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**Author**

Irwin, Christopher, Leveritt, Michael, Shum, David HK, Desbrow, Ben

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**Title:**

**Mild to moderate dehydration combined with moderate alcohol consumption has no influence on simulated driving performance**

**Authors:**

Christopher Irwin <sup>(1)</sup>, Michael Leveritt <sup>(2)</sup>, David H.K. Shum <sup>(3)</sup>, and Ben Desbrow <sup>(1)</sup>

- 1. School of Public Health & Centre for Health Practice Innovation, Griffith Health Institute, Griffith University, Gold Coast, Queensland 4222, Australia.*
- 2. School of Human Movement Studies, The University of Queensland, St Lucia, Brisbane Queensland 4072, Australia.*
- 3. School of Applied Psychology & Behavioural Basis of Health Program, Griffith Health Institute, Griffith University, Brisbane, Queensland 4122, Australia.*

**Corresponding Author:**

Chris Irwin

School of Public Health

Griffith University

Gold Coast Campus

Queensland, Australia, 4222

Ph. +61 7555 27708

Fax: +61 7555 28679

c.irwin@griffith.edu.au

## ABSTRACT

**Objective:** Many people consume alcoholic beverages following a period of physical activity that results in fluid loss through sweating (e.g. after sport, work). Adequate rehydration following physical activity may not occur, consequently resulting in the consumption of alcohol in a dehydrated state. This may have serious implications for the safety of individuals operating motor vehicles. Therefore, this study investigated the impact of mild-moderate dehydration in combination with moderate alcohol consumption on simulated driving performance.

**Methods:** Fourteen healthy males participated in a placebo-controlled cross-over design study involving 4 experimental trials (separated by  $\geq 4$ d). In each trial, participants were dehydrated by  $\sim 2\%$  body mass through exercise. After a 30 min recovery, participants completed a 15 min computerised simulated driving task (drive 1). In two of the trials, participants were provided with water equivalent to either 50% or 150% body mass loss and also received salt capsules (NaCl, 50mmol/L). A set volume

of alcohol or placebo was then consumed in each trial, incorporating the conditions: dehydration-placebo (DP), dehydration-alcohol (DA), partial rehydration-alcohol (PA), and full rehydration-alcohol (FA). The volume of the alcoholic beverage was individually calculated and intended to raise BAC to ~0.05%. The same driving task was then re-administered (drive 2). Primary outcome measures of driving consisted of standard deviation of lateral position (SDLP), number of side and centre line crossings (LC), number of failures to stop at red traffic signals (FTS), number of impacts/collisions with other vehicles or objects (IMP), and time to collision with a specified lead vehicle (TTC). In addition, reaction time (RT) and incorrect inhibition response (IIR) behaviour to critical events were collected throughout each experimental drive. Subjective ratings of mood and estimates of alcohol intoxication and driving impairment were also recorded in each trial.

**Results:** No effects of trial condition were observed on any of the driving performance measures or on subjective ratings of mood, alcohol intoxication, and driving impairment. Standard deviation of lateral position (SDLP) was higher following the consumption of alcohol compared to the placebo trial. However, no differences in SDLP were recorded between the alcohol trials, indicating that hydration level had no observable interaction with alcohol to influence SDLP performance.

**Conclusions:** Overall, it appears that dehydration does not exacerbate impairment in driving performance caused by mild-moderate alcohol intoxication. Further research is required to clarify the effects of alcohol and dehydration at various alcohol doses.

*Key Words: Ethanol, Hypohydration, Rehydration, Driving Performance*

## INTRODUCTION

The detrimental effects of acute alcohol consumption on driving performance and associated automobile related accidents have been well documented (Blomberg et al. 2005; Connor et al. 2004; Moskowitz and Fiorentino 2000). Alcohol impairs judgement and physical abilities on discrete tasks related to driving (Ogden and Moskowitz 2004) as well as actual driving performance (Moskowitz and Fiorentino 2000; Moskowitz and Robinson 1988). While there is some evidence that alcohol induced impairment begins at very low alcohol concentrations of 0.01 - 0.02% (Moskowitz and Burns 1990; Ogden and Moskowitz 2004), others suggest a threshold of 0.05% exists for alcohol related impairment (Mitchell 1985). Evidence from these studies has contributed to the development and application of blood alcohol limits for driving.

Using computer-based driving simulators, moderate doses of alcohol ( $\geq 0.05\%$  blood alcohol concentration (BAC)) have been associated with increased driving errors; including greater deviation in lateral position, more lane boundary line crossings, and greater rate of steering wheel movement (Fillmore et al. 2008; Harrison and Fillmore 2005; Helland et al. 2013; Marcziński et al. 2008), greater deviation in driving speed and acceleration (Fillmore et al. 2008; Marcziński et al. 2008; Quillian et al. 1999), prolonged reaction times to perform tasks (Liguori et al. 1999; West et al. 1993), increased stopping failures to red traffic signals (Fillmore et al. 2008) and more driving related accidents (Creaser et al. 2011; Marcziński et al.

2008). High transferability has been reported between behaviours observed on driving simulators and actual road based vehicles (Bedard et al. 2010; Lee et al. 2003; Mullen et al. 2011). However, external validity is specific to the driving simulator and test scenarios employed. Whilst simulator validation is not always performed, studies that have employed validated driving simulators have demonstrated the important safety implications alcohol consumption has on driving performance, crash risk, and driving-related fatalities (Creaser et al. 2011; Mullen et al. 2011).

Adequate hydration is important to human health and cognitive function (Grandjean and Grandjean 2007; Lieberman 2010). Performance on discrete cognitive tasks relevant to driving (e.g. attention, reaction time) has been shown to be negatively influenced by acute dehydration (Secher and Ritz 2012). Reductions in cognitive performance are often observed with fluid deficits at or above 2% body mass loss (Lieberman 2007; Shirreffs 2009), with performance deteriorations comparable to those observed following alcohol consumption (Kenefick and Sawka 2007). Following consumption, alcohol is quickly distributed throughout the water content of the body. Given the overlap in proposed mechanistic actions on the central nervous system such as changes in neurotransmitter actions and altered blood flow (Kempton et al. 2011; Kempton et al. 2009; Volkow et al. 1988; Watson and Little 2002; Wilson and Morley 2003), the effects of alcohol under dehydrated conditions may be amplified resulting in greater deterioration of cognitive function. Many people consume alcoholic beverages following a period of physical activity (e.g. after sport, work). Given that population groups such as industrial workers are often challenged by hydration issues, and may consume alcohol after work (Irwin, Leveritt, & Desbrow 2013), this may have serious consequences

for the safety of these individuals operating motor vehicles following physical exertion and subsequent permissible alcohol consumption.

