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Impairment of simulated motorcycle riding performance under low dose alcohol

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Crash statistics that include the blood alcohol concentration (BAC) of vehicle operators reveal that crash involved motorcyclists are over represented at low BACs (e.g., ≤0.05%). This riding simulator study compared riding performance and hazard response under three low dose alcohol conditions (sober, 0.02% BAC, 0.05% BAC). Forty participants (20 novice, 20 experienced) completed simulated rides in urban and rural scenarios while responding to a safety-critical peripheral detection task (PDT). Results showed a significant increase in the standard deviation of lateral position in the urban scenario and PDT reaction time in the rural scenario under 0.05% BAC compared with zero alcohol. Participants were most likely to collide with an unexpected pedestrian in the urban scenario at 0.02% BAC, with novice participants at a greater relative risk than experienced riders. Novices chose to ride faster than experienced participants in the rural scenario regardless of BAC. Not all results were significant, emphasising the complex situation of the effects of low dose BAC on riding performance, which needs further research. The results of this simulator study provide some support for a legal BAC for motorcyclists below 0.05%.

1. Introduction

It is widely recognised that limiting the legal blood alcohol concentration (BAC) for motor vehicle operators improves road safety by reducing crash risk. Although legal BAC limits differ from country to country, motorcycle riders are typically subject to the same limit as car drivers. Of 114 countries surveyed in a World Health Organisation report, almost 40% of countries had a BAC limit of 0.05%, while 25% of countries had a BAC limit of greater than 0.06% (WHO, 2004). It is important to investigate whether generic *vehicle* operation BAC limits are appropriate for motorcyclists, as motorcyclists are involved in crashes more often at lower BAC than car drivers (Sun et al., 1998). Further, the odds of being in a collision when a rider is under the influence of alcohol is 2.7 times greater than when sober (ACEM, 2009). While post hoc analysis of vehicle operator BAC from road collision data provides valuable information regarding the characteristics of riders who have been involved in crashes, the small numbers of actual cases of riders with positive BAC in such studies makes it difficult to draw firm conclusions. For instance, in Sun et al.'s (1998) study over a one-year period only 13 injured motorcycle riders had a positive BAC compared with 411 car drivers. Although frequency may be low, the consequences are high due to the high vulnerability of the rider compared with the driver; riders have higher injury rates for lower BAC (Sun et al., 1998; Huang and Lai, 2011; Jama et al., 2011) and alcohol impairment results in more fatal crashes (Siskind et al., 2011).

Two key studies have investigated the effect of low dose BAC on motorcycle riding. The first utilised riding on a test track (Creaser et al., 2009). Experienced riders completed riding tasks under zero alcohol, 0.02%, 0.05% and 0.08% BAC in a repeated measures design. Across almost all tasks, a BAC of 0.08% resulted in greater riding impairment compared with the other conditions. In particular, participants were significantly impaired at performing an offset weave task with a BAC of 0.08%. Additionally when riding a curved circuit, participants had significantly greater standard deviation of speed, and greater occurrence of lane departures when intoxicated, compared with sober. These findings suggest that riding on rural roads, which involves curve navigation, may be more difficult for intoxicated than sober riders. Riding on straight urban roads may also be affected by positive BAC as Creaser et al. (2009) found a significant main effect of BAC on travel speed in a straight line, reaction time in a hazard perception exercise and maximum deceleration during an emergency stop. The variety of vehicle handling skills impaired includes those likely to be required on both rural and urban riding situations. The authors suggest that the effects of BAC are likely to be exacerbated in novice riders. Using a test track study is invaluable for investigating the effects of alcohol on real vehicle handling skills; however, it does not allow for safe investigation of a range of typical road scenarios. On the other hand, simulation provides opportunity for investigating rider performance under relatively realistic road conditions that do not put the rider's or other road users' safety at risk.

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Using a motorcycle riding simulator to examine riding skills under different levels of BAC in experienced riders, Colburn et al. (1993) found increasing BACs of up to 0.1% to be associated with increased riding errors, particularly road departures. These impairments provided strong evidence against a BAC limit of 0.1%. However, when considering a BAC limit of 0.05%, interpretation of the data becomes more difficult. The lower levels of BAC were not well controlled, as participants drank fixed volumes of alcohol rather than having it tailored to their body size, resulting in varying BAC. Nevertheless, results point to a need for further research on low-dose (i.e., <.05% BAC) alcohol and riding.

Previous motorcycle riding studies have not all considered the effect of BAC on the higher order cognitive skills that are critical for rider safety, such as hazard perception. Arousal and attention are particularly impaired by alcohol consumption (Roehrs et al., 1992) and these skills are vital for successful hazard perception. Findings show that drivers' hazard perception (as measured by a secondary reaction time task) in a driving simulator is significantly impaired at low BAC (Lenné et al., 1999; Leung and Starmer, 2005). Motorcyclists appear to have better hazard perception than car drivers when sober (Shahar et al., 2010; Hosking et al., 2010) so it is possible that hazard perception in riders may not be as impaired by alcohol as it is in car drivers.

