ASSESSMENT OF INTOXICATED DRIVING WITH A SIMULATOR: A PILOT VALIDATION STUDY WITH ON-ROAD DRIVING

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ABSTRACT

Although driving simulators are often used to measure the performance of drivers under the influence of alcohol, the validity of simulators in these paradigms has not been definitively established. In this pilot study, 6 men and 4 women twice performed a low speed on-road driving task and corresponding fixed base simulation task after consuming a specified amount of ethanol or realistic placebo beverage, presented single-blind in randomized order. Measures and longitudinal vehicle control showed near significant intoxication effects in both the on-road and the simulation task; measures that were comparable between the on-road and simulator modes showed no significant difference in intoxication effect and near significant correlation in some instances. The results suggest that low cost driving simulators may be valid tools for detecting alcohol intoxication effects that are directly relevant to on-road driving performance, and that it would feasible to more fully explore simulator validity in further studies of similar design.

INTRODUCTION

Intoxicated driving remains a persistent public health risk in the United States, resulting in over sixteen thousand fatalities and an estimated three hundred thousand injuries related to intoxicated driving in the 1996 alone (l). One of the most common experimental tools in intoxicated driving research is the driving simulator, and many studies to date have employed driving simulators to assess the effects of alcohol and marijuana, as well as the effects of normal aging, sleep deprivation, and other adverse conditions upon driving and driving related skills (2-5). A persistent issue in these lines of research is the validity of driving simulators as compared to on-road measurement tools, particularly the predictive validity of low cost, fixed base simulation systems. While several studies have examined the validity of driving simulators in general and for certain adverse conditions (6-9) no study has directly addressed simulator validity in alcohol intoxication research.

In this study, the effects of alcohol on driving performance were measured using two experimental tools (modes): an on-road driving test facility involving an instrumented dual-control car with instrumented closed-course road and a fixed base commercial driving simulator. Measures of driving performance common to both the simulator and the experimental vehicle were calculated and analyzed with three primary objectives: (i) to detect intoxication effects within the simulation and real road experiments alone, (ii) to compare the intoxication effects observed in the simulator to those observed on the real road (iii) to determine in what ways the driving simulator detects intoxication effects that are relevant to real driving and suggest further avenues of experimentation.

MATERIALS AND METHODS

The study participants were 10 healthy men (N = 6) and women (N = 4) over 21 years of age (mean age 24.2 ± 5.8) with valid drivers licenses and good driving records (no major collisions, no DWI record, few or none lifetime moving violations). The study was performed at the Virginia Tech Transportation Institute (VT) over a period of two days; the road facilities and instrumented vehicle were provided by Virginia Tech, and the simulation equipment was provided by the Johns Hopkins team. The experimental protocol was reviewed and approved by both VT and Johns Hopkins Internal Review Boards.

At Virginia Tech, on the afternoon of Day 1, while sober, each subject navigated a simple course on the driving simulator until performance was at a maximal asymptotic level. He/she then drove the dual control car on the experimental highway, with a certified VT experimenter at the passenger-side dual control, until fully familiar with its operation.

On the afternoon of Day 1, subjects began performing experimental runs, each consisting of a driving simulation task and a corresponding real-road task, each 7 - 10 minutes in length, performed in close succession. Experimental runs continued until dusk and resumed on the morning of Day 2. Subjects completed an experimental run twice, once after ingesting an amount of alcohol calculated to produce a blood alcohol concentration (BAC) of 0.08 and once after ingesting a realistic placebo, in randomized order. BAC readings were acquired before, during and after the experimental runs. To reduce learning effects, both the simulation and real-road task were altered between a subject's first and second experimental session. Presentation order of the simulation and real road tasks was counterbalanced within and between subjects.

Subject Screening

Potential subjects were recruited by advertisement and word of mouth. After a telephone interview, potential subjects underwent a one-hour screening including personality testing and urine screen for drugs of abuse and (if appropriate),

pregnancy. Subjects were screened initially for emotional disturbance using the SCL-90 or the General Health questionnaire (10,11), with exclusion using established criterion cutoff scores. Subject inclusion criteria were: good physical health, light to moderate drinking habits (regular or moderate users of alcohol defined using structured interview using the SCID drugabuse module) (12), no history of drug or alcohol abuse (ascertained using the SCAN and MAST) (13,14), no history of alcohol abuse in first degree relatives, and good corrected or uncorrected eyesight.