In a recent study, the effects of dehydration, moderate alcohol consumption, and rehydration on a range of discrete cognitive functions from the Cambridge Neuropsychological Test Automated Battery (CANTAB) were assessed (Irwin, Leveritt, Shum, et al. 2013). Alcohol consumption caused deterioration of choice reaction time, executive function and response inhibition, with greater performance decrements observed when participants were dehydrated compared to fully rehydrated conditions. The findings suggest that adequate rehydration following exercise induced fluid loss can attenuate alcohol-related deteriorations of cognitive function. However, to date the combined effects of dehydration and moderate alcohol consumption on simulations of real-world performance, such as driving, are lacking. Therefore, the aim of this study was to investigate if mild or moderate dehydration combined with moderate alcohol consumption causes greater impairment in simulated driving performance compared to the consumption of alcohol under fully rehydrated conditions following exercise. It was hypothesised that the alcohol induced effects on driving performance would be greater when participants were dehydrated compared to trials where they were partially or fully rehydrated.

## **METHODS**

## Participants

Fourteen healthy males ( $23.6 \pm 5.9$  y,  $74.34 \pm 10.48$  kg body weight (BW),  $177.9 \pm 6.4$  cm; (mean $\pm$ SD)) volunteered to participate in this study. The number of participants was selected following a sample size calculation for one typically assessed driving outcome measure (standard deviation of lateral position, SDLP) using G\*Power Version 3.1.7 software. The results of Marczinski et al. (2008) indicated SDLP differences between placebo ( $1.2 \pm 0.4$  ft) and alcohol ( $1.9 \pm 0.9$  ft) conditions in non-binge drinkers had an effect size of 0.9. To be conservative, we anticipated an effect size of 0.8 and with a power ( $1-\beta$ ) of 0.8 and  $\alpha=0.05$  the prediction calculated a sample size of 12 participants was required. Fourteen subjects were recruited to accommodate some attrition due to the experimental burden. Volunteers were recruited via information posters placed around the university campus, with eligibility criteria stipulating that they were male, aged between 18 and 44 y, and had a current Australian driving license. Participants had a regular history of alcohol consumption of  $5.2 \pm 3.7$  y. The self-reported intake of alcoholic beverages was equivalent to  $5.5 \pm 3.0$  standard drinks (based on the consumption of alcohol from a range of sources including beer, wine and spirits that contain 10 g of ethanol) and drinking frequency was reported as  $1.2 \pm 1.5$  times per week using the personal drinking history questionnaire (Vogel-Sprott 1992). All participants were fully informed of the nature and possible risks of the study before providing written informed consent. The investigation was approved by the Universities Human Research Ethics Committee (PBH/25/11/HREC) and the procedures were conducted in accordance with the principles outlined by the agreement of Helsinki.



## **Preliminary Testing**

Each participant visited the laboratory on five occasions. The first visit involved preliminary screening and a familiarisation with the driving simulator and procedures of the study. Participants completed a medical screening questionnaire that provided information on demographics, drinking habits, drug use, and physical and mental health status. Individuals with a self-reported psychiatric disorder, head trauma, or other central nervous system (CNS) injury were excluded from the study. Individuals were also excluded if their responses to the screening questionnaire indicated current drug use, including the use of recreational drugs and psychoactive medications (e.g. benzodiazepines). As an additional screen for alcohol dependence, volunteers with a score of 5 or higher on the Short-Michigan Alcoholism Screening Test (S-MAST) (Selzer et al. 1975) were also excluded from the study. Eligible participants then performed a familiarisation on the driving simulator using a similar scenario to those employed in the experimental drives, in order to minimise the impact of possible learning effects.

## **Experimental Design**

Each participant undertook four experimental trials (Fig. 1). The four experimental treatments were randomised via an incomplete Latin square design.

INSERT FIG. 1 ABOUT HERE

## **Pre-Experimental Procedures**

Experimental trials were separated by at least 4 days and were conducted at the same time of the day under similar environmental conditions ( $25\pm 2^{\circ}\text{C}$ , 70-80% relative humidity). Participants were asked to refrain from using recreational drugs and non-prescriptive medications for the duration of the study, abstain from alcohol for 24 h, and caffeine-containing substances and moderate-strenuous exercise for 12 h prior to each experimental trial. During the 24 h period immediately preceding the first trial, participants recorded all food and beverages consumed as well as any exercise completed. A food and exercise record with this information was supplied to each participant and they were asked to repeat this on the day prior to all subsequent trials. Compliance to the pre-experimental procedures was verbally confirmed by participants on arrival to the laboratory. On the morning of each trial, participants were provided with a standardised meal for breakfast (Energy =  $25.2\pm 3.8$  KJ/Kg BW, CHO =  $0.9\pm 0.1$  g/Kg BW, Fat =  $0.2\pm 0.0$  g/Kg BW) which included a breakfast bar (Sanitarium one square meal, Australian Health & Nutrition Ltd.) and 200ml of apple juice (Just Juice, LD&D Australia Pty Ltd.). All dietary preparation and analysis was performed using Foodworks<sup>®</sup> Version 6.0, 2009, (Xyris Software, Australia) dietary analysis software.