The effect of alcohol on hazard perception in drivers is related to changes in visual scanning. Sober drivers demonstrate a wide visual scanning pattern, which means that they can maintain attention on the forward roadway and on-coming traffic as it passes. However, with a BAC of 0.08%, visual scanning range becomes narrower, which reduces hazard perception (Leung et al., 2003). Additionally, low dose alcohol has been linked to increased fixation duration. Using a road safety paradigm, Moser et al. (1998) reported that participants under 0.05% BAC demonstrated significantly longer gaze fixations viewing footage of traffic than when sober. Similar results have been reported using a simple scanning task with a BAC of 0.08% (do Canto-Pereira et al., 2007). This research suggests that increasing BAC in motorcycle riders may result in a tendency to fixate gaze on locations in the visual scene that are less meaningful for riding; for example, fixating on the speedometer at the expense of the forward road scene.

Motorcycle riders' visual scanning patterns change with increasing riding experience. For example, novice riders demonstrate narrower visual scanning patterns compared to experienced riders (Hosking et al., 2010). It is possible that experienced riders have a more flexible search pattern than novice riders, which may put them at an advantage when under the influence of alcohol. Although there is limited research on this issue, experience level would be predicted to interact with BAC so that novice motorcyclists' visual scanning behaviour would be impaired by alcohol to a greater extent than the scanning behaviour of more experienced riders.

In Australia, it is illegal to drive with a BAC of 0.05% or greater for private car and motorcycle licence holders. During the first three years of licensure motorcyclists are limited to zero or lower than 0.49% BAC, varying between states. The stricter requirement for BAC in the first years of driving or riding reflects a concern that alcohol has a greater impact on newly acquired skills than established ones. Graduated licensing schemes allow drivers and riders to gain experience under conditions of low risk whilst skills are still developing. In the Australian state of Victoria, a zero BAC restriction for motorcyclists over the age of 21 who also have a full car driver's licence applies only for the first 12 months post-licensure (VicRoads, 2010). Potentially, this regulation places novice riders with car driving experience (who comprise the majority of all novice motorcyclists in Australia) at greater risk than novice riders without car driving experience.

Uncertainties remain about the effects of low BAC on motorcycle riders with varying levels of experience. The present study used a riding simulator to investigate the effects of low-dose alcohol on vehicle handling and hazard perception. Based on previous findings, it was hypothesised that increasing low (<.05%) BACs would impair riding performance, hazard perception, and visual scanning patterns in a dose dependent manner for both novice and experienced riders. Secondly, it was hypothesised that the effects of low-dose alcohol would be more significant for novice, in comparison to experienced, riders.

2. Method

2.1. Design

A 3×2 mixed design was utilised with alcohol dose ('Dose') as the within-subjects factor (0, 0.02% BAC and 0.05% BAC) and riding experience ('Experience') as the between-subjects factor (experienced, novice). Order of alcohol dose administration was counterbalanced across participants. The research was approved by the Monash University Human Research Ethics Committee.

2.2. Participants

Participants were twenty experienced riders (two female) aged 23–54 years (mean = 37.1 years, SD = 9.9) with an average of 14.15 years (SD 10.3 years) riding experience, and twenty novice riders (two female) aged 18–53 years (mean = 27.2 years, SD = 10.8) who were learners or within the first two years of passing their motorcycle licence test. One additional experienced participant completed a practice ride but withdrew from the study due to simulator sickness; data from this participant are not included in this paper.

All participants were required to hold a driver's licence to ensure that all were experienced road users and to be regular consumers of alcohol reporting 2–10 standard drinks per week. Experienced participants were classified as riding regularly over the past five years covering at least 5000 km total. Participants were recruited from Monash University and the local community via online and newspaper advertisements and were compensated $40 per session for their time.

2.3. Equipment

2.3.1. Riding simulator

The MUARC advanced driving simulator was reconfigured as a motorcycle riding simulator for the purposes of the research program. The interactive riding simulator uses a real Honda NSR 150 motorcycle. Participants were able to realistically control the throttle, hand and foot brakes, and steering. The simulated scenario was displayed on a curved projection screen providing a 180° horizontal and 40° vertical field-of-view with an additional screen for the rearward view (see Fig. 1). The motorcycle was fixed in a static, vertical position to allow participants to have both feet on the foot pegs, emulating a real riding position; however, the simulator did not move dynamically in terms of pitch, roll, or heading. A digital speedometer was presented on the instrument panel of the motorcycle, to allow participants to monitor their speed. Lateral position, speed, throttle and brake use were recorded. Speed was recorded from when participants reached 500 m from the start point (to exclude acceleration up to speed), until the end of the ride.

2.3.2. Scenarios

Participants were presented with urban and rural road scenarios under each alcohol condition. The order of presentation was counterbalanced across participants, and remained consistent across the alcohol conditions. For both scenarios, oncoming traffic

Fig. 1. The Monash Univeristy Accident Research Centre riding simulator.

was presented at pre-determined intervals. Each scenario lasted approximately 6–10 min, depending on participants' speed.