Subject exclusion criteria were: DSM-IV (15) substance abuse or dependence, DSM-IV axis I criteria for any major mental disorder, current use of recreational drugs (e.g., cocaine, marijuana) as detected by urine screening, any central nervous system illness such as seizure disorder, multiple sclerosis, or stroke, and head injury leading to 30 min. or more of unconsciousness. Sober, informed consent was obtained in writing from all volunteers prior to research participation for this IRB-approved study.

On-road testing facilities

The on-road driving task was performed in Blacksburg, Virginia at the VT Smart Road, a 1.7 mile closed road meeting the specifications of a two-lane US highway (16,17). The experimental highway resembled a regular interstate highway, but no other traffic was present on it during the time the research was being conducted. A VT researcher drove subjects a brief distance from the Transportation Center to the entrance of the Smart Road (and back) for every practice session or experimental run.

After allowing subjects to become familiarized with the road as described above, lane obstructions consisting of three large traffic cones were placed on the road at varying intervals. A total of thirteen lane obstructions were placed along the course, and subjects were instructed to pass them on the left side. For the subjects' second sessions, the obstacles were redistributed at different intervals to provide a novel course. The speed limit was 25mph, and subjects were asked to drive as close as possible to the speed limit without exceeding it.

The experimental vehicle

A 1995 Oldsmobile Aurora with automatic transmission was used as the experimental vehicle for all participants. Specialized vehicle equipment included passenger side brake and wheel controls, several cameras located inside and outside the vehicle cab, physical sensors and an on-board data collection computer. For all experimental runs a trained VT researcher recorded subject behavior and operated a dual-control brake from a passenger side control panel.

The instrumentation in the vehicle provided the means to unobtrusively collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants. The steering wheel, speedometer, brake and accelerator were instrumented with sensors that transmitted information about position of the respective control devices. The steering wheel sensor provided steering position data accurate to within +/- 1 degree and the brake and accelerator sensors provided brake position to within +/- 0.1 inch. An accelerometer provided acceleration readings in the lateral and longitudinal planes of the vehicle, providing accurate values for vehicle acceleration and deceleration up to and including hard braking behavior, as well as intense turning. These metrics were sampled at a rate of 10Hz by a data collection computer, providing reliable data collection, manipulation, and storage under conditions present in the vehicle environment. The computer had a 16-channel analog-to-digital capability, standard QWERTY keyboard, and a 9-inch diagonal color monitor. A custom experimenter control panel was located in the vehicle and allowed the experimenter to record the occurrence of events in the data set by push-button input. A custom interface was used to integrate the data from the experimenter control panel, driving performance sensors, event flagger, and speedometer with the data collection computer.

An experienced VT researcher was in the front passenger seat to observe driver behavior and to operate the passenger side brake and wheel controls in the event that the subject lost control of the experimental vehicle (though this did not occur at any time during the experiment.) A Johns Hopkins researcher accompanied in the rear seat as an observer of driving behavior.

The Driving Simulator

The simulation task was performed on a Systems Technology, Inc. STISIM Drive 100 model driving simulator (STISIM), a low cost fixed-base interactive device that is operated from a PC equipped with 3D acceleration hardware (18-21). Input was

provided by a steering wheel, with acceleration and braking controlled by two wheel-mounted levers which, when holding the wheel, were within the grasp of the subjects' hands and provided an analogue response that approximated accelerator and brake pedals. The simulation output was directed to a high quality 21-inch CRT monitor placed approximately two feet from the subjects, slightly below eye level. Stereo headphones provided feedback on engine speed and tire noise from sudden braking.

Based on technical documentation of the Smart Road, the simulation course was designed to reproduce the features of the real road course, including road dimensions, radius and entry/exit spiral lengths for the road's two large curves, precise changes in grade and the changes in cross slope and super elevation. The cone obstacles were also reproduced in the simulation, and were reconfigured for the subjects' second run as was done on the real road. Because the simulator's automatic transmission required a gear shift at roughly 25mph, the sound feedback provided an unwanted audio cue to the vehicle speed. Thus, the subjects were told to drive as close as possible to, but not to exceed, a 30mph speed limit.

