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The effects of cannabis and alcohol on simulated arterial driving: Influences of driving experience and task demand

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ABSTRACT

This study compared the effects of three doses of cannabis and alcohol (placebo, low and high doses), both alone and in combination, on the driving performance of young, novice drivers and more experienced drivers. Alcohol was administered as ethanol (95%) mixed with orange juice in doses of approximately 0, 0.4 and 0.6 g/kg. Cannabis was administered by inhalation of smoke from pre-rolled cannabis cigarettes (supplied by the National Institute of Drug Abuse, USA). Active cigarettes contained 19 mg delta-9-THC. Using a counterbalanced design, the simulated driving performance of 25 experienced and 22 inexperienced drivers was tested under the nine different drug conditions in an arterial driving environment during which workload was varied through the drive characteristics as well as through the inclusion of a secondary task. High levels of cannabis generally induced greater impairment than lower levels, while alcohol at the doses used had few effects and did not produce synergistic effects when combined with cannabis. Both cannabis and alcohol were associated with increases in speed and lateral position variability, high dose cannabis was associated with decreased mean speed, increased mean and variability in headways, and longer reaction time, while in contrast alcohol was associated with a slight increase in mean speed. Given the limitations of the study, it is of great interest to further explore the qualitative impairments in driving performance associated with cannabis and alcohol separately and how these impairments may manifest in terms of crash characteristics.

1. Introduction

The association between alcohol-caused impairment and the increased risk of involvement in traffic crashes is well established. For example, Movig et al. (2004) showed that a Blood Alcohol Concentration (BAC) greater than 0.08% was associated with a 5.5 times higher crash risk relative to being alcohol and drug free, and driver culpability increases exponentially at BACs greater than or equal to 0.10% (Drummer et al., 2004).

Other drugs such as cannabis also represent a significant road safety concern. While the prevalence of drug driving in the general population appears low (Drummer et al., 2007; Dussault et al., 2002; Movig et al., 2004; Mura et al., 2003), the prevalence is higher in drivers apprehended for drug driving and in seriously and fatally injured drivers across a broad range of jurisdictions (Dussault et al., 2002; Jones et al., 2008; Laumon et al., 2005; Mura et al., 2003; Wei Ch'ng et al., 2007).

The presence of Δ9-tetrahydrocannabinol (THC), the active drug ingested when taking cannabis, has also been linked with increased crash culpability. Drummer et al. (2004) showed that culpable drivers had significantly higher odds of being positive to THC (≥5 ng/ml), alcohol and THC and alcohol combined than non-culpable drivers. Laumon et al. (2005) found increased odds of being exposed to alcohol and THC amongst culpable drivers compared to non-culpable drivers. In these studies the odds of culpability were much higher for drugs in combination with alcohol.

Much research has examined the effects of cannabis on driving skills and related those impairments to concentrations of THC in the body (Ramaekers et al., 2004; Ramaekers et al., 2006), and a consensus view is that THC levels of 7–10 ng/ml might represent a range at which impairment can be established (Grotenhermen et al., 2007). The predominant form of impairment observed after smoking cannabis alone is an increase in lane weaving behaviour (Ramaekers et al., 2004; Ronen et al., 2008). The decrements in

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lane weaving after a relatively high dose of THC (up to 300 μg/kg) reported by Robbe (1994) were estimated to be equivalent to impairments observed at a BAC of around 0.07% when compared to previous data (Louwerens et al., 1987). Use of cannabis alone (up to 200 μg/kg) has also been associated with increased variability in headway to a lead vehicle (Ramaekers et al., 2000). This is an important finding because it is commonly interpreted as reflecting the ability to perceive changes in the relative velocities of other vehicles and the ability to adjust one's own speed accordingly, which is suggestive of impaired perceptual abilities.

Many studies have shown that the effects of cannabis on driving and driving-related skills are relatively small (e.g. Smiley, 1986). It has been suggested that the effects of cannabis are small because participants are aware of their impairment and attempt to compensate for it by, for example, slowing down, focussing attention and not taking risks (Robbe, 1994; Smiley, 1986). However, while drivers may be able to use these strategies after ingesting cannabis, they may not be equally able to perform in situations of higher mental load such as when the driver encounters unexpected events and/or when the driver is placed in situations requiring continuous attention (Robbe, 1994).

When cannabis is combined with alcohol, performance on tasks such as those involving headway or lateral position maintenance is impaired to a greater extent than for cannabis alone (Ramaekers et al., 2000). Furthermore, drivers under the influence of both drugs take longer to react to task variation (e.g., changes in the speed of the lead car in a car following task), with the combination of a moderate dose of alcohol and cannabis found to produce impairment to a level observed at a BAC of up to 0.14% (Ramaekers et al., 2000; Robbe, 1994). The combination of alcohol and cannabis reduced the frequency of visual search for traffic at intersections suggesting that drivers may be less able to respond to peripheral traffic while maintaining performance on the central driving task (Lamers and Ramaekers, 2001).