## **Experimental Procedures**

Participants arrived at the laboratory fasted at ~0700-0800 h. Compliance to pre-experimental conditions was verbally acknowledged on arrival before a urine sample was collected to calculate urine specific gravity ( $U_{sg}$ ) as an initial measure of hydration status. Participants that recorded a  $U_{sg}$  reading  $>1.02$ , indicating some level of pre-existing hypo-hydration were provided with additional water until a urinary sample fell below the accepted threshold. Five participants required water (500-750ml) on a total of 7 occasions. Baseline measures of breath alcohol concentration (BrAC) and tympanic temperature ( $T_t$ ; Braun ThermoScan<sup>®</sup>, Welch Allyn) were taken and a baseline blood glucose (BGL) measure was recorded using a finger prick sample (Accucheck Advantage II<sup>®</sup>, Roche) before participants were provided with the standardised breakfast to consume in 30 min. Immediately following breakfast participants completed a subjective mood rating scale (MRS) questionnaire (Bond and Lader 1974) using a computerised visual analogue scale (Marsh-Richard et al. 2009). Participants were then asked to void their bladder completely and an initial nude body weight was measured.

After the body weight, dehydration was induced by intermittent exercise on a cycle ergometer (Monark, Ergomedic 828E, Vansbro, Sweden) at an intensity corresponding to 70-80% of age predicted maximum heart rate (220bpm - age). Details of the dehydration protocol have been outlined elsewhere (Irwin, Leveritt, Shum, et al. 2013). After a period of recovery from the exercise protocol, a computerised driving simulation task was used to measure driving performance (drive 1), which lasted for ~15 min. On completion of the driving test participants were either provided with no water (D), a small amount of water equivalent to 50% body mass loss (P), or a large amount of water equivalent to 150% body mass loss (F), consumed over a 2 h

time period. In addition, participants received 50mmol/L of sodium (given as NaCl capsules) in trials where water was consumed. Nude body weight was recorded each hour during the rehydration stage for all trials. Immediately prior to providing measures of nude body weight, participants were asked to void any urine, which was collected in containers and subsequently weighed to calculate cumulative urine loss.

Following the rehydration phase, participants consumed a beverage containing alcohol (A) or placebo (P) to incorporate four experimental conditions: dehydration-placebo (DP), dehydration-alcohol (DA), partial rehydration-alcohol (PA), and full rehydration-alcohol (FA). Alcohol was administered as vodka (Vodka O<sup>®</sup>, 37% v/v ethanol) made up with equal parts of non-alcoholic ginger beer cordial concentrate (Bickfords<sup>®</sup>, Australia) and diet ginger beer soft drink (Bundaberg Brewed Drinks Pty Ltd<sup>®</sup>), and one tenth the volume of lime cordial (Bickfords<sup>®</sup>, Australia). The volume of the alcoholic beverage was individually calculated and intended to raise BAC to ~0.05% (Watson, et al., 1981). In Australia, the legal blood alcohol limit for the operation of a motor vehicle is 0.05%. The placebo beverage was identical to the alcoholic drink however water was substituted for vodka. Details of the placebo beverage have been described elsewhere (Irwin et al. 2011). Participants were not informed of a placebo trial and expected to receive alcohol in all trials. The drink was consumed at a steady pace over 10 min. At the time of drinking the beverage, participants were asked to complete a tasting questionnaire as a measure of expectancy manipulation. The drinks were rated by perceived alcohol concentration (no alcohol, low alcohol, moderate alcohol, high

alcohol) and certainty of perception (not at all certain, somewhat certain, very certain, absolutely certain) using 4-point Likert scales.

Breath alcohol concentrations (BrAC) were analysed using a police grade Alcolizer LE breathalyser (Alcolizer Pty Ltd) with measurements taken 15 min and 30 min post ingestion. All breathalyser measurements were taken in duplicate, with a triplicate measure recorded if readings differed by  $\geq 0.005\%$ . The measures were averaged to provide the final assessment of BrAC. Participants were not informed of their BrAC measures until after completion of the entire study. Just prior to the 30 min breathalyser, a final MRS and a subjective impairment and intoxication scale (SIIS) were completed using computerised VAS questionnaires. A final BGL was also taken at this time. Immediately after the 30 min breathalyser, a second computerised driving simulation test was completed (drive 2) before a final BrAC, urine volume and body weight was recorded (~45 min post ingestion).

## **Driving Simulator**

A computerised driving simulation task was used to measure driving performance (SCANeR studio simulation engine – v1.2r95, OKTAL, Paris, France). The driving simulator was a fixed based model with original controls (accelerator and brake pedals, steering wheel, seat, safety belt, indicator, automatic gear shift, and hand brake) from a Hyundai Getz linked to

dedicated graphics computer equipment. Visual images were displayed on three 32-inch LCD monitors using three channels, set to provide a 100° front field of view (Fig. 2). A rear scene was displayed using a single channel on the central monitor to provide images associated with that produced by a typical car rear view mirror. Images from the simulation software were refreshed at a rate of 60Hz, with data sampled at a rate of 20Hz. Auditory and haptic feedback were provided using a stereo sound system and force feedback steering. The simulator also produced vibrations through the driving seat from a four channel sound system to provide a sense of motion. During each of the simulated driving tests, kinematic and behavioural data of the controlled vehicle was recorded by the simulator's software program, which included measures of lateral position, speed, pedal use, and steering wheel movements. SCANeR studio simulator software is equipped with an analysis module allowing recordings of each drive to be collected, which can subsequently be replayed as a video file to view the entire driving scenario or converted to a spreadsheet data set allowing analysis of mathematical determinants from the vehicle model.

INSERT FIG. 2 ABOUT HERE

The simulated vehicle used automatic transmission and for each drive participants were instructed to stay in the centre of the left-hand lane (traditional for Australian motorists) and adhere to all normal road rules and speed signs. A GPS included in the scenarios provided audio and visual directions (arrow) for the itinerary participants were required to follow. Crashes into

other vehicles resulted in the program being reset, with the driver placed in the centre of the left lane at the point of the crash and then allowed to resume the driving task. Because simulator sickness is often an issue in driving simulator studies (Brooks et al. 2010), participants were instructed prior to each drive if they experienced any symptoms of sickness whilst driving the simulator, to immediately cease driving and inform the researcher of their condition.

## **Experimental Drives**

Participants drove an itinerary defined course of 10 km, which required approximately 15 min to complete. The driving scenario was set during daylight conditions and comprised six main sections (Table 1). Other vehicles and pedestrians were present in the scenario but were not set to actively interact with the participant's vehicle. Critical events were included at random intervals within the scenario to test participant's reaction time and response inhibition behaviour. To reduce the predictability of the critical events, four parallel scenarios were used, with the events occurring in different sections of the driving task for each version. In addition, the four parallel versions of the driving test scenario were randomly assigned to the trials for each participant. The initial 3km of each experimental drive was set to allow participants a period of re-familiarisation. During this 3 km re-familiarisation section, participants experienced two reaction time critical events and two response inhibition critical events. Recording of driving performance data commenced after the 3 km re-familiarisation.

