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Use of Controlled Substances and Highway Safety

A Report to Congress
March 1988

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16. Abstract

This report reviews what is currently known about the relationship of drug use to highway safety. While much remains to be learned, we have made considerable progress in the last several decades in understanding the effects of drugs on driver behavior. This report:

- **Identifies the information that is needed in order to determine the nature and magnitude of the drug and highway safety problem and reviews the major methodological problems that must be overcome before substantial progress will be possible;**
- **Describes the best available information on the incidence of drug usage by drivers involved in crashes (or detained by the police);**
- **Summarizes the findings from laboratory research on the behavioral effects from drugs, from studies using driving simulators, and from on-the-road studies;**
- **Provides some general conclusions about the role of drugs in highway safety; and**
- **Describes the Department of Transportation's current plans to obtain some of the required information.**

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EXECUTIVE SUMMARY

This report on the use of controlled substances and highway safety was prepared in response to Public Law 99-570, The Anti-Drug Abuse Act of 1986, Title III, Subtitle G (Transportation Safety), Section 3402 - Drugs and Highway Safety.

For the purposes of this report, the term drugs is used to refer to all drugs, except alcohol, with the potential to impair driving ability (whether included in some definitions of controlled substances or not). The report focuses on the impact of drug use on highway safety only.

The report reviews what is currently known about the relationship of drug use to highway safety. It identifies the information that is needed in order for a more definitive understanding to be developed and reviews the major methodological problems that must be overcome before substantial progress will be possible. Finally, the report describes current plans to obtain some of the required information.

The data available are almost exclusively on the general driving population. Subgroups (e.g., commercial drivers, young drivers) may have different drug use patterns and driving problems that may exacerbate the effects of drugs. These issues are mentioned where appropriate.

CONCLUSIONS

While much remains to be learned, we have made considerable progress in the last several decades in understanding the effects of drugs on highway safety. Our knowledge can be summarized as follows:

- The use and abuse of drugs have become widespread in our society. Nearly 23 million people can be classified as current marijuana users, and some 5 million or more can be classified as current cocaine users. Psycho-active prescription drugs and over-the-counter medicines are used by an even greater percentage of the population.

- Many people who drive use drugs other than alcohol. Although there are not sufficient epidemiological data available to estimate the number of people driving after using drugs, given the large number of persons reporting drug use and the relatively long term effects of some drugs, the number driving after consuming drugs must be substantial.

- Information from studies of drivers involved in crashes indicates that many have used drugs. Our assessment of the existing research is that drugs may be present in somewhere from 10 to 22 percent of crash involved drivers, often in combination with alcohol. Specially trained officers from the Los Angeles Police Department have estimated that 20% of the drivers arrested for driving while impaired are under the influence of drugs other than alcohol.

- A growing body of literature suggests that certain drugs (such as marijuana) impair psychological and behavioral abilities that are functionally related to driving even though the extent to which drug impaired driving causes crashes cannot be inferred from this research. In particular, our knowledge of how the effects of a drug change with the dose level is very limited.

- Drugs that may impair driving include certain prescription and over-the-counter drugs as well as illegal drugs.

- Drugs are quite often used in combination with high doses of alcohol, so that understanding the combined effects of drugs and alcohol is important.

- It is clear that drugs other than alcohol contribute to highway crashes. The frequency with which drivers drive, are arrested, or crash while under the influence of drugs other than alcohol is not known accurately. However, the available data on drug use by crash involved drivers suggests that the drug and driving problem is substantially less than the alcohol and driving problem, since 40% of traffic fatalities involve at least one intoxicated driver or pedestrian.

- The drugs that appear to have the most potential to be serious highway safety hazards (based on currently available information on incidence and impairment) are: tranquilizers (e.g. (Valium(R)), sedatives and hypnotics (e.g. barbiturates), and marijuana.

- There are reasons for greater concern regarding drug use by commercial truck drivers than by the general driving public. Available evidence suggests that drug and alcohol use patterns differ between commercial drivers and the general driving public (less alcohol, more stimulants). In addition, commercial drivers are often driving while fatigued and are confronted with a much more demanding task. Thus, the use of drugs by commercial drivers presents a very different and potentially more serious problem. Limited information from an Insurance Institute for Highway Safety survey of tractor-trailer drivers indicated that 29% had alcohol, marijuana, cocaine, and/or prescription or non-prescription stimulants in either blood or urine.

CURRENT KNOWLEDGE AND INFORMATION NEEDS

The nature and extent to which drugs other than alcohol are a serious highway safety problem among the general driving population (i.e., impair driving ability and increase crashes) cannot be specified with certainty at this time. Several critical pieces of information are needed to determine the relationship between drug use and highway safety. A brief review of our current knowledge and information needs follows.

1. Which Drugs Impair Driving Ability?

The study of how drugs affect driving related skills has produced a large and diverse literature. Methods used have included laboratory studies of human performance and "driving related skills," use of driving simulators, and on-the-road studies (using actual vehicles, typically on a closed course).

Unfortunately, this research is limited by several factors which suggest caution in drawing conclusions based on the "impairment" observed in these studies. These problems include the very large number of drugs that need to be studied, the considerable disagreement that exists regarding the tasks, measurement methods and what constitutes critical driving skills, and the highly artificial and sometimes inappropriate nature of the tasks employed in the laboratory.

Despite these problems, the available data clearly show that many different drugs impair behavior on "driving related skills" (i.e., laboratory tasks of perceptual, motor, attention and decision making skills, driving simulator behavior, and driving behavior in on-the-road studies). Marijuana, sedatives and hypnotics (benzodiazepines, barbiturates), other depressants, antidepressants, antipsychotics, some antihistamines, and some hallucinogens have all been shown to fall into this category.

2. Which Drugs are Associated With Higher Crash Rates?

Two approaches can be used to determine which drugs are associated with increased crash rates.

- The incidence of drug use in crash and noncrash involved drivers can be measured. Finding that a drug was overrepresented in crash-involved drivers would strongly suggest that it played a role in increasing crash risk.

- Alternatively, the rate at which crash involved drivers are judged to have been responsible for their crashes can be measured. Finding increased crash responsibility rates for drivers having used specific drugs, as compared to drug-free drivers, would strongly suggest that the use of the drugs increases crash risk.

Very little research of this type has been conducted to date and virtually no useful data are available regarding the association of drug use with increased crash rates. However, the Department of Transportation is currently initiating a study to determine the incidence of drugs in fatally injured drivers that will use the alternative method described above to assess the role of drugs in leading to highway crash rates.

3. What Drug Dosage Levels Are Associated with Impaired Driving?

It is quite difficult to determine the relationship of drug dosage level to driving impairment and increased crash rates. This is due to the considerable individual differences that exist in the physiological and behavioral response to drugs, the poor correlation between psychological or behavioral effects and blood (or plasma) level for many drugs, the existence of sensitivity and tolerance effects (increased and decreased responses to repeated administrations), and the fact that many drugs (or their active metabolites) accumulate in the blood or other body fluids. Until these processes are better understood, it will not be possible to equate the presence of specific amounts of many drugs in the blood (or other body fluids) in an individual to a specific psychological or behavioral effect.

Little is currently known about the relationship between dosage level and driving impairment. The ability to predict the behavioral consequences of different dosage levels of most drugs is currently quite limited (i.e., only gross generalizations can be made, such as that high doses generally have a greater effect than small doses).

Useful information about the relationship of drug dosage levels and impairment of driving related behavior can be acquired through research using realistic driving simulators or computerized instrumented vehicles for selected drugs of interest. Simulator studies of a few common drugs would strongly suggest their potential for real driving impairment and would further our understanding of the effects of different drug-dosage levels.

4. How Frequently Are Drugs That Impair Driving Ability Being Used?

Blood samples must be collected and analyzed to determine the number of drivers who operate a motor vehicle while impaired by drugs. Many drugs will remain in some body fluids, like urine, for some time (days, and in some cases weeks) after the psychological and behavioral effects have passed. These fluids thus can provide a good record of drug use over time. Blood is currently the only body fluid that can indicate that the subject might have been under the influence of the drug detected, at the time the blood sample was collected. Research that involves collecting blood samples from drivers is expensive and difficult to conduct.

Other practical and methodological difficulties have limited the usefulness of past research on drug use by drivers. These have included an inability to detect and measure the presence of some drugs in drivers, the costs of screening for a wide range of possible drugs, and an inability to obtain representative samples of drivers for study. No useful data on drug use from noncrash involved drivers have been collected.

Within these limitations, studies of drug use by fatally injured drivers have shown that 10 - 15% of these drivers have taken psychoactive drugs. In the majority of cases alcohol was also present. The only recent study of drug use by injured drivers found that approximately 22% had used drugs other than alcohol.

Different studies generally report the highest drug use incidence rates for the same potentially hazardous drugs. They are (in order of decreasing frequency):

- o marijuana
- o diazepam (Valium(R))
- o barbiturates (e.g., secobarbital)
- o methaqualone
- o PCP (phencyclidine)

Recent advances in drug testing technology have made large-scale drug incidence studies much more feasible and useful than in the past. For example, research to determine the incidence of drugs in a representative sample of fatally injured drivers, reflecting current drug usage patterns, could be undertaken.

DOT RESEARCH AND DEMONSTRATION PLANS

Given the current state of knowledge, it is clear that additional information is needed. In light of this, the Department of Transportation plans to continue research programs designed to help define the nature and magnitude of the drug and driving problem. In addition, the Department will continue its current efforts to assist the police in enforcing the laws against driving while impaired by drugs.

The Department's research is directed at assessing the frequency of drug use by drivers, determining which drugs are associated with higher crash rates, and learning about the impairing effects of different dosage levels of selected drugs on driving related behavior. This research will take advantage of recent technological advances. As a result, the information obtained will be more useful and in greater depth than possible previously. The Department's two large scale studies, currently in their final planning stages, are described briefly below.

- o <u>Determine the Incidence and Role of Drugs in Fatal Crashes</u>

  This two year project is designed to determine the incidence and role of drugs in a sample of fatally injured drivers. Compared to previous studies that employed small non-representative samples, this study will sample a large number of fatally injured drivers from various regions of the country. Also, advances in drug testing technology will allow a more accurate and precise determination of drug usage for a wider selection of drugs. Finally, the improved quality of police accident reports will allow an estimation of the role drugs play in crash occurrence (through a "responsibility analysis"). This information will help us estimate the magnitude of the drug highway safety problem.

- Simulator Research

  This study will examine the effects of selected drugs on simulated driving behavior in a state-of-the-art driving simulator recently developed by the Mercedes-Benz company and located in Berlin, West Germany. This new simulator is very realistic and allows many more types of driving situations that require decision making in emergency situations to be simulated than was possible in earlier simulators. This research is planned as a joint effort with the West German government which is also very interested in drugs and highway safety. This study will provide information about the impairing effects on driving related behavior of drugs with high potential as highway safety hazards.

- Drug Evaluation and Classification Demonstration

  The Department has also been actively involved in efforts to develop and disseminate effective tools to assist the police in enforcing current laws against driving while impaired by drugs. We have recently completed both a laboratory and field evaluation of a drugged driver detection procedure developed by the Los Angeles Police Department. The procedure uses both physiological measures (eye gaze nystagmus, blood pressure, etc.) and behavioral measures (walk a straight line, one leg stand, etc.) to assess the nature of drug related impairment. The results of our testing indicate that the LAPD procedure is very effective. We are currently in the process of developing a training course for police officers that will teach this technique. The training course will be pilot tested in 10 states in 1988.

Taken together, the results of these two studies will increase our knowledge of the incidence and role drugs play in fatal accidents and of the impairing effects of selected high priority drugs on driving behavior. The demonstration will assist the police in enforcing current laws against driving while imnpaired. While much remains to be learned, this information should significantly advance our understanding of the relationship between the use of drugs and highway safety.

CHAPTER I

INTRODUCTION

PREFACE

On behalf of the Secretary of the Department of Transportation, the National Highway Traffic Safety Administration (NHTSA) has prepared this report on the use of controlled substances and highway safety. The report was undertaken in response to Public Law 99-570, The Anti-Drug Abuse Act of 1986, Title III, Subtitle G (Transportation Safety), Section 3402 - Drugs and Highway Safety. Section 3402 directed the Secretary to:

> ... conduct a study to determine the relationship between usage of controlled substances and highway safety. Such study shall include a simulation of driving conditions, emergency situations, and driver performance under various drug and dosage conditions. Such study shall determine the incidence of controlled substance usage in highway accidents resulting in fatalities and the dosage levels for controlled substances which are most likely to result in impairment of driver performance.

This report contains a brief discussion of what is known about the issues required to be addressed, it identifies the information that is needed in order for a more definitive answer to be provided, and describes current plans to obtain the required information.

