Validity of Driving Simulator Studies for Predicting Drug Effects in Real Driving Situations

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Experimental studies play an important part in establishing the nature and extent of possible impairment of driving-related skills by drugs. However, to perform such experiments by placing subjects in typical traffic situations while under the influence of a drug poses serious safety problems. Therefore, investigators have used two alternate methods to investigate the influence of drugs. One is using driving simulators, in which subjects are not exposed to real traffic hazards; the other is to use real cars in a closed driving course with curtailed traffic.

Driving simulators have generally been chosen in preference to the closed driving course. The disadvantage of the latter technique is that by restricting the environment to provide safety, many sources of stimulation characteristic of actual traffic situations are lost. Since one major reason for traffic accidents is failure to perceive important elements of the environment, an impoverished environment removes opportunities to study the effects of drugs upon perception. The simulator is the technique of choice also because it is more capable of ensuring replication of exactly the same stimulus presentation to all subjects. Finally, instrumentation is easier for simulators than for cars. This is true not only for stimulus presentation and response measurement but for measuring the time between stimulus and response.

SIMULATOR REQUIREMENTS

Given our need for such an instrument, what are the requirements for a simulator which will enable it to be an adequate research tool for the study of drug-driving interactions?

Primarily it requires that demands placed upon the subject include those behavioral elements which are required for driving and which have the potential to be affected by the drug under investigation.

Since researchers desire to investigate a wide variety of drugs and one cannot predict which behavioral elements each drug might affect, a driving simulator is required that contains a representative sample of all the behavioral demands of driving.

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Thus, to construct such a simulator, it is necessary to analyze driving systematically so as to describe and enumerate all major components of the driving task in their proper proportions. A representative sample of the behavioral items could then be incorporated into a simulator. Finally, to validate the simulator as a test instrument, the performance of subjects in the simulator must be correlated with their performance in typical traffic situations on the road. Unfortunately, no such simulator exists nor is likely to exist for some considerable time.

**Difficulties in Constructing the Ideal Simulator**

The first difficulty is that driving task analysis has not progressed to the point where one can confidently enumerate all the behavioral demands of driving. In an investigation of the behavior units of importance for driver education, a task force at the Human Resources Research Organization developed an incomplete list with more than 1,500 behavioral items believed important for a wide range of fairly common driving experiences (15). Not only was the list incomplete but their relative importance or their relationship to underlying behavioral skills remains unclear.

Another difficulty in achieving the optimal simulator, even if all that one wishes to incorporate into it could be specified, is the limitations of existing technology. For example, one of the prime sources of information about the driving environment is provided to the driver by the effect of inertial forces upon kinesthetic and vestibular receptors.

Only a few simulators are capable of applying inertial forces to the subject in conjunction with simulation of appropriate vehicle movement on a road. In these moving-base simulators, the cab in which the subject sits rotates, rolls, and yaws. These simulators are used by car manufacturers (for example, General Motors and Volkswagen) interested in the ability of subjects to control vehicles with different handling characteristics. Such a simulator has increased capabilities of reproducing the sensations experienced in cars with different chassis suspensions. However, even these are only capable of momentarily duplicating some of the inertial forces which are experienced in actual driving. Most simulators are incapable of producing any inertial cues.

At this time it appears impossible to build the ideal all-purpose research simulator because we are not able to specify all that it should contain, nor are we technically capable of building into it all that we already know is of importance for driving.

