Title:

Effects of Alcohol Intoxication Goggles (Fatal Vision Goggles) with a Concurrent Cognitive Task on Simulated Driving Performance

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ABSTRACT

Objective: Fatal vision goggles (FVGs) are image-distorting equipment used to simulate alcohol impairment in driver education programs. Unlike alcohol, which disrupts cognitive processes, FVG only induces visual impairment. Performing concurrent cognitive tasks while wearing FVG may reduce the wearer's attentional resources and provide a better simulation of alcohol intoxication. This study examined the impact of wearing FVG with/without administration of a concurrent cognitive task on simulated driving.

Methods: Twenty-one males (23 ± 3 y, mean $\pm$ SD) participated in this randomized, repeated-measures study involving two experimental trials. In each trial, participants completed a baseline drive then an experimental drive under one of two conditions: (1) FVG, and (2) FVG with additional cognitive demand (FVG+CD). The driving test included 3 separate scenarios (Task 1, 2, 3) lasting ~5min each. Lateral (standard deviation of lane position [SDLP]; number of lane crossings [LCs]) and longitudinal control parameters (average speed; standard deviation of speed [SDSP]; distance headway; minimum distance headway) were monitored in Tasks 1 and 2. Latency to two different stimuli (choice reaction time [CRT]) was examined in Task 3.

Results: In Task 1, SDLP and LC were unaffected by either condition. However, SDSP increased significantly from baseline with FVG, irrespective of cognitive demand. In Task 2, distance headway decreased significantly from baseline with FVG, but increased significantly with FVG+CD. Minimum distance headway was significantly decreased, while SDLP increased significantly and LC increased (although not statistically significant) in both conditions relative to baseline. In Task 3, a significant increase in CRT occurred with FVG+CD, but not with FVG alone.

Conclusions: Wearing FVG negatively impacted simulated driving performance. However, effects were isolated to specific performance outcomes and were dependent on complexity of the driving task. Addition of a secondary cognitive task exacerbates the effects of FVG on select driving outcomes (i.e. lane position, SDSP), influences the effect direction on other measures (i.e. distance headway), and has a detrimental effect on reaction time to stimuli embedded in the scenario, that is not observed with FVG alone. Future studies using FVG as a surrogate means to alcohol intoxication should consider these results, informing methodological decisions to reduce potential for confounding effects.

Keywords: alcohol, impairment, driving, cognition, cognitive demand

INTRODUCTION

Research on the impact of alcohol consumption prior to driving has clear implications for public health and safety. Early investigations demonstrated impairment of discrete cognitive skills needed to operate a motor vehicle following acute alcohol consumption (Moskowitz & Robinson, 1988). For the past two decades, studies using more applied methodologies (e.g. simulated driving), have confirmed these effects, particularly when alcohol doses are moderate-large (Irwin, Iudakhina, Desbrow, & McCartney, 2017). Regardless of the approach, studies typically require participants to consume alcohol, which presents several challenges, including risk to participants' health, significant participant burden (e.g. recovery time) and demand on researchers to manage intoxicated participants. It also precludes investigations on young, inexperienced, pre-licensed and recidivist drink-drivers, where it is unethical/illegal to administer alcohol, but in whom understanding the effects of alcohol is critical.

An alternative approach is to provide a realistic simulation of alcohol impairment. Fatal Vision Goggles (FVG) are image-distorting equipment (Innocorp, Ltd., Wisconsin, USA) designed to simulate alcohol impairment (Hennessy, 2005). Fresnel and lenticular protrusions embedded in the lenses distort and shift the location of the image so wearers are unable to accurately perceive their surrounding environment. These visual disturbances induce motor impairment, loss of equilibrium and spatial disorientation, with anecdotal reports suggesting they impede performance on basic field-sobriety tasks (Hennessy, Lanni-Manley, & Maiorana, 2006). Early studies demonstrated FVG were effective at changing attitudes toward drink-driving (Hennessy, 2005; Jewell & Hupp, 2005; Jewell, Hupp, & Luttrell, 2004). More recently, studies have employed FVG to examine effects on driving (McCartney, Desbrow, & Irwin, 2017; Rumschlag et al., 2015; Shirazi & Rad, 2014). In two initial investigations, participants' driving deteriorated with FVG (Rumschlag et al., 2015; Shirazi & Rad, 2014). However, in both studies, driving impairment was based on subjective ratings (Rumschlag et