The rural scenario consisted of a winding single carriageway, with an 80 km/h speed limit. The urban scenario consisted of a straight dual lane road passing through six blocks of buildings, with a 60 km/h speed limit. Participants' task was to follow the road, riding as they would on real roads, until they reached a red traffic light or stop sign. Two scenarios were designed so that riding could be observed during a straight (urban) and a curved (rural) course. The scenarios were presented as two different rides in order that the simulated scene was as realistic as possible.

At a pre-determined point in the urban scenario only, a pedestrian appeared from between parked cars onto the road in front of the participant. The pedestrian was triggered as the participant passed a point 100 m prior to its location. Release of the throttle, application of the brakes and steering movement > 4° in 100 ms from the 100 m prior mark were monitored as indicators of response. The pedestrian appeared in different sections of the ride in each alcohol condition and was not discussed with participants at any point during the study.

2.3.3. Eye tracking

Visual scanning of the road and speedometer was recorded using FaceLAB™ (Seeing Machines Ltd., Canberra, ACT). The system comprised two unobtrusive cameras set on an adjustable mounting plate on the front of the motorcycle. Participants wore their own helmets with the visor of their helmet removed so that the eye tracking system could be calibrated and eye tracking could be established.

2.3.4. Peripheral detection task (PDT)

While riding, participants were required to simultaneously perform a safety-relevant peripheral detection task (PDT), as used in previous work (Edquist et al., 2012; Rudin-Brown and Lenné, 2010). This task required participants to signal the location of a pedestrian icon which appeared intermittently to the far left or right of the centre of the screen. The icon was programmed to appear at randomised intervals of 200, 300, 400, 500 or 600 m (12–36 s at 60 km/h) and disappeared after 100 m (6 s) if a rider failed to respond.

2.3.5. Blood alcohol content measurement

BACs were measured using a Lion Alcolmeter SD-400 unit (Lion Laboratories, Glamorgan, UK) which measures alcohol exhaled in the breath and converts it to a BAC reading using a 1:2100 partition coefficient. To ensure accurate performance, the breathalyser was calibrated by Victoria Police prior to study commencement. The two target 'low' levels of BAC (0.02% and 0.05%) were chosen based on previous motorcycle research that evaluated these doses (e.g., Creaser et al., 2009; Colburn et al., 1993), as well as the common legal BAC criteria for novice motorcyclists in Australia (currently 0.02% in the ACT, zero limit in all other jurisdictions).

2.4. Procedure

All participants completed all three test sessions, separated by at least one day. Participants were instructed not to drink alcohol the night before and not to eat for at least two hours prior to testing. Participants were instructed to take a complimentary taxi to and from each test session.

Upon arrival at the laboratory, participants were breathalysed to ensure that no alcohol had been consumed. After completing a demographic and riding experience questionnaire, participants completed a five minute practice ride on the simulator to familiarise themselves with the controls of the riding simulator and the PDT.

Participants were then brought to another room where they consumed an alcohol dose relevant to condition. The alcohol dose (vodka, 37.5% alcohol) was administered as a beverage made up to 480 ml with chilled orange juice. Alcohol doses for each BAC were determined using a BAC calculator based on the Hume–Weyers formula (Hume and Weyers, 1971), which estimates total body water based on height, weight and gender to determine the volume of alcohol required to reach a desired peak BAC level.

Participants were blind to the BAC condition. In the zero alcohol condition a nominal amount (1 ml) was floated atop the beverage to make it smell like it might contain alcohol. Participants were required to drink 30 ml (a "sip") of liquid every minute for 16 min. Twenty minutes after drinking (to allow peak BAC to be reached), participants were instructed to rinse their mouth with water to remove residual alcohol, and were breathalysed again. This procedure is a common approach to administering alcohol and creating a zero alcohol condition (e.g., Oxley et al., 2006). Participants were then asked to give a subjective rating of how intoxicated they felt on a scale from 0 (completely sober) to 10 (extremely intoxicated).

Following the alcohol administration and completion of questionnaires participants were brought to the riding simulator, where the eye tracking system was calibrated and simulated riding commenced. After each scenario, participants scored their subjective workload on a modified version of the NASA Task Load Index (NASA-TLX) (Hart and Staveland, 1988) and underwent a breathalyser test. Each test session lasted approximately two hours in total.

2.5. Dependent measures

The dependent variables used to assess vehicle handling skills including lateral position of the vehicle within the lane, standard deviation of lateral position (SDLP), speed and standard deviation of speed. Riders' hazard perception ability was measured by whether or not they collided with a pedestrian programmed to walk onto the road, and reaction time to the PDT. Riders' visual scanning behaviour was measured by the proportion of total glance time focused on the speedometer. The vehicle handling skills measures are consistent with those used in many driving simulator and on-road studies including those of motorcyclists and low dose alcohol (e.g., Creaser et al., 2009; Colburn et al., 1993). Riders' reaction time to a PDT was chosen as a measure of hazard perception as it has been successfully used previously (Rudin-Brown and Lenné, 2010). Another measure of hazard perception ability, and which was subjected to binomial logistic regression analysis, was whether participants collided with an unexpected pedestrian or not, a measure that has also been used previously (Edquist et al., 2012). A subjective measure of perceived intoxication, where participants give a rating of how intoxicated they felt on a scale from 0 (completely sober) to 10 (extremely intoxicated), had previously been used successfully during pilot testing. Subjective workload was measured using an adapted version of the NASA Task Load Index (NASA-TLX) (Hart and Staveland, 1988). This scale assesses workload in six dimensions, each on a scale from 1 to 10: mental demand, pace of the task, success, hard work, annoyance, and safety. The scores were averaged to give a composite NASA-TLX score. This adapted scale has been used in previous simulator research (e.g., Edquist et al., 2012).