The effects of cannabis and alcohol are particularly important for young drivers. This road user group are among the most vulnerable road users – particularly during their first months unsupervised driving (Mayhew et al., 2003; McCartt et al., 2003; McKnight and McKnight, 2003) – and the associated deficits in performance and attentional strategies associated with driver inexperience are well documented (e.g., Blaauw, 1982; Underwood et al., 2003; Underwood et al., 2002). This is also the age when many young people experiment with cannabis use, often in combination with alcohol (Australian Institute of Health and Welfare, 2005). Driving abilities of inexperienced drivers are impaired, and crash risk further elevated, when associated with forms of impairment including sleep loss and/or alcohol (Lenné et al., 1998, 1999; Peck et al., 2008). However, the magnitude of the effects of cannabis on inexperienced drivers, who may not be sufficiently skilled at driving to use the compensatory strategies detailed above in relation to reasonably experienced drivers, is unknown.

Many questions remain regarding the effects of cannabis on driver safety. For instance, the effects of cannabis in combination with alcohol are poorly understood in terms of the additive nature of any effects and any qualitative differences between the two. These influences for different driver experience groups are not known. Similarly, the effects of cannabis in higher workload settings, using the functionality provided by the use of advanced driving simulators, remain largely unknown.

In order to examine whether the effects of driver experience can mediate the impairing effects of alcohol and cannabis we compared the effects of three doses of cannabis and alcohol, alone and in combination, on driving performance of inexperienced and experienced drivers. On the basis of the research detailed above, we expected that active doses of alcohol and cannabis would impair driving performance when compared to a placebo condition, that any observed impairment would be greater at the higher level of each drug, and would be greatest in the conditions in which both drugs are administered. Secondly, we expected that the degree of cannabis- and alcohol-induced impairment would be greater for less experienced than experienced drivers. Finally, we expected that impairments to performance would increase as task demands increased and that the increased impairment would be greater for inexperienced drivers.

2. Method

2.1. Participants

Twenty-two young novice drivers aged between 18 and 21 yrs with less than 2 yrs of driving experience, and 25 experienced drivers aged between 25 and 40 yrs with at least 7 yrs of driving experience participated in the study. All participants received a psychiatric and medical examination before participation. Only those judged healthy with no history of substance use disorder (DSM-IV criteria excluding tobacco dependence) by a trained psychiatrist were allowed to participate. Participants had a history of both alcohol and cannabis use.

Participants were compensated $300 for participation in a maximum of nine experimental sessions. Ethics approval was obtained from the Monash University Standing Committee on Ethical in Research involving Humans

2.2. Drug administration

Active alcohol doses were administered as ethanol (95%) mixed with orange juice (480 ml constant volume) in doses of either 0.4 or 0.6 g/kg. The low and high doses were selected to produce peak blood alcohol concentrations below (0.025%) and up to the legal limit in the state of Victoria (0.05%) respectively. Placebo alcohol consisted of 480 ml orange juice only. Drinks were divided into sixteen equal volumes (30 ml each). To mask the immediate olfactory cues of both alcoholic and placebo drinks, the top half of the cup from which the participants drank from was wrapped with an alcohol-soaked wristband (Heishman et al., 1997).

Cannabis was administered by inhalation of smoke from pre-rolled cannabis cigarettes (supplied by NIDA). Each active cigarette contained 19 mg Δ9-THC. The smoking procedure was adapted from previous research (Heishman et al., 1988), and involved a total of 8 puffs per cigarette with ad lib puff duration, smoke to be retained in the lungs for 15 s, and a 60 s inter-puff interval to be timed from the start of each puff. Participants were pre-trained in the smoking procedure using placebo cigarettes.

The order of drug conditions was counterbalanced across participants and administered under double-blinded, double-dummy conditions. To this effect, during each session participants received a single dose of alcohol or alcohol placebo together with two cigarettes (two active, one active and one placebo, or two placebo cigarettes, depending on the treatment condition). During each session, 16 × 30 ml drinks and 16 puffs (from two cigarettes) were consumed. Participants consumed one 30 ml drink during each 60 s inter-puff interval so that drinks and puffs alternated during a 20 min drug administration period.

2.3. The driving simulator

The mid-range simulator is located at the Monash University Accident Research Centre. It consists of a sedan with normal interior features. A curved projection screen located in front of the vehicle provided a field of view subtending angles of approximately 180° horizontally and 40° vertically from the driver's viewpoint. The rear

screen provided a field of view subtending angles of approximately 60° horizontally and 40° vertically.