CONTROLLED SUBSTANCE DEFINED

One common definition of controlled substance stems directly from Federal legislation designed to restrict the availability of narcotics and other dangerous drugs. The Controlled Substances Act of 1970 (Public Law 91-513) places drugs of abuse into one of five "schedules" depending on their potential for abuse, value in medical treatment, and risk of creating a physical or psychological dependence. Thus, for example, heroin is classified as a schedule I drug (with no currently accepted medical use and high potential for abuse), while Valium(R) (a tranquilizer) is classified as a schedule IV drug (with currently accepted medical use and low potential for abuse).

There are drugs that are not controlled substances under this definition that can affect behavior and possibly impair driving ability. Some over-the-counter cold and allergy medicines and sleeping aids are in this category. The majority of states, in their own driver control legislation, have statutory definitions of drugs broad enough to cover most if not all drugs. For the purposes of this report, the term drugs includes all drugs except alcohol with the potential to impair driving ability (whether included under the Federal definition of controlled substances or not).

REPORT PREPARATION AND ORGANIZATION

This report is based upon currently available information. Due to the short time frame provided, no new data collection was undertaken. A literature review was conducted to ensure that the most up to date information was incorporated into the report.

The report focuses on the impact of drug use on highway safety only. That current data is inadequate to prove that specific drugs severely impair driving ability should not be interpreted as an endorsement that those drugs are safe or advisable to use. No such implication is intended. In many cases evidence of the impairing effects of specific drugs may be lacking due only to the fact that no research has been conducted on the effects of those drugs. Many other reasons also exist to suggest that drug use should be avoided (e.g., legal, social, and medical).

This report consists of four chapters. Chapter I provides an introduction and background. Chapter II describes the best available information on the incidence of drug usage by drivers involved in crashes (or detained by the police). Chapter III summarizes the findings from laboratory research on the behavioral effects of drugs, from studies using driving simulators, and from on-the-road studies.

Chapter IV summarizes current knowledge about the role of drugs in highway safety. It discusses the information needed to determine the nature and magnitude of the drug and highway safety problem and points out some of the difficulties in obtaining this information. It describes the Department of Transportation's current programs to acquire some of this information. These new programs are consistent with the direction provided by Congress in the Anti-Drug Abuse Act of 1986 (Section 3402).

BACKGROUND

One of the NHTSA's original goals was to reduce motor vehicle crashes involving alcohol. While progress has been made on this problem, other drugs also are involved in motor vehicle crashes. Growing evidence points to the combined use of alcohol and other drugs by drivers involved in crashes. As a result, NHTSA began to study drugs and driving in the early 1970s. The agency's initial efforts focused on collecting information about the nature and magnitude of the problem. These efforts did not clearly define which drugs and dosages were associated with increased accident risk. These early efforts revealed that the potential drug problem is not as simple to define as the alcohol problem. It readily became apparent that significantly improved drug detection and measurement techniques would be required in order to determine what drugs were safety hazards when used by drivers.

Despite the fact that the nature and magnitude of the drug and driving problem in this country can not be specified clearly, the existence of a drug and driving problem is assumed. The view that drugs other than alcohol contribute to traffic crash risk stems from several pieces of information.

First, the use and abuse of drugs has become widespread in our society. What was once a problem found only in certain subgroups of our population has spread to a point where a measurable segment of the country's population is involved. Recent estimates suggest that over 60 million Americans have tried marijuana, and approximately 20 million have sampled cocaine. Nearly 23 million people can be classified as current users of marijuana (used within the last 30 days), and some 5 million or more can be classified as current cocaine users (National Survey on Drug Abuse, 1983).

Psychoactive prescription drugs and over the counter medicines are used by an even greater percentage of the population. For example, in 1975 an estimated 1.5 billion prescriptions were filled. Diazepam (Valium (R)) is the most frequently prescribed drug in the country, with an estimated 2 million persons taking the drug. Legal drugs obtainable without a prescription (over the counter) are used even more widely than prescription drugs.

Second, most controlled substances and other drugs have the potential to impair driving skills. It is widely acknowledged that most drugs, at high doses, can alter human behavior and impair a variety of skills presumed necessary for the safe operation of a motor vehicle. Obviously, not all drugs will impair driving ability at low doses.

Third, many people who drive use drugs other than alcohol. No one can currently estimate the number of people who drive after having consumed drugs. The relevant epidemiological data are not available. However, given the large number of persons reporting use of these drugs, and the relatively long term effects of some drugs (measurable effects have been detected up to 24 hours after ingestion), the number driving after having consumed drugs must be substantial.

Finally, information from studies of drivers involved in accidents indicate that many have used drugs other than alcohol. It appears that drugs are detected in somewhere from 10 to 22 percent of accident involved drivers (Compton & Anderson, 1985), often in combination with high levels of alcohol. Related information comes from Los Angeles, California, where specially trained police officers estimates suggest that 20% of drivers arrested for driving while impaired are under the influence of drugs other than alcohol (Burns, 1987).

INFORMATION REQUIRED TO DETERMINE THE RELATIONSHIP BETWEEN DRUGS AND HIGHWAY SAFETY

In order to determine the nature and extent to which drugs other than alcohol contribute to the occurrence of traffic crashes several pieces of information are needed. We need to know what drugs, and at what doses, impair driving ability and increase crash risk. We also need to know the frequency with which persons are driving while under the influence of drugs that increase crash risk.

Determining which drugs, at what dosages, impair driving ability is not a simple matter. Many laboratory studies have been conducted that measure performance on tasks that utilize driving related skills (e.g., divided attention, visual tracking, reaction times to sudden events). However, there is no general agreement as to which of the many driving-related tasks used in the laboratory contain the critical combination of skills necessary for the safe operation of an automobile. Also, the fact that performance impairment results under the artificial and non-life threatening situations necessary in the laboratory does not automatically mean that this same performance impairment would be evident under real world driving conditions. It may be increased or decreased depending on the driver's physical and mental state and reactions to specific traffic situations being experienced.

These observations do not mean that laboratory data about the performance decrements that result from drug use have no utility in assessing the drugs and driving problem. On the contrary, drugs that impair driving related performance in the laboratory can be considered potentially hazardous, whereas drugs that do not produce performance impairment (such as non-narcotic analgesics like asprin and acetaminophen) can be considered of less concern. The failure to detect performance impairment in a laboratory study, of course, may be due to the drug dose administered, or the specific tasks employed. Laboratory data can be used to focus attention on the drugs most likely to be a highway safety problem.

Given that a drug has been shown to produce driving related performance impairment in the laboratory, we then need to know the frequency with which persons drive after having consumed that drug, and the extent to which crash risk is increased. Determining the frequency with which persons drive after having consumed drugs may be approached in several different ways. These include questionnaires that obtain self-reported data from drivers about their use of drugs and roadside surveys that involve the collection and chemical analysis of drivers' body fluids (blood) for the presence and amount of drugs.

Studies that do not include the analysis for drugs in body fluids are not considered valid and reliable indicators of drug use by drivers. Self-report data concerning behavior of this type are too unreliable to be useful for this purpose. Therefore, the standard approach involves roadside surveys of the general driving population in which body fluids are collected. Large scale studies of this type have not been conducted. Prior to undertaking such a study a number of factors would have to be weighed, including the inconvenience to the public (e.g., trip delays), privacy issues, cost/benefit analysis, and the difficulty of obtaining blood samples.

Estimating the crash risk caused by drug use is important because some drugs that are known to impair performance on laboratory driving related tasks may not measurably increase real world crash risk. Thus, for example, persons using carefully administered doses of prescription drugs may adapt to the behavioral effects of these drugs and not be at substantially increased crash risk as a result of the drug use.

One scientifically accepted approach to determining the crash risk associated with drug use involves a comparison of the frequency of drug incidence in crash and noncrash involved drivers. A finding that the incidence of drugs in crash involved drivers is higher than in noncrash involved drivers is strong evidence that the drugs may have contributed to the occurrence of the crashes. If use of the drugs were unrelated to crash risk, then one would not expect to find a difference between number of crash and noncrash involved drivers using the drugs (other explanations are possible; for example, persons who use drugs may have certain personality characteristics that predispose them to drug use, as well as to engaging in driving behaviors that lead to crashes).

Knowing only the frequency with which crash involved drivers use drugs does not allow one to know the danger posed by drugs. It may simply reflect the general drug usage pattern in the driving public at large. For example, finding that 30% of crash involved drivers have nicotine in their blood does not imply that nicotine was involved in the occurrence of their crashes. It may be that 30% of the general driving population smokes cigarettes and the smoking of cigarettes is unrelated to crash occurrence. Finding that a drug was overrepresented in crash involved drivers (as compared to noncrash involved drivers) would strongly suggest it played a role in increasing crash risk. However, this approach requires knowing the drug usage rate of the general driving public, something we do not know and can not easily determine.

An alternative approach, that overcomes the need for a noncrash involved control group, is known as a "responsibility" analysis (Terhune, 1986). In this approach, crash involved drug-free drivers are used as the control group rather than noncrash involved drivers. Each driver involved in a crash is independently rated regarding his responsibility for the crash. Drivers in whom drugs are detected and drug-free drivers are compared in terms of the rate at which they are estimated to have been responsible for their crashes. Increased crash responsibility rates for drivers having used specific drugs, as compared to drug-free drivers, would be strongly suggestive that the use of the drugs increased crash risk. This method has not been used extensively, but appears to be a practical alternative to obtaining a control sample of noncrash involved drivers in order to estimate the probable role drugs play in increasing crash risk. In fact, the Department of Transportation is currently initiating a project to study the incidence and role of drugs in fatally injured drivers that utilizes this technique (see Chapter IV).

PROBLEMS IN DETERMINING DRUG USAGE AND DOSAGE LEVELS

An important topic necessary to the understanding of the role of drugs in highway safety is the relationship of drug levels (or dosage levels) to degree of driving impairment. While knowing that a drug can impair driving ability is useful, knowing at what level (or dose) performance impairment will result in increased crash risk is critical. From an enforcement point of view, most State laws prohibiting "driving under the influence of drugs" require some evidence of impairment, beyond proof that the individual had used the drug.

Thus, identifying the drug level at which behavioral impairment increases crash risk is an essential issue in understanding the relationship between drug use and highway safety. The topic of drug or dosage levels that correlate with impairment is unfortunately not simple or straightforward. However, because of the importance of this topic, some of the issues that complicate the attempt to specify the relationship between drug level and impairment level are briefly reviewed below.

The ability to predict the behavioral consequences of taking most drugs is currently limited. Certain generalizations can be made, such as that high doses generally have a larger effect than small doses, that well learned tasks are less affected than are novel tasks, and that certain variables like previous exposure to the drug can reduce expected effects. Nevertheless, the ability to precisely predict an individual's performance at a specific dosage is minimal.

Most psychoactive drugs are chemically complex molecules, whose absorption, action and elimination from the body are poorly understood (Chiang & Hawks, 1986). In addition, there are considerable differences between individuals in the rates with which these processes occur. Alcohol, in comparison, is a relatively simple substance with fairly consistent effects on individuals. It has been relatively easy to trace and measure alcohol in body fluids, to establish a strong correlation between BAC level (blood alcohol concentration) and impairment level, and to establish the relationship between BAC level and crash risk.

Factors that make similar prediction difficult for most other psychoactive drugs include:

* the large number of different drugs that would need to be tested

* poor correlation between psychological or behavioral effects and blood or plasma levels (peak behavioral effects do not necessarily correspond to peak blood levels, detectable blood levels may persist beyond the behavioral effects or the behavioral effects may be measurable when the drug can not be detected in the blood)

* sensitivity and tolerance (accentuation and diminution of psychological and behavioral effects with repeated exposure)

* individual differences in absorption, distribution, action and metabolism (some individuals will show evidence of impairment at drug concentrations that are not associated with impairment in others; wide ranges of drug concentrations for different individuals have been associated with equivalent levels of impairment)

* accumulation (blood levels of some drugs or their metabolites may accumulate with repeated administrations if the time-course of elimination of the drug is insufficient)

The result of all of these factors is that the presence of a drug at a certain concentration in the blood of an individual can not usually be equated with a specific effect (McBay, 1986). It is tempting to think that in time a correlation between the level of a drug in the blood (or other body fluids) and behavioral impairment will be established for drugs other than alcohol. However, for the reasons cited above, it is entirely possible that a precise relationship will not be possible to establish for many psychoactive drugs.

SPECIAL POPULATIONS

Almost all the available information about drug use by drivers is on the general driving population. However, there is evidence to suggest that certain subgroups of drivers may have different drug use patterns. The effects of drug use on driving behavior may also differ for these subgroups.

Young drivers appear to use different types of drugs and with a different frequency than do older drivers. For example, one study of drug incidence in young male fatally injured drivers (Williams, et al., 1985) found a higher rate of drug use (approximately 51%) than has been reported in studies of drivers of all ages (where the average is 10 - 15%). These young drivers appeared to use marijuana and cocaine more frequently than do older drivers. The effect of drug use on young drivers may differ from more mature drivers given their relative lack of experience at both using drugs and at driving.