Therefore, it can be concluded that all current simulators sample only a restricted range of the possible behavioral demands met upon the road. This limits the conclusion to be drawn from the presence or absence of any drug-performance interaction found in a given simulator. Thus, if we desire to examine the reliability and validity of drug simulator studies, it is necessary, firstly, to understand the specific behavioral demands of the simulator used and secondly, to compare drug-performance changes in the simulator with the nature of accidents when under the influence of the drug. Unfortunately, there has been no systematic analysis of what various simulators require from the behavior of subjects. They have been constructed to sample behavior either in accordance with the builder's theoretical assumptions (which are rarely explicaded), or they have been built to incorporate whatever is available in the technological state of the art in constructing simulators. As a result of the lack of clarity regarding the behavior demands on the subjects in different simulators, the source of variability in results cannot be determined.
TYPES OF SIMULATORS

The above discussion bears on an issue arising from the literature where simulators are dichotomized as either whole- or part-task simulators (24). Whole-task simulators are defined as those in which the driver makes acceleration, braking and steering adjustments appropriate to the changing visual scene. A part-task simulator is presumed to simulate only part of the environment and response demands of actual driving. Such a dichotomy is misleading since no simulator exists which contains a representative set of stimuli sources and response demands of driving. In fact, all are truly only part-task simulators.

The differences in the behaviors sampled by different simulators will be understood if we examine the range of devices which have been used as driving simulators in drug studies. There are both programmed and unprogrammed simulators. A programmed simulator is one in which the driver’s reaction to the visual scene has no effect upon that presentation. Such a simulator was used by Crancer, et al. to study the effects of marijuana and alcohol (8). Subjects viewed a film and were required to manipulate a steering wheel, brake and accelerator appropriately, but nothing of what they did affected the presentation.

The visual presentation of unprogrammed simulators change in response to the driver’s behavior, and they vary considerably in response capability. In the UCLA simulator used to study the effects of alcohol and marijuana, the driver could change speed by manipulation of the accelerator and brake, which in turn controlled the speed of the filmed projection (16, 19). By use of the steering wheel the driver produced a rotation of the film projector resulting in a lateral movement of the visual scene.

Other unprogrammed simulators have even greater ability to respond to the subject’s control. These include simulators which utilize television cameras moving over a model road, and point light source simulators which have a shadow projection from a moving model landscape.

The most versatile unprogrammed simulator is one where the subject faces a television screen with a road scene which is generated by computer (11). The computer memory bank allows subjects a choice of different paths at various junctions. Volkswagen has such a simulator in operation.

In general, the versatility of the unprogrammed simulators is bought at the cost of an increasingly sparse presentation of the complex elements of the environment. For example, they often encompass small visual angles in contrast to the wide visual demands of driving. Further, the more elaborate unprogrammed simulators permit the subject to choose his pathway by forsaking the use of filmed presentations. Yet one of the more important issues is the effect of drugs upon the perception of the visual scene. In this respect, films are (so far) the best means of realistically presenting the objects in the environment with sufficient detail to examine the subject’s choice of observational behavior. It is desirable to examine the effects of drugs upon the distribution of drivers’ attention to playing children, older pedestrians, other cars, and other such variables.

Some Studies

Only sparse visual elements are presented by many simulators used in drug research. For example, the simulator used by Landauer et al. to study alcohol and amitriptyline was simply a step type pursuit tracker with five bulbs in a horizontal line (13). The
pointer above the bulbs was controlled by a steering wheel which the subject moved to align the pointer with the lit bulb.

Binder, studying marihuana and alcohol, used an array of 96 bulbs in 6 rows and 16 columns (3). On a random basis one bulb was lit and by use of a joy stick subjects tracked to that bulb with a circular light indicator. Both of these studies included requirements for the subject to respond simultaneously to a subsidiary task while performing the primary pursuit tracking task.

These last two studies placed prime emphasis on the tracking task with a simplified visual scene. In contrast, Buikhuisen and Jongman studied the effects of alcohol on performance in a simulator which required no measurable motor response (4). Subjects simply viewed a film presentation and the distribution of their eye movements and fixations were recorded.

The above review suggests that not only is there no simulator which adequately samples the totality of behavioral driving demands, but that the simulators in current use differ greatly so that it is unlikely the behavioral demands upon the subjects are the same.

Therefore, there is no existing simulator in which we can test a subject under the influence of a drug and conclude that if there is no change in performance as compared to placebo condition, there will be no effect upon actual driving.