A quadraphonic sound system provided realistic traffic sounds such as tyre squeals, engine noises, horn blasts, and low frequency vibrations. The system simulated Doppler shift and atmospheric damping effects. Simulations were designed and run using: a Silicon Graphics Indy (primarily for developing, running and replaying simulation scenarios); a Silicon Graphics Onyx (primarily for graphics generation, handling vehicle data inputs and outputs, controlling the audio system and vehicle dynamics, and road database development); and a PC (for generating sounds).

The car was mounted on a motion platform which produced realistic road feel and vehicle dynamics and had three actuators: the front two actuators were placed under the front axle, while the rear was placed in the centre of the rear axle, allowing for up/down movements and for pitch and roll rotations. The experimenter controlled driving simulations from a control room located adjacent to the simulation room. Measures collected using the mid-range driving simulator have been validated against on-road driving (Godley et al., 2002).

2.4. Procedure

Participants attended a practice session on the simulator within one week of the first test session. During each session participants received a single dose of alcohol (either placebo alcohol, low alcohol, or high alcohol), and two cannabis cigarettes (for the placebo condition, two placebo cigarettes; low cannabis condition, one placebo cigarette and one active cigarette; and the high cannabis condition, two active cigarettes). Driving performance measures were collected 5 min post completion of drug administration. All participants were expected to be tested under all nine conditions with a counterbalanced design.

Experimental drives occurred over a 6.6 km length of mainly straight arterial road with two or three lanes of traffic in each direction, intersections every 300–600 m (participants approached on a green traffic signal and were not required to stop), and houses and factories on both sides of the road. Task demand was varied through the use of headway maintenance and reaction time (RT) tasks both alone and in combination. Participants were instructed to drive in accordance with the posted speed limit (70 kph) except when performing the headway maintenance task.

The experimental drive was divided into three stages. The first stage of the drive involved car following, following a lead vehicle at a fixed distance of 40 m, while the speed of the car in front varied from 60 to 80 kph at an acceleration rate of 0.3 m/s^2. The participant was required to perform two tasks: to maintain a 40 m gap between the simulator vehicle and the red sedan in front, and to position the simulator vehicle at all times in the same lane as the sedan. For this first stage (1.2 km) there was no additional task. During the second stage of the drive the participants continued the car following task for another 2.4 km while also performing an RT task involving sign detection.

The sign detection task involved responding to 48 signs which were located on the left and right sides of the roadway at varying distances from the road edge (1, 3, and 9 m). Each sign contained three letters that were either all consonants (non-words; e.g., "VLM"), or a consonant–vowel–consonant letter combination forming a real word (e.g., "DOG"). Twenty-four signs appeared on each side of the road. Of these, eight were at each distance. Of these, four signs contained a word and four contained a non-word. The signs were positioned at random distances apart with an average distance of 100 m, ranging from 70 to 130 m apart. The order in which the signs appeared on either side of the road, the distances of signs from the road edge, and the orders of presentation of words and non-words were randomised. A tree was positioned approximately 3 m in front of each sign so that the signs could not be seen from a distance. Not all trees, however, had signs behind them. Signs appeared only on straight sections of road. The participant's task was to detect a sign and press a button on the steering wheel in response: the right button for a real word, and the left button for a non-word. The final stage of the drive involved the RT task only, participants being asked to maintain an appropriate speed for the conditions.

Across the drive the measures of interest were mean speed and standard deviation of speed (kph) and standard deviation of steering wheel angle (degrees). Standard deviation of lateral position (m) was calculated only for the third driving stage when participants were not engaged in the car-following task. For the car-following task the dependent measures were mean and standard deviation of headway (m), while RT (s) was the outcome of interest in the sign detection task.

2.5. Data analysis

Only 33 participants completed all nine sessions of the study. In order to maximise the use of the data obtained from the participants who failed to complete all of the sessions a series of mixed model generalised least squares regressions were undertaken with participant treated as a random effect, using the xtreg procedure in Stata (v9SE). Standard errors were estimated using bootstrapping in order to account for evidence of non-normal distribution of some of the key outcome variables. Main effects models were estimated for all outcome measures in which alcohol condition, cannabis condition, driver experience and driver gender were entered as independent variables. These main effects models included drive stage for the speed, steering, reaction time and headway maintenance measures and sign distance for the reaction time task. While 3-way interactions of interest (e.g., between experience, alcohol condition, and cannabis condition) were examined using indicator variables derived from using the 'xi3' command (Chen et al., 2003).

