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Effects of acute alcohol consumption on measures of simulated driving: A systematic review and meta-analysis

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ABSTRACT

Driving simulators are used in a wide range of research settings to help develop an understanding of driver behavior in complex environments. Acute alcohol impairment is an important research topic for traffic safety and a large number of studies have indicated levels of simulated driving impairment imposed by alcohol across a range of performance outcome variables. The aim of the present study was to examine the impact of acute alcohol consumption on simulated driving performance by conducting a systematic review and meta-analysis of the available evidence. The online databases PubMed (MEDLINE), Web of Science (via Thomas Reuters) and Scopus were searched to identify studies that measured simulated car driving performance under control ('no alcohol' or 'placebo alcohol' ingestion) and intervention (acute alcohol ingestion) conditions, using repeated-measures experimental designs. Primary research outcomes were standard deviation of lane position (SDLP) and standard deviation of speed (SDSP); (total number of lane crossings (LC) and average speed (Speed) were secondary research outcomes). Meta-analytic procedures were used to quantify the effect of acute alcohol consumption on vehicle control, and to determine the influence of methodological variables (i.e. the duration of the simulated driving task, the limb of the BAC curve (ascending vs. descending) and the type of driving simulator employed (i.e. car vs. PC-based)) on the magnitude of the performance change due to alcohol consumption. 423 records were screened, and 50 repeated-measures trials ($n = 962$ participants, 62% male) derived from 17 original publications were reviewed. 37 trials ($n = 721$ participants) used a 'placebo alcohol' comparator to determine the effect of alcohol consumption on SDLP (32/37) and SDSP (22/37). Alcohol consumption significantly increased SDLP by 4.0 ± 0.5 cm (95% CI: 3.0, 5.1) and SDSP by 0.38 ± 0.10 km·h^{-1} (95% CI: 0.19, 0.57). Regression analyses indicate BAC ($p = 0.004$) and driving simulator platform ($p < 0.001$) influence the magnitude of the SDLP change, such that higher BAC levels and the use of PC-based driving simulators were associated with larger performance decrements ($R^2 = 0.80$). The limb of the BAC curve and the duration of the driving task did not significantly alter the magnitude of the performance change. Eleven trials ($n = 205$ participants) used a 'no alcohol' comparator to measure the effect of alcohol consumption on SDLP (10/11); few trials assessed SDSP (3/11). Alcohol consumption resulted in a small significant increase in SDLP under these conditions (standardized difference in means = 0.23, 95% CI: 0.06, 0.39). These results demonstrate that lateral (SDLP and LC) and longitudinal (SDSP) vehicle control measures in a driving simulator are impaired with acute alcohol consumption. However, SDLP appears to be a more sensitive indicator of driving impairment than other driving performance variables and the results of the present study support its use as a performance outcome when examining alcohol-induced simulated driving impairment.

1. Introduction

Acute alcohol intoxication causes impaired driving (Moskowitz and Burns, 1990; Moskowitz and Fiorentino, 2000; Ogden and Moskowitz, 2004) with relative risk increasing exponentially as blood alcohol concentration (BAC) rises (Compton and Berning, 2015). Recent reports indicate the risk of motor vehicle crashes increases with BAC as low as 30 mg·dL^{-1} (Compton and Berning, 2015). Despite this, current legislation in many jurisdictions permits drivers to operate motor vehicles at intoxication levels above this, with typical enforceable limits being 50–80 mg·dL^{-1} BAC. For example, countries such as Australia, New Zealand and South Africa have adopted a 50 mg·dL^{-1} drink driving limit, while others such

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as the United States and the United Kingdom have a 80 mg·dL^{-1} national maximum legal BAC limit (World Health Organization, 2015). The tolerance for some alcohol to be consumed prior to driving demonstrates a need for continued research into the effects of acute alcohol consumption on driving performance.

Driving a motor vehicle is a complex task, requiring a coordinated array of sensory, perceptual, cognitive, and motor control components (Anderson et al., 2005; Jeong et al., 2006). Clearly, there are obvious risks and ethical issues associated with using road-based vehicles to examine the effects of alcohol on driving performance (Creaser et al., 2011). Driving simulation provides an alternative experimental approach that allows researchers to examine all of the necessary skills required to operate a motor vehicle without the risk of injury (Allen et al., 2011). In addition, driving simulation allows greater experimental control; eliminating environmental inconsistencies that would otherwise influence on-road study results (Risto and Martens, 2014). Importantly, simulated driving has also demonstrated direct translation to on-road driving (Risto and Martens, 2014; Gawron and Ranney, 1988; Lee et al., 2003; Mayhew et al., 2011), making driving simulation a critical tool for the assessment of driving performance under the influence of alcohol.