Commercial truck drivers present another subgroup that appear to use alcohol and drugs differently. The available information suggests that the use of alcohol by commercial drivers and the involvement of alcohol in truck crashes is substantially lower than found for drivers of other types of vehicles. For example, in 1985 approximately 34% of the drivers of passenger vehicles involved in fatal crashes had been drinking while only 5% of the drivers of heavy trucks had been drinking (NHTSA, 1987).

Self-report data on alcohol and drug use by commercial drivers who occasionally or regularly violate the hours of service limit has revealed a large percentage reporting use of stimulants and a small percentage the use of alcohol (Wyckoff, 1979). A small study of drug use by randomly selected commercial truck drivers, in which blood and urine samples were tested for the presence of drugs, provides evidence similar to the self-report data (Lund et al., 1987). This study found that less than 1% of the truck drivers tested positive for alcohol while 9% were found to have stimulants in their blood. THC was detected in the blood of just 3% of the drivers. The relatively high incidence of stimulants in this population is different from that found in crash involved drivers in general.

The relationship between drug use and highway safety for these special populations of drivers may be different from that found for the general driving public. The risk posed by drug use may be higher for these special groups. For commercial truck drivers the available evidence suggests that their drug and alcohol use patterns are different from the general driving public (less alcohol, more stimulants). In addition, commercial drivers are often driving while fatigued and are confronted with a much more demanding task (Clark et

al., 1987). Thus, the use of drugs by commercial drivers presents a very different and potentially more serious problem. Similarly, the use of drugs by young drivers may represent a greater risk than that found in the general driving population.

CHAPTER II

FREQUENCY OF DRUG USE BY DRIVERS

One main aspect of the current focus of research on drugs and driving is to determine the frequency of drug use by drivers and its consequences for highway safety. Different approaches have been used to study this question. Some have used direct measurement of the presence of various drugs in body fluids of crash involved drivers, while others have relied upon self-report data on drug use by drivers. Studies relying on self-reported data are not considered reliable and valid indicators of the extent of drug use by drivers, and will not be reported on here.

This chapter summarizes the present state of knowledge regarding the frequency of drug use by drivers. The information comes from studies of drug use by drivers in which body fluids were tested for the presence of various drugs. Almost exclusively, these studies looked at only crash involved drivers or drivers detained by the police. In addition, a brief discussion and critique of past research methodology is presented.

PROBLEMS IN CONDUCTING FIELD RESEARCH

Several practical and methodological difficulties have limited the utility of most past research on drug use by drivers. The methodological problems have arisen from an inability to obtain representative samples of drivers, while practical problems have concerned the ability to detect and measure the presence of drugs in drivers.

All of the past studies have involved either small or non-representative samples of drivers. Typically, only a local area (e.g., county) is covered. Often all eligible cases are not available to the researchers so that a random or representative selection of drivers for inclusion in the study is not possible. Thus, it is not possible to generalize much from these studies.

Until recently, chemical analysis techniques made the detection and measurement of many drugs in body fluids difficult, if possible at all. While considerable progress has been made in the last several years in analytic technology, there are some drugs (e.g., "designer" drugs, in which molecules are moved or substituted to create a new drug which has similar effects to the original drug) for which assay techniques still are unavailable. Also, screening for and confirming the presence of a wide range of possible drugs that can impair behavior has been very expensive, and required technical expertise and equipment available in only a few labs around the country. This has served to limit the types of drugs researchers have included in their studies. As a result, many previous studies looked for only a few drugs, and reports of drug-free drivers indicated only that certain specified drugs were not detected. Previous studies therefore may be considered to provide conservative estimates of drug use.

Many drugs and/or their metabolites will remain in some body fluids, like urine, for some time (days, and in some cases weeks) after the psychological and behavioral effects have passed. These fluids thus can provide a good record of drug use over time.

To determine if a drug was used recently, and in particular to estimate if a drug may have impaired recent driving performance, drug presence in blood must be analyzed. Blood is currently the only body fluid that can indicate that the subject might have been under the influence of the drug detected, at the time the blood sample was collected. Unfortunately, many drugs of interest rapidly disappear from the blood. This means that, in studies of crash victims, it is necessary to collect a blood sample within one or two hours of the time of the crash. Any further delay might result in a failure to detect the presence of drugs active at the time of the crash.

In the remaining sections of this chapter, past studies concerning the frequency of drug use by fatally injured drivers, injured drivers, and noncrash involved drivers detained by the police will be briefly reviewed.

FATALLY INJURED DRIVERS

There have been relatively few studies conducted of the incidence of drugs other than alcohol in fatally injured drivers. Typically, in these studies, the number of drugs tested for has been limited and the sample sizes small and non-representative.

A study of the use of alcohol, marijuana, and other drugs in 600 fatally injured drivers killed in single vehicle crashes in North Carolina, during the period of 1978 - 1981, reported a fairly low incidence rate for drugs other than alcohol (Mason & McBay, 1984). The most commonly detected drugs were: marijuana (THC) found in 7.8%, methaqualone in 6.2%, and barbiturates in 3% of the sample. Phencyclidine (PCP), opiates, cocaine and benzoylecgonine, and other volatile substances were detected only rarely. Approximately 14% of the drivers had used any of the drugs tested for in this study.

Alcohol was detected in 79% of the drivers, with 68% of these drinking drivers having blood alcohol levels greater than or equal to 0.10% weight/volume. Most of the drivers in whom drugs other than alcohol were detected also had consumed alcohol. The drug concentrations found were usually within or below the accepted therapeutic dosage range. According to the authors, only a very small number of drivers could possibly have been impaired by drugs and most of these drivers had high blood alcohol levels.

A recent study of 440 fatally injured young male southern California drivers looked for the presence of 23 drugs or drug groups (Williams, Peat, Crouch, & Finkle, 1985). This study focused on a special population selected to maximize the chances of finding drug use. Approximately 51% of the drivers were reported to have used drugs other than alcohol. Evidence of marijuana was detected in 37% of the drivers. This number should be interpreted cautiously as it includes drivers in whom only very small quantities of THC were found (at levels other researchers would have treated as false positives). The next most commonly found drug was cocaine detected in 11% of the drivers. The rest of the drugs were found in only very small numbers.

Alcohol was found in 70% of the drivers. In most cases drugs were found in combination with high blood alcohol levels. A crash responsibility analysis revealed that only alcohol was significantly related to crash responsibility. However, this analysis was constrained by the small sample size and high overall responsibility rates found.

In a simple descriptive study of drug use by 401 fatally injured drivers in the province of Ontario, Canada, alcohol was found in 57% of the drivers (Cimbura, Lucas, Bennett, Warren and Simpson, 1982). Psychoactive drugs were found in the blood of 9.5% of the drivers, though the authors report that in many of these cases the concentrations of drugs detected other than alcohol were just trace amounts. The psychoactive drugs detected most frequently were THC (a metabolite of marijuana) in 3.7% and diazepam (Valium(R)) in 3% of the drivers. A number of other drugs were found in even smaller numbers of drivers.

Psychoactive drugs were rarely found alone (3.7% of the time); typically they were detected in combination with alcohol. The authors of the study report finding drugs other than alcohol in 26% of the fatally injured drivers. However, this number is quite misleading for two reasons. First, this study screened for a large number of "drugs" that probably do not impair driving ability such as salicylate (aspirin) and acetaminophen (tylenol). Secondly, in many of the cases drugs were detected only in urine, but not in blood. This implies that the drivers had used the drugs sometime in the past but may not have been under the influence at the time of their accident.

A second, more recent study conducted in Ontario, Canada, looked for the presence of marijuana and alcohol in 1169 fatally injured drivers (Donalson, Cimbura, Bennett & Lucas, 1985). Only these two drugs were tested for in this study. Marijuana alone was found in the blood of 1.7% of the drivers tested. Marijuana in combination with alcohol was found in 9% of the drivers. Alcohol alone was detected in 57%.

In summary, these studies report finding drugs other than alcohol in from 10 - 15% of the fatally injured drivers tested. Drugs were found alone very infrequently; they were typically detected in combination with alcohol (some 50 - 80% of the drivers using drugs having also used alcohol). In comparison, alcohol turned up in approximately 64% of these fatally injured drivers. Most of the drivers who were found to have used drugs in these studies, were impaired by alcohol (i.e., they had BACs over 0.10% w/v). The most commonly

found drug was marijuana, but it was rarely found alone. Usually it was detected in combination with high blood alcohol levels. Other drugs detected with less frequency were the tranquilizers and sedatives (diazepam, barbiturates, methaqualone), cocaine, codeine, PCP, and amphetamines.

INJURED DRIVERS

Joscelyn, et. al. (1980), in a review of the state of knowledge on drugs and highway safety, noted that drug usage incidence rate data for injured drivers in the U.S. were virtually nonexistent. Only one large scale study of accident involved drivers in the U.S. has been conducted since that time. Several studies have recently been conducted in other countries (in Europe, Scandinavia, and New Zealand) that cannot be assumed to be representative of American drivers.

The role of alcohol, marijuana and other drugs in the accidents of 497 injured drivers in Rochester, N.Y. was examined in the one relevant large scale study (Terhune and Fell, 1982). The authors were unable to obtain a representative sample of injured drivers in this jurisdiction (only one hospital agreed to participate) so the results should be interpreted with caution.

They found that approximately 22% of the drivers had used drugs other than alcohol. The drugs detected were:

Drug	Percent of Drivers
Marijuana	9.5%
Tranquilizers	7.5%
Sedatives/hypnotics	2.8%
Cocaine	2.0%
Anti-convulsants	2.0%
Other	Less than 2%

Multiple drug use occurred in 10.5% of the drivers. Many of the drivers found to have used drugs had also used alcohol (42%). Most of the drivers in whom alcohol was detected had high blood concentrations. The concentrations of marijuana found were mostly quite low, and over half of the drivers in whom marijuana was found also had alcohol present.

In this study an accident responsibility analysis was conducted, based upon police accident reports and driver interviews. The results indicated that the drivers with high blood alcohol concentrations were significantly more likely to be judged responsible for their crashes than were drug-free drivers. No other drugs were found associated with a significantly higher responsibility rate, though the sample sizes were too small to allow definitive conclusions to be drawn.

A recent study has been reported on the use of marijuana by 398 severely injured drivers in Baltimore, M.D. (Soderstrom et al., 1986). This study did not obtain a representative sample of injured drivers and the sample was heavily male and young (those most likely to use this drug). Marijuana was the only drug, other than alcohol, tested for in this study. Thus, these findings should be viewed with caution. They report that almost 32% of these severely injured drivers had consumed marijuana.

One foreign study is interesting because it represents one of the few attempts to collect comparison data from nonaccident involved drivers. This small scale study was conducted in Helinski, Finland (Hokanen, et al. 1980). The use of alcohol and selected prescription drugs was compared between 201 injured drivers and 325 nonaccident involved drivers. The nonaccident involved drivers were selected randomly at gas stations (matched to the accident involved drivers by day of week, time of day, and roadway). Many nonprescription drugs of abuse like marijuana, cocaine and other narcotics were not included in the analytic screen used in this study.

The results showed that more injured drivers (5%) had used drugs than had nonaccident involved drivers (2.5%). Due to the small sample size, however, this difference was not statistically significant. Diazepam was the drug found most often. Alcohol was found in 15% of the injured drivers and in only 1% of the noninjured drivers. This study is one of the few conducted to date that has provided some direct evidence that drug use is overrepresented in injured drivers compared to nonaccident involved drivers. This suggests that the use of drugs may have been partially responsible for the accidents of these drivers.

DRIVERS DETAINED BY THE POLICE

There have been a number of studies conducted to determine the incidence of drug use by drivers believed by the police to be impaired by drugs, who were not involved in accidents (drivers arrested under "Driving Under the Influence of Drugs" laws).

The typical approach used in these studies is to make use of blood samples drawn at police request from drivers arrested for suspicion of driving under the influence of alcohol and to screen all or a sample of these specimens for selected drugs. Usually the specimens selected for study are those that have a blood alcohol concentration below 0.10% weight/volume (the level at which a driver is presumed to be impaired in most states). In other words, the drivers selected have a profile that would strongly suggest drug involvement. They are drivers whose behavior appeared to the police to be severely impaired and whose blood alcohol concentration was relatively low. None of these studies looked for a wide variety of drugs, thus some of the drivers may have used drugs not detected by the assay techniques used.

A study conducted in the State of Virginia analyzed the blood of 788 drivers arrested for driving under the influence (Valentour, McGee, Edwards and Goza, 1980). These drivers had a blood alcohol concentration of below 0.10% w/v. They were among a very small percentage of drivers given a blood test rather than a breath alcohol test. They were tested for a variety of drugs.

The results showed that 16% of the samples contained drugs other than alcohol. The most frequently detected drugs were reported to be the tranquilizers (diazepam, chloriazepoxide), methaqualone, phenobarbital, and phencyclidine (PCP). The authors did not provide any indication of the number or percentage of drivers using the individual drugs. Eighty-four percent of the drug positive samples also contained alcohol.