2.6. Data analysis

All statistical analyses were conducted using PASW 18.0 statistical software. An alpha level of .05 was used to determine statistical significance. Dependent variables were analysed using a mixed measures ANOVA with the within-subjects factor of alcohol Dose (3 levels: zero alcohol, 0.02% BAC and 0.05% BAC) and the between-subjects factor of riding Experience (2 levels: experienced and novice). Data for the collision with the unexpected pedestrian were non-parametric and were analysed using logistical regression within a generalised estimating equation (GEE) framework to accommodate the repeated measures design. Post hoc pairwise comparisons were conducted using Bonferroni tests. To supplement the interpretation of the results, partial η^2 was used as an estimate of effect size. Trends were interpreted where results were statistically non-significant ($.05 < p < .10$) yet effect sizes were moderate or above (.0588), as a moderate-to-large effect size suggests a result is more likely to be statistically non-significant due to small sample size rather than large variation. Non-significant results with small effects sizes are not reported.

Where required, square root transformations were used to correct for skewness. An arcsine transformation was used on all eye tracking percentage data so that it could be analysed by ANOVA. Where Mauchley's test indicated that the assumption of sphericity had been violated, degrees of freedom were corrected using Huynh–Feldt estimates of sphericity, epsilon values are listed accordingly.

3. Results

3.1. Participant characteristics

Experienced participants were on average significantly older than novice participants (37.1 vs. 27.2 years), and had significantly more riding experience both in terms of years they had held a licence, average riding hours per week and riding trips per month. Descriptive and inferential statistics for participant riding characteristics are presented in Table 1.

3.2. BAC readings

There were no significant differences in BAC readings between the two experience groups at test session midpoint under either 0.02% BAC or 0.05% BAC. Similarly, there was no significant change in BAC readings over time in the 0.05% BAC condition. However, BAC readings did decrease slightly over time in the 0.02% BAC condition (from 0.028% BAC at the beginning of the test session to 0.017% BAC at the conclusion, $p < .05$).

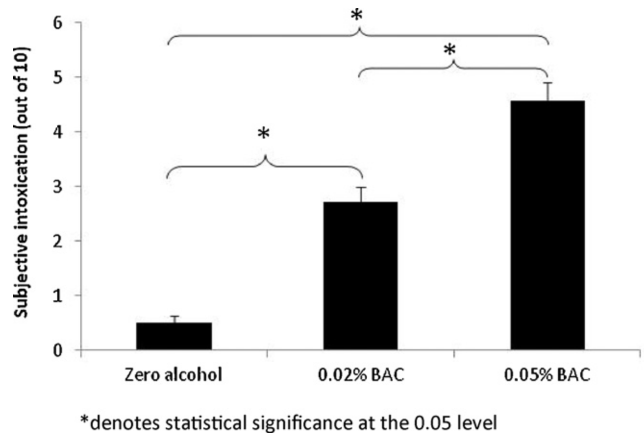

Fig. 2. Subjective ratings of intoxication (out of 10) (error bars represent standard error). *denotes statistical significance at the .05 level.

3.3. Subjective ratings of intoxication

A mixed measures ANOVA of subjective ratings of intoxication scores (out of 10) revealed a significant main effect of Dose, $F(1.7, 64.9) = 133.70$, $p < .001$, partial $\eta^2 = 0.78$, $\varepsilon = 0.854$. Alcohol was associated with a dose-dependent increase in scores; pairwise comparisons revealed the 0.02% BAC condition to be associated with significantly higher ratings than the zero alcohol condition, and the 0.05% BAC condition to be associated with significantly higher ratings than zero alcohol and 0.02% BAC conditions ($p < .05$) (Fig. 2). There was no effect of Experience or any interaction between Dose and Experience on subjective ratings of intoxication.

3.4. Vehicle handling skills

3.4.1. Rural environment

Overall, novice participants' mean riding speed (76.35 km/h, s.e. 0.40) in the rural environment was significantly faster than experienced participants' (73.13 km/h, s.e. 0.61), $F(1, 37) = 8.66$, $p < .01$, partial $\eta^2 = 0.181$. Maximum riding speed, variability of speed, lateral position and SDLP were not significantly affected by BAC or Experience in the rural environment. There were no significant interactions.

3.4.2. Urban environment

A moderate effect size indicates that novice participants tended to reach faster maximum speed than experienced participants (64.3 km/h vs. 62.6 km/h) in the urban environment, although the difference was not statistically significant; $F(1, 38) = 3.33$, $p = .076$, partial $\eta^2 = 0.081$.

Table 1
Participant riding characteristics, comparison between experience levels by independent *T* test.