The data output was similar to that from the real vehicle, that is, several variables describing both user input (accelerator position, steering wheel input, etc.) and vehicle output (latitudinal and longitudinal acceleration, heading error, etc.) sampled at a rate of approximately 10Hz. The experimental vehicle and simulator shared several output variables in common, such as longitudinal velocity, steering wheel position and throttle position.

Ethanol Administration

Each subject was provided with a beverage to consume over a ten-minute period that contained an individualized dose of alcohol calculated by a computer algorithm based on body weight age, sex and race, designed to produce a BAC of 0.08, (i.e. the level of legal intoxication in most states) (22). Subject diet was controlled throughout both test days to ensure consistent alcohol absorption between subjects. The alcohol beverage was administered orally as 190pf (95% v/v) ethanol diluted in fruit juice to a constant volume, consumed over 10 minutes. After drinking this beverage, most subjects felt moderately intoxicated. The placebo was prepared by replacing the volume of ethanol with water and then "floating" a few milliliters of ethanol at the top of the drink. An ethanol-soaked pad was wrapped around the rim of both the placebo and ethanol containing drinks, masking the alcohol content of the beverage. The principal investigator, a licensed physician, oversaw dosing and administration. Post-alcohol, subjects were supervised for one hour after testing, until the principal investigator determined that any alcohol effects had worn off.

Blood levels of ethanol were determined immediately before and after a simulation or on-road testing session, similarly to prior designs (23,24) by breath testing with a commercial sensor (Alco-Sensor IV; Alco-Pro, Inc., Knoxville, TN). The Alco-Sensor IV has an electronic memory so that readings could be taken without display so as to maintain blindness to subjects of levels. Subjects also took brief computer-administered tests of intoxication and performed visual analog scale tests of subjective intoxication.

Subjects began their experimental driving or simulation sessions 15 minutes after finishing their beverages. Some subjects were administered both placebo and alcohol on Day 2, and these subjects were all administered the placebo beverage before the ethanol beverage.

ANALYSIS

The data analysis for this pilot study focused on assessing the drivers' control of the speed of the real and simulated vehicles, first, because longitudinal vehicle control is often studied in intoxication research (2-5,25,26,28,29,31) and second, because the longitudinal speed data was the most robust information available from both the simulator and the experimental vehicle.

The raw variable used for all analyses was vehicle speed, which was recorded as a time series with a roughly 10Hz sampling rate in both experimental modes for the duration of testing. Before analysis, the vehicle speed data sampled during each driver's initial acceleration and final deceleration was removed, and the continuous time series data from the simulator was resampled into a discrete time series that more closely resembled the output from the experimental vehicle. Then both the simulator and vehicle data were smoothed with a time-averaged mean with a centered 1.1s window.

From the raw vehicle speed variable, two outcome measures were calculated, and these measures were the focus of all statistical tests. One was the total amount of time that a driver spent over the speed limit during a driving or simulation session. This was chosen because it is a measure of a driver's ability to control his speed relative to an explicit speed limit

and is an aspect of driving performance that is relevant to driver safety and law enforcement in real world driving situations. This measure will be referred to as <u>speed-time</u>. The second measure chosen was an index of speed variability, the summed change in speed over the course of a driving session; this was calculated by finding the absolute difference between the speed reported at a given time point and the speed reported at the point previous to it, repeating this for all points reported during a driving/simulation session, and adding all of these absolute differences. This measure was chosen because it is a rough index of a driver's acceleration and deceleration behavior over the course of the experiment, and is therefore more sensitive to erratic driving behavior than is the measure of speed variance, which is only sensitive to the general distribution of driver speed during the experiment and is not sensitive to how the speed changed over a given period of time. This will be referred to as <u>speed-delta</u>. These two outcomes were calculated for each of a subject's 4 experimental trials: sober in the real vehicle, intoxicated in the vehicle, sober in the simulator and intoxicated in the simulator.

A first set of analyses was performed with two objectives in mind: to examine the changes in driver performance due to intoxication and to examine the similarity (or difference) between the simulator and the vehicle in reporting driver performance.

The difference between subjects' intoxicated driving and sober driving was assessed using paired t-tests. Two sets of tests were performed, one testing <u>speed-time</u> and <u>speed-delta</u> in the simulator, the other testing <u>speed-time</u> and <u>speed-delta</u> in the vehicle (null hypothesis = no difference between intoxicated and sober driving, alternative hypothesis = an increase in <u>speed-time</u> and <u>speed-delta</u> in intoxicated driving.) One subject who failed to reach a sufficiently high peak BAC (0.0325) was excluded from this analysis.

