Accid. Anal. & Prev. Vol. 25, No. 3, pp. 259–265, 1993
Printed in the U.S.A.

0001-4575/93 $6.00 + .00

THE EFFECT OF CELLULAR PHONE USE UPON DRIVER ATTENTION

A. JAMES McKNIGHT and A. SCOTT McKNIGHT

National Public Services Research Institute, 8201 Corporate Drive, Landover, MD 20785, U.S.A.

(*Received 22 July 1991*)

Abstract—In this study, 150 subjects observed a 25-minute video driving sequence containing 45 highway traffic situations to which they were expected to respond by manipulation of simulated vehicle controls. Each situation occurred under five conditions of distraction: placing a cellular phone call, carrying on a casual cellular phone conversation, carrying on an intense cellular phone conversation, tuning a radio, and no distraction. All of the distractions led to significant increases in the proportion of situations to which subjects failed to respond. However, significant age differences of nonresponse appeared. Among subjects over age 50, nonresponses increased by about one-third under all of the telephone distractions. The response rate of younger subjects increased by a lesser degree except under intense conversation. Results were not influenced by gender or prior experience with cellular phones. The authors conclude that older drivers might reduce their accident risk during attention-demanding traffic conditions by avoiding use of cellular phones and that other drivers might do so by refraining from calls involving intense conversation.

INTRODUCTION

One of the most popular innovations in automobile travel over the past decade is the cellular phone system, which allows motorists to carry on telephone conversations while driving. Since early 1984, when the first complete cellular phone systems became operational, the number of users in the United States has grown to over 2 million. By the mid-90s, when cellular service will be available throughout most population centers in the United States, the number of subscribers is expected to reach between 10 and 20 million. The prospect of that many drivers placing, receiving, and handling telephone calls while driving raises legitimate concern.

An early study by Brown, Tickner, and Simmonds (1969) found that use of the telephone while driving had little effect upon routine driving skills, but did impair the perception of gaps in traffic. A more recent study by Stein, Parseghian, and Allen (1987) examined lanekeeping and found significant performance degradation when placing phone calls in straight driving or on curves, with older drivers showing the greatest performance degradation. Brookhuis, De Vries, and De Waard (1991) found that placing mobile telephone calls reduced mirror checks in light traffic, slowed responses to headway changes, and increased the variance of steering wheel movements. Their sample size did not permit reliable age comparisons.

The effect of phone use upon the attentional responses of drivers could well constitute a greater threat to safety than its interference with vehicle control. *First*, attentional processes play a far greater role in automobile accidents than does vehicle control. "Improper lookout" and "inattention" have been identified as the two leading contributors to automobile accidents (Treat et al. 1977). *Second*, while the extent to which cellular telephone calling interferes with vehicle control can be reduced by dialing aids (e.g. speed dial), the effect of phone use upon attentional processes is not readily ameliorated.

The objective of the study here described was to assess the effect of telephone use upon the driver's ability to attend to the demands of the highway traffic environment. Specifically, it attempted to answer the following research questions: (i) what effect does use of cellular phones have upon attention to highway-traffic situations? (ii) how does this effect relate to the complexity of telephone conversations? and (iii) how do any effects vary with age?

METHODS

The effect of cellular phone use upon driver attention was studied by confronting samples of drivers with simulated highway and traffic situations and comparing the responses occurring under ordinary driving with those occurring when drivers were using cellular telephones. Results were analyzed in terms of (i) type of phone use and (ii) age of driver.

Cellular phone tasks

The relationship under study was the potential effect of cellular telephone use upon the driver's attention to the traffic environment. Studies cited earlier indicate that the handling of telephone equipment itself disrupts performance only when the driver is placing a call. However, these studies did not investigate the possible distraction from cellular phone conversations involved. The potential effect of such distraction would presumably endure for the duration of the conversation. It is also possible that calls involving intense conversation, such as negotiating business deals, might be particularly attention demanding.