A relatively ambitious study has been reported on the use of sedative/hypnotics by over 8,000 drivers arrested for impaired driving in Orange County, California (White, Clardy, Graves, Kuo, McDonald, Wiersema and Fitzpatrick, 1981). The sample was collected over a six year period from 1973 to 1978. As in the previous study only drivers whose BAC was below 0.10% w/v were included. The blood samples were screened for barbiturates (e.g., secobarbital, amobarbital), benzodiazepines (e.g., Valium(R), Librium(R)), methaqualone (Quaalude(R), meprobamate, and ethchlorvynol (e.g., Placidyl(R)).

The results showed that these tranquilizers and sedative drugs were found annually in 30 - 50% of the drivers tested. The usage rate for sedative/hypnotic drugs appeared to show a substantial drop in 1977 and 1978. The researchers felt this reflected a shift in drug usage patterns away from drugs detectable by their analytic screen (e.g., toward increased use of drugs like PCP, marijuana, and cocaine that were not detectable). The most commonly found drugs in the drivers tested were barbiturates (diazepam and methaqualone).

Another study conducted in California reported on the use of marijuana by impaired drivers (Zimmermann, Yeager, Soares, Hollister and Reeve, 1983). Approximately 1800 arrested drivers who submitted to a blood alcohol test were chosen for study. These drivers were selected in a fashion that suggests they are not representative of impaired drivers and possibly not even those detained drivers who chose to give a blood sample rather than a breath sample.

The results of the analyses performed by Zimmermann et al. indicate that 14.4% of the drivers tested were positive for THC (a metabolite of marijuana). Some 84% had measurable quantities of alcohol in their blood. The drivers who had a BAC of below 0.10% (10% of the sample), had a 23% marijuana positive rate. The percentage of drivers using marijuana increased with driver age (from 13% for drivers under 21 years of age to 19% for drivers 40-61 years old). This finding is at variance with the patterns of usage reported from other sources and raises questions concerning the possibility that this sample was highly unusual.

In summary, these studies of drug use by impaired drivers detained by the police are particularly difficult to interpret. The drivers dealt with in these studies are a special subsample of the general driving population. Because the study samples are not drawn in a random or unbiased fashion, they are not representative of the general driving public, nor necessarily of drivers who use drugs, or even drivers who the police detain for suspicion of drug use. Most drivers detained by the police for suspicion of impaired driving elect to take a breath test rather than a blood test. In these studies, 90% or more of the small number of drivers who took a blood test had BACs over 0.10% w/v, and thus no tests for other drugs were performed. The study samples came from the remaining 10% or less of the drivers who had low BACs. Such a sample is not representative of any population other than the one from which the data were collected.

While the drivers in these studies came to the attention of the police as a result of committing some illegal or aberrant driving behavior, one cannot assume that the drugs they consumed were necessarily responsible for their deviant driving. Most of the drivers found to have consumed drugs had also consumed alcohol (the percentage of drivers in whom drugs were detected who had also used alcohol ranged from 40% to 100%). Thus, one does not know whether their driving was impaired (drivers not under the influence of alcohol or drugs also commit driving violations), and if it was impaired, whether it was due to the drug or the alcohol they had consumed, or due to the drug enhancing the effects of the alcohol.

One can conclude from these studies that a significant percentage of the drivers the police stop for suspicion of impaired driving, who agree to take a blood test, and whose BAC tests out below 0.10% w/v, have consumed drugs. These studies suggest this percentage ranges from 14% to 50%.

SUMMARY

The data reviewed in this chapter indicate that drugs are detected in 10% to 22% of the crash-involved drivers. Drugs by themselves, (i.e., without alcohol), were found in only 2% to 15% of the crash-involved drivers. The majority of the drug using drivers (53% to 77%) were found to have high levels of alcohol in combination with the drugs. The 10% to 22% range gives an upper bound of the effect of drugs on drivers in crashes. Drug presence (especially for prescription or over-the-counter drugs) need not imply impairment. When drugs and alcohol are both present, alcohol may have been primarily responsible for the crash. For the studies reviewed it was not possible to factor out the alcohol effects from the drug effects, or to determine whether there were any combined alcohol and drug effects. When alcohol is not considered, multiple drug use is relatively infrequent in drivers in whom drugs were detected.

The studies reviewed in this paper tend to report the highest drug use incidence rates for the same potentially hazardous drugs. However, since many of these studies only tested for a few drugs (e.g., marijuana) or drug classes (e.g., sedatives and tranquilizers), the repeated reporting of the same drugs may be as much a function of what drugs were looked for, as what the drivers were using. Those drugs (or drug classes) most frequently detected are (in order of decreasing incidence):

- Marijuana
- Diazepam (Valium(R))
- Barbiturates (e.g., Secobarbital)
- Methaqualone
- PCP (phencyclidine)
- Cocaine

Research is needed to determine more accurately the extent and actual effects of drug use by drivers of motor vehicles.

CHAPTER III

STUDIES OF THE EFFECTS OF DRUG USE ON SIMULATED DRIVING

INTRODUCTION

Basic research on the effects of drugs on driving behavior is designed to assess the potential increase in the likelihood of traffic crashes due to the use of drugs. Several different research approaches have been used to measure drug effects. These include laboratory studies using behavioral tests or test batteries, driving in automobile simulators, and driving in actual vehicles (often instrumented to record various aspects of the driver's behavior).

The study of drug effects on driving related skills has produced a large and diverse literature. There have been numerous reports of drug related impairment on laboratory tasks. Considerably fewer studies have been conducted using driving simulators or actual driving behavior in a closed course. The result of all this effort has provided little definitive information relating drug effects to driving performance or crash risk.

There are many reasons for this current lack of knowledge. The more important reasons include the very large number of drugs that need to be studied, the wide range of methods used to measure behavior in the laboratory and field, the lack of agreement on what skills are essential to safe driving or related to crash risk, the current inability to relate performance in the laboratory to real world driving, and the relatively few research groups available or interested in conducting the type of applied research needed.

For many decades, behavioral scientists have attempted to define the parameters relevant to safe operation of a motor vehicle and to relate these parameters to crash occurrence risk. No consensus in this area has been reached. It is therefore difficult to speak of laboratory tasks which actually measure critical car driving skills that can be used to estimate the impairing effects of drugs. Laboratory tasks that measure manual dexterity, reaction time, tracking ability, etc., are certainly related in some general sense to the skills required to operate a motor vehicle. Many of these tasks have some surface validity, that is, they appear rationally to involve skills we think are important to safe driving. However, given the large individual differences that exist in these skills between normal people, it is difficult to specify how performance differences produced by drugs on these tasks relate to driving ability and crash risk. Thus, observed changes in performance on the tasks traditionally used in the laboratory to investigate the effect of prescription and illicit drugs have not been related in any direct way to driving ability or crash risk.

The ability to operate a motor vehicle is so well established in most of us that we take this skill for granted and fail to realize the complexity of the task. Many variables enter into our ability to drive and they interact in subtle ways. Some factors that are important are relatively obvious, for example, coordination skills, reaction time, and perceptual ability. Other considerations are less obvious but may be equally important; for example, subjective factors such as risk taking, emotional states (anger, fear, stress, hostility, etc.), and personality style (relaxed, tense) play a role in how we drive. Some simple variables like fatigue, physical and mental health, degree of hunger, distraction (by the radio, smoking, conversation, thinking to oneself) are extremely difficult to define in operational terms. As a result, we find that the driving task is only poorly understood, in spite of the many studies that have been conducted to define it.

A major problem encountered in conducting studies to measure the effects of drugs on driving behavior stems from the artificiality of the research environment. To a lesser or greater extent, the subject performs a task only somewhat similar to real world driving. Subjects participating in research studies are well aware that their behavior is being observed and measured. They undoubtedly assume (correctly) that precautions have been taken for their protection. These and other factors resulting from the research environment will alter the subject's behavior in many subtle ways that make it difficult to interpret experimental behavior in terms of real world behavior (Sanders, 1986). It is not possible at this time to estimate the extent of this effect.

Another interesting complication arises from the fact that many people who use prescription and nonprescription drugs do so as treatment for some psychological or physical condition. It is not unlikely that if left untreated, these conditions could increase the likelihood of a traffic crash. For example, an aggressive or anxious person who takes a tranquilizer or a depressed or suicidal person who takes antidepressants may suffer from less overall impairment as a result of the drug use than if they had refrained from appropriate treatment. Unfortunately, persons typically used in studies of drug effects are healthy individuals (for ethical and practical reasons). The effects of these drugs on normal individuals may well be different from those whose symptoms indicate a need for their therapeutic effects.

Experimental research on the effects of drugs can be conceptualized as spanning a continuum ranging from an assessment of physiological functioning (i.e., effects on the circulatory, respiratory, or nervous system), to basic psychophysical functions (i.e., sensory, perceptual, motor, or simple cognitive), to simple behavioral effects, to effects on driving related skills, to simulated driving, and finally to actual driving performance. The farther removed one gets from actual driving, of course, the more tenuous any inferences become.

In the rest of this chapter, the laboratory research on the effects of drugs on human performance measures and driving related behavior, in automobile simulators and in on-the-road studies, will be reviewed briefly in terms of what we have learned from this effort about the relationship between the use of drugs and highway safety.

LABORATORY STUDIES

Numerous laboratory studies have been conducted on the effects of a variety of drugs on human performance and driving related skills. This literature is far too voluminous and complex to be reviewed in any detail here. In addition, the conclusions that can be drawn with any degree of certainty from this research regarding the impairing effects of drugs on driving performance are limited.

Laboratory studies have employed a variety of dependent measures that have ranged from traditional tests of perceptual ability, simple reflex responding, coordination, and reaction time, to more elaborate measurements of psychomotor performance, tracking ability, divided attention, and decision making. Some examples of typical tasks that have been used are: having subjects attempt to keep a dot on a CRT screen centered when random movements are programmed, trying to keep a needle on a dial centered in the face of random lateral movements, and responding to auditory or visual signals as rapidly as possible. Other commonly used tasks have included assessing critical flicker frequency (at which two brief flashes are perceived as one), measuring digit symbol substitution performance, copying symbols, measuring choice reaction time (e.g. responding correctly to the appearance of a number of visual and acoustic stimuli), and determining divided attention ability (e.g., simultaneously responding to the presence of any one of a number of lights while separately responding to color sequences).

Many different drugs have been investigated using these laboratory tasks with various types of effects reported for different drug classes (i.e., central nervous system depressants, stimulants, etc.). For example, marijuana has been shown to impair tracking and perceptual abilities (Moskowitz, 1985), various benzodiazepines (e.g., diazepam, chlordiazepoxide, flurazepam) have frequently been found to impair tests of vigilance, choice reaction time and motor coordination (Kleinknecht & Donaldson, 1972), while barbiturates (sedatives and hypnotics) typically produce effects similar to those found with alcohol including drowsiness, inattention, decreased motor coordination, and poorer oculomotor function (Sharma, 1976).

Stimulants such as amphetamines, when administered in clinical doses, do not appear to produce detrimental effects on laboratory performance (Hurst, 1976). Unfortunately, ethical considerations have precluded experimentation with human subjects using more acute doses of stimulants (i.e., amphetamines, cocaine), during chronic ingestion, or during withdrawal when the more deleterious effects are likely to occur.

Certain antidepressants (e.g., amitriptyline, doxepin, imipramine) have been found to impair cognitive and psychomotor functions on tasks of vigilance, attention, tracking, etc. (Landauer et al., 1969). Also, some antihistamines have been shown to have sedative effects on behavior, while others do not apparently produce the same impairment of central nervous system function (Nicholson & Stone, 1986).

This type of research is important in furthering our understanding of how different drugs affect behavior. However, because of the difficulty in relating performance on laboratory tasks to real world driving ability, it has little immediate practical relevance to understanding the potential effect of drugs on highway safety.

DRIVER SIMULATOR STUDIES

Relatively few studies have been conducted using driving simulators in the U.S. The few available studies employed somewhat crude simulators that lack any strong sense of realism. Early simulators were typically deficient in terms of the car dynamics or the visual scene presented to the driver. These simulators typically did not provide any feedback response to movements made by the drivers. For example, movements of the steering wheel or accelerator pedal did not result in corresponding changes in the visual scene. Often, the vehicle was nothing more than a driver training apparatus with a steering wheel, gear shift lever, turn signal lever, accelerator and brake pedals.

However, in comparison to on-the-road studies which involve subjects driving actual vehicles, research employing simulated driving has several real advantages. These advantages include the ability to administer higher doses of drugs than might be risked if the subject was actually going to be operating a real vehicle, allowing for a standardized set of experiences to occur in exactly the same fashion for each subject, and allowing "dangerous" situations to occur (i.e., crashes can occur in a simulator without any risk to the subject or others).