al., 2015; Shirazi & Rad, 2014) rather than objective performance outcomes. Furthermore, neither of the studies validated the FVG against an alcohol treatment prior to use. The most recent investigation examined the validity of FVG to produce alcohol-related driving impairment (directly comparing against alcohol) (McCartney et al., 2017). In this study, FVG (manufacturer's estimated BAC=0.070-0.100%) impaired driving similar to alcohol intoxication (BAC ~0.060%). However, comparable decrements were only observed on specific measures (i.e. standard deviation of lane position, SDLP) and in complex scenarios (i.e. curved roadways and car-following task). Such inconsistencies may be an artefact of FVG only providing a visual disturbance, rather than inducing a cognitive deficit. However, they may also be related to FVG providing a consistent visual disturbance, while the effects of alcohol are transient. Indeed, acute tolerance and protracted error may accompany the onset and recovery from moderate alcohol doses (Starkey & Charlton, 2014). Nonetheless, it highlights challenges associated with detecting effects of lower alcohol doses except in complex driving scenarios.

Alcohol causes changes in physiological functioning (other than visual impairment) that may disrupt cognitive processes required to safely operate a motor vehicle (Moskowitz & Fiorentino, 2000). Given FVG do not inhibit mental processing, the wearer could employ compensatory mechanisms; reducing the magnitude of driving impairment experienced. One potential approach to counteract this is to increase the cognitive demand of the task, by having the driver (wearing FVG) undertake concurrent cognitive duties. Thus, allocation of greater cognitive resources may reduce information processing capacity, thereby decreasing the driver's ability to compensate for the visual distortion.

The aim of this study was to examine the impact of wearing FVG with and without administration of a concurrent cognitive task on simulated driving performance. It was hypothesized that a decrement in driving would be observed when participants wore FVG

relative to baseline (no FVG), and that these effects would be exacerbated when driving under increased cognitive demand.

METHODS

Participants

Twenty-one healthy males (age: 23.5 ± 2.5 y, weight: 79.1 ± 13.0 kg; height, 178.7 ± 7.1 cm; mean $\pm$ SD) participated in this investigation. Participants had held an Australian drivers license for 4.6 ± 2.7 y. All participants received an explanation of the study requirements/risks before providing written consent. The study was approved by the University's Human Research Ethics Committee (AHS/57/14/HREC).

Preliminary Screening

Participants presented to the laboratory and completed a medical screening questionnaire. Individuals were excluded from the study if they indicated a psychiatric disorder, head trauma, CNS injury, or current use of recreational/psychoactive drugs. Eligible participants performed a 15min familiarization drive on the simulator prior to experimental trials to reduce practice effects (Irwin, Shum, & Desbrow, 2013). Because simulator sickness can occur with simulated driving (Brooks, Goodenough, Crisler, Klein, & Alley, 2010), participants were instructed to immediately cease driving if they experienced any symptoms. No reports of simulator sickness were made in the study.

Experimental Design and Pre-Experimental Procedures

This study employed a randomized, repeated-measures design involving two experimental trials. In each trial, participants completed a baseline drive then an experimental drive under either: (1) FVG or (2) FVG with additional cognitive demand (FVG+CD). Participants were to

abstain from alcohol for 24h, caffeinated beverages and strenuous physical activity for 12h and consume ~2-3L of water the day prior to assist with euhydration. In the 24h preceding the first trial, participants recorded their dietary intake and exercise activity. A copy of the record was given to the participant to repeat this behavior before the next trial.

Experimental Procedures

Participants arrived at the laboratory in a fasted (≥ 2 h) state and were breathalyzed to verify zero BAC. The Stanford Sleepiness Scale (SSS) (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) was administered to evaluate alertness. A urine sample was collected to determine urine specific gravity (U_{sg}) and verify euhydration ($U_{sg} < 1.024$) (Armstrong et al., 2010). Blood glucose levels (BGL) were determined using a finger-prick sample to confirm participants were not hypoglycemic ($BGL > 3.5$ mmol/L). Baseline driving performance was then assessed. Driving assessment was repeated following a 5min rest under one of the conditions. Computerized driving simulation tasks were used to measure driving performance (SCANeR studio simulation engine, v1.2r95, OKTAL, Paris, France). Details of the driving simulator have been outlined elsewhere (Irwin, Leveritt, Shum, & Desbrow, 2014).