While "driving" a simulator to videotaped highway traffic scenes, a sample of drivers simulated placing calls and carrying on conversations over a cellular phone. Since the study was concerned only with potential distraction, and not direct physical interference, "hands-free" operation of phones was simulated. Only when placing calls was it necessary to remove a hand from the steering wheel.

To allow differences in the intensity of conversation to evidence possible effects upon degree of distraction, conversation took place at two levels, *casual* conversation, in which subjects talked with the experimenter about a variety of largely inconsequential topics, and *intense* conversation in which the subjects engaged in a set of problem-solving exercises.

A distraction with which operation of in-vehicle equipment is sometimes compared is that involved in tuning a radio. (Stein et al. 1987; Brookhuis et al. 1991). To provide a familiar benchmark, radio tuning was included among the distractions with which telephone conversations were compared.

To summarize, the five conditions creating different types and degrees of potential distraction were as follows: (i) No distraction—the absence of any planned distraction, (ii) Placing a call—subject dialing a telephone number on a key pad located close to the subject's line of sight, (iii) Casual conversation—social chit-chat between subject and administrator, (iv) Intense conversation—subject solving problems presented orally by the administrator, and (v) Tuning a radio—subject adjusting a car radio to a predetermined station.

For simplicity, the conditions involving use of the radio and cellular phone will be referred to as "distractors," even though it is their potential in this regard that was under study.

Driving situations

The extent to which cellular phones become a distraction was assessed through measures of response to situations in the highway traffic environment that require the driver to alter speed or direction, such as a car ahead slowing down or a pedestrian about to step into the street. The measure of distraction effect was the difference between the subject's response rate when no distraction was present and the response rates under each of the four distraction conditions.

Reliable comparisons of responses across potential distractors requires allowing subjects to face a common array of highway traffic situations under the differing conditions of distraction. The only practical means of presenting different drivers with the same array of highway traffic situations was through visual simulation of driving scenes. Further, given the complexities of the highway traffic environment, video recording of actual traffic scenes represented the only suitable form of simulation. Some 10 driving scenes were video-recorded through the windshield of a moving automobile in order to create the driving tasks to which subjects would respond. The 10 scenes, totalling 25 minutes of driving, included 45 situations requiring a response on the part of subjects. The situations can be categorized as shown in Table 1.

Of the situations presented, seven were staged while the remainder arose naturally, either as elements of the selected route or as fortuitous traffic occurrences. While none of the situations was necessarily accident-producing, a prudent driver would have responded to them (and subjects did respond in the majority of instances).

Sample

The final sample included 45 young (17–25 years), 56 mid-age (26–49 years), and 49 older (50–80 years) drivers, for a total of 150. The mean age of the sample was 39 years, coincidentally corresponding exactly to the national average for cellular phone users reported by Sextro (1989). Experienced cellular phone users made up one-third of the sample, including a third of the young, half of the mid-age, and slightly over a tenth of the older subjects. The total

Table 1. Video-recorded traffic situations requiring response on the part of subjects

Situation	Number of occurrences in video
Vehicles—stopping, turning, entering, crossing, etc.	16
Road configuration—lane end, lane restriction, narrow bridge, etc.	10
Pedestrians or animals	4
Route change	4
Road sight limitations	3
Roadside construction	3
Traffic control signal	3
Road surface conditions	2

sample was equally divided between males and females, with only small departure from an equal distribution within each age group. More of the males had cellular phone experience, 40% to 30%.

Testing procedure

A ¾-inch copy of the Betacam master of the video scenes was played back onto a 50-inch screen rear-projection television. As a subject "drove along" with the video scene, a data recording video camera and VCR recorded subject responses as follows: (i) steering and turn signal use were directly visible to the data-recording video camera, and (ii) acceleration and braking were recorded by displays that registered control application and were mounted in the camera field of view.