Next, the relationship between the output measures from the simulator and the real vehicle was assessed by calculating the correlation and the paired differences between outcomes in both modes. Two sets of Pearson's *r* coefficients were calculated, one for the correlations between simulated and real driving while sober, the other for the correlations between simulated and real driving while sober, the other for the correlations between simulated and real difference t-tests (null hyp.: no difference, alt. hyp.: non-zero difference) were performed, one set testing the difference between simulated and real driving while sober, the other testing the difference between simulated and real driving while sober, the other testing the difference between simulated and real driving while sober, the other testing the difference between simulated and real driving while sober, the other testing the difference between simulated and real driving while sober, the other testing the difference between the simulated and real driving while sober, the other testing the difference between the simulated and real driving while sober, the other testing the difference between the simulated and real driving while sober, the other testing the difference between the simulated and real driving while sober, the other testing the difference between the simulated and real driving while sober, the other testing the difference between the simulated and real driving while sober.

Because individuals can vary widely in driving skill, a second analysis was performed in with the purpose of examining the *change* in driver performance due to intoxication and ignoring any variability in overall driving skill between individuals. Furthermore, because detailed records of subject BAC levels throughout the experiment were available, it seemed appropriate to design an analysis that would take these into account.

To quantify the change in driving behavior, a new outcome measure was calculated based upon the <u>speed-time</u> and <u>speed-delta</u> performance measures: the change in each outcome per unit BAC. For example, the change in <u>speed-time</u> per unit BAC in the simulator was calculated by subtracting a subject's time over speed limit recorded while sober in the simulator from that recorded while intoxicated in the simulator and dividing this difference by that subject's mean BAC during the simulation nn. A corresponding change in <u>speed-time</u> was also calculated for real vehicle performance. This value is literally the slope of the regression line for a subject's <u>speed-time</u> versus BAC, and its magnitude is analogous to the *effect* of alcohol intoxication upon an outcome variable in each experimental mode.

The slope was calculated for each subject in each mode for both the <u>speed-time</u> and <u>speed-delta</u> outcomes. As before, they were analyzed for the size of intoxication effect using t-tests (null hyp.: slope = 0, alt. hyp.: slope > 0) and were analyzed for similarities or differences between simulated and real driving using paired t-tests (null hyp.: no difference, alt. hyp.: non-zero difference) and a calculation of Pearson's *r* coefficient. Again, the tests for intoxication effect excluded the one low-BAC subject mentioned above. The tests for similarity between the simulator and the vehicle did not exclude this subject.

Additionally, outcome measures indexing lateral vehicle control were analyzed within each mode, although no direct comparison between the simulator and vehicle outcomes was possible. In the experimental vehicle the subjects received verbal reminders from the accompanying VT researcher to stay within the right lane whenever a lane deviation occurred or appeared immanent; the number of reminders issued was recorded for each experimental run. From the simulated course, the lateral position of the vehicle was recorded and an obstacle-free, 1100-foot section selected for analysis.

RESULTS

The mean peak BAC for the ten subjects was $0.066 \pm 0.015\%$; maximum BAC was 0.0865%, the minimum, 0.0325%.

The effects of intoxication upon the <u>speed-time</u> and <u>speed-delta</u> outcomes in each experimental mode are shown in Table 1. Both outcome measures showed increases due to intoxication in the simulator and in the experimental vehicle; however, only the increase in <u>speed-time</u> in the simulator, 25.8 ± 34.9 s, was statistically significant (p < 0.029).

OUTCOME	Paired difference (t-test n=9)		
MEASURE	Real vehicle	Simulator	
speed-time (s)	28.6 ± 63.0 (0.105)	25.8 ± 34.9 (0.029)	
speed-delta (m/s)	10.3 ± 39.8 (0.231)	33.3 ± 66.4 (0.086)	

Table 1 Intoxicated versus sober driving. The values indicate the increase in <u>speed-time</u> or <u>speed-delta</u> recorded during the intoxicated driving sessions as compared to during the sober driving runs. The values in parentheses indicate the one-tailed p-value of each statistic.