Fatal Vision Goggles Condition (FVG)

Clear FVG (manufacturer's estimated BAC=0.070-0.100%) were used. Participants were familiarized to the equipment by completing simple sobriety tasks (i.e. walking a straight line) before commencing the drives. The visual distortion with FVG from a driver's perspective is illustrated in Fig. 1.

INSERT FIG 1 HERE

Fatal Vision Goggles with Cognitive Demand Condition (FVG+CD)

Participants were allocated a 30s period to memorize a 7-digit sequence of numbers and letters (e.g. 3w847dh). They then commenced the drives, wearing the FVG. Throughout the task, the investigator posed questions about the sequence and participants attempted to provide correct responses. Questions consisted of basic numerical calculations (e.g. multiply 1st digit by 5th digit) and linguistic problems (e.g. state a word including at least two letters in the sequence). The investigator read these from a pre-determined script of 20 questions. A new sequence was presented before the next driving task.

Experimental Driving Test

The simulated driving test comprised three tasks (Task 1, 2, 3). In Task 1, participants drove along a straight bi-directional single-lane road (4.0m lane width) at 80km/hr (~7.0km), with several gentle hills requiring minor speed adjustments. Light oncoming traffic exhibiting non-conflicting behavior was present. Longitudinal (average speed, standard deviation of speed [SDSP]) and latitudinal (SDLP; average lane position; number of lane crossings [LC]) control parameters were assessed, although longitudinal data during the initial acceleration period (60s) was intentionally discarded, such that analysis was limited to the speed maintenance phase of the drive (~5.5km).

For Task 2, the drive occurred along a bi-directional three-lane freeway (4.0m lane width) with gentle contours and hills requiring minor speed adjustments. Participants were instructed to maintain a given distance headway (50m) between their vehicle and a lead vehicle for drive duration (~8.5km). The lead vehicle was programmed to accelerate to 100km/hr and then maintain a constant speed. Longitudinal (the distance gap between the front of the driver's vehicle and the back of the vehicle directly in front [distance headway] and the smallest distance gap between the vehicles [minimum distance headway]) and latitudinal (SDLP,

average lane position, LC) control parameters were assessed, although distance headway data collected during the initial acceleration period (60s) was intentionally discarded, such that analysis was limited to the distance headway maintenance phase of driving (~6.7km).

In Task 3, participants drove along a straight bi-directional single-lane road (4.0m lane width) at 80km/hr (~7.0km), with several gentle hills. Participants performed a two-choice reaction-time (CRT) task embedded within the scenario. Latency to stimuli was recorded, although the fastest and slowest response times were intentionally removed prior to analysis. On 12 occasions, a colored hexagon presented in the top right-hand corner of the center monitor. Participants pressed their brake pedal (CRT_{brake}) or flashed their headlights (CRT_{lights}) upon detecting a red or green hexagon respectively. Three versions of the scenario were designed with order and location of stimuli varied to reduce familiarity of stimulus order. The scenario versions were administered randomly.

Subjective Concentration Ratings

A visual analog scale was used to assess participant's ratings of concentration needed to complete the drives under each condition. The scale was administered via the computerized software program, Adaptive Visual Analog Scales (AVAS) (Marsh-Richard, Hatzis, Mathias, Venditti, & Dougherty, 2009), with participants placing a mark along a 100mm line between the anchors 'Very Little' (0mm) and 'A Lot' (100mm).

Statistical Analysis

All statistical procedures were performed using IBM SPSS, Version 25.0. All measures were examined for normality using the Shapiro-Wilk test. Statistical analysis for each of the main dependent driving variables and AVAS data were performed using paired samples *t*-tests to compare experimental drives with their respective baseline drives. Repeated measures

intervention effect sizes (ES) were calculated as Hedges' g . The mean difference between each intervention and baseline performance score was standardized against the SD of change and corrected for bias due to small sample size (Hedges, 1981) using the supplementary spreadsheet by Lakens (2013). Data from SSS, U_{sg} and BGL measures were examined using paired samples t -tests to compare differences between experimental trials. Statistical significance was accepted as $p < 0.05$. Data are presented as mean $\pm$ SD, unless otherwise indicated.

RESULTS

Pre-Trial Compliance

All participants verbally acknowledged compliance with pre-experimental procedures. Initial breath samples indicated no detectable levels of alcohol. Participants began each trial in a similar state of alertness according to the SSS (FVG=2.5 $\pm$ 1.0, FVG+CD=2.3 $\pm$ 0.8; $t(20)=0.777$, $p=0.446$). All drives were completed with BGL above the reference limit for hypoglycemia.