The three telephoning tasks and the benchmark radio-tuning task were controlled by the test administrator in the following manner:

> *Radio Tuning*—To initiate the radio-tuning task the administrator would press a button that turned on a radio with a speaker located near the subject. This would be the cue to the subject to turn on a radio located to the right of the steering wheel and to try to match the test administrator's station by means of a continuous tuning knob.
>
> *Call Placing*—To initiate a call-placing task, the administrator would press a button that activated a light just under the video screen. This was the cue to subjects to place calls to their home phone numbers (use of made-up numbers would have introduced the additional distraction of listening to the test administrator for the number and having to remember it).
>
> *Casual Conversations*—The test administrator initiated discussions on such topics as what subjects did for a living, what they did with their free time, etc.
>
> *Intense Conversations*—The test administrator called upon subject to solve math and short-term memory problems. The math problems consisted of a string of simple computations (e.g. $2 + 3 + 4 + 1 / 2 \times 3 + 4 + 6$). In the short-term memory task, subjects were read a list of five or six digits and were then asked whether certain digits were in that list.

Each of the first five highway traffic situations was encountered under each one of the five distraction conditions (one of which was *no distraction*). The same sequence of distractions was repeated in the next five situations, and so on until each subject had faced nine situations under each of the five distractions (9 replications of 5 distraction conditions covers the total of 45 situations).

The sequence of driving scenes remained constant. However, the distracting conditions were introduced in five different sequences counterbalanced such that within each age group and across the entire study sample, each one of the five distraction conditions (one being *no distraction*) would be paired equally often with each highway traffic situation. Because of inability to fill age quotas exactly, *N*s in two of the age groups were not multiples of five and consequently counterbalancing fell one short of being complete within these groups.

Subjects were told to observe the driving scenes and to use the vehicle controls to respond to the evolving scenes the same way as they would in driving their cars. Instructions stressed the fact that the purpose of the controls was simply to indicate the way in which they would respond to what they encountered; their operation would not alter the apparent motion of the vehicle. Subjects were not specifically alerted to watch for highway traffic situations or given any reason to suspect that it was their attention to these situations that was under study. Such knowledge might have influenced their responses under the various distractors.

It is obvious that vehicle control responses are an imperfect measure of driver attention. Drivers might attend to a situation and yet decide not to respond. However, since all subjects were tested under all five potential distractions, inter-subject differences in the tendency to respond to various situations should not have biased comparisons across distractors.

Performance was scored in terms of whether or not subjects responded to each of the 45 situations they encountered. A "response" was any threat-reducing vehicle control input—deceleration, braking, or turn away from the threat—introduced at any point between the time the threat first became visible and the time that it was too late to respond. The introduction of distractors was programmed to coincide with and encompass these time windows. Latency of response was not considered as a dependent variable since it (i) was not critical in responding to most of the situations, (ii) is influenced by many things other than attention, and (iii) would have had to be combined in some artificial way with nonresponses to provide a valid measure of distraction.

RESULTS

Figure 1 displays the mean proportion of situations to which subjects did not respond under each of the five conditions of potential distraction. The