Use of a simulator allows the researcher to introduce a variety of events during the "drive" that might prove difficult or impossible to employ during an actual driving session. For example, passing tasks can be programmed into the trip the subject takes, wind gusts may occur requiring corrective movements to keep the vehicle on the roadway, or obstacles (e.g., a large box) can appear suddenly in the roadway to test the subject's ability to respond quickly to unexpected events.

A number of different drugs have been studied in driving simulators. In most cases there is not a sufficient body of consistent evidence regarding the effects of specific drugs to allow one to conclude very much from this research. Marijuana, on the other hand, is one of a few exceptions in that it has been used in a number of research programs studying drug effects on driving related behavior using driving simulators. This literature is briefly described below to illustrate the nature and findings of simulator research.

In an early study by Crancer et al. (1969), drivers viewed a filmed presentation of a short drive and were provided with a steering wheel, turn signal, speedometer, brake and accelerator pedals, none of which affected the filmed scene. The only effect of the marijuana dose given the subjects was on their ability to maintain a predetermined speed.

Smiley (1986) in a review of simulator studies on the effects of marijuana noted that all of the pre-1980 research found no significant effects of the drug on the driver's ability to control the vehicle. Smiley felt this may have resulted, at least in part, from the unrealistic car dynamics presented by these simulators. The marijuana administered to the subjects in these studies was found to affect decision making in the sense that it increased the time to start and stop (Rafaelson et al., 1973) and the time to decide whether to pass another vehicle (Dott, 1972). Risk taking behavior was found to be reduced after administration of marijuana (Ellingstad et al., 1973, Dott, 1972).

Two fairly recent research programs have examined the effects of marijuana on simulated driving behavior in which an interactive simulator with relatively realistic car dynamics was used. Smiley et al. (1981, 1985) described a study in which subjects sat in a cut down car cab and viewed a simplified roadway scene close to life size. The simulation was interactive in that the subject's use of the steering wheel, accelerator and brake pedal caused corresponding changes in the visual scene. The simulator had fairly realistic car dynamics (the simulator had the touch and feel of a real vehicle with appropriate feedback from the visual scene to control movements made by the subject). The visual presentation was, however, only a caricature of the real world.

A number of different tasks were presented to the subjects during their "drive". These included curve following, controlling the car in wind gusts, following a lead car that was moving at a variable speed while maintaining a constant distance, route sign following, emergency decision making (making a stop or swerve decision after the sudden appearance of an obstacle), and passing a car between obstacles. In addition, in order to simulate the demands on the driver to attend to other traffic, pedestrians, etc., a peripheral light cancellation task was included. Red and green lights were presented on the right and left sides of the car which had to be turned off by pressing the appropriate foot pedal. Subjects drove a 45 minute simulator run of approximately 24 miles.

According to Smiley, this study did show significant effects of marijuana on car control variables. Variability of speed and lateral position increased during curve following and during simulated wind gusts. Also, car following distance was more variable. Negative effects on decision making, similar to those found in earlier studies were also found. Subjects were more likely to crash during the sudden appearance of an obstacle. Reaction time to the subsidiary light cancelling task was increased, while risk taking appeared to be reduced as indicated by greater following distances in some tasks.

Stein et al. (1983) have also looked at the effects of marijuana on simulated driving employing a fully interactive simulator that was similar to the one described above. Both marijuana and alcohol alone, and in combination, were given to the subjects. The subjects had full control over both steering and speed in this simulator, while following a video projected two-lane roadway. As with the Smiley simulator, the car dynamics were fairly realistic while the visual scene was relatively simple. Subjects drove a 10 mile drive that took about 15 minutes to complete.

A variety of events were encountered during the driving scenario including wind gusts, winding roads, lane changes both in emergency and non-emergency conditions, obstacles and isolated curves. A secondary task of sign detection and recognition was required during tracking. The primary measures of safety were simulated crashes (hitting obstacles, running off the roadway by a full car width) and speeding tickets (speed checks at predetermined points during the drive).

The results revealed that alcohol was associated with significantly increased crashes and incidents of speeding. The crashes were primarily caused by an increase in driving speed, steering control variability and reaction time. Overall, driver steering and speed control deteriorated as a function of increasing BAC. Response speed and accuracy also decreased with increased BAC. The marijuana doses used did not lead to consistent driver impairment in the control tasks measured by the driving simulator. They did, however, lead to a general decrease in vehicle speed. Finally, the combined effects of alcohol and marijuana, each at the highest tested dose levels, caused an increase in simulated crashes over those found when alcohol or marijuana were administered alone.

The results of these studies seem to show that marijuana produces a delay in response time and more conservative behavior (lower speed, longer following distances). The two recent studies (by Smiley, 1985, and Stein, 1983), employing similar doses and equipment, reported somewhat inconsistent results on car control measures. The reasons for this are not clear. Many subtle differences existed between the simulators and tasks involved in these two studies that could have accounted for the disparate results.

Smiley et al. (1985) used the same simulator and driving tasks (with different subjects) to examine the effects therapeutic doses of secobarbital (1.1 mg/kg body weight), diazepam (.11 mg and .77 mg/kg body weight) and alcohol (blood alcohol levels of .05% and .08% weight/volume) on simulated driving behavior. They report that negative changes in performance were detected resulting from these drugs though primarily at the higher doses administered to the subjects. Secobarbital, diazepam and alcohol all impaired psychomotor tasks such as maintaining lane position and a constant posted speed.

In comparing the magnitude of the effects of secobarbital, diazepam, marijuana and alcohol, Smiley concluded that the greatest change in behavior was found for subjects administered secobarbital, followed by diazepam, then alcohol, and with the least measured effect from marijuana. Of course, without knowing the importance for safe driving of the specific measures in which differences were detected, it is not possible to meaningfully interpret this sort of comparison between the effects of different drugs.

In summary, studies measuring the effects of marijuana on simulated driving performance have found statistically significant changes in performance (when compared to the same drivers performance when drug free). This information is quite useful in suggesting the ways in which marijuana may effect driving behavior. However, until simulator performance can be objectively related to actual crash risk, we will not know the meaning of the observed changes in simulated driving performance.

ON-THE-ROAD STUDIES

On-the-road studies attempt to determine the effects of drugs on driving behavior by administering drugs to subjects who then drive an actual vehicle through a proscribed route. The driving may take place on a public roadway in the midst of actual traffic, or more typically, on a closed course. Use of a closed course involves substantially less risk to the driver. The roadway environment can be made much safer (no hazardous obstacles like parked cars, sign posts, embankments or ditches) and there is no unpredictable risk from other drivers. On the other hand, the driving environment typically encountered on a closed course is much less perceptually rich than that found under real world conditions, and thus does not present as realistic a scenario.

Performance in on-the-road studies can be measured by simple observation, in which trained raters record specific aspects of the drivers behavior, or by use of an instrumented vehicle that automatically measures and records the driver's performance. There has been a tendency for researchers to use trained observers, rather than instrumented vehicles, undoubtedly as a result of the reduced costs. Unfortunately, many published studies have failed to provide any indication that the observer's ratings were reliable or valid measurements of the subjects driving behavior. When vehicles are instrumented, it is not uncommon that so many different variables are recorded that one almost always finds significant changes on a few (as would be expected by chance alone). Interpreting these observed changes, in the face of many variables which show no effects from the drugs used, then becomes very problematic. Certainly, some changes in behavior are not necessarily indications that the driver's behavior is more hazardous.

The appeal of on-the-road studies is the apparent face validity of the task for measuring the effects of drugs on driving behavior. Real people are driving real vehicles, sometimes in the midst of real traffic. However, there are many reasons some scientists consider this research approach as much a simulation of driving as any other. Some of the more obvious reasons include:

- Considerable care is always taken to prevent harm to the driver (if a closed course is not used, then a route is selected to minimize the dangers possible - uncongested two lane roads, with few distractions).

- The driver is under constant observation (either by one or more observers seated in the vehicle, or by unusual equipment in the vehicle to record the drivers behavior).

- The driver is aware he is part of a study and not completely responsible for his own behavior (he has been given a drug as part of an experiment, the observer riding with him often has a second brake pedal or ignition key, he is often instructed not to converse with the observer or listen to the radio, eat or drink anything while driving, not to smoke, chew gum, etc.).

- The route to be driven is not of the driver's choice. His motivation is not at all similar to when he is actually out driving for some purpose but rather concerns the fact that he is performing a task in which his behavior is being recorded.

- The driver is often instructed to perform an artificial secondary task, to simulate the divided attention often present in real world driving (for example, mental arithmetic).

An important consideration in the design of an on-the-road study is that the driving task be representative of normal driving behavior, and perhaps more importantly, representative of the types of situations in which crashes are most likely to occur (Smiley, 1986b). It is possible that the deleterious effects of many drugs may only be clearly evident in the unusual situations that often precede an accident occurring and not necessarily during routine driving tasks. Thus, a closed course study in which the driving task involves a repetitive course delineated with cones, perhaps requiring following a lead car at a set distance, or passing situations, may not measure the real world situations and behaviors that precede accidents.

Previous research on the behavioral causes of crashes has repeatedly found that judgmental and attentional factors predominate over what may be termed inappropriate vehicle control maneuvers. Factors such as inattention, excessive speed, and improper lookout (Treat et al., 1979) are more often associated with accidents than are inappropriate responses to environmental and situational occurrences. The implications of this are that small difficulties in maintaining lane position, cornering, judging gaps or closing speed are not the typical events occurring prior to accidents. Rather, the failure to quickly notice and respond to events, or to anticipate events, occur much more frequently prior to accidents. These latter situations are the ones that should be measured, if at all possible.

The final consideration in designing an on-the-road study is the selection of which behaviors to measure. These should have some clear relevance to safe driving or conversely be related to the causes of crashes. They should be reliably measured, with relatively low variance. There is a tendency by researchers to treat any change in performance as indicative of impairment, though this is not always the case. Until the relevance for safe driving of many behaviors that are measured in these studies is better understood, small statistically significant changes are not necessarily meaningful. For example, one behavior frequently measured in these studies is "steering wheel reversals", or changes in the direction the steering wheel is turned. It is not clear whether an increase in the number of steering wheel reversals is an indication of poorer or better performance.

In summary, it is fair to say that despite the obvious appeal of measuring the effects of drugs on driving behavior in an on-the-road approach, this methodology is still very much at a developmental stage. The driving tasks employed are frequently highly artificial and do not appear to represent normal driving. Ideally, we would like to better understand why crashes occur so that the situations and circumstances that typically precede accidents could be reflected in the driving tasks employed in these studies. Likewise, the measurement of driving behavior needs to become much more informed and sophisticated so that behaviors that are clearly relevant to the occurrence of crashes are measured.

A few relatively recent on-the-road studies on the effects of marijuana on driving performance are briefly described below in order to illustrate some of the problems one faces in interpreting this type of research. These studies all used a closed course driving task, with fairly small numbers of subjects, and involved the administration of alcohol and marijuana, alone and in combination.

Hansteen et al. (1976) had sixteen subjects repeatedly drive a 1.1 mile course while drug free and after dosing with alcohol (to a BAC of 0.07%) or marijuana (either a low or high dose of 21 or 88 micrograms). The subjects drove the course immediately after dosing and again three hours later. The course was laid out with poles and cones. Subjects engaged in some slow speed forward and backward maneuvers and higher speed straight and curved sections. They were instructed to drive the course as quickly as possible. The study found that both the alcohol and marijuana treatment resulted in more cones being hit in the slalom portion of the course than compared to the drug-free trials. Under a high marijuana dose driving speed was lower than the drug-free condition. Three hours after dosing the differences among conditions were substantially reduced.

Casswell (1977) studied the effects of moderate doses of alcohol and marijuana, given alone and in combination. The driving task involved more normal maneuvers than often found in studies of this type. They included such events as driving through narrow spaces, around a hairpin turn, passing, and responding to road signs and traffic signals. A secondary task required the subjects to respond to an auditory signal as quickly as possible while on the closed course. Drug doses were administered at staggered intervals to the thirteen subjects who drove during three treatment sessions.

The results indicated that, under the effects of alcohol, fine steering wheel reversals decreased from the drug-free condition, while lateral positioning became more variable. Speed also increased under the alcohol and alcohol plus marijuana conditions. The only significant effect of marijuana alone was a decrease in speed. The author suggested that drivers under marijuana appeared to compensate for the perceived effects of the drug on their driving ability by slowing down. Alcohol, on the other hand, appeared to result in the subjects driving faster and making less of an effort at vehicle control.

A similar closed course study by Attwood et al. (1981) used higher doses of marijuana. Eight subjects performed a variety of driving tasks during a 25 minute drive including speed maintenance at 60 and 80 kph and following a lead car moving at a variable speed. Subjects drove an instrumented vehicle after receiving both alcohol and marijuana alone, and in combination. No secondary task was used to distract the subjects or increase the information processing load. The results of this study revealed few obvious effects due to alcohol and marijuana either alone or in combination. The small changes in behavior reported were subtle effects which the author admits would not be readily detected through observation.