### BEHAVIORAL DEMAND CHARACTERISTICS

No simulator samples all stimulus inputs and demand characteristics of driving. A drug might be potentially detrimental to some behavioral mechanism not required in the simulator. On the positive side, since simulators do sample a restricted sub-set of behaviors, to the extent that we can specify that sub-set, we are in a position to generalize to potential drug effects on that behavioral sub-set in actual road conditions.

It should be noted that speaking of a sub-set of behaviors is not meant as a reference to the specific response measures of the simulator. Drug impairment of a behavioral mechanism such as vigilance could be reflected in performance decrements on many simulator measures from frequency of steering wheel reversals to brake pressure. An example may clarify this last issue. Moskowitz reported two studies on the effects of approximately .10% blood alcohol concentration (BAC) on performance in the UCLA film simulator (16). The subject’s responses permit the derivation of 25 performances measures of car control and tracking. It is of interest that in the first study none of the car control and tracking measures showed impairment under the rather high alcohol intake. The study was then replicated with the inclusion of a simple subsidiary task which required the driver to respond appropriately to two colored lights presented at one of two positions on a random basis with a frequency roughly 1 per minute during a 31 mile drive. Under the additional information-processing requirement of the subsidiary task, not only did the alcohol produce impairment in performance of the subsidiary task, but also in 12 of the 25 car control and track measures which formerly demonstrated no alcohol effect.

Thus, “behavioral demand characteristics of a simulator” refers to the character of the psychological demands upon the driver. A drug which affects the ability of a subject to process information from the traffic environment may produce a performance decrement in any or all of a large variety of response measures. In the case just cited, a large group of specific response measures was unaffected by the drug
under one condition of psychological demand and significantly affected under other behavioral demand conditions.

Only by specifying precisely what the simulator is testing, that is, what behaviors are required for performance in that simulator, can we investigate the validity of those simulator measures for driving performance in the real world.

This view can be illustrated by examination of several issues. 1) Do simulators which share common behavioral elements show similar responses by subjects under the same drug, that is, is performance in driving simulators under drugs reliable? 2) If the performance changes under drugs are reliable and are the same for simulators examining common behaviors, is there a relationship between these changes and performance changes under drugs in actual driving situations; i.e., are the measures valid indices of real world driving?

A review of studies of the effect of alcohol on performance in driving simulators was performed by Heimstra and Struckman (12). They examined 14 studies and classified the effects of alcohol into seven categories of behavior within these studies, namely, tracking, steering wheel reversals, accelerator reversals, brake usage, speed, signaling errors and tasks involving higher mental functions. They concluded that "there appears to be no behavior on which the effects of alcohol have been reported more than once with complete consistency. In many cases, alcohol appears to have had opposite effects on the same behaviors in different investigations." The authors did note, however, that performance deficits occurred under the influence of alcohol in six of the seven studies which included demands for higher mental processes.

CLASSIFICATION OF DRUG EFFECTS ON DRIVING

As suggested earlier, a classification of drug effects based on response output categories is not the most productive method of analysis unless one is examining drugs which are assumed to act primarily on peripheral motor networks. An alternate approach to these simulator and other laboratory studies of the effects of alcohol has utilized categories suggested by Stephens and Michaels (25). They suggested that driving could be initially and broadly categorized into a compensatory tracking task, an environmental search and recognition task, and a joint time-sharing system for performing the two tasks.

Using these categories, Moskowitz noted that most experimental studies of either compensatory tracking or of visual search-and-detection tasks when undertaken in isolation, showed little impairment until beyond a BAC of .20% (17, 18). However, both these task systems showed impairment, often at BACs well below .05% when subjects were required to perform two or more tasks concurrently. Therefore, analysis of drug effects for alcohol at least, requires the specification of the demands for information processing by the subject in that situation. It is apparently the brain's capacity of handling two tasks simultaneously that is most susceptible to alcohol impairment. Which performance task or tasks will exhibit the deficit under the drug is a matter of individual emphasis by the subject.