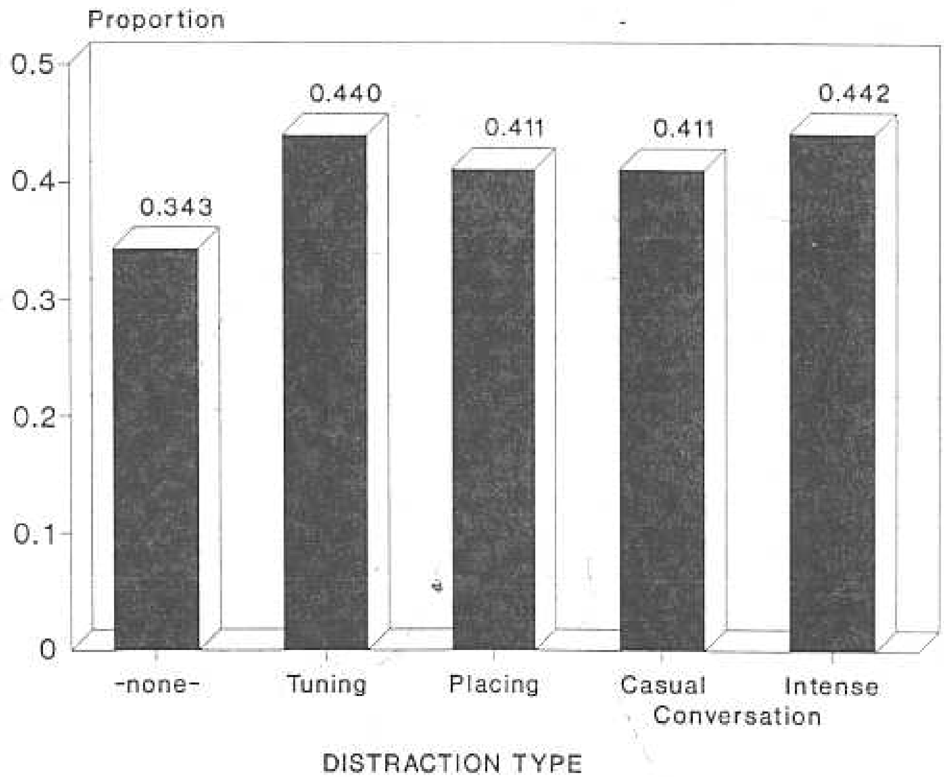

Fig. 1. Proportion of subjects failing to respond to highway traffic situations: total sample.

higher the bar, the less responsive the subjects were to highway traffic situations encountered.

The extent to which the use of cellular phone and tuning the radio served as a distraction can be seen in the differences between results under each of these distraction conditions and the condition in which no distraction was present. A repeated measures analysis of variance shows the difference between no-distraction and the combined scores across the four distractions to be highly significant ($F = 36.07$; $df = 1{,}136$; $p < .01$). Also significant were the differences between no-distraction condition and each of the four distractions individually ($p < .01$). Intense phone conversations and radio tuning yielded the greatest distraction. The increase in the proportion of nonresponse, expressed in percentage change, is 29% and 28% for each of these two distractions, respectively. Placing calls and carrying on casual conversation yielded a lower percentage change—20% in both cases.

An analysis of variance shows the collective differences among the individual distractions not to be significant ($F = 2.133$; $df = 3{,}134$; $p = .10$). However, the only two distractors that would be expected to differ from one another in a specified direction are casual and intense conversation. The intense conversations were found to be significantly more distracting than casual conversations ($t = 2.03$; $df = 134$; $p = .02$).

Comparisons involving the entire sample conceal marked age differences as evidenced by a significant overall age effect of ($f = 2.88$; $df = 8.28$; $p < .01$) as well as a significant interaction between age and distraction ($f = 2.79$; $df = 8{,}288$; $p < .01$). Figure 2 displays the proportion of subjects failing to respond to highway traffic conditions under each distraction, as subdivided by age. It is evident that subjects in the older category show the greatest differences in proportions failing to respond to highway traffic safety conditions when using the cellular phone versus when not distracted. Within this age group, increases in nonresponse were statistically significant for placing calls ($t = 3.36$; $df = 48$; $p < .01$), casual conversation ($t = 2.55$; $df = 48$; $p < .01$), and intense conversation ($t = 3.52$; $df = 48$; $p < .01$). Expressed in percentage terms, these represent increases in nonresponse of 33%, 27%, and 25%, respectively.