The experimental drives were intended to assess naturalistic driving performance, with the exception of reaction time and response inhibition tasks, in order to increase the application of the investigation to real-world driving. As such, participants were given minimal instructions on how to drive during the scenarios, and were provided no task priorities, incentives or performance feedback.

INSERT TABLE 1 ABOUT HERE

## **Driving Performance Measures**

Several pre-defined primary measures of driving performance were obtained during the experimental drives. Table 2 provides a list and description of each of the performance variables recorded. The driving aspects that were measured were chosen on the basis of their established sensitivity to the disruptive effects of alcohol as demonstrated in previous research (Fillmore et al. 2008). These measures provide a method of assessing vehicle control or the degree of weaving of the car on the road (SDLP, LC), violation of driving regulations (FTS), and interactive traffic behaviour (IMP, TTC) which are associated with driving safety and increased risk of traffic accidents (Retting et al. 2003; Verster and Roth 2011). In addition, reaction time and response inhibition behaviour to critical events were collected throughout each experimental drive.



INSERT TABLE 2 ABOUT HERE

## **Reaction Time Events**

During each experimental drive, participants were required to respond to stimuli on five occasions in order to test reaction time. For each reaction time event, the stimulus was the presentation of a stop signal image on the right side of the centre screen. Participants were instructed to brake as quickly as possible when the stimulus appeared. Once they had come to a complete stop, the stimulus disappeared from view and participants could resume driving.

## **Response Inhibition Events**

During the experimental drive, participants were presented with a response inhibition task on five occasions. For each event, a stop signal image was presented on the right side of the centre screen. A short auditory tone was played after a 400 ms delay on visual presentation of the stimulus. Participants were instructed to withhold their usual brake response to the stop signal stimulus if they heard the auditory sound. This test provided a measure of participant's ability to inhibit a pre-potent response.

## **Headway Events**

On one occasion during the experimental drive, participants encountered a vehicle placed on the road ahead of them travelling at a speed set 10 km/hr below the designated speed limit (100 km/hr). This event was set to occur at a pre-defined location in each test drive scenario. The road was a single carriageway section with solid centre line markings to avoid having the participant overtake and pass the vehicle. The lead vehicle was present for the headway event until the next intersection and required participants to follow for a total distance of 1.5 km. This event was used to examine participant's car following behaviour, with time to collision (TTC) between the interactive vehicle and back of the vehicle ahead measured for the duration of the following task. Participants were not provided with any instructions on how close to follow the lead vehicle.

## **Red Traffic Signals and Stop Signs**

During the experimental drives, participants encountered 15 intersections. One intersection had a stop sign and required the driver to stop completely before resuming driving and passing through the intersection. The other 14 intersections were equipped with traffic lights. At five of the intersections, the traffic light was red and required the driver to stop until the light turned green. At three intersections the traffic light was green and did not require the driver to stop. At the remaining six intersections, the light turned from yellow to red as the vehicle approached with enough time and distance for the driver to stop at the intersection. Order of the traffic lights was randomly allocated throughout each test drive scenario. Failing to stop at

intersections with the stop sign, red traffic lights, and traffic lights that changed from orange to red as the vehicle approached were recorded as a failure to stop performance measure (total stops required = 12).

## **Subjective Ratings**

Adaptive Visual Analogue Scales (AVAS) were used to assess mood (Bond and Lader 1974), and subjective ratings of intoxication and impairment (Fillmore 2001; Harrison et al. 2007). Each scale was administered using a computerised modifiable software program - AVAS (Marsh-Richard et al. 2009) on the screen of a laptop computer.

The mood rating scale consisted of five separate analogue scales. These scales have been used in previous research and relate to a factor of mood representing alertness (Bond and Lader 1974). Participants were presented with a 100mm line, the ends of which were marked with antonyms (alert-drowsy, confused-clearheaded, well coordinated-clumsy, incompetent-competent, lethargic-energetic), and they adjusted the position of a cursor on each line using a mouse to indicate how they felt at that moment. The score was taken as the cursor position based on percentage of scale length.

The degree of subjective intoxication and impairment was measured on separate 100mm visual-analogue scales. Participants rated intoxication by how much they “feel the effects of alcohol” between anchors of ‘not at all’ and ‘very much’. Subjective impairment was estimated based on the degree to which participants felt their driving performance was impaired after drinking. Ratings were obtained on a scale between ‘no impairment’ and ‘extreme impairment’. Three driving-related

questions were also used to ascertain: (a) “How able are you to drive a car at this time?”, (b) “How willing are you to drive a car at this time?” and (c) “How willing are you to drive a car a short distance (less than 5km) at this time?” Ratings were reported between ‘not at all’ and ‘very much’. These scales have been used in other studies of alcohol and driving and are sensitive to the effects of the drug (Fillmore 2001; Fillmore et al. 2008; Harrison et al. 2007).

## **Statistical Analysis**

All statistical procedures were performed using SPSS for Windows, Version 21.0 (SPSS Inc., Chicago, IL). All measures were examined for normality and outliers. Planned comparisons were performed to test our specific hypothesis that alcohol induced effects on driving performance parameters would be greater when participants were dehydrated compared to those observed during rehydration trials. In this case, statistical analysis for each of the main dependent variables on the driving task were conducted using paired samples *t*-tests to compare drive 1 and drive 2 for each trial where data were normally distributed. On the non-normally distributed data, differences between driving tests were explored with the Wilcoxon matched pairs signed rank test. Comparisons between trials were conducted using one-way repeated-measures analysis of variance (ANOVA) for normally distributed data and pairwise comparisons were performed where significant main effects were present. On the non-normally distributed data, Friedman’s tests were performed to compare observations between trials and contrasts were explored with the Wilcoxon signed rank test. Scores derived from the MRS were subjected to a two-way ANOVA; Protocol

(DP, DA, PA, FA) x Time (first, second, third), with both as repeated measures factors. Post hoc analysis was performed on all significant  $F$  ratios ( $p < 0.05$ ). All other measures (comparisons between trials and across time for BrAC, physiological measures, level of hydration and body mass changes) were analysed by one-way repeated-measures ANOVA, and pairwise comparisons were performed where significant main effects were present. For all analyses, when main effects were obtained that required post hoc analysis, least significant difference (LSD) tests were used. When interactions were obtained, paired sample  $t$ -tests were used, applying the Bonferroni correction for multiple comparisons. Statistical significance was accepted at  $p < 0.05$ . All data are reported as mean  $\pm$  standard deviation.