Driving Performance

Analysis of trial order effects for SDLP, distance headway and CRT at baseline in each of the scenarios indicated no significant effect of trial order (p 's > 0.05). Measures of simulated driving (including effect size estimates) at baseline and under experimental conditions are summarized in Table A1.

Performance outcomes for Task 1 are summarized in Table 1. SDLP and LC did not differ significantly from baseline under either (FVG or FVG+CD) experimental condition (p 's > 0.05). However, when FVG were worn (irrespective of cognitive demand), participants significantly altered their average lane position compared to corresponding baseline drives ($p < 0.001$); positioning the vehicle more centrally in the lane. Average vehicle speed did not differ between

baseline and corresponding treatment condition drives (p 's>0.05). However, SDSP increased significantly from baseline when FVG were worn (irrespective of cognitive demand) (FVG, $p=0.006$; FVG+CD, $p<0.001$).

INSERT TABLE 1 HERE

Performance outcomes for Task 2 are summarized in Table 2. Distance headway decreased significantly from baseline with FVG, $t(20)=3.696$, $p=0.001$, but increased significantly with FVG+CD, $t(20)=-2.848$, $p=0.010$. Minimum distance headway was significantly decreased with both FVG; $t(20)=4.453$, $p<0.001$, and FVG+CD; $t(20)=2.137$, $p=0.045$, relative to baseline. SDLP increased significantly from baseline with both FVG, $t(20)=-3.048$, $p=0.006$, and FVG+CD, $t(20)=-2.325$, $p=0.031$. A corresponding increase in LC was also observed for both conditions relative to baseline however these differences were not statistically significant (p 's>0.05). Lane position was also influenced with FVG+CD, $t(20)=-3.027$, $p=0.007$, with participants more inclined to position the vehicle closer to the centre of the lane.

INSERT TABLE 2 HERE

Performance outcomes for Task 3 are summarized in Table 3. A significant increase in response latency was identified with FVG+CD for CRT_{brake} , $t(20)=-5.417$, $p<0.001$, and CRT_{lights} , $t(20)=-4.538$, $p<0.001$, compared to their corresponding baseline values. No differences in CRT_{brake} and CRT_{lights} were observed with FVG compared to baseline (p 's>0.05).

INSERT TABLE 3 HERE

Cognitive Demand Task Performance

In each task, participants answered most of the 20 questions (Task 1: 18 ± 3 (11-20); Task 2: 15 ± 3 (11-20); Task 3: 18 ± 2 (13-20); Mean $\pm$ SD (range)), with 9, 3 and 13 participants completing all 20 questions on Tasks 1, 2 and 3, respectively. Accuracy of responses was similar across all situations (Task 1: $77 \pm 25\%$ (25-100%); Task 2: $83 \pm 16\%$ (50-100%); Task 3: $80 \pm 21\%$ (16-100%), $F(2,40)=0.987$, $p=0.382$).

Subjective Concentration Ratings

Ratings for level of concentration are displayed in Fig. 2. Relative to baseline, participants rated their need to concentrate significantly higher with FVG, $t(20)=-5.118$, $p<0.001$, $ES=1.40$, and FVG+CD, $t(20)=-6.170$, $p<0.001$, $ES=1.53$, relative to baseline.

INSERT FIG 2 HERE

DISCUSSION

The present investigation examined the impact of FVG with and without a concurrent cognitive task on simulated driving. Overall, impaired driving was observed when participants wore FVG relative to baseline measures. However, the magnitude of these effects was not always greater (as was anticipated) when participants performed the drives under increased cognitive demand.

The current results indicate that driving scenario complexity is likely to be a determining factor for the impact of FVG on simulated driving. For example, in Task 1 (a simple scenario on a straight roadway), neither FVG nor FVG+CD influenced lateral vehicle control (SDLP, LC). Whereas, in Task 2 (a complex scenario involving curvature/car-following), a significant increase in SDLP and corresponding increase in LC (although not statistically significant) was