	Experienced mean (SD)	Novice mean (SD)	*t* value (degrees of freedom)	*p* value
Age	37.1 (9.9)	27.2 (10.8)	3.02(38.0)	.004*
Years held a motorcycle licence	14.2 (10.3)	1.7(3)	5.21(22.3)	<.001*
Years held a car licence	18.6 (10.3)	9.1 (10.4)	2.91(38.0)	.006*
Hours ridden per week	8.2 (6.7)	3.4 (2.4)	3.06 (23.9)	.005*
Times ridden per month	21.6 (13.5)	12.2 (12.8)	2.23 (37.0)	.032*

* Statistical significance at the .05 level.

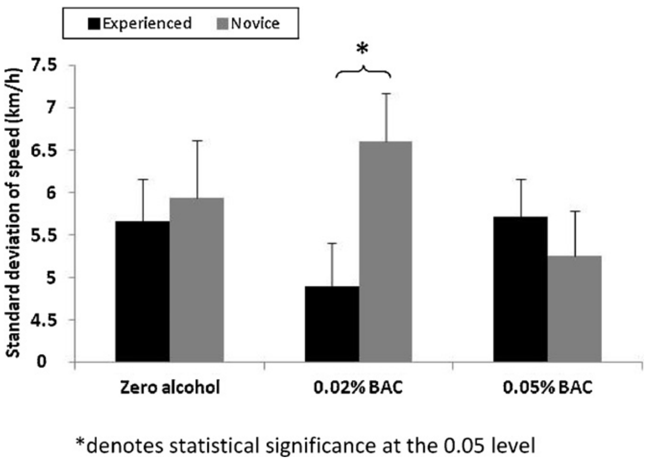

Fig. 3. Standard deviation of speed in the urban scenario (error bars represent standard error). *denotes statistical significance at the .05 level.

For speed variability, the Dose by Experience interaction approached statistical significance and had a moderate effect size, $F(2, 76) = 3.027$, $p = .054$, partial $\eta^2 = 0.074$, with novice participants' speed deviation being significantly greater at the 0.02% BAC dose compared to experienced participants at this dose ($p < .05$) (Fig. 3). The main effects of BAC and experience were not significant.

There was a significant main effect of Dose on the SDLP $F(2, 76) = 6.633$, $p < .01$, partial $\eta^2 = 0.149$. Pairwise comparisons showed the 0.05% BAC condition to be associated with significantly greater deviation within the lane than the zero alcohol condition ($p < .01$), regardless of participants' experience level (Fig. 4). There was no significant effect of Dose or Experience on lateral position. There was no main effect of experience or any Dose × Experience interaction on SDLP.

3.5. Hazard perception—response to pedestrian

Responses to the unexpected pedestrian were recorded for only 19 participants in each experience group due to technical difficulties.

Speed of response remained consistent across the three alcohol conditions (Zero alcohol = 1.55 s, 0.02% BAC = 1.55 s, 0.05% BAC = 1.51 s) and was not significantly affected by experience.

Binary logistic regression analysis was conducted on the number of collisions with the unexpected pedestrian in the urban environment. The model assessed for main effects of Experience (using experienced participants as the reference group) and Dose (using the zero alcohol condition as the reference group) and interactions between Experience and Dose (using experienced, sober participants as the reference group). Sober, experienced riders were chosen as the reference group for the interaction model as this group was considered to possess the best riding performance and hazard perception abilities and, therefore, be least likely to collide with the pedestrian. A significant effect of Dose was found; compared to when sober, riders at 0.02% BAC had 2.96 times greater odds of colliding with the pedestrian, $\chi^2(1) = 4.15$, $p = .042$. At 0.05% BAC, riders had 2.04 times greater odds of colliding with the pedestrian; however, this effect was not statistically significant, $\chi^2(1) = 1.71$, $p = .191$. Compared to experienced riders, novices had 1.62 times greater odds of colliding with the pedestrian; but again this was not statistically significant, $\chi^2(1) = 1.71$, $p = .248$. The frequency of collisions across each BAC condition is shown in Table 2. Overall there was no significant interaction between Experience and Dose.

To augment the analysis, binary logistic regression was also run comparing each combination of Experience and Dose using experienced participants in the zero alcohol condition as the reference group (Table 3). Compared to sober, experienced riders, there was a trend for the experienced riders in the 0.02% BAC condition to have 4.15 times greater odds of crashing with the pedestrian, $\chi^2(1) = 2.54$, $p = .111$. Novice riders at 0.02% BAC had 7.36 times greater odds than sober, experienced riders of crashing with the pedestrian, $\chi^2(1) = 5.26$, $p = .022$.

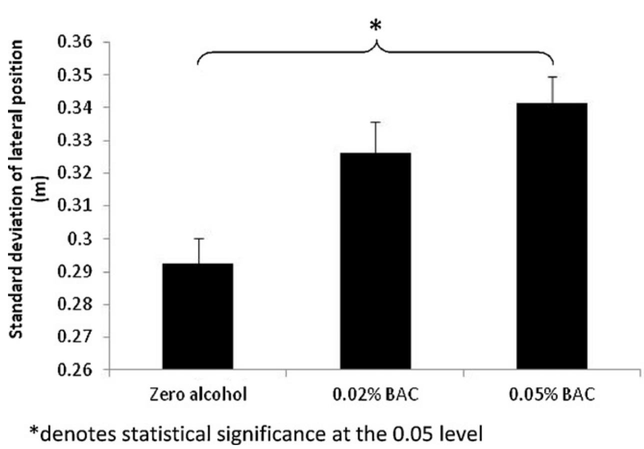

Fig. 4. Standard deviation of lateral position (SDLP) in the urban scenario (error bars represent standard error). *denotes statistical significance at the .05 level.

