received the active marijuana cigarette rated themselves as significantly higher [male M = 6.4 (SD 1.7); female M = 7.2 (SD 1.8)] than those who received the placebo [male M = 2.6 (SD 2.3); female M = 3.5 (SD 1.5); F = 65.1, $p < 0.001$]. Immediately after driving, in addition to the dose-related effect in which active marijuana [male M = 5.7 (SD 1.5); female M = 7.4 (SD 1.1)] was rated as significantly higher than placebo [male M = 2.0 (SD 2.0); female M = 2.9 (SD 1.8); F = 84.8, $p < 0.001$], a sex difference was observed for highness ratings in which women rated themselves as higher than men for both active marijuana and placebo [F = 4.6, $p = 0.04$ and F = 9.0, $p < 0.005$]. No sex by drug interaction was evident. A similar, expected, increase in heart rate following the active marijuana cigarette [male M = 113.5 (SD 24.8); female M = 115.5 (SD 21.3)] was seen for both sexes when compared to the placebo [male M = 75.3 (SD 13.5); female M = 78.3 (SD 11.2); F = 66.4, $p < 0.001$]. The statistical difference in heart rate was still evident after driving [active marijuana: male M = 95.7 (SD 20.2); female M = 93.9 (SD 14.6); placebo: male M = 68.5 (SD 10.9); female M = 70.8 (SD 7.0); F = 47.2, $p < 0.001$]. No sex differences or interactions of sex and drug were noted. Subjective ratings of sleepiness based on the Stanford Sleepiness Scale increased significantly in participants receiving the active cigarette, but not the placebo cigarette. This increase was not evident immediately after smoking [active marijuana: male M = 3.0 (SD 1.0); female M = 2.7 (SD 1.1); placebo: male M = 2.5 (SD 1.0); female M = 2.8 (SD 0.8); F = 0.5, $p = 0.5$] but was evident after driving [active marijuana: male M = 3.1 (SD 1.1); female M = 3.6 (SD 0.9); placebo: male M = 2.2 (SD 1.1); female M = 3.1 (SD 1.1); F = 6.0, $p < 0.02$]. There was a significant sex difference after driving, with males being less sleepy than females [$F(1,71) = 4.6$, $p < 0.04$]. No drug × sex interaction was evident in sleepiness. No significant difference in motivation levels were reported between the sexes or for groups receiving the placebo [male M = 5.5 (SD 1.4); female M = 6.3 (SD 0.9)] or active cigarettes [male M = 5.7 (SD 1.6); female M = 5.8 (SD 1.6); F = 0.94, $p = 0.43$]. Marijuana did not appear to protect against simulator adaptation syndrome (data not shown) and two female participants (one who received active marijuana and one who received a placebo) did become nauseated from the simulator.

As shown in Table 2, participants receiving the active and placebo cigarettes performed similarly on the baseline “uneventful” segment of the driving task and no sex differences were observed. No group differences were seen in the means or standard deviations of the mean speed or steering wheel position. During the “eventful” segments of driving, a within-subjects comparison of PASAT performance prior to smoking and during driving showed a trend in the interaction between placebo vs. active marijuana and practice vs. driving PASAT performance [F = 3.36, $p = 0.07$)]. Persons smoking the placebo cigarette showed an improvement in performance of the PASAT during the driving task, likely attributable to practice effects. Under the influence of marijuana, however, no differences were found between PASAT performance during practice testing and while driving. Participants who smoked active marijuana decreased their speed during this section of the drive, suggesting additional compensatory skills were used. While women performed significantly worse than men on the PASAT during both practice and driving administrations, no sex differences were observed in respect to driving performance or practice effects. No differences during the PASAT were seen in the standard deviation of speed, the mean steering wheel position or the standard deviation of the steering wheel position, suggesting the decrease in speed allowed participants to successfully compensate for the effects of marijuana. All participants safely went through the Go/No-Go task intersection while the light was yellow. No group differences in speed, steering position, time to first reaction or type of reaction were

observed in response to passing the emergency vehicle. The frequency of dog and car incursions and the tactics used to avoid collisions were similar between groups, as was the mean speed of impact for those colliding. No sex differences or interactions of sex and drug were observed.

Because of the significant increase in Stanford Sleepiness Scale scores for those receiving the active marijuana cigarettes, follow-up Multivariate Analyses of Variance (MANOVA) were performed controlling for the rating of sleepiness after driving. No differences were seen in the mean speed during the baseline segment of driving [$F = 1.77$, $p = 0.14$], during the distracted driving section [$F = 2.23$, $p = 0.08$] or while passing the emergency response vehicle [$F = 1.43$, $p = 0.20$]. No significant effects were seen for speed at which participants collided with the dog and/or intersection incursion vehicle.