observed for both conditions. Previous reports have demonstrated similar outcomes with FVG along straight (McCartney et al., 2017; Rumschlag et al., 2015) versus complex (McCartney et al., 2017) roadways. Collectively, these results suggest FVG do not impair an individual's ability to maintain lateral control during simple driving tasks, and despite higher cognitive demand (FVG+CD), individuals were able to compensate for the visual disturbance to hold the vehicle on a dedicated path within the lane confines. On the other hand, FVG appear to negatively influence lateral vehicle control in scenarios that require greater steering deviations to navigate the road architecture. The fact that the added cognitive task resulted in lower effect estimates for changes in SDLP and LC and slightly higher effect estimates for changes in ratings of concentration suggests that drivers may prioritize various aspects of the task, dedicating more cognitive resources to ensure lateral control is maintained. Indeed, at least two previous studies have identified improvements in lane-keeping performance with addition of a cognitive load (Brookhuis, de Vries, & de Waard, 1991; Engström, Johansson, & Östlund, 2005). Of note, is that in one of these investigations, improvements were accompanied by an increase in gaze concentration toward the center of the road, suggesting that drivers may reduce peripheral visual scanning to maintain lateral control when attentional resources are limited (Engström et al., 2005). However, no cognitive task only condition (without FVG) was included in the present study to determine if accuracy on the secondary task was impacted. It is also possible that the AVAS scale employed to measure concentration "maxed out" (i.e. the anchor 'A Lot' may not represent maximal cognitive load), particularly with the additional cognitive task (i.e. values started high and appeared to reach a ceiling with FVG). Furthermore, participants ratings of concentration were only assessed on completion of all driving tasks rather than after each task. As such, we are unable to determine if participants concentration varied in response to task complexity.

Several measures of longitudinal control (SDSP, distance headway, minimum distance headway) were influenced in the present study. While average speed was unaffected in Task 1, SDSP significantly increased with FVG. Furthermore, larger effect estimates for comparisons against baseline were observed with FVG+CD. Elevated SDSP typically indicates poor speed vigilance; a consequence of attention deficits with diminished information processing capacity (Marczinski & Fillmore, 2009). Thus, the visual disturbance with FVG appears to increase attentional demands, which are slightly exacerbated when performing a secondary cognitive task. In Task 2, FVG reduced distance headway and minimum distance headway, indicating greater likelihood of tailgating behavior with visual disturbance. In contrast, while minimum distance headway was reduced with FVG+CD, distance headway was increased. This behavior is consistent with evidence that drivers attempt to expand their safety margins to better cope with distractions imposed (Rakauskas et al., 2008); however, this compensatory mechanism failed to prevent tail-gating occurrences completely. These results suggest drivers may have devoted little attention to the movements of the lead car and were primarily concerned with conserving basic elements of vehicle control under the more demanding conditions.

Choice reaction time was not influenced by FVG in Task 3. In contrast, CRT increased significantly with FVG+CD. While few studies have directly examined CRT performance embedded within a simulated drive, McCartney et al (2017) observed a trend ($p=0.084$) for slower reaction times following actual alcohol consumption (BAC ~0.060%). Although not statistically significant (likely a consequence of the low BAC achieved relative to estimated FVG), these results suggest that alcohol may produce unfavorable effects on reaction time during simulated driving. Other investigations have also observed detrimental effects of distracting stimuli (e.g. texting, eating) on reaction time during simulated driving (Irwin, Monement, & Desbrow, 2014). Furthermore, previous research has demonstrated that the disruptive effects of texting on driving are significantly increased with FVG (Rumschlag et al.,

2015). While results from the present study suggest the visual disturbance induced by FVG does not appear to influence CRT during simulated driving, FVG may have utility for simulating alcohol intoxication effects if employed in combination with other cognitive tasks. It is important, however, to recognize that the contribution of FVG and cognitive demand task cannot be separated under the current study design. Thus, impairment observed may be derived exclusively from the additional demand required to complete the secondary cognitive task, with no contribution from FVG. In addition, as the tasks (both the CRT stimuli and questioning for +CD) were intermittent in nature, presentation of questions relative to reaction stimuli may have influenced results. Nonetheless, these results suggest FVG may exacerbate distraction-based driving impairments.

This study did contain limitations. Firstly, it only involved young males. While this population group was targeted, given vehicle occupant fatalities involving alcohol affected drivers are overwhelmingly male, aged 17-34y (International Traffic Safety Data and Analysis Group, 2014), results may not be generalizable to the broader population. It is also important to recognize limitations of driving simulators in research. Specifically, results from simulator studies may not generalize to real-world driving if the simulator lacks behavioral validity (Mullen, Charlton, Devlin, & Bédard, 2011). Indeed, driving simulator studies appear only to approximate effects observed in on-road driving, but with directional similarities (Mullen et al., 2011). Thus, the driving performance values obtained in the present study cannot be translated directly into on-road values to gauge crash risk. Finally, FVG only provide a visual disturbance; thus, do not replicate changes in physiological functioning with alcohol, disrupting cognitive processes required to safely operate a motor vehicle (Moskowitz & Fiorentino, 2000). Nonetheless, this was the intention of the study; increasing the cognitive demand of individuals wearing FVG by including a concurrent cognitive task to determine if effects were exacerbated. Furthermore, whether adaptation occurs to the distorting effects of FVG is currently unknown.