## RESULTS

### **Trial Drink Ratings**

Under all trial conditions participants rated the beverage as having alcohol, indicating that the placebo beverage was effective in establishing a belief that alcohol had been received. There was no difference in certainty of perception between the trials, with participants reporting mean certainty ratings between ‘somewhat’ and ‘very’ certain under all conditions. Only one participant was able to correctly identify the placebo beverage as having no alcohol at the time of drinking. This participant was only ‘somewhat certain’ in their perception.

## Driving Performance Measures

All participants completed the experimental drives with no complications or simulator sickness reported. The performance of the 14 participants in the four experimental conditions are summarised in Table 3. A significant increase in SDLP was observed between driving tests (drive 1 vs. drive 2) for all alcohol trials (DA, PA, FA;  $p < 0.05$ ), with no difference noted between the drives for the placebo trial (DP;  $p > 0.05$ ). Mean reaction time to critical events and TTC increased in the DA trial after receiving alcohol and decreased in all other trials after consuming the beverage, however these differences were not significant ( $p > 0.05$ ). No other differences in measures of driving performance between experimental drives for each of the trials were observed.

Off road and other vehicle impacts were infrequent in this driving scenario. One participant recorded two impacts during drive 1 of the PA trial, and one impact in drive 2 of both the DP and FA trials. Two other participants recorded an impact each, one being in drive 2 of the DP trial and one being in drive 1 of the FA trial. The infrequency and low number of overall impact events throughout the study precluded statistical analyses for this performance measure.

INSERT TABLE 3 ABOUT HERE

## Mood Ratings

Table 4 shows the results of ANOVA analysis from the MRS questionnaires. A significant main effect for time was observed on all MRS scales and a significant protocol x time interaction was found for the well coordinated-clumsy scale ( $p < 0.05$ ). No significant main effect for protocol was found on any of the scales ( $p > 0.05$ ). Post hoc analysis revealed higher ratings of drowsiness at time 3 (drive 2) compared to time 1 (beginning of trial) for all trials ( $p < 0.05$ ). For the confused-clear headed scale, higher ratings of confusion were observed at time 3 (drive 2) compared to previous measures for all trials ( $p < 0.05$ ). On the well coordinated-clumsy scale, higher levels of clumsiness were observed at time 3 (drive 2) compared to previous times for all alcohol trials, and higher levels of clumsiness at time 3 compared to time 1 for the placebo trial ( $p < 0.05$ ). For the incompetent-competent scale, higher levels of incompetence were reported at time 2 (drive 1) and 3 (drive 2) compared to time 1 for all trials ( $p < 0.05$ ). For the lethargic-energetic scale, participants were less energetic at both time 3 and time 2 compared to time 1 ( $p < 0.05$ ), but there was no difference in ratings between the two driving times (time 2 and 3,  $p > 0.05$ ), indicating that participants driving performance measures were most likely not influenced by fatigue.

INSERT TABLE 4 ABOUT HERE

## **Subjective Intoxication and Perceived Ability to Drive**

Participants' subjective ratings of alcohol effects and level of impairment were not different between the three alcohol trials. Ratings for the placebo trial were significantly lower than alcohol trials ( $p < 0.05$ ), however, there was still some indication of alcohol effects and impairment reported for the placebo trial with mean values on these scales greater than zero. Participants reported that they were less able and less willing to drive a car following alcohol consumption compared to placebo, irrespective of hydration status ( $p < 0.05$ ).

## **Levels of Hydration and Body Mass Changes**

The exercise protocol was successful in achieving similar levels of dehydration between trials (Table 5). Significant differences in percentage of body mass loss were recorded between trials after rehydration had occurred ( $p < 0.05$ ). These differences remained significant with the final body weight measurement taken after test drive 2 ( $p < 0.05$ ).

INSERT TABLE 5 ABOUT HERE

## **Fluid Intake and Urine Volume**



Total fluid intake (including alcohol/placebo consumption) was significantly different between the two rehydration trials and between both rehydration and dehydration trials as expected ( $p < 0.05$ ). A significantly greater urine output was measured between both rehydration (PA and FA) trials and the dehydration (DP and DA) trials (Table 4,  $p < 0.05$ ). There was also a significant difference in urine output between the two rehydration (PA and FA) trials ( $p > 0.05$ ).

## Physiological Measures

As expected, tympanic temperature recordings indicated an increase in body temperature following exercise for all trials. Temperature measurements recorded prior to both Drive 1 ( $\sim 36.5 \pm 0.5^\circ\text{C}$ ) and Drive 2 ( $\sim 36.5 \pm 0.3^\circ\text{C}$ ) were significantly higher than pre-trial ( $\sim 36.1 \pm 0.4^\circ\text{C}$ ) measures for all trials ( $p < 0.05$ ), however the differences were not considered clinically significant and were generally within the error margins indicated for accuracy of the tympanic device ( $\pm 0.2^\circ\text{C}$ ). Blood glucose responses revealed that participants were never in a hypoglycaemic state when completing the test drives. Values were significantly higher at Drive 1 measures compared to pre-trial measures for the DA and PA trials ( $\sim 7.1 \pm 1.0 \text{ mmol/L}$  vs.  $\sim 6.4 \pm 0.9 \text{ mmol/L}$ ,  $p < 0.05$ ) but not for the DP and FA trials ( $\sim 7.1 \pm 1.3 \text{ mmol/L}$  vs.  $\sim 6.6 \pm 1.3 \text{ mmol/L}$ ,  $p > 0.05$ ). Following consumption of the placebo or alcohol beverage blood glucose levels increased significantly in all trials ( $\sim 10.0 \pm 1.4 \text{ mmol/L}$ ,  $p < 0.05$ ).