Driving simulators have been used to test the effect of alcohol on driving performance for almost four decades (Creaser et al., 2011). In this time, significant technological advancements have seen driving simulators develop into complex multi-functional pieces of equipment, employing immersive scenarios and real-world driving experiences. As such, a large number of performance measures can be recorded during driving. However, there is no standard set of driving scenarios for testing alcohol impaired driving (Creaser et al., 2011). Despite this, a number of performance measures are commonly reported in simulator studies investigating the effects of alcohol, including lateral vehicle control parameters (standard deviation of lane position (SDLP) (Helland et al., 2016; Helland et al., 2013; Irwin et al., 2014; Mets et al., 2011; Verster et al., 2014; Verster and Roth, 2014a; McCartney et al., 2017), number of lane marking crossings (LC) (McCartney et al., 2017; Fillmore et al., 2008; Kenntner-Mabiala et al., 2015; Weafer and Fillmore, 2012)), and longitudinal vehicle control parameters (standard deviation of speed (SDSP) (Mets et al., 2011; McCartney et al., 2017; Marczinski and Fillmore, 2009; Marczinski et al., 2008; Rupp et al., 2007; Veldstra et al., 2012; Weafer et al., 2008), average driving speed (AVSP) (Mets et al., 2011; McCartney et al., 2017; Kenntner-Mabiala et al., 2015; Marczinski et al., 2008; Veldstra et al., 2012; Berthelon and Gineyt, 2014; Laude and Fillmore, 2015; Laude and Fillmore, 2016)). SDLP provides a method of assessing a driver's ability to maintain a given lane position and may also be regarded as a measure of driver safety (Verster and Roth, 2014a). That is, with increases in SDLP, the likelihood of crossing lane boundaries increases, which could result in the vehicle deviating into the lane of adjacent or oncoming traffic, increasing the chances of traffic crashes (Verster and Roth, 2014a; Owens and Ramaekers, 2009). However, many studies do not collect or report all of these driving performance measures and even when they do, some degree of variability is observed in performance outcomes. This may in part, be due to differences in the research question, study methodology (e.g. alcohol dose administered, timing of alcohol administration), simulator capabilities (e.g. low- or high- complexity systems) and the simulation scenarios (e.g. driving duration, driving environment) employed.

Therefore, the aim of the present study was to examine the impact of acute alcohol consumption on simulated driving performance by performing a systematic review and meta-analysis of the available evidence. Findings from this study will clarify the magnitude of effect that alcohol intoxication has on simulated driving performance measures. This information will provide researchers with greater confidence in simulated driving scenario design, the performance measures employed to test the effects of alcohol on simulated driving, and assist with the interpretation of driving performance data when conducting alcohol experiments using simulated driving tasks. It will also permit benchmarking of performance changes observed with alcohol impairment against other factors that may cause impaired driving (e.g., fatigue, distraction), allowing greater comparison to established driving impediments in future research studies.

2. Aim(s)

The purpose of this review is to investigate the effect of acute alcohol consumption on lateral and longitudinal vehicle control measures during simulated driving performance using meta-analytic procedures. More specifically, this study intends to:

1) Quantify the magnitude of simulated driving impairment at a given BAC using select indicators of driving performance;
2) Explore the dose-response effect of acute alcohol intoxication on simulated driving performance;
3) Determine the influence of methodological variables, such as the duration of the simulated driving task, the limb of the BAC curve (ascending vs. descending) and the type of driving simulator employed (i.e. car vs. PC-based), on the magnitude of the performance change.

3. Methods

The methodology of this review was devised in accordance with specifications outlined in the *Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols PRISMA-P 2015 Statement* (Moher et al., 2015) and registered at the International Prospective Register for Systematic Reviews (identification code: CRD 42015023802) ahead of the formal literature screening process.

3.1. Literature search

Potential research studies were identified by searching the online databases PubMed (MEDLINE), Web of Science (via Thomas Reuters) and Scopus from inception until June 2016 using the terms alcohol and ethanol in combination with "driving simulat*" and "simulat* driving". The star symbol was used to capture all words beginning with *simulat* (e.g. simulation, simulated, simulator) and the enclosed quotation marks were used to search for an exact phrase. Two investigators (D.M. and E.I.) independently screened the potential research studies to identify relevant texts. After records were identified and duplicates removed, titles were screened. All titles that indicated alignment to the topics of cognitive function/performance (as these papers may employ simulated driving tasks as a secondary measure when examining cognition) or psychoactive substances (any) were included for subsequent screening. All irrelevant titles were discarded. The remaining articles were systematically screened for eligibility by abstract and full text, respectively. The decision to include or discard potential research studies was made between three investigators (D.M., E.I. and C.I.). Any discrepancies were resolved in consultation with a fourth investigator (B.D.). The reference lists of all included studies were hand searched for missing publications. Full details of the screening process are displayed in Fig. 1.