A relatively large scale closed course study of the effects of alcohol and marijuana on driving performance was reported recently by Biasotti et al. (1986). Approximately 80 male subjects received either alcohol, marijuana, alcohol and marijuana, or no drugs. They subsequently drove over a test course four times at one hour intervals. The driving course included a variety of tasks including a chicane (series of tight turns of opposite direction), forced lane change, emergency stop, sign and route following, turning, maintaining a constant speed with the speedometer covered, and gauging the width of narrow gaps. A variety of different driver behavior measures were made that included computerized vehicle measures (speed, accelerator reversals, brake presses, steering control, and lateral placement), subjective judgments by in-car raters and other observers, impairment ratings by police officers in a following car, and self assessment.

Out of several hundred variables that were analyzed, a small number showed significant effects due to marijuana alone. Subjects touched fewer cones during the chicane task and they also drove slower in this task. Marijuana subjects instructed to drive at a predetermined speed drove faster with the speedometer covered than uncovered. The more subjective measures showed that the subjects given marijuana were rated as driving through the chicane less smoothly, stopping less accurately, and having poorer overall driving quality. The self assessments and officer ratings also correlated well with the drug treatments. For example, the officers in a car following the subjects indicated that they thought the driver was impaired about 60% of the time for the subjects receiving both alcohol and marijuana, about 50% of the time for subjects on alcohol alone, 32% of the time for subjects on marijuana alone, and 15% of the time for drug free drivers.

The above measures, as well as others, were also affected by the alcohol treatment, often to a greater extent than from the marijuana treatment, as well as by the combined alcohol and marijuana treatment. The only objective difference was that more, rather than fewer, cones were touched in the chicane task. The authors concluded that in general the combined drug dose appeared to increase the detrimental effects of the alcohol treatment (which were more severe than the marijuana effects). Thus, the strongest effects were observed in the combined alcohol and marijuana condition, followed by the alcohol condition, with the least effects from marijuana alone.

This last finding was also reported by Smiley et al. (1986) who examined the effects of marijuana alone and combined with alcohol on driving an instrumented car in a closed course study. Smiley had subjects perform various driving tasks including curve following, following a lead car, route navigation, obstacle avoidance, and decision making. The subjects performed an unrelated visual discrimination task while driving. The results indicated that the marijuana dose led to significantly longer car following distances, while the alcohol treatment led to higher speeds on both some straight and curved roadway sections. The combined marijuana and alcohol treatment produced essentially additive effects.

SUMMARY

A variety of drugs has been shown by this research to impair skilled performance. These drugs include the sedatives and tranquilizers (e.g., bezodiazepines and barbiturates) like diazepam and secobarbital, marijuana, antihistamines, antidepressants, antianxiety agents, and hypnotics (Hindmarch, 1986). The data from these studies of simulated driving suggest that these drugs may be prime targets for further investigation as potential highway safety hazards.

The study of the effects of drugs on driving performance using simulated driving is just beginning. The research conducted to date has been limited by a number of problems that will not be easy to remedy. Clearly the most difficult of these problems is the need to define the driving task operationally and to establish the relationship between driving performance and actual accident involvement rates. Once the relationships between critical aspects of driving skill and accident risk have been established, it will be possible to study the impairing effects of drugs through simulated driving. Driving tasks and performance measures can then be selected so that the results of these studies can be interpreted in terms of highway safety or crash risk.

Currently we are faced with interpreting the meaning of studies that have shown psychomotor impairment on tasks only abstractly related to real world driving. For example, while we know that divided attention and tracking ability is required for driving, it does not necessarily follow that performance on a highly novel and complex task designed to magnify performance decrements is correlated with actual real world performance or accident risk.

Some additional methodological problems that will need to be solved before much progress can be made in studying the effects of drugs on simulated driving behavior are:

- problems of subject motivation
- lack of realism in the driving task
- lack of standardized tasks and performance measures
- lack of control for previous drug usage experience

In spite of these problems, the research to date has provided important information about how some drugs affect different driving related skills. While much remains to be learned, considerable progress has been made in understanding the ways various drugs affect skilled performance.

CHAPTER IV

CONCLUSIONS AND DEPARTMENT OF TRANSPORTATION RESEARCH PLANS

CONCLUSIONS

The precise nature and extent to which drugs other than alcohol are a highway safety problem (i.e., impair driving ability and increase crashes) cannot be specified at this time. In order to determine the relationship between drug use and highway safety several critical pieces of information are needed. These are:

1. Which drugs impair driving ability,

2. Which drugs are associated with higher crash rates,

3. What drug dosage levels are associated with impaired driving or higher crash rates, and

4. How frequently are the drugs that impair driving ability and are associated with higher crash rates being used by drivers.

Data on how specific drugs both impair driving ability and are associated with crashes are needed to establish a causal link between those specific drugs and higher crashes. Knowing which drugs impair driving ability is important because drugs that impair driving ability have the potential for increasing crash risk. Also, this information allows attention to be focused on the drugs that are likely to be a serious highway safety problem.

Knowing that a drug impairs driving ability, however, is insufficient to establish that it leads to more crashes. A drug may impair some aspects of driving ability and not necessarily be associated with increased crashes, at least to the extent that it can be measured. People have an ability to compensate for certain types of behavioral deficits (e.g., they may pay more attention to the driving task, drive more conservatively, etc.). Also, the driving environment is in many ways quite forgiving. Thus, it is important to have evidence that specific drugs are associated with higher crash rates.

On the other hand, a drug may be found to be associated with higher crash rates (i.e., be overrepresented in crashes) without necessarily impairing driving ability. For example, persons who use particular drugs may have certain personality characteristics that predispose them to drug use, as well as to engaging in driving behaviors that lead to crashes.

In addition, some drugs may impair driving ability or be associated with increased crashes only at certain dosage levels. At low levels, no impairment or increased risk may occur, while doses exceeding a certain value may produce these effects. Finally, there may be some drugs that have the potential to produce severe driving impairment, but are not being consumed by the driving public at a time that would affect driving.

Information about which drugs impair driving ability will come primarily from laboratory and simulator research, while information about which drugs are associated with increased crash rates will come primarily from epidemiological research. Ultimately, one would like to be able to specify which drugs (and at what dosages) increase crash risk. Determining the crash risk associated with drug use requires firm evidence that a causal relationship exists between drug use and crash occurrence. The ability to make such a causal inference will require evidence produced by these complementary sources.

In summary, evidence from all four types of data is needed to establish that specific drugs are highway safety problems. The role of alcohol in traffic crashes, for example, has been well established by evidence from all four of these sources. We know that alcohol impairs driving ability, is overrepresented in crashes, is used frequently by the driving public, and the relationship between BAC and impairment is known. To establish that other drugs are serious highway safety problems will require that similar evidence be developed.

Each of these four categories of information is discussed briefly below.

1. Determining Which Drugs Impair Driving Ability

The study of how drugs affect driving related skills has produced a large and diverse literature. Methods used have included laboratory studies of human performance and "driving related skills," use of driving simulators, and on-the-road studies (using actual vehicles, typically on a closed course).

Laboratory and simulator research have been the primary methods used to determine which drugs impair driving ability. Previous research of this type was limited by a number of problems that preclude interpreting observed impairment on laboratory, driving simulator, and on-the-road tasks as implying that significant impairment of actual driving skill would result. Problems encountered include the wide range of tasks different researchers use, the diversity of methods used to measure behavior in the laboratory and field, the lack of agreement about what constitutes critical driving skills, and the highly artificial and sometimes inappropriate nature of the tasks employed.

Future success in determining which drugs have the potential to impair driving will not be easy. Many drugs need to be tested. The process of evaluating the effects of a drug on driving ability is a complex, time consuming and costly undertaking. An optimal approach to this issue will require that the driving task be better understood. When the critical skills necessary for safe driving have been determined, then research can be conducted to assess the extent to which specific drugs, at various doses, impair these skills.

Until then, progress will still be possible through improved research methods to assess the effects of drugs on "driving related" behavior in the laboratory, through simulated driving, and in on-the-road studies. This work will continue to be suggestive of the type of psychological and behavioral deficits different drugs produce. No precise inference to actual driving impairment or increased crash risk will be feasible. Even this limited progress will require other improvements in research methodology (e.g., more realistic simulation of driving, standardized selection of tasks that measure critical driving skills, standardized measures of performance, assessment of various combinations of drugs and alcohol that parallel typical usage patterns).

There is promise of greater progress in the near future in this area as a result of recent methodological improvements that have made simulator and on-the-road research more likely to yield useful information. More realistic simulators and computerized data processing technology for instrumented vehicle research have made these research techniques capable of producing more useful information than could be obtained previously.

2. Determining Which Drugs Are Associated with Increased Crash Rates

A different approach is required to determine which drugs increase crash rates. In this case one needs to look directly at crash data. Several alternative methods could be used to collect information pertaining to the role drugs play in crashes. Research could be conducted to determine the incidence of drug use in crash and noncrash involved drivers so that an estimate of the extent to which the drugs contributed to the occurrence of the crash could be made. The finding that a drug was overrepresented in crash involved drivers would suggest strongly that it played a role in increasing crash risk.

Previous studies of the incidence of drug use by crash involved drivers have not collected acceptable drug use data from noncrash involved drivers. An empirical determination of drug use requires the collection of body fluid samples (primarily blood). Such studies are not contemplated at this time by the Department of Transportation.

Another way to estimate the role drugs play in crash occurrence would be to determine the rate at which crash involved drivers are estimated to have been responsible for their crashes, and then to compare these crash responsibility rates between drivers in whom specific drugs are detected and drug-free drivers. Increased crash responsibility rates for drivers under the influence of specific drugs, as compared to drug-free drivers, would strongly suggest that the drug use increased crash risk. In this approach, drug-free drivers are used as the control group rather than noncrash involved drivers. This method has not been used extensively, but appears to be a practical alternative to obtaining a control sample of noncrash involved drivers. NHTSA recently used this method in a small study of injured drivers. NHTSA is currently initiating a larger study of fatally injured drivers that will involve this type of crash responsibility analysis.

3. Determining What Drug Dosage Levels Are Associated With Impaired Driving

Little is currently known about the relationship between dosage level and driving impairment. The ability to predict the behavioral consequences of different dosage levels of most drugs is currently quite limited (i.e., only gross generalizations can be made, such as: high doses generally have a greater effect than small doses).

Future progress in determining the relationship of drug dosage level to driving impairment and increased crashes will be difficult for many drugs with potential for abuse. Most psychoactive drugs are chemically complex molecules, whose absorption, action and elimination from the body are poorly understood. Considerable differences between individuals exist in the rates at which these processes occur. Other problems that will have to be overcome in order to understand the relationship between drug dosage level and driving impairment are:

- o the poor correlation between psychological or behavioral effects and blood or plasma level for many drugs,
- o sensitivity and tolerance effects (after repeated administrations of psychoactive drugs the body's response changes),
- o accumulation in the blood or other body fluids (the drug or metabolites are not quickly eliminated from the body).

Currently it is not possible to equate the presence of specific amounts of many drugs in the blood, or other body fluid, of an individual with a specific psychological or behavioral effect. At present, this type of research is difficult and costly, requiring expensive equipment for drug assays. Dosages that may be given to volunteer subjects are limited by ethical considerations. Sophisticated experimental procedures must be used. Many drugs must be tested, alone and in combinations, while new drugs are constantly being introduced.

It is possible that, for some drugs with the potential to impair driving ability, it will not be technically feasible to establish a specific dosage level that is indicative of impairment for all drivers. With this in mind, further consideration needs to be given to alternative approaches, for example, the development of a performance test that would be indicative of driving impairment.

In the interim, useful information about the relationship of drug dosage levels and impairment of driving related behavior can be acquired for selected drugs of interest through research using more realistic driving simulators or computerized instrumented vehicles. Well designed studies of this type for a few frequently used drugs would allow their potential for real driving impairment to be better gauged and would further our understanding of the effects of different drug-dosage levels.

4. Determining the Frequency of Drug Use By Drivers

Determining the incidence with which noncrash involved drivers drive after taking drugs will also be difficult to accomplish. This information is important for several reasons. Some drugs may be shown to severely impair driving ability, but if people do not typically drive after using them then they do not represent a serious highway safety hazard. From a highway safety standpoint, these drugs will be of less concern than those drugs used by large percentages of drivers. Secondly, the enforcement of laws against driving while impaired by drugs may require the ability to test body fluids for the presence of specific drugs. Knowing what drugs are commonly used by drivers allows enforcement agents to focus their attention on these high priority drugs. Finally, knowing the frequency of driver drug usage is important for determining the significance of this problem and thus the resources that should be devoted to reducing it.

Practical and methodological difficulties have limited the usefulness of past research on drug use by drivers. Methodological problems have stemmed primarily from an inability to obtain representative samples of drivers for study. Most studies of crash involved drivers and drivers detained by the police have used small or non-representative samples. Consequently, the results cannot be generalized. The practical problems that have hindered previous research on drug use by drivers have arisen from the inability to detect and measure the presence of some drugs in drivers and the costs of screening for a wide range of possible drugs, resulting in only a few drugs being included in most studies.