## Breath Alcohol Concentrations (BrACs)

No significant difference in BrAC was recorded between alcohol trials at any of the measured time points ( $p>0.05$ ). Breath alcohol concentrations achieved 30 min post alcohol ingestion when participants were required to complete the driving test were  $0.045\pm 0.006\%$ ,  $0.043\pm 0.003\%$ , and  $0.043\pm 0.006\%$  for the DA, PA and FA trials respectively. As expected, no measurable breath alcohol was detected for the DP trial (Fig. 3). The driving test was performed 30 min after drinking and lasted for 15 min. Final BrACs measured at the end of the driving test were not significantly different from pre-driving BrAC levels ( $p>0.05$ ) indicating that the task was performed when alcohol concentrations were relatively stable ( $0.045\pm 0.005\%$ ,  $0.044\pm 0.004\%$ , and  $0.044\pm 0.007\%$  for DA, PA, and FA trials respectively on completion of the driving test).

INSERT FIG. 3 ABOUT HERE

## DISCUSSION

To our knowledge the present investigation is the first to examine the impact of exercise induced dehydration and moderate alcohol consumption on simulated driving performance. Contrary to our hypothesis, no observable interactive effects were found between mild to moderate dehydration and moderate alcohol consumption on individual measures of driving performance. These results suggest that individuals' who consume moderate amounts of alcohol (eliciting a BrAC below

0.05%) following a period of physical activity causing fluid loss, are unlikely to experience further impairment in driving related performance than that observed with alcohol alone.

In this study, participants completed a 15-minute naturalistic driving task, in which measures of vehicle control (SDLP, LC), violation of driving regulations (FTS), interactive traffic behaviour (IMP, TTC), and other associated discrete tasks (RT, IIR) were assessed throughout. On measures of vehicle control, no observable effects of alcohol combined with various levels of hydration status were detected. Standard deviation of lateral position was higher following the consumption of alcohol irrespective of hydration status. However, in the placebo trial SDLP between driving tests was unchanged. These results support the findings of previous work in which a moderate dose of alcohol (~0.04%) has been shown to have a significantly positive correlation with SDLP (Helland et al. 2013). The absolute values in SDLP were also similar for both the placebo and alcohol conditions to those observed in previous driving simulator studies (Helland et al. 2013; Mets et al. 2011). Collectively, these results suggest that a moderate dose of alcohol (inducing BrACs between 0.04-0.05%) increases deviation in lane position. Standard deviation of lane position is regarded as a potential index of driving safety (Verster and Roth 2011) and increases in SDLP could potentially lead to lane crossings into adjacent traffic lanes or the road shoulder that may have severe consequences. However, one could argue that the magnitude of change observed following alcohol consumption in the present study (~2-3cm) may not have meaningful relevance in terms of traffic safety. Verster and Roth (2011) suggest a clinical relevant cut-off point of impairment for SDLP is important, with studies often using +2.4 cm at alcohol concentrations of

0.05% as comparative data. However these results refer to the standardised Dutch on-road driving test and Helland et al. (2013) observed considerably higher SDLP values in simulated driving compared to real driving using identical test scenarios. In addition, Helland et al. (2013) reported higher BAC-related increases in SDLP in simulated driving compared to real driving. Thus, whilst significant increases in SDLP were observed following alcohol consumption in the present study, these results may not directly translate to increases in real driving related accident risk.

Similar results were observed for number of line crossings during the driving tests. Whilst results were not statistically significant, the number of line crossings increased following the consumption of alcohol under all hydration conditions but was reduced in the placebo trial when directly compared to the initial driving tests. Previous work has reported more roadway departures and a higher number of centre and side line crossings following the consumption moderate alcohol doses (Arnedt et al. 2001; Fillmore et al. 2008). However, in these studies blood alcohol concentrations were higher than those in the current study (0.055-0.086%), which may explain the more definitive results observed. Absolute values for the number of line crossings were also much higher in the present study compared to previous studies. The relatively demanding driving scenario that was used in our experiment may account for these differences. Participants were required to complete a number of left and right hand turns during the drive, which may have led to more over and under steering, thus increasing the chances of deviating outside the driving lane and recording a line crossing. Taken together, this indicates that alcohol consumption is likely to

increase the number of line crossings, but the magnitude of any such increase may be dependent on the volume of alcohol consumed and the difficulty of the driving task.

No interactive effects between alcohol and hydration status were observed for violations of driving regulations and interactive traffic behaviour measures in this study. Guidelines for the safe driving of motor vehicles in Australia indicate that individuals should not drive closer than two to three seconds from the vehicle ahead in good driving conditions (Transport: Roads and Maritime Services 2012). No significant differences in TTC between the different trial conditions were observed and participants drove within the recommended guidelines for safe following behaviour under all trial conditions, indicating that participants were able to apply safe car following techniques regardless of hydration status or alcohol intoxication. Number of stopping failures was not different between drives for all trial conditions. Given that very few stopping failures were made under all trial conditions it is possible that decision errors or misjudgements by participants (they thought they could clear the intersection before the red light but failed) explain these results. An increase in stopping failures has been observed after alcohol consumption in previous work (Fillmore et al. 2008), however alcohol doses were considerably higher (~0.08%) than observed in the present study. Further investigation of hydration conditions with higher doses of alcohol on this driving performance measure is required.

Performance on discrete tasks such as reaction time and response inhibition critical events was not influenced by alcohol and hydration status in this study. Our previous work has shown that choice reaction time and response inhibition performance

is adversely affected when alcohol is consumed under dehydrated conditions, yet unaffected when adequate rehydration occurs prior to the consumption of alcohol (Irwin, Leveritt, Shum, et al. 2013). Whilst no significant differences were observed in this study, interestingly a small increase in reaction time was seen following alcohol consumption on the DA trial and small decreases were observed in all other trials. In our previous work, choice reaction time was assessed using an isolated task on the CANTAB instrument and alcohol intoxication levels were slightly higher during the performance task (~0.06%). The critical event task in the present study was more typical of a simple reaction time task, although the overall task demands may have been higher given that participants were required to perform the reaction tasks whilst driving. It is possible that the intoxication level attained in this study was not high enough to influence performance on these tasks. Alternatively, the critical events employed may not have been sensitive enough to detect significant changes between trial conditions.