The t-test results and correlation values for the comparisons made between simulated and real driving are shown in Table 2. For the paired difference tests, no significant difference is found for <u>speed-time</u> in either condition, while there is a significant difference for <u>speed-delta</u> while sober (74.0 \pm 39.8 m/s p < 0.0002), and a near significant difference for <u>speed-delta</u> while intoxicated (57.3 \pm 84.6m/s p < 0.061). For the correlation tests, a near-significant correlation between modes was found for <u>speed-time</u> under both sober and intoxicated conditions (r = 0.593, p < 0.071 and r = 0.578, p < 0.080, respectively). A non-significant, negative correlation was found for <u>speed-delta</u> in both states.

OUTCOME	Paired difference (t-test n=10)		Correlation (Pearson's r n=10)	
MEASURE	Intoxicated	Sober	Intoxicated	Sober
<u>speed-time</u> (s)	23.0 ± 75.5 (0.361)	18.0 ± 72.8 (0.454)	0.578 (0.080)	0.593 (0.071)
speed-delta (m/s)	57.3 ± 84.6 (0.061)	74.0 ± 39.8 (0.000)	-0.370 (0.292)	-0.072 (0.843)

Table 2 Simulated versus real driving. The values for the paired difference tests indicate the absolute mean difference between <u>speed-time</u> or <u>speed-delta</u> values recorded in the simulator as compared to the real vehicle, (in both intoxicated and sober states.) The values for the correlation tests are Pearson's r statistic for simulated as compared to real driving for both sober and intoxicated states. For all values, the parentheses indicate the two-tailed p-value of the statistic.

Table 3 shows the results of the t-tests performed upon the <u>speed-time</u> and <u>speed-delta</u> slopes. Only the change in <u>speed-time</u> in the simulator was significant (452.9 \pm 596.6, p < 0.026), however, the change in <u>speed-delta</u> was nearly significant (540.8 \pm 955.1 p < 0.064) and the other two values indicate a possible trend towards significance.

OUTCOME	Mean change in outcome per unit BAC (slope)			
MEASURE	(Single sample t-tests, n=9)			
	Real Vehicle	Simulator		
<u>speed-time</u> (s)	452.9 ± 596.6 (0.026)	596.6 ± 1386.4 (0.116)		
<u>speed-delta</u> (m/s)	$183.3 \pm 478.0 \ (0.142)$	540.8 ± 955.1 (0.064)		

Table 3 Intoxication effects expressed as change in outcome per unit BAC (slope). The values indicate the mean change per unit BAC for <u>speed-time</u> and <u>speed-delta</u> in both the simulator and real vehicle. The values in parenthesis indicate the one-tailed p-value of each statistic.

Finally, Table 4 shows the paired t-test and correlation between the per-unit BAC changes in <u>speed-time</u> and <u>speed-delta</u> in simulated as compared to real driving. No significant differences or correlations are present. The highest correlation between simulated and real driving is for the <u>speed-time</u> outcome, r = 0.424, p < 0.222.

OUTCOME MEASURE	Paired difference (t-test n = 10)	Correlation (Pearson's <i>r</i> n=10)
<u>speed-time</u> (s)	143.7 ± 1558.5 (0.789)	0.424 (0.222)
<u>speed-delta</u> (m/s)	357.5 ± 1221.9 (0.402)	-0.232 (0.518)

Table 4 Correlation between intoxication effects (slopes). The t-test values indicate the absolute mean paired difference between the intoxication effects seen in the simulator and in the real vehicle. The correlation values indicate Pearson's coefficient r for the comparison between simulator and real road intoxication effects. The values in parenthesis indicate the two-tailed p-value of each statistic.

The mean number of verbal lane reminders issued during the on-road experiments to non-intoxicated drivers was 13.40 ± 1.08 and the number issued to intoxicated drivers was 14.43 ± 1.65 . A one tailed t-test indicated a significant difference (p < 0.05). From the lateral position variable acquired from the simulator, the lateral range was determined from each run. As was done for the <u>speed-time</u> and <u>speed-delta</u> outcomes, each subject's intoxication effect slope was calculated and the mean effect was 2.63 ± 2.85 meters per unit BAC, p < 0.018. Considering that the lane reminder outcome is not a continuous variable and is, at best, a crude measure of lateral vehicle control as compared to lateral range, it is not appropriate to directly compare the intoxication effects between the simulator and the vehicle or to infer that a significant deficit in lateral control was present in both simulated *and* real driving. However, observing the effect of intoxication upon lateral range may prove fruitful in future validation studies.