Discussion

This study investigated sex differences in the effects of acute marijuana use on driving performance. Eighty-five participants (N = 50 men; N = 35 women) were randomly assigned to smoke either an active or placebo marijuana cigarette in a double-blind between-subjects design. Participants then completed a simulated drive lasting approximately fifteen minutes and an additional hour of neuropsychological testing. No sex differences or interactions of sex and marijuana were observed for any of the driving tasks. Participants receiving active marijuana decreased their speed more so than those receiving the placebo cigarette during a distracted section of the drive. An overall effect of marijuana was seen for the mean speed during the distracted driving (PASAT section). While no other changes in driving performance were found, marijuana appeared to hinder practice effects on the PASAT task, suggesting individuals may not be able to adequately use information and experience previously acquired while under the influence of marijuana. While only minimal differences in driving performance were found, this failure to benefit from prior practice may be detrimental to driving performance. Research has shown that graduated driver's licensing programs in which participants receive more on the road training results in a decrease in fatal crashes in 16-year-olds (Baker, Chen & Li 2006). If marijuana indeed impairs one's ability to use prior experience to improve performance, this will likely impair driving under pretrained conditions (e.g., steering into a skid, allowing increased stopping time on slippery roads, etc).

The present study's subtle finding of decreased speed under the influence of acute marijuana is generally consistent with the literature, which has found that marijuana's effects on driving can be subtle. In Berghaus's review of the literature prior to 1995, 45% of driving simulator studies showed no impairment from marijuana within the first hour after use (Berghaus, Scheer & Schmidt 1995). More cautious driving behaviors were found in several studies (Lamers & Ramaekers 2001; Stein et al. 1983; Ellingstad, McFarling & Struckman 1973; Rafaelsen, Bech & Rafaelsen 1973; Dott 1972), while an increased reaction time for stopping was the most common finding (Liguori, Gatto & Robinson 1998; Rafaelsen, Bech & Rafaelsen 1973). Moskowitz (Ziedman and Sharma 1976) also found slowed reaction times for a visual choice-reaction time task administered while driving and Smiley, Moskowitz and Zeidman (1981) found increased variability in velocity and lateral position while following curves and while controlling the car in gusts of wind with a high dose of marijuana (200 mcg/kg THC) but not with a lower dose (100 mcg/kg THC). They also found an increase in variability of headway and lateral position while following other cars.

The decreased speed during the simulated drive could be interpreted as an attempt to compensate for perceived cognitive impairment. Alternatively, marijuana may not have affected decision making and judgment and the reduction in speed would improve safety

margins. While the clinical significance of a 3% to 5% decrease in speed may be questioned, previous research suggests such a decrease will result in approximately a 7% decrease in all injuries and a 15% decrease in fatalities (Nilsson 1981). Use of an alternate task design in which subjects are requested to drive as quickly and as safely as possible rather than following a posted speed limit may provide more insight into compensatory strategies employed while driving under the influence of marijuana. Use of a more challenging road paradigm (e.g., icy or gravel roads) which capitalizes on the use of practice effects may aid in identifying differences in driving performance under the influence of marijuana. There was significant between-subject variability in driving measures and future studies would be further strengthened by using a within-subjects design.

Doses administered were standard National Institute of Drug Abuse cigarettes and not adjusted by subject's weight. As expected, men weighed significantly more than women although there was not a significant sex difference in body mass index. Results may be further strengthened by using weight-adjusted doses. This would also increase the likelihood that participants are comfortable smoking the entire active cigarette. To ensure consistency in the doses administered, findings from only the 75 participants who completely smoked the cigarettes are presented here. Twenty-five percent of men and twenty percent of the women who received and completed the active marijuana cigarette reported a highness rating of 5 or less. It is possible that the 20% to 25% of participants who did not reach their average level of highness attenuated behavioral findings, similar to the increase in errors that is observed in driving performance as breath alcohol concentrations (BAC) increase (Moskowitz & Fiorentino 2000). While no differences were observed in duration or frequency in which participants reported using marijuana, the percentage of men testing positive for THC at the time of the study was higher than that of women, which suggests men had more recent experience with marijuana.

While this study was not adequately powered to further divide participants based on highness ratings, an exploratory analysis using highness ratings after the drive for participants completing the active cigarette demonstrated the number of mathematical errors made during the PASAT test was positively correlated with highness ratings ($R = 0.52$, $p < 0.01$, $N = 32$). However, driving performance was not correlated with highness. A similar correlation was *not* found for individuals receiving the placebo cigarette ($R = 0.02$, $p = 0.92$, $n = 41$) further implicating cognitive impairment following marijuana smoking. Because the simulated drive always occurred immediately after smoking when participants subjectively reported the most impairment from the marijuana, the time of the driving assessment post-drug administration was likely not a factor contributing to the limited findings. In this study, it appears participants were able to compensate for driving but not cognitive impairments following marijuana use.