Initial exploration of the data revealed no 3-way interactions. In the absence of such a 3-way interaction separate models for the 2-way interaction between cannabis and alcohol were estimated for each outcome measure, controlling for the independent effects of the remaining variables. Models involving 2-way interactions between the drug conditions and, (1) driver experience, and (2) drive stage (task demand) were also estimated, controlling for the independent effects of the remaining variables. Models involving 2-way interactions between driver experience and the drive variables (stage for steering, speed and reaction time; sign distance for reaction time only) were also estimated to examine whether performance under different workload conditions varied according to driver experience.

3. Results

A series of main effect models were run on all of the outcome measures of interest. These model results are detailed in Tables 1–4 along with associated means, grouped according to which of the measures collected in the three stages of the arterial drive were included. The results are presented in relation to each

Table 1
Mean and standard deviation of BAC and THC levels for placebo, low and high dose conditions.

Dose	Alcohol (BAC)			THC (ng/ml)		
	Mean	SD	Range	Mean	SD	Range
Placebo	0.00	0.00	0.00–0.00	0.00	0.00	0.00–0.00
Low	0.02	0.01	0.01–0.05	7.40	3.87	1.00–20.65
High	0.05	0.01	0.02–0.08	12.01	5.53	3.67–26.82

Table 2
Mean and standard deviation of speed (km/h), and standard deviation of steering angle (°), for all independent variables along with coefficients and 95%CI's derived from main effect models.

Main effect	Mean speed	β	LCI	UCI	SD speed	β	LCI	UCI	SD steering	β	LCI	UCI
												Alcoholdose
Placebo	68.72	Ref			7.35	Ref			4.24	Ref		
Low	69.40	0.72*	0.03	1.41	7.78	0.44*	0.06	0.81	4.37	0.13	−0.01	0.27
High	69.10	0.51	−0.11	1.14	7.45	0.08	−0.23	0.38	4.41	0.18*	0.02	0.34
												Cannabisdose
Placebo	69.59	Ref			7.23	Ref			4.30	Ref		
Low	69.03	−0.50	−0.96	−0.04	7.46	0.29	−0.04	0.62	4.33	0.06	−0.06	0.17
High	68.59	−0.97*	−1.74	−0.19	7.87	0.62**	0.22	1.02	4.39	0.12	−0.02	0.25
												Experience
Experienced	68.42	Ref			7.30	Ref			4.23	Ref		
Inexperienced	69.69	1.15	−0.05	2.35	7.74	0.44	−0.34	1.21	4.45	0.21	−0.09	0.50
												Gender
Female	68.79	Ref			7.55	Ref			4.25	Ref		
Male	69.25	0.38	−0.81	1.57	7.50	−0.09	−0.78	0.60	4.39	0.16	−0.11	0.43
												Stage
1	70.68	Ref			8.72	Ref			4.52	Ref		
2	71.16	0.48	−0.95	1.90	8.36	−0.37	−0.91	0.17	5.09	0.57**	0.38	0.76
3	65.35	−5.33**	−6.72	−3.94	5.48	−3.25**	−3.68	−2.83	3.40	−1.12**	−1.34	−0.89
Constant		69.92	67.94	71.89		8.16	7.60	8.71		4.13	3.82	4.43

* $p < 0.05$.
** $p < 0.01$.

of the measures analysed. Main effects of variables are described where there was no interaction of interest, otherwise the effects of the independent variables are described in the context of evidence of interaction. Table 1 shows the mean BACs and blood-THC levels across conditions. All subjects demonstrated a dose–response relationship across the three drugs conditions for both alcohol and cannabis.

3.1. Speed and steering measures across the drive

Table 2 shows the main effects of the independent variables analysed on the speed and steering measures collected across all three stages of the arterial drive. For mean speed, main effects of cannabis dose condition (high dose only), alcohol dose condition and drive stage were evident. In the high dose cannabis condition participants maintained an average speed that was around 1 km/h less than in the placebo condition. While both active alcohol doses appeared to increase mean speed compared to placebo, this difference was significant only for the low dose alcohol condition (around 0.72 kph less than placebo). During stage 3 of the arterial drive, where the workload demands on participants related only to the RT task, participants maintained a more conservative mean speed more than 5 km/h slower than in the first and second stages of the drive that involved headway maintenance ($M = 70.68$ and 71.16 kph for stages 1 and 2 respectively). There were no significant two-way interactions between the variables of interest.

Standard deviation of speed varied significantly across cannabis dose such that in the high dose cannabis condition the standard deviation of participants' speed increased by an average of 0.62 kph compared to placebo. There was a significant interaction between alcohol dose condition and driving experience such that the difference in standard deviation of the speed maintained by the

Table 3
Mean and standard deviation of headway maintenance (m) for all independent variables along with coefficients and 95%CI's derived from main effect models.