Overall, the results of this study indicate that dehydration through sweat loss in combination with moderate alcohol consumption (to levels permissible with legal driving laws of Australia) does not influence measures of driving performance. However, these results may not be replicated at higher alcohol concentrations. Given that legal alcohol limits for driving are higher in other countries (e.g. 0.08% in the USA), and results from our previous work indicate effects on cognitive performance at slightly higher alcohol intoxication levels (Irwin, Leveritt, Shum, et al. 2013), it may be important to explore the effects of these conditions on driving performance with different doses of alcohol.

Hydration level did not have any effect on BrAC measures in this study. Similar results have been reported in our previous

work (Irwin et al. 2012; Irwin, Leveritt, Shum, et al. 2013). Interestingly however, whilst identical alcohol doses were used between studies, peak BACs achieved in the present study were lower than those from the previous study (~0.04% vs. ~0.06% respectively). An explanation for this is likely due to the differences in carbohydrate content of the alcohol containing beverage. Manufacturers for the ginger beer cordial concentrate used in the previous study no longer produced a sugar-free product. Thus for the current study we were required to use a regular sugar sweetened ginger beer mixer. Recent work by Marczinski and Stamates (2012) support these findings, reporting elevated BrACs when alcohol was mixed with a diet soft drink compared with the same amount of alcohol mixed with sugar-sweetened beverage.

Alcohol and dehydration have independently been associated with a deterioration in mood state (Heishman et al. 1997; Lex et al. 1988; Lieberman 2007; Shirreffs 2009). Human factors such as emotion and mood are likely to influence behaviours such as aggressive driving, thereby attributing to factors that cause traffic accidents (Hu et al. 2013; Matthews et al. 2011; Moller 2011). Previous work has found no effect of combined alcohol and dehydration conditions on subjective ratings of mood (Irwin, Leveritt, Shum, et al. 2013). Similarly, in this study no effect of trial condition was observed on subjective ratings of mood, indicating that hydration level had no observable impact on mood state when alcohol was consumed. Participants' rating of clumsiness was increased after the consumption of alcohol regardless of hydration status, which may suggest that the effects of alcohol outweigh the effects of dehydration on some subjective states. However, overall the results of this study suggest that subjective perceptions of effects from the different trial conditions were not instrumental in the inability to detect

observable changes in driving performance.

One of the limitations of the current study is that the study design did not include placebo protocols for the partial rehydration and full rehydration trials. It is therefore difficult to make accurate conclusions about the relative effects of hydration and alcohol on driving performance because the effects of alcohol and level of dehydration cannot be readily separated. Whilst it was not the intention of this study to investigate dose response effects, incorporation of a placebo arm under different hydration conditions may provide greater insight into the effects of these conditions. A limited sample size was also employed in this study, which may reduce the power of the results. However, due to the considerable time requirement and burden placed on participants, in addition to the exhaustion of resources, a larger sample size was not possible. The use of a repeated measures study design was employed to assist with statistical power and reduces the variance of estimates of treatment effects. This study also involved a naturalistic driving scenario, however, measures of reaction time and response inhibition were assessed throughout drives using discrete tasks that were hardly naturalistic. The use of these elements may not reflect performance in the real world, thus reducing the ecological validity of some results. Finally, studies comparing performance on this particular simulator with road driving measures have not been conducted. Thus, translation of results from the simulator into real-world driving performance outcomes cannot readily be made. Whilst it was not the intention of this study to compare driving performance to on-road driving, and rather compare the effects of hydration and alcohol treatments on changes in simulated driving performance, this remains a limitation of the current study and further research is required.



In summary, this study investigated the impact of mild and moderate dehydration combined with moderate alcohol consumption on measures of simulated driving performance. Results found no overall difference in driving performance between trial conditions and it appears that dehydration does not seem to have an effect in exacerbating impairment in driving performance caused by alcohol intoxication. However, alcohol doses used in this study produced intoxication levels (0.04%) slightly below the legal driving limit for Australian motorists (0.05%). Further research is required to clarify and establish the effects of alcohol and dehydration at different alcohol doses.

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**TABLES**

**Table 1.** Driving simulator scenario for experimental test drives

<b>Section</b>	<b>Description</b>	<b>Length (Km)</b>	<b>Configuration</b>	<b>Critical Events</b>
1	Re-familiarisation	3.00	2 lane single carriageway. 50, 80 & 100km/hr sign posted sections. 2 intersections with traffic signals, 1 intersection with stop sign. Few buildings and lightly landscaped areas. Light traffic present.	2 RI + 2 RT events
2	Highway 1	0.55	2 lane single carriageway. 80km/hr sign posted section. Few buildings and lightly landscaped areas. Light traffic	1 RI event



			present.	
3	City 1	0.70	4 lane dual carriageway. 50km/hr sign posted section. 5 intersections with traffic signals. Many buildings and highly landscaped areas. Moderate traffic present.	1 RT event
4	Rural / Suburban	2.20	2 lane single carriageway. 50km/hr sign posted sections. 4 intersections with traffic signals, 1 intersection with stop sign. Few buildings and lightly landscaped areas. Light traffic present.	1 RI + 2 RT events
5	Highway 2	2.60	2 lane single carriageway. 80 & 100km/hr sign posted sections. 1 intersection with traffic signal. Few buildings and lightly landscaped areas. Light traffic present travelling in opposite direction.	1 RI + 1 RT + 1 Headway* event
6	City 2	0.95	4 lane dual carriageway. 50km/hr sign posted sections. 4 intersections with traffic signals. Many buildings and highly landscaped areas. Moderate traffic present.	2 RI + 1 RT events

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Note: example of critical events provided is from test scenario 1. Parallel versions of test scenarios may have differed in arrangement of critical events. RI – response inhibition event, RT – reaction time event. \* Headway

event occurred in a section separate from RI and RT events. Light traffic – may encounter 2-3 other vehicles, Moderate traffic – may encounter 6-8 other vehicles.