If repeated exposure results in habituation (and possibly changes in strategy or compensatory mechanisms) reducing the magnitude of impairment, this may impact results. Thus, future research should determine if wearers of FVG demonstrate any habituation to the visual disturbance following repeated use.

While there are obvious limits to how well FVG replace studying the actual effects of alcohol, there may be particular benefit in using FVG to facilitate education sessions with young, inexperienced or pre-licensed drivers. If these individuals develop a sense of the impairment and understanding of dangers associated with drink-driving, it may have important implications, such as preventing drink-driving behavior. While previous studies have demonstrated that FVG may reduce favorable attitudes towards drink-driving (Hennessy, 2005; Jewell & Hupp, 2005; Jewell et al., 2004), the effectiveness of FVG to prevent drink-driving behavior requires further consideration. Future research where participants are exposed to drink-driving education programs incorporating FVG and simulated driving, with long-term follow up of participants' drink-driving attitudes and behaviors might offer insight into the effectiveness of the intervention and enhance existing alcohol education programs.

Overall, results from this study indicate that FVG negatively impact simulated driving. However, these effects are isolated to specific performance outcomes and are dependent on driving scenario complexity. Addition of a secondary cognitive task appears to exacerbate effects of FVG on select driving parameters (i.e. lane position, SDSP), influences the effect direction on other measures (i.e. distance headway), and has a detrimental effect on reaction time to stimuli embedded in a drive, which was not observed with FVG alone. These results will assist methodological development of future investigations and decisions to employ concurrent cognitive tasks when FVG are used to explore alcohol-impaired driving or facilitate education sessions simulating alcohol intoxication.

ACKNOWLEDGEMENTS

This research project was funded by an internal University project grant.

REFERENCES

- Armstrong, LE, Pumerantz, AC, Fiala, KA, Roti, MW, Kavouras, SA, Casa, DJ, & Maresh, CM. 2010. Human hydration indices: acute and longitudinal reference values. *Int J Sport Nutr Exerc Metab*, 20(2), 145-153.
- Brookhuis, KA, de Vries, G, & de Waard, D. 1991. The effects of mobile telephoning on driving performance. *Accid Anal Prev*, 23(4), 309-316.
- Brooks, JO, Goodenough, RR, Crisler, MC, Klein, ND, & Alley, RL. 2010. Simulator sickness during driving simulation studies. 42(3), 788-796.
- Engström, J, Johansson, E, & Östlund, J. 2005. Effects of visual and cognitive load in real and simulated motorway driving. *Transp Res Part F Traffic Psychol Behav*, 8(2), 97-120.
- Hedges, LV. 1981. Distribution theory for Glass's estimator of effect size and related estimators. *J Educ Stats*, 6, 107-128.
- Hennessy, D. (2005). *The Effects of Fatal Vision Goggles on Drinking and Driving Intentions in College Students*. Paper presented at the Canadian Multidisciplinary Road Safety Conference, Fredericton, NB, Canada.
- Hennessy, D, Lanni-Manley, E, & Maiorana, N. (2006). *The effects of Fatal Vision Goggles on dinking and driving intentions in college students*. Paper presented at the Canadian Multidisciplinary Road Safety Conference, Fredericton, NB, Canada.

Hoddes, E, Zarcone, V, Smythe, H, Phillips, R, & Dement, WC. 1973. Quantification of sleepiness: a new approach. *Psychophysiology*, 10(4), 431-436.

International Traffic Safety Data and Analysis Group. 2014. Road Safety Annual Report 2014 Summary. Report No:

Irwin, C, Iudakhina, E, Desbrow, B, & McCartney, D. 2017. Effects of acute alcohol consumption on measures of simulated driving: A systematic review and meta-analysis. *Accid Anal Prev*, 102, 248-266.

Irwin, C, Leveritt, M, Shum, DHK, & Desbrow, B. 2014. Mild to moderate dehydration combined with moderate alcohol consumption has no influence on simulated driving performance. *Traffic Inj Prev*, 15(6), 652-662.