Main effect	Mean headway	β	LCI	UCI	SD headway	β	LCI	UCI
Alcohol dose								
Placebo	86.76	Ref			18.21	Ref		
Low	84.78	−2.36	−8.26	3.54	18.30	0.07	−2.62	2.77
High	85.13	−3.07	−8.49	2.35	18.17	−0.53	−2.87	1.80
								Cannabisdose
Placebo	76.54	Ref			14.00	Ref		
Low	85.90	8.76**	2.55	14.97	18.41	4.29**	1.64	6.93
High	94.27	16.76**	8.45	25.06	22.27	7.78**	4.23	11.33
								Experience
Experienced	95.38	Ref			20.95	Ref		
Inexperienced	75.90	−17.57*	−31.59	−3.55	15.52	−4.77	−9.81	0.28
								Gender
Female	86.64	Ref			18.02	Ref		
Male	84.83	−0.54	−12.98	11.90	18.34	0.64	−4.62	5.89
								Stage
1	76.63	Ref			14.04	Ref		
2	94.49	17.86**	10.64	25.09	22.39	8.33**	5.82	10.84
Constant		79.31	66.36	92.26		12.41	7.37	17.46

* $p < 0.05$.
** $p < 0.01$.

Table 4
Mean RT (s) for all independent variables along with coefficients and 95%CI's derived from main effect models.

Main effect	Reaction time	β	LCI	UCI
Alcohol dose				
Placebo	1.070	Ref		
Low	1.062	−0.004	−0.031	0.022
High	1.078	−0.001	−0.018	0.016
Cannabis dose				
Placebo	1.047	Ref		
Low	1.066	0.019	−0.011	0.049
High	1.098	0.051*	0.008	0.094
				Experience
Experienced	1.140	Ref		
Inexperienced	0.999	−0.144**	−0.227	−0.060
				Gender
Female	0.997	Ref		
Male	1.121	0.141**	0.043	0.240
				Stage
2	1.102	Ref		
3	1.039	−0.063**	−0.083	−0.044
Constant		1.068	1.003	1.134

* $p < 0.05$.
** $p < 0.01$.

experienced drivers compared to the inexperienced drivers in the placebo condition ($M = 7.32$ and 7.37 kph respectively) increased in the low dose alcohol condition ($M = 7.28$ and 8.26 kph for experienced and inexperienced respectively, $\beta = 0.82$, 95%CI = 0.25–0.40, $p < 0.01$), but not significantly so in the high dose alcohol condition ($M = 7.28$ and 7.61 kph for experienced and inexperienced respectively, $\beta = 0.24$, 95%CI = −0.40 to 0.89). There was also a stage by driving experience interaction such that the difference in standard deviation in speed maintained by the experienced drivers in stage 1 ($M = 8.36$ and 9.08 kph for experienced and inexperienced drivers respectively) was similar in stage 2 ($M = 7.93$ and 8.79 kph for experienced and inexperienced drivers respectively, $\beta = 0.17$, 95%CI = −0.66 to 0.99), but reversed in stage 3 ($M = 5.60$ and 5.35 kph for experienced and inexperienced drivers respectively, $\beta = -0.97$, 95%CI = −1.78 to −0.16, $p < 0.05$). There were no other significant two-way interactions.

Table 2 shows that there was a significant main effect of alcohol dose condition (high dose only) and drive stage on the standard deviation of steering wheel angle. In the high alcohol dose condition participants showed an increase in standard deviation of steering angle of around 0.18 compared to placebo from a mean of 4.24–4.41. Steering variability was highest in the dual-task condition in stage 2 (car following and RT tasks, $M = 5.09$), followed by the car following only (stage 1, $M = 4.52$) and RT only (stage 3, $M = 3.40$) segments.

The steering variability data also showed a significant interaction between cannabis dose condition and driving experience that is detailed in Fig. 1. The difference in standard deviation of steering wheel movements by the experienced drivers compared to the inexperienced drivers in the placebo condition increased as cannabis dose increased to low ($\beta = 0.21$, 95%CI = 0.00–0.42, $p < 0.05$) and high dose conditions ($\beta = 0.29$, 95%CI = 0.06–0.51, $p < 0.05$).

3.2. Headway maintenance

Table 3 shows the main effects of the independent variables analysed on the headway maintenance task performed alone (stage 1) or in combination with the RT task (stage 2). There were significant main effects of cannabis dose condition, driving experience and drive stage on mean headway, however these need to be interpreted in light of significant interactions between cannabis dose condition and driving experience, cannabis dose condition and stage and stage by driving experience.