**Table 2.** Driving simulator performance measures

<b>Performance Measure</b>	<b>Description</b>
SDLP	Standard deviation of the driver’s average within-lane position.
LC	When the interactive vehicle moved outside the lane, either crossing the centre line into the oncoming traffic lane (centre line crossings) or crossing the road shoulder (side line crossings). The total number of line crossings was recorded.
IMP	The number of off-road crashes (with objects in the environment) and impacts involving other vehicles during the test.
FTS	The number of times a participant failed to stop at a red traffic light or road stop sign throughout the test.
TTC	Time between the interactive vehicle and the back of any vehicle ahead, where a collision between the two vehicles would occur if the collision course and speed difference are maintained.

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RT                    Speed of responding to target stimuli during the driving scenario was measured by the participant's average reaction time.

IIR                    The number of times a participant applied the brake pedal when presented with the stop signal stimulus when an inhibitory auditory tone was also present.

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**Table 3.** Performance measures for experimental drives and change in performance ( $\Delta$ ) under each of the trial conditions

	DP			DA			PA			FA		
	D	Drive	$\Delta$	Drive 1	Drive 2	$\Delta$	Drive 1	Drive 2	$\Delta$	Drive 1	Drive 2	$\Delta$
SDLP (cm)	29	28.6 (4.2)	-0.5	28.2 (6.41)	30.5 (5.93) *	+2.3	27.6 (6.5)	30.5 (7.69)	+2.9	26.9 (4.70)	29.5 (5.78) *	+2.6
RT (ms)	1070	1071	-12	1062 (162)	1089 (186)	+27	1081	1061 (166)	-20	1083 (192)	1074 (123)	-9
LC (n)	16	15.4 (5.7)	-1.2	13.6 (7.02)	15.6 (6.60)	+2.0	14.4 (7.3)	15.7 (7.68)	+1.3	12.2 (4.79)	15.5 (8.50)	+3.3
TTC (s)	3.	3.09 (1.6)	0.48	3.14 (2.17)	3.35 (2.18)	+0.21	2.87 (1.0)	2.49 (1.47)	-0.38	2.87 (1.34)	2.77 (1.08)	-0.10
FTS (n)	0.	0.29 (0.4)	0	0.00 (0.00)	0.21 (0.43)	+0.21	0.36 (0.6)	0.21 (0.58)	-0.15	0.29 (0.61)	0.57 (0.76)	+0.28
IIR (n)	29	1.93 (2.17)	0.36	1.43 (1.87)	1.36 (2.02)	-0.07	1.36 (1.50)	1.36 (1.74)	0	1.00 (1.57)	1.57 (1.65)	+0.57

DP, dehydration-placebo trial; DA, dehydration-alcohol trial; PA, partial rehydration-alcohol trial; FA, full rehydration-alcohol trial. SDLP = standard deviation of lane position, RT = reaction time to critical events, LC = number of centre and side line crossings, TTC = time to collision with lead vehicle, FTS = number of failures to

stop at red lights and stop signs, IIR = number of incorrect inhibition responses to response inhibition critical events. \*Significant difference compared to Drive 1 measures ( $p < 0.05$ ). Values are mean (SD).

**Table 4.** Subjective mood rating scale ANOVA results

Scale	ANOVA		
	Protocol F(3,39)	Time F(2,26)	Protocol x Time Interaction F(6,78)
Alert-Drowsy	0.76	6.47 *	1.12
Confused-Clear Headed	0.45	11.47 *	1.01
Well Coordinated- Clumsy	0.35	26.87 *	3.20 *
Incompetent- Competent	0.53	16.33 *	0.71
Lethargic-Energetic	0.47	8.96 *	0.64

\* Significant main or interaction effect ( $p < 0.05$ ).

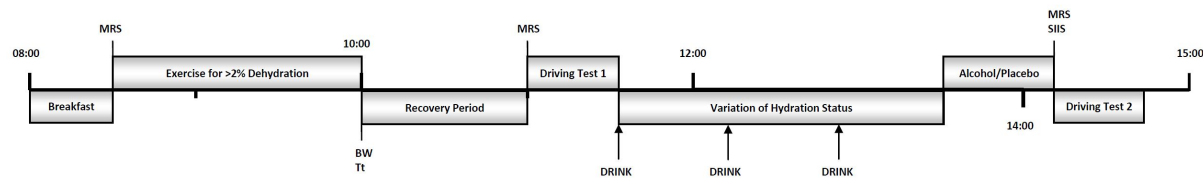
**Table 5.** Mean percentage of body mass loss compared with initial body weight measure and cumulative urine volume for each trial ( $n=14$ )

Trial	Mean percentage of body mass loss/gain (%)			Cumulative Urine Volume (ml)
	Post Exercise	Post Rehydration	Post Drive 2	
DP	-2.20 ± 0.31	-2.52 ± 0.37	-2.13 ± 0.40	166
DA	-2.16 ± 0.30	-2.50 ± 0.39	-2.13 ± 0.38	185
PA	-2.20 ± 0.44	-1.53 ± 0.37 *	-1.52 ± 0.58 *	452 *
FA	-2.21 ± 0.36	+0.06 ± 0.40 *	-0.57 ± 0.52 *	1334 *

DP, dehydration-placebo trial; DA, dehydration-alcohol trial; PA, partial rehydration-alcohol trial; FA, full rehydration-alcohol trial. \*Significant difference from all other trials ( $p<0.05$ ). Values are mean ± SD.

## FIGURE LEGENDS

**Fig. 1.** Experimental protocol design. Each participant underwent four experimental sessions. Driving Test 1 and 2 correspond to the two simulated driving performance assessments. MRS refers to administration of the mood rating VAS and SIIS refers to the administration of the subjective intoxication and impairment VAS. Drink corresponds to rehydration trials where 50% (P, partial) or 150% (F, full) of fluid loss is replaced.



**Fig. 2.** Setup of the driving simulator. Fixed base system with original vehicle equipment controls and the visual screen appearance.





**Fig. 3.** Breath alcohol concentration post beverage administration for each trial. DP, dehydration-placebo trial; DA, dehydration-alcohol trial; PA, partial rehydration-alcohol trial; FA, full rehydration-alcohol trial. Values are mean  $\pm$  SD.