Determining the number of drivers who operate a motor vehicle after having consumed drugs requires the collection and analysis of blood samples. The use of body fluids other than blood cannot currently provide this information. Many drugs will remain in some body fluids, like urine, for a considerable period of time (days, and in some cases weeks) after the psychological and behavioral effects have passed.

Ascertaining the frequency with which specific drugs are being used by drivers requires roadside surveys of the general driving public in which blood samples are collected. There has been virtually no useful research of this type conducted to date. Since such research is expensive to conduct and would require a major effort to obtain sufficient cooperation, it is unlikely that this type of research could be conducted until there is widespread recognition of the potential benefits to society.

On the other hand, determining the incidence of drug use by crash involved drivers is something that could be accomplished. Recent advances in drug testing technology have made large-scale drug incidence studies much more feasible and likely to produce useful data than in the past. For example, research to determine the incidence of drugs in a representative sample of fatally injured drivers, reflecting current drug usage patterns, could be undertaken without the problems associated with obtaining blood samples from live drivers.

General Conclusions

It is obvious that many drugs have the potential to impair driving and increase crash risk when used in inappropriate ways. This includes virtually all illegal drugs and many prescription drugs. Not all instances of drug use will lead to impairment of driving ability. Prescription drugs, when used to treat conditions which may themselves impair driving ability, may reduce or eliminate the impairment, thus having a beneficial effect on driving. Also, many drugs that may not produce significant driving impairment at a moderate dose may produce impairing effects at a high dosage.

We know that many people drive after having taken drugs. Studies of drug use by drivers involved in crashes indicate that drugs other than alcohol are detected in 10 to 22% of these drivers. A significant number of drivers detained for suspicion of driving while intoxicated have also been shown to have taken drugs. It is not possible to say whether the drugs used by drivers involved in crashes were responsible for the occurrence of the crashes. Mere incidence statistics alone can not answer this question. Incidence rates may simply reflect drug usage rates in the general driving population.

While much remains to be learned, we have made considerable progress in the last several decades in understanding the effects of drugs on driver behavior. Our knowledge can be summarized as follows:

- The nature and extent to which drugs, other than alcohol, are a serious highway safety problem cannot be specified with certainty at this time.

- A growing body of literature suggests that certain drugs (e.g., marijuana) impair psychological and behavioral abilities that are functionally related to driving, even though the extent to which drug impaired driving causes crashes can not be inferred from this research. The accumulating evidence suggests there is a risk posed by driving after consuming some drugs at high dosage levels.

- Drugs that may impair driving include certain prescription and over-the-counter drugs as well as illegal drugs.

- Drugs are quite often used in combination with high doses of alcohol, so that understanding the combined effects of drugs and alcohol is important.

- The frequency with which drivers drive, are arrested, or crash while under the influence of drugs other than alcohol is not known. However, the available data on drug use by crash involved drivers suggests that the drug and driving problem is substantially less than the alcohol and driving problem.

- It may not be possible to establish specific levels of drugs in body fluids that are associated with driving impairment (as has been done with alcohol).

- The drugs that appear to have the most potential to be serious highway safety hazards (based upon currently available information regarding incidence and impairment) are: tranquilizers (e.g., Valium(R)), sedatives and hypnotics (e.g., barbiturates), and marijuana.

DOT RESEARCH AND DEMONSTRATION PLANS

Given the current state of knowledge, it is clear that additional information is needed for a fuller understanding of the relationship between drug use and highway safety. In light of this, the Department of Transportation plans to continue research and demonstration programs designed to help define the nature and magnitude of the drug and driving problem.

The Department of Transportation has had an active research program on drugs and driving since the early 1970s. The initial projects focused on the collection of information about the nature and magnitude of the potential problem. Preliminary efforts to identify the incidence of drugs in crashes and in the driving population were undertaken. The results of these studies were not conclusive, primarily because drug testing (assay) technology had not advanced to current levels. The early results indicated the existence of a potential problem that was not as simple to define as the alcohol highway safety problem. These early studies also defined the need for significantly improved detection and measurement methods so that specific drugs and dosages that were actually hazardous to driving could be identified and so that enforcement efforts could be undertaken as warranted.

The Department, through the NHTSA and in cooperation with the National Institute on Drug Abuse, has continued to support work in this area. For example, the development of more sophisticated driving simulators and their use to investigate the effects of selected high priority drugs was supported. A series of symposia and workshops were sponsored to bring together leading researchers and practitioners to examine the problem of drugs and driving. Also, a behavioral drug recognition technique for police use was investigated and found promising.

Current research efforts are directed at assessing the frequency of drug use by fatally injured drivers, determining which drugs are associated with higher crash rates, and learning about the impairing effects of different dosage levels of selected drugs on driving related behavior. This research is designed to provide the most useful information possible at a reasonable cost. The research planned by the Department will be able to take advantage of technological advancements that have occurred in recent years. As a result, the information to be obtained will be more useful and in greater depth than possible previously.

The Department of Transportation currently has two large scale research studies in their final planning stages. One project is designed to determine the incidence and role of drugs in fatally injured drivers. Compared to previous studies that employed small non-representative samples, this study will sample a large number of fatally injured drivers from various regions of the country.

Also, advances in drug testing technology will allow a more accurate and precise determination of drug usage for a wider selection of drugs. Finally, police drug reporting has been improved through the inclusion of drug data as a standard part of police accident report forms. These improved reports will allow an estimation of the role drugs play in crash occurrence. This information will help us estimate the magnitude of the drug highway safety problem.

The other research study will examine the effects of selected drugs on simulated driving behavior in a state-of-the-art driving simulator recently developed by the Mercedes-Benz company. This new simulator is very realistic and allows many more types of driving situations that require decision making in emergency situations to be simulated than was possible in earlier simulators. This research is planned as a joint effort with the West German government which is also very interested in drugs and highway safety. This study will provide information about the impairing effects on driving related behavior of drugs with high potential as highway safety hazards.

Data collection for both these projects is planned for initiation in CY 1988.

The Department has also been involved in the evaluation of a behavioral drug detection procedure for police use. This procedure focuses on detecting the use of drugs that are believed to impair driving performance with special attention given to abused substances such as cocaine, marijuana, and phencyclidine (PCP).

Incidence and Role of Drugs in Fatal Accidents

The primary objective of this two year effort in selected states is to determine the extent to which specific drugs (and associated blood levels) are found in fatally injured drivers. Currently available data come from studies in isolated locales with small sample sizes that do not allow any generalizations to be made. This study is designed to obtain as complete a sample of fatally injured drivers in the selected sites as is possible.

Strictly speaking, these data will not be a nationally representative sample. The data will however, more closely reflect the nation's drug incidence rate than previous research.

The second major objective is to study the role drugs play in causing these fatal accidents. To this end, a "responsibility analysis" will be performed to compare the rate at which drivers are estimated to have been responsible for their crashes, between drivers in whom drugs are detected and drug-free drivers. A finding of significantly higher responsibility rates for drivers in whom specific drugs are detected as compared to drug-free drivers will strongly suggest that the drugs played a role in the accident. This analysis will only be meaningful for those drugs detected with relatively high frequency.

Based on preliminary contacts with a number of state medical examiners, we expect that five or six states will participate in the study. A sample size of approximately 2,500 to 3,000 fatally injured drivers (motorcycle, passenger vehicle or light truck) should be obtained. Only drivers who died in the crash

or within one or two hours after the crash occurred (to reduce the effects of either continued drug metabolism or elimination) will be included. Data collection will occur over a one year period.

The blood samples will be screened at a laboratory, approved by NHTSA, using the latest assay techniques for a wide variety of drugs. Positive samples will then be confirmed using a different technique (e.g., mass spectrometry and gas chromatography). The drugs to be tested for will include:

- alcohol (ethanol)
- cannabinoids (marijuana)
- hallucinogens (e.g., PCP, LSD)
- stimulants (e.g., cocaine, amphetamines)
- depressants (e.g., barbiturates, benzodiazepines, tranquilizers, hypnotics)
- narcotics (opiates, analgesics)
- antihistamines
- antidepressants (e.g., Lithium)
- antipsychotics (e.g., Chlorpromazine)

Finally, any association between driver characteristics (e.g., age, sex), situational factors (e.g., type of crash, time of crash, etc.) and drug incidence will be determined.

Simulator Research

Valuable information can be obtained from examining the effects of drugs on performance in a driving simulator, if the simulator is as realistic as possible. Significant performance impairment in this situation would strongly indicate the potential for real driving impairment. Based on a review of available driving simulators worldwide, it appears that the simulator newly developed by Daimler-Benz (Mercedes) in Berlin is the most "realistic" and sophisticated currently in existence. No previous drug research has been conducted in a state-of-the-art driving simulator like this.

This simulator has accurate interactive car dynamics. The key elements of this simulator are a highly realistic motion system with six degrees of freedom, and a projection system to simulate the vehicle environment with a sharply focused seamless 180 degree picture in the driver's visual field. A complex mathematical model of dynamic vehicle behavior simultaneously guides a number of computers in simulating motion, reaction forces of the steering wheel, brake and accelerator pedals, as well as the visual field and noises associated with the simulated drive. With this simulator it is possible to program a variety

of routine and emergency driving situations, varying the road type and condition, weather conditions, and visibility.

A cooperative agreement is currently being negotiated between the Department of Transportation (National Highway Traffic Safety Administration) and the Federal Republic of Germany's Ministry of Transport (Bundesanstalt fur Strassenwesen [BASt]) to conduct a study of the effects of selected drugs on driving performance in the Mercedes simulator. The purpose of this project is to assess the degree of performance impairment associated with specific drugs and dose levels.

The actual research data will be collected in Berlin where the Daimler-Benz driving simulator is located. The project implementation will be coordinated by personnel from BASt.

Two drugs will be evaluated, diazepam (Valium, a tranquilizer) and diphenhydramine (an antihistamine). Each drug will be tested at two dose levels, and a placebo (no drug) condition also will be used. The two dose levels represent typical medium and heavy dosages. These two drugs each represent a different class of drugs selected for their potential as highway safety hazards. The tranquilizer Valium has appeared frequently among drugs found in fatally injured drivers and is also widely used in the general population. The antihistamine diphenhydramine represents a class of widely used over-the-counter drugs that have been shown in the laboratory to impair driving related performance.

A different group of male volunteers will receive each drug, at each dosage level. The subjects will drive a fixed course in the simulator, during which a number of different scenarios will be encountered. These include stopping at traffic lights, following a leading car, emergency stopping, and avoiding obstacles in the roadway under a variety of environmental and weather conditions ranging from well lit dry roadways to snow covered road conditions.

This study is scheduled to begin in late spring 1988 and will last approximately one year.

Drug Evaluation and Classification Demonstration

The Department of Transportation has been involved in the evaluation of a behavioral drug detection procedure for police use. Recently, NHTSA completed an evaluation of a drug recognition procedure developed by the Los Angeles Police Department to enable police officers to identify different types of drug impairment (Bigelow et al. 1985 and Compton 1986). This procedure focuses on detecting the use of drugs that are believed to impair driving performance, with special attention given to abused substances such as cocaine, marijuana and phencyclidine (PCP).

The procedure involves training officers to detect the patterns of behavioral and physiological symptoms associated with major drug categories (e.g., stimulants, depressants, hallucinogens). It consists of three components, an

interview (concerning the suspect's medical and drug use history, recent eating, sleep, drug and alcohol use), measurement of objective physiological symptoms (pulse rate, blood pressure, oral temperature, pupil size, perspiration, salivation, reaction to light and dark, nystagmus, etc.), and a battery of behavioral tests of psychomotor function (e.g., the one-leg-stand, and walk-and-turn tests).

In cooperation with the Los Angeles Police Department, NHTSA conducted a two-part evaluation of the drug recognition procedure. First, a small scale laboratory study was conducted. The field evaluation was designed to obtain data from a wider range of officers looking for a larger number of drugs in actual suspects under field conditions.

The results of the two studies showed that the drug recognition procedure enabled experienced police officers to accurately recognize the symptoms of many types of drug use by drivers. When the officers identified a suspect as having used particular drugs, a blood test almost always confirmed their judgment. Blood tests are not currently conducted on a routine basis because the cost of testing for many possible drugs is prohibitive. Because this procedure allows the police to focus on a few specific drugs, the necessary blood tests should be much less expensive and could therefore be used more routinely. Information regarding the particular drugs used by drivers should increase successful prosecutions. Thus, this procedure appears to be a useful tool that will greatly enhance the enforcement of "driving under the influence of drugs" laws.

NHTSA has recently completed development of a training course to teach this drug recognition procedure to police officers. The training course will be tested in approximately 10 sites across the country during 1988, in preparation for widescale dissemination to police departments across the country.