Fig. 1 illustrates that the interaction between cannabis dose and driving experience was such that the difference in mean headway maintained by the experienced drivers compared to the inexperienced drivers in the placebo condition increased as cannabis dose increased to low ($\beta = -12.63$, 95%CI = −24.78 to −0.49, $p < 0.01$) and high dose ($\beta = -21.72$, 95%CI = −42.65 to −0.78, $p < 0.01$) conditions. The interaction between cannabis dose condition and drive stage, illustrated in Fig. 2(panel A), was such that the difference in mean headway maintained in stage 1 and stage 2 in the placebo condition increased as cannabis dose increased to low ($\beta = 9.40$, 95%CI = −2.11 to 16.69, $p < 0.01$) and high dose ($\beta = 18.71$, 95%CI = 9.56–27.86, $p < 0.01$) conditions. Finally, the interaction between drive stage and experience was such that the difference in mean headway maintained by the experienced drivers across stages ($M = 82.31$ and 108.61 m for stages 1 and 2 respectively) was far greater than that maintained by the inexperienced drivers ($M = 71.09$ and 80.71 m for stages 1 and 2 respectively, $\beta = -16.67$, 95%CI = −31.93 to −1.42, $p < 0.01$). There was no significant interaction between cannabis and alcohol dose conditions.

Analysis of the data for the standard deviation of headway showed similar results. There were significant main effects of cannabis dose condition and drive stage that are best interpreted in the context of significant two-way interactions between cannabis and drive stage and experience by drive stage. The interaction between cannabis dose condition and drive stage, shown in Fig. 2(panel B), was such that the difference in the standard deviation of the headway maintained in stages 1 and 2 in the placebo condition increased in the high dose cannabis condition

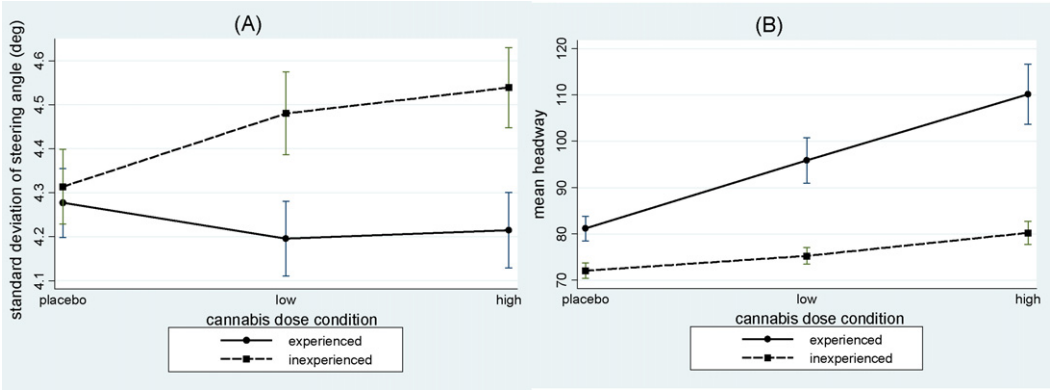

Fig. 1. The effect of cannabis dose and driving experience on the standard deviation of steering angle (panel A) and mean headway (panel B). The figure highlights the interaction between the two variables for both performance measures.

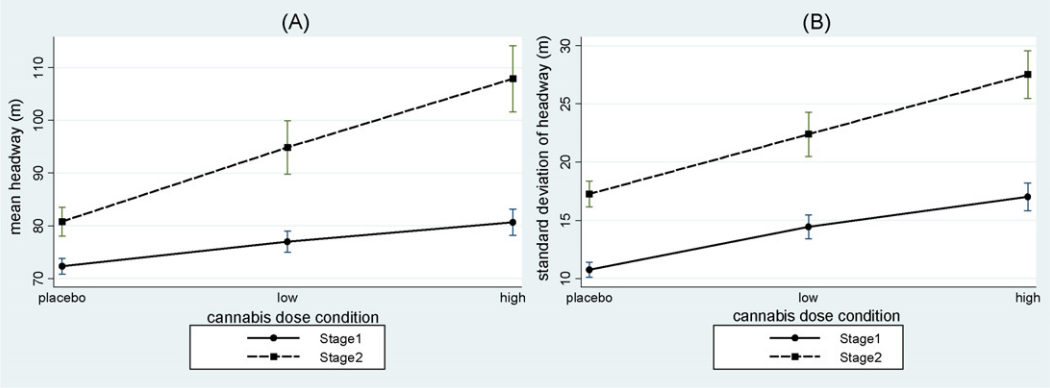

Fig. 2. The effect of cannabis dose and task demand (stage) on the mean (panel A) and standard deviation of headway (panel B). The figure highlights the interaction between the two variables for both performance measures.