Considering that very few measures of driver intoxication and between-mode correlation yielded statistically significant results, several power analyses were performed for the purpose of determining what sample size would be sufficient demonstrate significant intoxication effects and correlations, as well determining what sample sizes would be sufficient to reveal significant differences between simulated and real driving modes in this paradigm. All sample sizes were calculated using $\alpha = 0.05$ significance level and $\beta = 0.20$ power level.

The first power analysis focused on the <u>speed-time</u> outcome; it was found that a sample size of roughly 30 subjects would be sufficient to show significant simulated and real-driving increases in <u>speed-time</u> due to intoxication (refer to Table 1). This sample size would also be sufficient to show a significant positive correlation between simulated and real driving (refer to

Table 2, right side). In order to show a significant *difference* between simulated and real driving by a paired t-test (refer to Table 2, left side), a sample size of roughly 90 subjects would be sufficient.

For the <u>speed-delta</u> outcome, the same analysis was performed. Roughly 100 subjects would demonstrate a significant increase due to intoxication, while a sample size of only 40 would be sufficient to demonstrate significant differences between simulated and real driving. The correlation between simulated and real driving is negative, indicating that a positive correlation may not exist; however, a sample size of over 1500 would be necessary to show a significant negative correlation in both intoxicated and sober driving.

This analysis was also performed on the <u>speed-time</u> and <u>speed-delta</u> slope calculations. To show a significant positive <u>speed-time</u> slope a sample size of about 50 would be sufficient, whereas to show a significant <u>speed-delta</u> slope, a sample size of 40 would be sufficient (refer to Table 3). To show a significant positive correlation between simulated and real driving for the <u>speed-time</u> slope would require a sample size of roughly 60 subjects, whereas to show a significant <u>negative</u> correlation for the <u>speed-delta</u> slope would require 190 subjects (Table 4, right side). To show a significant paired difference between simulated and real driving would require roughly 1000 subjects for the <u>speed-time</u> slope and roughly 100 subjects for the <u>speed-delta</u> slope.

DISCUSSION

This pilot study focused on the effects of intoxication upon two measures of longitudinal vehicle control in a closed circuit on-road driving course and a in corresponding simulation task: total time spent driving over the speed limit (<u>speed-time</u>) and the sum of moment-to-moment speed changes over the course of the experiment (<u>speed-delta</u>). It was shown that <u>speed-time</u> increased during intoxicated driving both on the simulator and on the real road, that the measurements of <u>speed-time</u> from the simulator and real vehicle were positively correlated during both sober and intoxicated driving, with no statistically discernable difference between them, and that similar results were obtained by analyzing the intoxication-induced change in <u>speed-time</u> relative to subject BAC levels. It was shown that <u>speed-delta</u> also increased due to intoxication, but that there was a *negative* correlation as well as a near-significant difference observed between measurements from the simulator and real vehicle; change in <u>speed-delta</u> relative to subject BAC showed near-significant increases due to intoxication as well as a negative correlation between modes, but did not show a significant difference between modes. These results were consistent with previous studies (27-31).

As this study is of a pilot nature, these results cannot definitively answer issues regarding the validity of driving simulators in intoxication research. However, the results can guide the design of future studies, suggest appropriate methods of data collection and analysis, and lend insight into the strengths and weaknesses of the current study design.

Two previous studies have examined intoxication effects on both a driving simulator and a real road course (25,26); however, they did not directly compare the results from the two modes and they did not address the issue of simulator validity in intoxication experiments. The largest and most comprehensive of these employed many design elements similar to the current study, such as customized alcohol dosing, masked placebos and obstacle avoidance, and analyzed many of the same outcome variables, such as lane position range and speed variability. The findings indicated general performance deficits associated with high BAC levels in both the simulation and the road experiment; however, the outcomes common to both experimental modes were not directly compared and in nost instances did not show similar intoxication effects. In the current study, using a simulator and real vehicle that employ identical data collection methods is a major improvement over previous designs in that it facilitates the direct comparison between simulated and real driving.