Table 2
Number of collisions and relative odds of collision with the unexpected pedestrian in the urban scenario (reference group = sober group).

	Zero alcohol	0.02%	0.05%
Experienced no collision (frequency)	18	13	14
Experienced collision (frequency)	2	6	6
Novice no collision (frequency)	15	11	14
Novice collision (frequency)	5	9	6
Relative odds (reference 'Sober')	–	2.96*	2.04

* Significant at the .05 level.

3.6. Hazard perception—peripheral detection task (PDT)

Throughout the rides participants were required to respond to a PDT. A response was considered to be a 'miss' in instances where the participant did not respond to the PDT stimuli within six seconds (3.9% of all PDT presentations). In calculating average reaction times, missed stimuli were not included, as this was determined to be preferable to including an artificial reaction time.

Due to technical difficulties reaction times were not recorded for two novice riders in the urban scenario and one experienced rider in the rural scenario. There was a significant main effect of Dose on PDT reaction time in the rural scenario, $F(2, 74) = 3.64$, $p < .05$,

Table 3
Collisions and relative odds of collision with the unexpected pedestrian in the urban scenario (reference group = experienced, sober group).

	Collisions (frequency)	Relative odds (reference 'Experienced, sober')
Experienced sober	2	–
Experienced 0.02%	6	4.15
Experienced 0.05%	6	3.86
Novice sober	5	3.00
Novice 0.02%	9	7.36*
Novice 0.05%	6	3.86

* Significant at the .05 level.

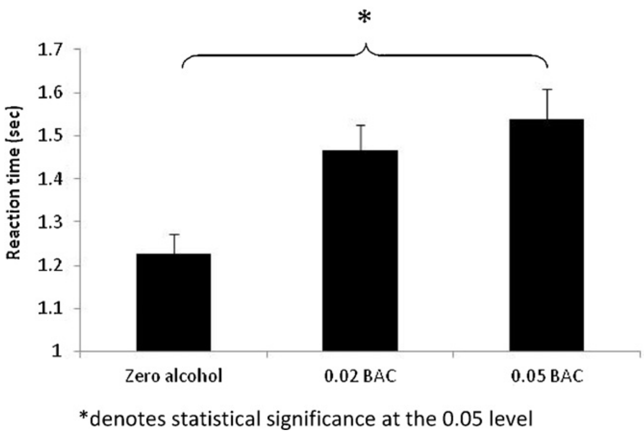

Fig. 5. Effect of dose on reaction time to the peripheral detection task in the rural scenario (error bars represent standard error). *denotes statistical significance at the .05 level.

partial $\eta^2 = 0.090$ (Fig. 5). Pairwise comparisons revealed a significantly slower reaction time at the 0.05% BAC dose compared with zero alcohol, but no significant difference between 0.02% BAC dose and zero alcohol or between 0.02% BAC and 0.05% BAC. Reaction time in the urban scenario was not significantly affected by Dose $F(2, 74) = 2.37$, $p = .101$, partial $\eta^2 = 0.062$. The moderate effect size in this case indicates that increasing BAC tended to slow reaction time in the urban scenario, although the difference was non-significant. There were no significant interactions between Dose and Experience in either riding scenario, nor a significant main effect of Experience.

3.7. *Subjective workload*

Scores on the modified NASA-TLX were used as an indicator of subjective workload. There was a significant effect of Dose on overall subjective workload ratings in the urban scenario, $F(2, 76) = 8.30$, $p < .01$, partial $\eta^2 = 0.179$ (Fig. 6). Pairwise comparisons showed both alcohol conditions to be associated with significantly greater ratings of workload than the zero alcohol condition ($p < .05$); however, workload scores for the two alcohol doses did not differ significantly from one other. There was no significant effect of Dose on workload ratings in the rural scenario.

In the urban scenario there was a non-significant trend towards a main effect of Experience on workload ratings, $F(1, 38) = 3.34$, $p = .076$, partial $\eta^2 = 0.081$, suggesting that novice participants

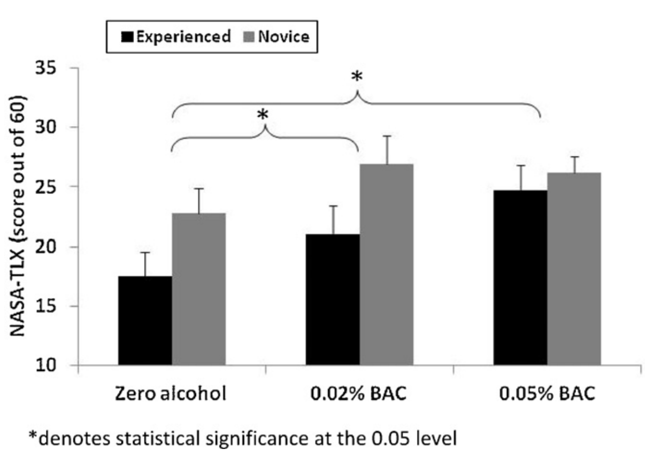

Fig. 6. The effect of BAC condition on subjective workload in the urban road environment (error bars represent standard error). *denotes statistical significance at the .05 level.