(β = 4.01, 95%CI = 0.81–7.21, $p < 0.05$), but not the low dose cannabis condition (β = 1.45, 95%CI = −1.15 to 4.05). The interaction between drive stage and experience was such that the difference in standard deviation of the headway maintained by the experienced drivers across stages (M = 15.52 and 26.46 m for stages 1 and 2 respectively) was far greater than that maintained by the inexperienced drivers (M = 12.63 and 18.41 for stages 1 and 2 respectively, β = −5.17, 95%CI = −10.24 to −0.95, $p < 0.05$).

3.3. Reaction time

Table 4 shows the main effects of the independent variables on correct RT to the sign detection task. Main effects of cannabis dose condition (high dose only), experience, gender, and stage were evident. Participants' RT in the high dose cannabis condition was some 0.05 s slower than in the placebo condition. Inexperienced drivers were around 0.14 s faster than the experienced drivers. Similarly, the females were around 0.14 s faster than the males. There were no significant two-way interactions of interest.

3.4. Lateral position

Table 5 shows the main effects of the independent variables analysed on the standard deviation of lateral position maintained during the third stage of the arterial drive. Both cannabis and alcohol dose conditions increased the standard deviation of lateral position. Both alcohol doses produced similar increases of around 0.05 m compared to placebo from 0.36 to 0.41 m. The cannabis dose conditions produced effects of similar magnitude to the alcohol dose conditions. While the deviation increased from 0.35 m for the placebo condition to 0.39 m for the low cannabis dose condition and 0.43 m for the high cannabis dose condition, these differences were not statistically significant. There were no significant two-way interactions between the variables of interest.

Table 5
Standard deviation of lateral position (m) for all independent variables along with coefficients and 95%CI's derived from main effect models.

Main effect	SD lateral position	β	LCI	UCI
Alcohol dose				
Placebo	0.36	Ref		
Low	0.41	0.05**	0.01	0.09
High	0.41	0.05**	0.01	0.09
Cannabis dose				
Placebo	0.35	Ref		
Low	0.39	0.04*	0.00	0.07
High	0.43	0.07**	0.04	0.11
				Experience
Experienced	0.38	Ref		
Inexperienced	0.40	0.02	−0.03	0.08
				Gender
Female	0.37	Ref		
Male	0.40	0.03	−0.03	0.08
Constant		0.29	0.25	0.33

* $p < 0.05$.
** $p < 0.01$.

4. Discussion

In this study we examined the effects of cannabis, alone and in combination with alcohol, on the simulated driving performance of inexperienced and experienced drivers. Moderate workload was imposed by having the drivers undertake a car-following task while driving, or by measuring reaction to signs while driving. Task demand was manipulated through the completion of both tasks simultaneously.

We expected that active cannabis and active alcohol would impair performance. However, the pattern of findings was mixed. Cannabis did impair simulated driving as evidenced by increased variability in speed, headway, and lateral position, in accord with previous research (Ramaekers et al., 2000; Robbe, 1998; Ronen et al., 2008). In most cases these effects were dose-dependent. The decrements in standard deviation of lateral position for high dose cannabis were greater than those observed in the high alcohol condition. RTs were also slower in the high dose cannabis condition. Performance in the cannabis conditions was associated with an increase in mean headway and a decrease in mean speed. These effects of cannabis were observed at levels similar to those believed to be indicative of performance impairment (Grotenhermen et al., 2007; Ramaekers et al., 2006).

Alcohol was found to have fewer effects on performance. In support of our earlier work, alcohol did increase variability in speed and lateral position (Lenné et al., 1999), while also increasing steering variability, however there was no effect on RT. As the detrimental effects of alcohol on simulated driving performance are well documented, this finding suggests that the levels used in this study were insufficient to induce significant impairment.

Headway maintenance and RT tasks were used alone and in combination to manipulate task demands. The results suggest that our manipulation was effective. Participants performed worse during the dual-task condition (stage 2) compared to when each task was performed alone, and this was consistent across measures of variability in speed, steering and headway, as well as RT. Mean headways were larger in the dual-task condition (stage 2) than in stage 1.

The effects of cannabis were influenced by task demands for both measures of headway maintenance. Measures of headway and headway variability are believed to be representative of vehicle control abilities and have been shown to be affected by both cannabis and alcohol (Ramaekers et al., 2000; Robbe, 1994). In our study mean headway maintenance and variability (high cannabis dose condition only) generally increased as task demands increased. The mean headway result could suggest that participants were actively compensating for the effects of cannabis—the participants were aware of their impairment under the influence of cannabis and thus left larger headways. However, the increase in headway variability suggests that this compensation comes at a control cost and is consistent with other measures of vehicle control collected in our study (speed, steering), and RT, that showed impaired performance of participants while under the influence of cannabis.