In addition, the findings in previous studies indicated some significant differences in response to intoxication between the two modes, owing, the authors claim, to lack of kinesthetic feedback in the fixed base simulator used in their experiments (25). In the current study, simulator kinesthetic feedback issues were addressed by using a low speed design which significantly reduced the kinesthetic cues experienced in the on-road task (as confirmed by subject self reports and experimenter observation) and improved the comparability between measurements from the real vehicle and the simulator.

In considering the design of future studies, it is useful to note that of the two outcome measures analyzed, the <u>speed-time</u> measurement was the most robust in this experiment. This measurement not only showed sensitivity to intoxication effects (Table 1), but it also showed remarkable comparability when reported by the simulator and real vehicle (Table 2). While the <u>speed-delta</u> measurement may have shown sensitivity to intoxication (Table 1), there is very little comparability between

measurements reported in simulated and real driving (Table 2). These relationships were also apparent in the slope and slope analyses: the <u>speed-time</u> showed good sensitivity to intoxication and good correlation between tests modes, while the <u>speed-delta</u> slope showed sensitivity to intoxication but no correlation between test modes.

In addition, the power analyses indicated that by using a sample size of 30 subjects, it would be feasible to conduct a similar study that showed significant intoxication effects in <u>speed-time</u> without revealing significant differences between the driving and simulation modes. Power analyses for the <u>speed-time</u> slope calculations showed that a significant intoxication effect could be demonstrated with a sample size of only 50 subjects. These sample size calculations also suggest that for large-scale studies of this kind, the <u>speed-time</u> slope calculations might be the most appropriate, as significant *differences* between the test modes might only be revealed with sample sizes of 1000 subjects or larger. For the <u>speed-delta</u> measurement, the sample size required to show significant intoxication effects (100) exceeds the sample size that would show significant differences between simulated and real driving (40). Thus, in future validation studies it may be of great use to analyze driver time over the speed limit or some related variable.

In both outcome measures studied, it was found that while alcohol intoxication caused overall worsened performance, some subjects showed improved performance in those measures, as well as in several other measures not discussed here. In designing a large-scale, detailed validity study, it would be most desirable to sample from a more homogenous population than was tested here. While the current study's screening methods attempted to include only moderate drinkers with good driving records, they could not control for such factors as physiological tolerance, number of years of drinking experience, personal attitudes towards alcohol, etc. These factors may have interesting effects upon intoxicated driving behavior, but in the context of simulator validity research these effects are confounding. Obtaining a relatively homogenous subject sample might be accomplished by applying more stringent screening than was applied in the current study, or by recruiting from a relatively homogenous population as has been done in recent studies of low-dose alcohol intoxication in maritime cadets (32, 33).

In this current study, the mean peak BAC of the ten subjects was only $0.066 \pm 0.015\%$, despite the customized dosing designed to produce a 0.08% peak BAC. In any intoxication research it is critical to be able to control the extent of intoxication, therefore future studies should employ a more sophisticated dosing algorithm than used in the current study, or should perform dose and response testing for each subject prior to the experimental sessions.

Finally is also important to address the intractable limitations of any simulation experiment design. For example, the low speed design of the current study avoids kinesthetic feedback issues which may be manifest in high speed studies (25); therefore, the conclusions made about simulator validity at low speeds might not hold true for high speed studies. The current study also limits its scope to a relatively non-interactive driving course (i.e. the use of cone obstacles as opposed to actual vehicles, dry road daylight conditions as opposed to more adverse conditions); though our simulator setup (STISIM) is capable of reproducing these conditions, the validity of its measurements in such experiments can only be speculated upon.

The effects of alcohol intoxication on driving can be observed through the study of its individual cognitive components; however, as with any complex task, studying the complete behavior is the most desirable in some situations and can provide the most salient and relevant results. The low cost and flexibility of simulation systems such as the STISIM Drive 100 make them ideal tools for studies involving a large number of subjects or studies performed under conditions which for various reasons may not be replicable on a real road testing facility; however, it is critical that observations derived from a simulator be commensurate to actual driving skills and behavior. The results of current study suggests that the low cost STISIM Drive system is able to measure driving deficits that are relevant to real-world driving situation. Further validation studies are needed to fully characterize fixed-base simulator validity, and to explore the uses of simulators in intoxicated driving research.

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