Irwin, C, Monement, S, & Desbrow, B. 2014. The Influence of Drinking, Texting and Eating on Simulated Driving Performance. *Traffic Inj Prev*, 16(2), 116-123.

Irwin, C, Shum, D, & Desbrow, B. (2013). *Test-retest reliability of simulated driving performance: a pilot study*. Paper presented at the Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Bolton Landing, New York.

Jewell, J, & Hupp, S. 2005. Examining the effects of fatal vision goggles on changing attitudes and behaviors related to drinking and driving. *J Prim Prev*, 26(6), 553-565.

Jewell, J, Hupp, S, & Luttrell, G. 2004. The effectiveness of Fatal Vision Goggles: disentangling experiential versus onlooker effects. *J Alcohol Drug Educ*, 48(3), 63-84.

Lakens, D. 2013. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol*, 4, 863-875.

- Marczinski, CA, & Fillmore, MT. 2009. Acute alcohol tolerance on subjective intoxication and simulated driving performance in binge drinkers. *Psychol Addict Behav*, 23(2), 238-247.
- Marsh-Richard, DM, Hatzis, ES, Mathias, CW, Venditti, N, & Dougherty, DM. 2009. Adaptive Visual Analog Scales (AVAS): a modifiable software program for the creation, administration, and scoring of visual analog scales. *Behav Res Methods*, 41(1), 99-106.
- McCartney, D, Desbrow, B, & Irwin, C. 2017. Using alcohol intoxication goggles (Fatal Vision® goggles) to detect alcohol related impairment in simulated driving. *Traffic Inj Prev*, 18(1), 19-27.
- Moskowitz, H, & Fiorentino, D. 2000. A Review of the Literature on the Effects of Low Doses of Alcohol on Driving-Related Skills. Washington, DC, USA; National Highway Traffic Safety Administration. Report No: DOT HS 809 028
- Moskowitz, H, & Robinson, C. 1988. Effects of Low Doses of Alcohol on Driving-Related Skills: A Review of the Evidence. Washington, DC, USA; National Highway Traffic Safety Administration. Report No: DOT HS 807 280
- Mullen, N, Charlton, J, Devlin, A, & Bédard, M. (2011). Simulator Validity: Behaviors Observed on the Simulator and on the Road. In *Handbook of Driving Simulation for Engineering, Medicine, and Psychology* (pp. 1-18).
- Rakauskas, ME, Ward, NJ, Boer, ER, Bernat, EM, Cadwallader, M, & Patrick, CJ. 2008. Combined effects of alcohol and distraction on driving performance. *Accid Anal Prev*, 40(5), 1742-1749.

Rumschlag, G, Palumbo, T, Martin, A, Head, D, George, R, & Commissaris, RL. 2015. The effects of texting on driving performance in a driving simulator: The influence of driver age. *Accid Anal Prev*, 74(0), 145-149.

Shirazi, MM, & Rad, AB. 2014. Detection of Intoxicated Drivers Using Online System Identification of Steering Behavior. *IEEE T Intell Transp*, 15(4), 1738-1747.

Starkey, NJ, & Charlton, SG. 2014. The effects of moderate alcohol concentrations on driving and cognitive performance during ascending and descending blood alcohol concentrations. *Hum Psychopharmacol*, 29(4), 370-383.

FIGURES & TABLES:

Fig. 1. A visual of the simulated driving scene from the driver's perspective without FVG (A) and with FVG (B). FVG, Fatal Vision Goggles.

Fig. 2. Participants' AVAS ratings for level of concentration required to perform the driving test at baseline and under each of the experimental conditions. FVG, Fatal Vision Goggles; FVG+CD, Fatal Vision Goggles with additional cognitive demand task. *Significant difference compared to corresponding baseline driving performance ($p < 0.05$). Columns are Mean and error bars are SD.

Table 1. Performance measures on driving Task 1 for each experimental condition

	FVG Trial		FVG+CD Trial	
	Baseline	FVG	Baseline	FVG+CD
Task 1				
SDLP (cm)	21.4±6.0	22.2±5.3	21.5±6.3	20.9±8.4
LC (total no.)	0.62±1.86	0.19±0.60	0.76±1.95	0.67±1.93
Avg. lane pos. (cm)	-45.8±19.3	-28.2±16.8*	-46.7±20.0	-22.8±22.1*
SDSP (km/hr)	2.18±0.51	2.75±0.98*	2.20±0.76	3.56±1.50*
Avg. speed (km/hr)	79.1±1.7	79.4±2.9	79.2±1.1	79.2±5.0

FVG, Fatal Vision Goggles; FVG+CD, Fatal Vision Goggles with additional cognitive demand task; LC, number of lane crossings; SDLP, standard deviation of lane position; SDSP, standard deviation of speed. Values are mean±SD. *Significant difference compared to corresponding baseline driving performance ($p<0.05$).