Summary

Taken together, the results of NHTSA's two research studies will increase our knowledge of the incidence and role drugs play in fatal accidents and of the impairing effects of selected drugs on driving behavior. While much will remain to be learned, this information should significantly advance our understanding of the relationship between the use of drugs and highway safety. In the interim, the drug recognition training program will continue the Department's efforts to assist enforcement of existing laws regarding driving while under the influence of drugs.

REFERENCES

Attwood, D.; Williams,R.; McBurney, L. & Frecker, R. (1981) "Cannabis, Alcohol And Driving: Effects on Selected Closed Course Tasks," In Alcohol, Drugs and Traffic Safety, edited by Golberg, L., Vol. III., Almqvist and Wiksell, Stockholm.

Biasotti, A. A.; Boland, P.; Mallory, C.; Peck, R. & Reeve, V.C. (1986) "Marijuana and Alcohol Performance Study - A Final Report," CA/OTS Project # 087902, Sacramento, CA: California Department of Justice, September 1986.

Bigelow, G.E.; Bickel, W.E.; Roache, J.D.; Liebson, I.A. & Nowowieski, P. (1985) "Identifying Types of Drug Intoxication: Laboratory Evaluation of a Subject-Examination Procedure," (Report DOT HS 806 753) Washington, D.C.: National Highway Traffic Safety Administration, May 1985.

Burns, M. (1987) "Sobriety Tests For the Presence of Drugs," In Alcohol, Drugs and Driving, Edited by Moskowitz, H., Vol. 3, No. 1, January-March 1987, pp. 25-29.

Casswell, S. (1977) "Cannabis and Alcohol: Effects On Closed Course Driving Behavior," In Proceedings of the Seventh International Conference on Alcohol, Drugs and Traffic Safety, edited by Johnson, I., Melbourne, Australia.

Chiang, C.N. & Hawks, R.L. (1986) "Implications of Drug Levels in Body Fluids: Basic Concepts," In Urine Testing For Drugs Of Abuse, Research Monograph Series #73, U.S. Department of Health and Human Services, DHHS Publication No. (ADM) 87-1481.

Cimbura, G.; Lucas D.N.; Bennett, R.C.; Warren, R.A. & Simpson, H.M. (1982) "Incidence and Toxicological Aspects of Drugs Detected in 484 Fatally Injured Drivers and Pedestrians in Ontario," Journal of Forensic Sciences, Vol. 27, No. 4, October 1982, pp. 855-867.

Clarke, R.M.; Leasure, Jr., W.A.; Radlinski, R.W. & Smith, M.F. (1987) "Heavy Truck Saftey Study - Prepared in Response to: Section 216: P.L. 98-554, October 30, 1984 of the Motor Carrier Safety Act of 1984," National Highway Traffic Safety Administration, Report No. DOT HS 807 109, U.S. Department of Transportation, Washington, D.C. March 1987.

Compton, R.P. (1986) "Field Evaluation of the Los Angeles Police Department Drug Detection Procedure," (Report DOT HS 807 012) Washington, D.C.: National Highway Traffic Safety Administration, February 1986.

Compton, R.P. & Anderson, T.E. (1985) "The Incidence of Driving Under the Influence of Drugs: An Update of the State of Knowledge," (Report DOT HS 806 900) Washington, D.C.: National Highway Traffic Safety Administration, December 1985.

Crancer, A.J.; Dille, J.M.; Delay, J.C.; Wallace, J.E. & Haken, M. (1969) "Comparison of the Effects of Marijuana and Alcohol on Simulated Driving Performance," Science, Vol. 164, pp.851-845.

Donelson, A.C.; Cimbura, G.; Bennett, R.C. & Lucas, D.M. (1985) "The Ontario Monitoring Project: Cannabis and Alcohol Use Among Drivers and Pedestrians Fatally Injured in Motor Vehicle Accidents From March 1982 Through July 1984," Final Report from The Traffic Injury Research Foundation of Canada, 171 Nepean, Ottawa, Ontario, Canada K2P 0B4, January 1985.

Dott, A.B. (1972) "Effect of Marijuana On Risk Acceptance in a Simulated Passing Task," Report ICRL-RR-71-3, DHEW Publication No. HSM-72-10010, Washington, D.C.: Public Health Service.

Ellingstad, V.S.; McFarling, L.H. & Struckman, D.L. (1973) Alcohol, Marijuana and Risk Taking, Vermillion Human Factors Laboratory, South Dakota University.

Hansteen, R.S.; Miller, R.D. & Lonero, L. (1976) "Effects of Cannabis and Alcohol On Automobile Driving and Psychomotor Tracking," Annals of the New York Academy of Sciences, Vol. 282, pp. 240-456.

Hindmarch, I. (1986) "The Effects of Psychoactive Drugs On Car Handling and Related Psychomotor Ability: A Review," In Drugs and Driving, Edited by O'Hanlon, J.F. & DeGier, J.J., Taylor & Francis, London, 1986, pp. 71-82.

Honkanen, R.; Ertama, L.; Kinnoila, M.; Alah, M.; Lukkari, I.; Karlsson, M.; Kiviluto, O. & Puro, M. (1980) "Role of Drugs in Traffic Accidents," British Medical Journal, Vol. 281, 1980, pp. 1309-1312.

Hurst, P.M. (1976) "Amphetamines and Driving Behavior," Accident Analysis and Prevention, Vol. 8, pp. 9-13.

Johnson, C.A. & Keltner, J.L. (1983) "Incidence of Visual Field Loss in 20,000 Eyes and its Relationship to Driving Performance," Archives of Opthamology, Vol. 101, pp. 371-375.

Joscelyn, K.B. & Donelson, A.C. (1980) "Drugs Research Methodology. Vol. II. The Identification of Drugs of Interest in Highway Safety." National Highway Traffic Safety Administration, Report No. DOT HS-805-299, U.S. Department of Transportation, Washington, DC 1980.

Joscelyn, K.B.: Donelson, A.C.; Jones, R.K.; McNair, J.W. & Ruschmann, P.A. (1980) Drugs and Highway Safety, 1980. National Highway Traffic Safety Administration, Report No. DOT HS-805-461, U.S. Department of Transportation, Washington, DC.

Kleinknecht, R.A. & Donaldson, D. (1975) "A Review of the Effects of Diazepam on Cognitive Function and Psychomotor Performance," Journal of Nervous and Mental Disease, Vol. 161, pp. 399-411.

Landauer, A.A.; Milner, G. & Patman, J. (1969) "Alcohol and Amitriptyline Effects on Skills Related To Driving Behavior," Science, Vol. 163, p. 1467.

Lund, A.K.; Preusser, D.F.; Blomberg, R.D. & Williams, A.F. (1987) "Drug Use by Tractor-Trailor Drivers," Unpublished report by the Insurance Institute for Highway Safety, Watergate 600, Washington, D.C. 20037.

Mason, A.P. & McBay, A.J. (1984) "Ethanol, Marijuana, and Other Drug Use in 600 Drivers Killed in Single-Vehicle Crashes in North Carolina, 1978-1981," Journal of Forensic Sciences, Vol. 29, No.4, October 1984, pp. 987-1026.

McBay, A.J. (1986) "Drug Concentrations and Traffic Safety," In Alcohol, Drugs and Driving: Abstracts and Reviews, Vol. 2, No. 3-4, July-December 1986, pp. 51-59.

Moskowitz, H. (1985) "Marijuana and Driving," Accident Analysis and Prevention, Vol. 17, pp 323-345.

"National Survey on Drug Abuse: Main Findings 1982" (1983) U.S. Department of Health and Human Services, DHHS Publication No. (ADM) 83-1263.

NHTSA (1987) "Fatal Accident Reporting System 1985," National Highway Traffic Safety Administration, Report No. DOT HS 807 071, U.S. Department of Transportation, Washington, D.C. February 1987.

Nicholson, A.N. & Stone, B.M. (1986) "Antihistamines and Sedation," In Drugs and Driving, Edited by O'Hanlon, J.F. & DeGier, J.J., Taylor & Francis, London, 1986, pp. 71-82.

Owens, S.M.; McBay, A.J.; & Cook, C.E. (1983) "The Use of Marijuana, Ethanol, and Other Drugs Among Drivers Killed in Single-Vehicle Crashes," Journal of Forensic Sciences, Vol. 28, No. 2, April 1983, pp. 372-379.

Rafaelsen, L.; Christup, H. & Bech. P. (1973) "Effects of Cannabis and Alcohol on Psychological Tests," Nature, Vol. 242, pp. 117-118.

Sanders, A.F. (1986) "Drugs, Driving and the Measurement of Human Performance," In Drugs and Driving, Edited by O'Hanlon, J.F. & DeGier, J.J., Taylor & Francis, London, 1986, pp. 3-17.

Sharma, S. (1976) "Barbiturates and Driving," Accident Analysis and Prevention, Vol. 8, pp. 27-31.

Smiley, A.M. (1986a) "Marijuana: On-Road and Driving Simulator Studies," In Alcohol, Drugs and Driving, Vol. 2, No.3-4, July-December 1986, pp. 121-133.

Smiley, A.M. (1986b) "Assessment of Drug Effects On Driving Performance Using On-The-Road Studies," In Drugs and Driving, Edited by O'Hanlon, J.F. & DeGier, J.J., Taylor & Francis, London, 1986, pp. 51-64.

Smiley, A.M.; Moskowitz, H. & Zeidman, K. (1981) "Driving Simulator Studies of Marijuana Alone and In Combination with Alcohol," Proceedings of the 25th Conference of the American Association for Automotive Medicine, San Francisco, California, October 1-3, 1981.

Smiley. A.M., Moskowitz, H.M. & Ziedman, K. (1985) "Effects of Drugs on Driving: Driving Simulator Tests of Secobarbital, Diazepam, Marijuana, and Alcohol," U.S. Department of Health and Human Services, DHHS Publication No. (ADM) 85-1386, 1985.

Smiley, A.M.; Noy, Y.I. & Tostowaryk, W. (1986) "The Effects of Marijuana, Alone and In Combination With Alcohol, On Driving An Instrumented Car," Proceedings of the 10th International Conference on Alcohol, Drugs, and Traffic Safety, Amsterdam.

Soderstrom, C.A.; Trifillis, A.L.; Shankar, B.S.; Clark, W.E. & Cowley, R.A. (1986) "Marijuana and Alcohol Use Among 1023 Trauma Patients: A Prospective Study," Paper presented at the 30th Annual Conference of the American Association for Automotive Medicine, Montreal, Canada, October 6-8, 1986.

Stein. A.C.; Allen, R.W.; Cook, M.L. & Karl, R.L. (1983) "A Simulator Study of the Combined Effects of Alcohol and Marijuana on Driving Behavior - Phase II," National Highway Traffic Safety Administration, Report No. DOT HS 806-405, U.S. Department of Transportation, Washington, D.C., February 1983.

Terhune, K.H. (1986) "Problems and Methods in Studying Drug Crash Effects," In Alcohol, Drugs and Driving: Abstracts and Reviews, Edited by Moskowitz, H., Vol. 2, No. 3-4, July-December 1986, pp. 1-14.

Terhune, K.W. & Fell, J.C. (1982) "The Role of Alcohol, Marijuana and Other Drugs In the Accidents of Injured Drivers," NHTSA Technical Report DOT HS-806-181, U.S. Department of Transportation, Washington, D.C., March 1982.

Treat, J.; Tumbas, S.; Shinar, D.; Hume, R.; Mayer, R.; Stansifer, R. & Castellan, V. (1979) "TRI-Level Study of the Causes of Traffic Accidents," National Highway Traffic Safety Administration, Report No. DOT HS 805-099, U.S. Department of Transportation, Washington, D.C., May 1979.

Valentour, J.C.; McGee, M.P.; Edwards, R.P. & Goza, B.S. (1980) "A Survey of Drug Use Among Impaired Drivers in Virginia," Medico-Legal Bulletin, Vol. 29, No. 5, September/October 1980, pp. 1-7.

White, J.M.; Clardy, D.O.; Graves, M.H.; Kuo, M.C.; MacDonald, B.J.; Wiersema, S.J. & Fitzpatrick, G. (1981) Clinical Toxicology, Vol. 18, No. 8, 1981, pp. 945-957.

Williams, A.F.; Peat, M.A.; Crouch, J.K. & Finkle B.S. (1985) "Drugs in Fatally Injured Young Male Drivers," 1985 Public Health Reports, Vol. 100, No.1, January-February 1985, pp. 19-25.

Wyckoff, D. (1979) "Truck Drivers in America," D.C. Heath and Company, Lexington, Mass.

Zimmermann, E.G.; Yeager, E.P.; Soares, J.R.; Hollister, L.E. and Reeve, V.C. (1983) "Measurement of Delta-9 - Tetrahydrocannabinol (THC) in Whole Blood Samples from Impaired Motorists," Journal of Forensic Sciences, Vol. 28, No. 4, October 1983, pp.957-962.