The effects of alcohol did not vary across task demand, which may suggest that the effects of cannabis are more sensitive to variations in task than the effects of alcohol or simply that that the measures used in our study are more sensitive to impairment observed after taking cannabis than alcohol. However, the absence of any effects may merely confirm the fact that the levels of alcohol used in this study were not sufficient to produce observable impairment.

We expected effects of driver experience on simulated driving, specifically that the degree of cannabis- and alcohol-induced impairment would be greater for less experienced compared to more experienced drivers. Some effects of driving experience were indeed found. Steering behaviour was more variable for inexperienced drivers, and this variability increased as the level of cannabis increased, providing some suggestion that cannabis may have a greater effect for inexperienced drivers compared to their more experienced counterparts. Inexperienced drivers also displayed higher deviations in speed for two of the drive segments. Together these results suggest a poorer level of vehicle control compared to the more experienced driver group, although while performing the car-following and sign recognition tasks the inexperienced drivers had faster RT and smaller variability in headway. As found in previous research, inexperienced drivers maintained smaller headways (Mitsopoulos-Rubens et al., 2007; Taieb-Maimon and Shinar, 2001). However, the headways maintained in the present study were larger than reported in other studies using our simulator (Mitsopoulos-Rubens et al., 2007). The mean and standard deviation of headway maintained by the experienced drivers increased further in the high cannabis condition, perhaps suggesting that experienced drivers compensate for the extra demand of responding to signs under the influence of cannabis by driving more conservatively, although this remains unclear.

As with many other areas of transportation research, simulation has proven to be a reliable tool to study the influences of alcohol and other drugs on driving performance. In addition to reasons related to experimental control, for legal and ethical reasons simulation has been a primary research method to examine in detail the effects of alcohol and other drugs on attentional strategies and performance. Advances in simulation (preferably involving validation against on-road driving) will therefore continue to provide important insights into the effects of alcohol and other drugs on driving-related skills. Future research should further capitalise on the functionality provided by more advanced simulators to explore in more depth behavioural responses to cannabis and other substances in unexpected and more demanding environments than those used in this study. Further, previous researchers have noted the need to examine the effects of cannabis when drivers encounter unexpected events and/or when the driver is placed in situations requiring increased mental load or continuous attention (Robbe, 1994; Smiley, 1986). Our study has gone some way to addressing these issues, but further research is required.

This study is not without limitations. Many obvious dose–response relationships failed to reach statistical significance due to lack of power, evidenced by the large confidence intervals detailed in Tables 2–5. Further, the manipulation of task demand in this study was predictable in the sense that the events required continuous attention but could not be regarded as unexpected. The use of more demanding and unexpected events may shed more light on some of the compensatory and/or perceptual mechanisms that might underpin performance observed after consumption of cannabis compared to other drugs. It would also be interesting to examine whether the effects of driver inexperience would remain similar if a different indicator such as km driven was used to define this group. Finally, participants in the high alcohol dose condition in this study did not consistently reach the desired BAC level of around 0.08%. Future research should use higher levels of alcohol to further explore the effects of cannabis and alcohol combined on driving performance.

Novel features of this study include the use of cannabis and alcohol, both alone and in combination, the inclusion of driver experience as a variable of interest, and the variation in task demand. This study has shown distinct effects of cannabis and alcohol, while the effects of cannabis were influenced by task demand. Both cannabis and alcohol increased variability in lateral position, while cannabis also impaired additional aspects driving, as evidenced by increased variability in speed and headway. Importantly cannabis also slowed RT to events occurring outside the vehicle, suggesting that driver safety could possibly be compromised in real world driving conditions. There were also signs of greater impairment from cannabis in inexperienced drivers. Together these data confirm the impairments associated with cannabis use and highlight risks to inexperienced drivers. The extent to which drivers might be able to compensate for the effects of cannabis, suggested by the lower speed and increased headway, remains unclear but these effects would be at least partially offset by the impairing effects of cannabis that were evident on the other measures included in the study.

Given the limitations of the study it is of great interest to further explore the qualitative impairments associated with THC and alcohol separately, and how these impairments may manifest in terms of crash characteristics. Some of our previous work suggests that a higher proportion of fatal crashes involving alcohol or other drugs are single vehicle crashes involving the driver leaving the roadway and colliding with a fixed object (Lenné et al., 2007), however this warrants further examination and consideration of the potential role of driver experience and task demand in mediating the effects of drug use on driving.

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