It can be argued that the PASAT is not a realistic and generalizable proxy measure for cognitive resources used during an interactive conversation or talking on the telephone. The PASAT is often used to provide an estimate of the amount of information that can be handled at one time (Gronwall 1977). Others consider the PASAT as a measure of some central information-processing components similar to that seen in reaction-time and divided-attention tasks (Ponsford & Kinsella 1992; Stuss et al. 1989). Some believe the PASAT is just as much a test of mathematical ability as it is of attention (Sherman, Strauss & Spellacy 1997). The PASAT relies on auditory-verbal and working-memory, sustained attention, and executive function, making it very different than demands required for uneventful highway driving which might rely on overlearned, automatic cognitive processes (Rizzo et al. 2005 **[b]**). The failure to achieve a correlation between highness and mathematical errors on the PASAT in the placebo group may reflect the restricted range of highness responses in the placebo group.

It should further be noted that seldom is marijuana the only drug being used while driving. Often marijuana is combined with alcohol; this combination has consistently been shown to impair driving and results from this study do not imply that it is safe to drive under the influence of marijuana (NHTSA 2000; Ramaekers, Robbe & O'Hanlon 2000; Robbe 1998; Peck et al. 1986; Smiley, Noy & Tostowaryk 1986). Further, the finding that cognitive impairment during the PASAT section of the drive was positively correlated with highness ratings suggests marijuana does have a negative impact on brain function which may impact other driving abilities not tested, such as dealing with heavy traffic conditions, altered weather, or city driving.

Summary and Conclusions

This study assessed sex differences in the effects of acute marijuana use on driving performance in a double-blinded, placebo controlled, between-subjects design. Under the influence of active marijuana, participants exhibited increased drowsiness, although this did not appear to affect their driving. Participants under the influence of marijuana failed to benefit from prior experience on a distracter task as evidenced by a decrease in speed and a failure to show expected practice effects. This study supports the existing literature that marijuana does affect simulated driving performance, particularly on complex tasks such as divided attention. It is anticipated that many teenagers and young adults driving under the influence of marijuana are doing so while conversing with friends in the car, listening to music, talking on the cell phone and/or text messaging others. These behaviors divide the driver's attention and are particularly dangerous under the influence of marijuana.

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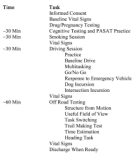

FIGURE 1. Flow of Tasks for Each Participant

FIGURE 2. View of the Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN Cab and Front Screens

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TABLE 1

Demographic and Baseline Testing

Task	Placebo		Active THC		Overall F	Sex F	THC F	Sex × THC F
	Males (n = 25)	Females (n = 15)	Males (n = 24)	Females (n = 9)				
Age	19.8 (2.1)	21.0 (2.6)	20.2 (2.6)	21.4 (3.6)	0.25	0.06	0.49	0.97
Education	12.8 (1.3)	14.1 (2.0)	13.1 (1.3)	13.8 (1.5)	0.03*	< 0.01*	0.95	0.44
Weight (kg)	76.7 (10.1)	71.1 (14.0)	80.1 (10.1)	68.7 (17.2)	**0.02***	< **0.01***	0.87	0.30
Body Mass Index (BMI)	23.8 (2.6)	25.1 (5.0)	24.4 (2.9)	25.7 (6.1)	0.50	0.17	0.52	0.99
Handedness (% Right Handed)	84.0%	82.4%	92.0%	83.3%				
Frequency of Marijuana Use (Times per Month)	4.6 (2.8)	4.5 (2.9)	4.9 (2.8)	4.1 (3.0)	0.85	0.50	0.91	0.60
Duration of Marijuana Use (# of Months)	27.5 (19.2)	34.3 (27.7)	33.8 (19.6)	38.2 (25.9)	0.53	0.29	0.34	0.82
Alcohol Use (Drinks per Week)	11.0 (6.3)	7.4 (8.7)	12.6 (8.1)	9.1 (7.4)	0.19	**0.05***	0.34	0.97
ANART Estimated IQ	114.9 (5.1)	115.3 (5.6)	114.8 (4.2)	113.9 (4.0)	0.87	0.81	0.51	0.58
Matrix Reasoning Scaled Score	12.4 (2.1)	12.4 (2.7)	11.8 (1.9)	12.6 (2.2)	0.68	0.48	0.68	0.43
Time Spent Playing Video Games in Hours per Week	2.2 (2.9)	1.8 (2.8)	2.6 (2.3)	0.9 (1.4)	0.15	**0.05***	0.64	0.24
Driving Experience (Years)	3.7 (1.9)	4.7 (2.8)	3.8 (2.0)	5.8 (3.8)	0.06	**0.02***	0.32	0.46
Estimated Miles Driven per Week	4755 (5018)	6711 (5914)	5031 (6579)	3343 (4710)	0.42	0.92	0.23	0.16
Dula Dangerous Driver Index								
Negative Emotions	19.9 (3.5)	22.1 (4.0)	22.9 (5.5)	22.0 (6.3)	0.34	0.59	0.21	0.16
Aggressive Driving	12.5 (3.2)	10.1 (2.8)	12.1 (4.6)	13.2 (5.3)	0.15	0.51	0.14	0.06
Risky Driving	24.2 (4.6)	17.0 (4.6)	21.2 (5.6)	23.5 (5.7)	< **0.01***	**0.04***	0.13	< **0.01***
Dula Total Score	58.8 (8.5)	47.1 (9.9)	55.3 (15.0)	59.7 (15.0)	**0.01***	0.19	0.11	< **0.01***