Table 2. Performance measures on driving Task 2 for each experimental condition

	FVG Trial		FVG+CD Trial	
	Baseline	FVG	Baseline	FVG+CD
SDLP (cm)	24.5±6.0	27.7±6.0*	24.4±6.3	26.9±8.9*
LC (total no.)	0.86±1.49	2.71±5.43	1.52±3.03	2.95±6.55
Avg. lane pos. (cm)	-49.5±13.5	-48.6±16.5	-52.0±13.1	-41.0±16.1*
Headway (m)	56.1±15.9	46.5±16.6*	55.3±16.0	72.1±38.5*
Min. headway (m)	34.9±8.3	29.2±9.9*	35.6±6.6	31.4±9.3*

FVG, Fatal Vision Goggles; FVG+CD, Fatal Vision Goggles with additional cognitive demand task; LC, number of lane crossings; SDLP, standard deviation of lane position; SDSP, standard deviation of speed. Values are mean±SD. *Significant difference compared to corresponding baseline driving performance ($p<0.05$).

Table 3. Performance measures on driving Task 3 for each experimental condition

	FVG Trial		FVG+CD Trial	
	Baseline	FVG	Baseline	FVG+CD
CRT _{brake} (ms)	921±144	943±117	911±142	1132±218*
CRT _{lights} (ms)	901±169	888±176	899±190	1193±318*

FVG, Fatal Vision Goggles; FVG+CD, Fatal Vision Goggles with additional cognitive demand task; CRT_{brake}, choice reaction time to red stimulus – brake pedal response; CRT_{lights}, choice reaction time to green stimulus – headlight flash response. Values are mean±SD. *Significant difference compared to corresponding baseline driving performance ($p<0.05$).

Table A1. Performance measures and effect size estimates for the three driving tasks in each experimental condition

	FVG Trial			FVG+CD Trial		
	Baseline	FVG	ES	Baseline	FVG+CD	ES
Task 1						
SDLP (cm)	21.4±6.0	22.2±5.3	0.14	21.5±6.3	20.9±8.4	0.08
LC (total no.)	0.62±1.86	0.19±0.60	0.34	0.76±1.95	0.67±1.93	0.05
Avg. lane pos. (cm)	-45.8±19.3	-28.2±16.8*	0.96	-46.7±20.0	-22.8±22.1*	1.11
SDSP (km/hr)	2.18±0.51	2.75±0.98*	0.75	2.20±0.76	3.56±1.50*	1.18
Avg. speed (km/hr)	79.1±1.7	79.4±2.9	0.13	79.2±1.1	79.2±5.0	<0.01
Task 2						
SDLP (cm)	24.5±6.0	27.7±6.0*	0.52	24.4±6.3	26.9±8.9*	0.32
LC (total no.)	0.86±1.49	2.71±5.43	0.47	1.52±3.03	2.95±6.55	0.29
Avg. lane pos. (cm)	-49.5±13.5	-48.6±16.5	0.06	-52.0±13.1	-41.0±16.1*	0.74
Headway (m)	56.1±15.9	46.5±16.6*	0.58	55.3±16.0	72.1±38.5*	0.61
Min. headway (m)	34.9±8.3	29.2±9.9*	0.62	35.6±6.6	31.4±9.3*	0.52
Task 3						
CRT _{brake} (ms)	921±144	943±117	0.17	911±142	1132±218*	1.21
CRT _{lights} (ms)	901±169	888±176	0.07	899±190	1193±318*	1.14

FVG, Fatal Vision Goggles; FVG+CD, Fatal Vision Goggles with additional cognitive demand task; LC, number of lane crossings; SDLP, standard deviation of lane position; SDSP, standard deviation of speed; CRT_{brake}, choice reaction time to red stimulus – brake pedal response; CRT_{lights}, choice reaction time to green stimulus – headlight flash response. Values are mean±SD and Hedges' g effect sizes (ES). *Significant difference compared to corresponding baseline driving performance ($p<0.05$).