(mean = 25.3, s.d. = 7.7) may have experienced greater subjective workload than experienced participants (mean 20.5, s.d. 8.8) in this scenario. There were no significant interactions between Dose and Experience in either scenario.

3.8. *Eye tracking*

The percentage of total ride time that a participant's gaze was focused on the road vs. on the speedometer was calculated. There was no effect of Dose or Experience on the percentage of time spent looking at the speedometer in the urban or rural scenario.

4. Discussion

The ingestion of low doses of alcohol (0.02%, and 0.05% BAC) by novice and experienced riders resulted in increases in subjective ratings of intoxication and impairment of some measures of vehicle handling skills and hazard perception compared to a zero alcohol condition. These effects tended to be most significant at the highest (0.05% BAC) dose. These findings are consistent with previous studies investigating low dose alcohol in motorcyclists (Colburn et al., 1993; Creaser et al., 2009).

The increase in subjective ratings of intoxication as alcohol dose increased is promising, since participants correctly rated that they were most intoxicated at the 0.05% BAC dose and least intoxicated when sober. The ability to perceive impairment is vital as it could potentially assist riders when they are faced with the real-world decision about whether it is safe to ride.

Standard deviation of lateral position (SDLP) was sensitive to the effects of alcohol in the urban scenario. Both novice and experienced participants deviated within the lane significantly more under 0.05% BAC than in the zero alcohol condition. This impairment is in line with the results of a previous test track study (Creaser et al., 2009) that found variability of lateral position to increase with low dose BAC while riding a curved circuit and during an emergency stop task. However, low dose BAC in the present study did not affect SDLP in the rural environment. It is possible that the relatively greater overall lane position variability observed in the rural environment, which was due to the more curved trajectory, may have masked any detrimental effects of alcohol on this measure.

Hazard perception ability, as measured by responses to a PDT, was impaired following alcohol ingestion in the rural scenario. Response times were significantly slower in the 0.05% BAC condition compared to both zero alcohol and 0.02% BAC. Although a similar trend occurred in the urban scenario, it was not statistically significant at the $p < .05$ level. Further, the odds ratio of participants colliding with the unexpected pedestrian in the urban scenario increased three-fold at 0.02% BAC compared to when sober. Collectively, these findings support previous research which has demonstrated impaired reaction times as a result of alcohol consumption at similar tasks using a test track protocol (Creaser et al., 2009). The curent findings are also consistent with the effects on simulated car driving at higher BACs (Lenné et al., 1999; Leung and Starmer, 2005).

SDLP in the rural scenario did not increase with increasing BAC. These results were unexpected considering that Creaser et al. (2009) reported a significant main effect of alcohol on curve navigation. However, comparison tests in Creaser et al. (2009) did not reveal a significant difference between 0.05% BAC and zero alcohol. The lack of difference in the current study may suggest that vehicle handling skills are maintained at the expense of hazard perception. In contrast, in the urban scenario SDLP was impaired in the 0.05% BAC condition while, at the same time, hazard perception did not show a significant decline. This suggests that riders may retain either their general riding ability *or* their hazard perception ability following low-dose alcohol consumption. If riding ability is maintained, then a consequence may be slower response times to potentially safety critical events.

In the context of driving, previous research has found visual scanning patterns to deteriorate with a low dose BAC of 0.08% (Leung et al., 2003). The current visual scanning results do not support these findings as the proportion of time that riders spent looking at the speedometer compared to the road ahead was similar across all BAC conditions. This suggests that the current study's participants were able to maintain their pattern of visual scanning despite increasing BAC. However, Leung et al. (2003) did not use an eye tracker; their findings were based on responses to images presented in participants' peripheral vision. It is not possible to determine whether the visual scanning of motorcyclists is less affected by positive BAC than drivers or rather if differences are due to the different methodological approach used. Additionally, the lower doses used in the current study may not have been enough to induce the impairment reported by Leung et al. (2003).

A secondary aim of this study was to examine whether low dose alcohol impairs riding performance to a greater extent in novice, in comparison to experienced, riders. In the rural scenario, novice participants rode significantly faster than experienced participants regardless of BAC, and the same trend approached significance ($p = .076$) in the urban scenario. In the urban scenario, novice participants showed greater deviation in speed and higher maximum speeds compared to experienced participants. Since our study did not separate the confounding influence of age and experience, it is possible that age rather than riding experience accounts for the differences in performance. However, within the context of road safety, the effects of age are predominantly seen among teenage drivers (i.e., those aged 16–19 years) and the average age of riders in the current study was 27. Beyond the teenage years, a driver's inexperience has more significant implications than age (Mccartt et al., 2009).