ANART = Adult North American Reading Test

*Statistically significant at $p < 0.05$.

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TABLE 2

Driving Performance after Smoking

Task	Placebo		Active THC		Overall F	Sex	THC	Sex by THC
	Males (n = 25)	Females (n = 15)	Males (n = 24)	Females (n = 9)				
Uneventful Driving								
Mean Speed in MPH	60.1 (6.0)	57.7 (5.9)	58.2 (4.2)	59.7 (6.3)	0.49	0.77	0.96	0.18
SD of Mean Speed in MPH	1.8 (1.2)	1.9 (0.7)	1.7 (0.9)	1.6 (1.9)	0.85	0.92	0.39	0.63
Steering Wheel Position	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	0.72	0.86	0.75	0.39
SD Steering Wheel Position	1.3 (1.3)	1.3 (0.5)	1.3 (0.5)	1.4 (0.5)	0.95	0.77	0.58	0.75
PASAT								
PASAT Errors Before Smoking and Driving**	13.2 (6.7)	16.5 (7.7)	11.7 (6.5)	16.3 (7.0)	< **0.01***	< **0.01***	0.74	0.48
PASAT errors after smoking and while driving**	9.3 (5.0)	12.5 (8.3)	9.7 (3.7)	15.8 (5.8)				
Mean Speed in MPH	60.5 (5.2)	59.1 (6.3)	57.9 (3.7)	57.1 (2.6)	0.19	0.41	0.07	0.82
SD of Mean Speed in MPH	1.9 (1.0)	2.3 (1.1)	2.3 (1.4)	2.9 (2.1)	0.32	0.17	0.13	0.65
Steering Wheel Position	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	0.62	0.25	0.64	0.37
SD Steering Wheel Position	1.4 (1.3)	1.2 (0.6)	1.4 (0.7)	1.3 (0.4)	0.93	0.63	0.76	0.86
Go/No Go								
% Driving thru Yellow Light	100%	100%	100%	100%				
Emergency Response Vehicle								
Mean Speed in MPH	60.1 (5.1)	56.5 (7.5)	57.6 (6.5)	55.3 (6.1)	0.15	0.06	0.25	0.68
Steering Wheel Position	1.9 (1.2)	2.0 (0.9)	1.5 (1.8)	1.7 (0.9)	0.65	0.68	0.31	0.89
Time to First Reaction	13.5 (6.2)	13.1 (4.1)	12.4 (4.0)	12.9 (1.9)				
Type of First Reaction								
Lane Deviation (%)	20%	20%	29.2%	20%				
Brake (%)	68%	60%	54.2%	60%				
No Reaction (%)	12%	20%	16.7%	20%				
Dog Incursion								
Speed at First Contact	41.6 (12.4)	37.4 (9.9)	41.0 (12.6)	37.1 (11.6)	0.70	0.24	0.90	0.96
Tactic								
Safe Avoidance	4%	0%	12.5%	0%				
Unsafe Avoidance	24%	11.1%	33.3%	11.1%				

Task	Placebo		Active THC		Overall F	Sex	THC	Sex by THC
	Males (n = 25)	Females (n = 15)	Males (n = 24)	Females (n = 9)				
Crash	72%	88.9%	54.2%	88.9%				
Car Incursion								
Speed at First Contact	43.2 (16.1)	42.3 (11.5)	39.3 (19.5)	49.2 (11.0)				
Tactic								
Safe Avoidance	12.5%	11.1%	18.2%	11.1%				
Unsafe Avoidance	50%	22.2%	40.9%	22.2%				
Crash	37.5%	66.7%	40.9%	66.7%				

* Statistically significant at $p < 0.05$.

** Tasks were analyzed with a mixed model repeated measures analysis of variance.