Another example of the lack of relevance of focus on the specific motor response variable can be seen by examining four studies of compensatory tracking under alcohol (5, 7, 20, 22). In all of these studies, the effect of alcohol upon compensatory tracking by itself was negligible. However, all studies reported significant alcohol effects upon compensatory tracking when the tracking task was to be performed concurrently with another task, or while the subjects were influenced by another stressor, such as anoxia.
Alcohol Effects

If we re-examine simulator studies under alcohol and isolate those where it can be clearly seen that there is a requirement for concurrent performance of several sub-tasks, as is typically found in driving between tracking and environmental search and perception tasks, then good agreement is found that performance is impaired at low to moderate BACs. Newman and Fletcher found impairment when subjects performed a pursuit tracking task and a subsidiary visual recognition task at .095% BAC (21). Asknes found impairment at .05% BAC in a Link trainer when subjects had to track a course, monitor seven instruments and map their course (1). Loomis and West found impairment at .05% BAC for a combined tracking task with a visual recognition and response task (14). Von Wright and Mikkonen found impairment at approximately .05% BAC for a combined tracking and visual recognition task (26).

In studies by Moskowitz (16), and Chiles and Jennings (5), the presence of the additional tasks were experimentally manipulated and it was shown that the primary tracking tasks were unaffected by alcohol except in the presence of the secondary task. In both of the last two studies it was concluded that “A decrease in the ability of the subject to time-share the performance of tasks requiring the exercise of different psychological functions may be the most important detrimental effect of alcohol . . . .” (5).

It is interesting to note that whenever the subject in the simulator was required to perform a joint tracking task and a subsidiary task, usually of a visual signal detection or recognition nature, the secondary task showed the greatest degree of impairment. This is not because tracking has intrinsically greater resistance to alcohol impairment, but is due to the greater emphasis on the tracking task. Tracking presents a continual demand for attention in contrast to the usually intermittent character of the attention demands for the detection or recognition aspects of driving.

Evaluating Alcohol Studies

We can conclude that there is considerable reliability in the sense of agreement among simulator studies when the emphasis of the analysis is upon the psychological function affected by the drug, rather than upon the response variable in which the particular psychological function is exhibited. Thus, to examine the issue of the validity or relevance of the results in the simulator, one must first isolate the behavioral functions that are being affected by the drugs.

If we accept the foregoing analysis which suggests that the most common alcohol effect found in simulator studies is impairment of the capacity for information processing, especially as required in time-sharing of several concurrent tasks, how can we validate these results from actual road traffic studies? One criterion for validation of the simulator would be data describing the nature of the accidents of persons under the influence of drugs. Unfortunately, there are few such studies. While there are many epidemiological studies showing a correlation between the presence of alcohol and increased probability of accidents and injury, little has been done with on-site accident investigations to determine the causal character of the accidents. There appears to be one such published study with alcohol-related accidents including analysis of road-users’ errors (6). In this study of 10 accidents involving the presence of alcohol, six were ascribed to either misperception or failure to look, two to excessive speed, and two to decision errors. All but the two due to speed conform to error classifications likely to have occurred if alcohol interfered with information processing and/or time-
sharing tasks. In the simulator studies noted above, when subjects were unable to maintain performance on both tracking and visual search-and-recognition tasks, it was the visual task which suffered the larger performance decrement, agreeing with this study of on-site accident causation.

Perhaps the most direct confirmation of the simulator studies comes from an experimental study of the effects of alcohol on airplane flying (2). The study has considerable value since nearly all the typical behavioral performance demands of flying were present. In this study by Billings, Wick, Gerke and Chase, sixteen subjects took off, instrument-flew and landed a plane under four alcohol treatments, resulting in 0, .04, .08 and .12% BAC. Eight of the subjects were highly experienced professional pilots, while the other eight were fairly experienced non-professionals. Flights took place with a safety co-pilot plus a physician located behind the pilot in order to incapacitate him, if necessary. Although the tracking demands of flying are more difficult than those of driving, the experienced pilots suffered no significant decrement in their tracking ability even at the highest dosage. However, beginning at the lowest dosages they committed procedural errors which were a hazard to flight. At the highest dose level, the safety co-pilot had to take command of the plane 11 times to prevent an imminent accident. The inexperienced pilots exhibited impairment in their tracking skills and accumulated far more procedural errors including taking off with full flaps, flying without lights, taking off with carburetor heat on, turning the wrong way in response to instructions, and flying a landing approach tuned to the wrong frequency. Catastrophic procedural errors included loss of control in flight, turns towards oncoming traffic and landing errors that would involve striking the ground. The authors comment:

If we assume that instrument-rated pilots, flying ILS approaches, consider the job of guiding their aircraft to a position from which a visual landing can safely be made as their primary task, then it follows that the other, discrete, procedures involved, while no less essential to safe operations, are relegated to a secondary role. The evidence is clear this is in fact the hierarchy which exists. It is equally clear that as pilots are progressively affected by alcohol, they become progressively less able to cope with the various facets of their task, and it is the secondary tasks which suffer first and most. (2)

Thus, while there is little validating data from either on-site accident studies or experimental field studies, what there is conforms with conclusions regarding the nature of alcohol impairment drawn from studies done in simulators.

It should be noted that in the preceding discussion, there has been no attempt to assess the quantitative increase in accident probability likely from performance decrement in a simulator. While the advantage of a simulator over other forms of laboratory studies is that it is sampling behaviors known to be of significance to driving, the relative proportions of these behaviors and their difficulty level in a given simulator may be unrepresentative of actual driving. Without that additional information, only qualitative judgments about the role of a drug can be offered.

For example, some studies of tracking functions have used input functions unlikely to be found in driving situations other than under unusual circumstances. While this undoubtedly increases the sensitivity of the tracking measures to the drug influence, it decreases our ability to generalize regarding the drug influence on normal levels of demand for tracking skill.
Marihuana Effects

The second most examined drug in simulators probably is marihuana. Three simulators examined visual detection and recognition (two in conjunction with tracking and car control) while two others examined risk-taking. If one examines the nature of the psychological functions under test in these 5 studies, there is considerable agreement or reliability in regard to the effects of marihuana. The studies of Crancer et al (8), Moskowitz et al (19), and Rafaelsen et al (23) examined attention or perceptual functioning and found impairment by marihuana. The Moskowitz et al and Rafaelsen et al studies also examined tracking and car control performance and found no impairment. Studies by Dott (9) and Ellingstad et al (10), examined risk-taking performance and found no impairment.

Again it should be noted that the agreement is in respect to behavioral functions involved in the drug effect rather than in general agreement across simulators. The simulators differed greatly ranging from those completely programmed (8, 10) to those only partly programmed (9, 19, 23).

Unfortunately, there is no means by which the validity of the results can be assessed since there has been no reported analysis of the types of accidents associated with marihuana use. In fact, there is scant epidemiological data to link driving accidents with the presence of marihuana.

While other drugs have been examined in conjunction with driving simulators, there appears insufficient data to permit determination of simulator reliability, much less validity.

SUMMARY

Driving simulator studies are a form of laboratory examination of the effects of a drug, presumably upon some aspect of driving. In general, as regards the behavioral aspects being examined in specific simulators, the results appear reliable for these functions across simulators. The validation process for simulator studies of drug can only refer to the specific behavioral aspects under study. This requires analysis of the nature of driving accidents under that drug in comparison with the behaviors examined in the simulators. As far as alcohol (the only drug for which such data are available) is concerned, the results of the simulator studies agree on the nature of the impairment in accidents.

These conclusions suggest that simulators are of value in the study of drug-driving interactions. However, such studies require an understanding of the character of the behavioral demands of the specific simulator under examination and of how these behavioral demands are reflected in actual driving situations. Unfortunately, there is no simple manner in which simulators can be used as a general technique to evaluate drug effects on driving.

REFERENCES