Novice riders were at statistically significant increased (7.36) odds of colliding with an unexpected pedestrian in the urban environment compared to sober, experienced, riders. In comparison, the relative risk of an experienced participant at 0.02% BAC colliding with the pedestrian was 4.1 times (ns) greater than a sober, experienced rider. A possible explanation for the greater risk of collision for novice participants may be as a result of the greater deviation of speed within this group. It is not possible to determine whether the increased variation in speed is due to a more erratic choice of speed or to a reduced ability to control speed in novices compared to experienced riders. Alternatively, as the main effect of 0.02% BAC on the odds of colliding with the pedestrian was also statistically significant, it is possible that that experienced participants were also impaired to some degree at this alcohol Dose (supported by the observed, non-statistically significant, increased odds of collision among this group). It is possible that the lack of statistical significance of the odds of 0.02% BAC in experienced drivers increasing the likelihood of collision is because of the small number of collision events recorded.

Collisions were rare; in total only 15 riders collided with the pedestrian under 0.02% BAC and 12 under 0.05% BAC. If future research is to consider the specific impairment of collision in cases of unexpected events a larger sample size may be necessary to ensure a sufficient number of these rare events occur. Although conclusions from this analysis cannot be certain, it is beneficial to include them because of the high implications of such events. It is not possible to say for sure that 0.02% BAC is more dangerous than 0.05% BAC but what is certain from this analysis is that riding under 0.02% BAC should be further investigated as this legal alcohol dose may potentially cause impaired response to hazards.

The limitations of the current study should be acknowledged. The alcohol was administered in a controlled scenario; drunken behaviour is more likely to occur when alcohol is consumed in a social scenario (Fromme and Dunn, 1992). This suggests that, in a real situation, riding impairment may be more significant than observed in the current study. Riding performance was assessed using a simulator as this is considered to be a safe environment in which to test the effects of alcohol. It is possible that, because participants were in no real danger, they may have ridden in a riskier manner than they would have on real roads. However, use of a repeated measures design should have motivated participants to ride equally safely across the three test conditions. Unexpected pedestrian events were presented in each urban ride, so it is possible that participants responded faster because of a learning, or order, effect. To reduce the likelihood of an order effect, unexpected pedestrians were programmed to appear at different points in each ride. Analysis showed no effect of ride order on PDT response times, so effects were consistent across conditions. Finally, the motorcycle was fixed in a static, vertical position, which may limit the generalisability of the observed results to real world riding. When riding a real motorcycle, steering is achieved through a combination of leaning (tilting) and movement of the handlebars. Due to the impracticalities of enabling tilting of the simulator in a safe manner, it was decided to fix the motorcycle base in place. All participants completed a practice ride prior to the test rides to ensure they were comfortable with the controls of the simulator, however, and none reported any unease.

The impairment effect of 0.05% BAC on measures of vehicle handling was more consistent compared to 0.02% BAC. It appears fair to say, therefore, that 0.05% BAC impairs riding performance. Although there was evident impairment at 0.02% BAC for some riding performance measures, there was no effect, or even a positive effect, on some other measures, demonstrating the complexity of the relationship between low-level BAC and riding performance. Not all of the results in the current study were statistically significant at the $p < .05$ level. Nevertheless, it was felt important to report all results due to the potentially devastating consequences in the real world. For many results where statistical significance was not quite achieved, a moderate effect size has been reported. Moderate effect size suggests that non-significant results should not be dismissed as a moderate effect size indicates and increased likelihood that statistical significance may be reached with a larger sample size. These results therefore suggest that future research on the effects of intermediate (i.e., 0.025–0.045%) BAC level on riding performance would be worthwhile. Furthermore, the contrasting findings between urban and rural scenarios are of particular interest. Future studies could be designed to compare vehicle handling skills and concurrent PDT performance in different road environments with the aim of establishing contributing factors at different levels of impairment. An alternative approach for future research would be to investigate fatigue or time-of-day effects. Positive BACs are more likely to be observed when roadside breathalyser testing is carried out at night (Kasantikul et al., 2005; Jama et al., 2011), which introduces rider sleepiness or fatigue as a potential factor that was not considered in the scope of the current study. Simulated driving impairment due to alcohol consumption has been shown to be exacerbated by the added pressure of sleep restriction (Horne et al., 2003). In an effort to minimise any confounds associated with fatigue or time-of-day effects, the current study was conducted during the day. It is possible that effects of low doses of alcohol on riding performance would be more significant if a study was conducted at night time.

Results from the present study have implications for real world motorcycle riding and related road safety policy. Riding performance and hazard perception ability were shown to be impaired by 0.05% BAC. Twenty-five percent of WHO member countries have a legal BAC limit of 0.06% or higher (WHO, 2004). It is probable that any impairment evident at 0.05% BAC will be apparent and likely exaggerated at 0.06% BAC or higher. Further research would be beneficial to assess the appropriateness of current worldwide BAC limits for improving road safety. Another avenue for future research would be to conduct a similar study in car drivers, particularly in those jurisdictions outside of Australia where zero BAC limits do not apply to young, novice drivers.

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