Within the young group, conversation-related distractions produced effects that were smaller, but still significant, an increase in nonresponse of 23% for casual conversation ($t = 2.09$; $df = 44$; $p < .05$) and 33% for intense conversation ($t = 3.45$; $df = 44$; $p < .01$). The effect of placing calls was small and nonsignificant ($p = .48$). The largest increase (52%)

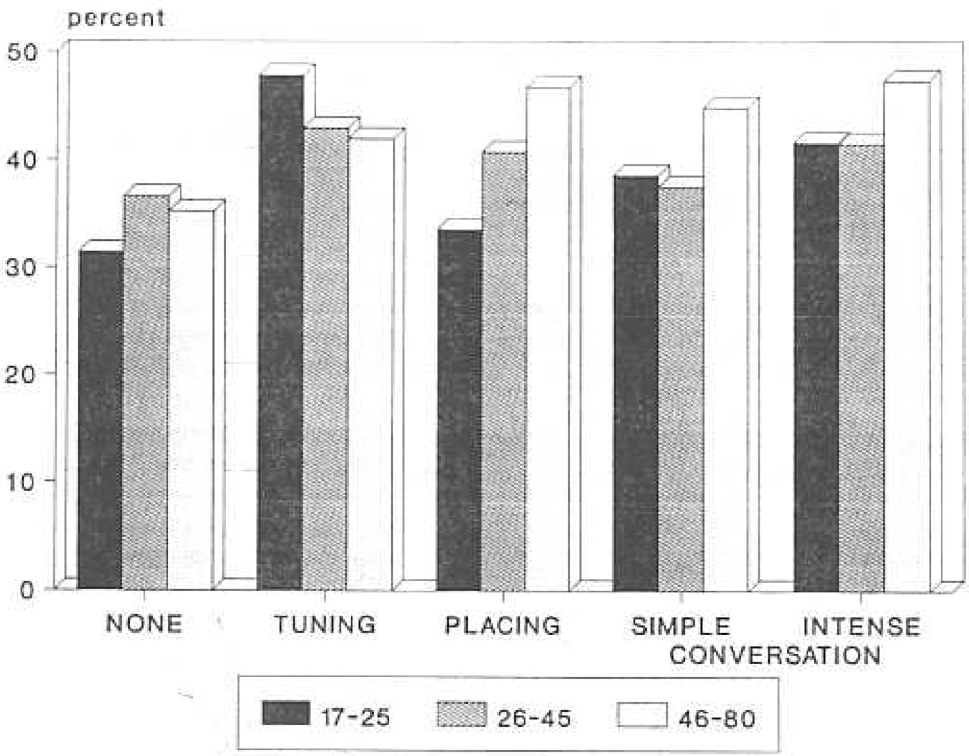

Fig. 2. Proportion of subjects failing to respond to highway traffic situations: by age.

was produced by radio tuning (t = 5.88; df = 44; $p < .01$). Among the mid-age subjects, the only telephone distraction yielding a significant effect was intense conversation, with a 14% increase in nonresponse (t = 2.09; df = 55; $p < .05$). The smaller relative increase among the mid-age group may be attributable in some part to its high nonresponse rate when no distraction was present. Radio tuning yielded an 18% increase that was also significant (t = 2.48; df = 55, $p < .01$).

Turning from within-age group to between-age group differences, the three groups did not differ significantly from one another in their performance when undistracted (F = 1.17; df = 2,148; p = .32), nor were differences in the degree of distraction significant when aggregated across the three telephone distractions (F = 1.38; df = 2,148; p = .22). The significant interaction of age and distraction noted earlier resulted from the benchmark task of radio-tuning (F = 3.61, df = 2,148; p = .03). The obvious source of this difference is the distraction experienced by the young age group.

On an a priori bases, we might expect the major source of age differences in distraction from phone use to arise primarily from the older age group. When comparing the older group with the two younger groups combined, the age differences are significant for telephone calling (F = 7.96; df = 1,141; $p < .01$), and casual phone calls (F = 5.13; df = 1,141; $p <$ .05), but not intense phone calls (F = 2.34; df = 1,141; p = .13).

Prior experience with cellular phones appeared to have no significant effect upon distraction resulting from phone use or tuning the radio. Across all distractions collectively, differences between experienced and inexperienced subjects in degree of distraction, with age and gender held constant, were statistically nonsignificant (F = 0.39; df = 4,114; p = .81), and were virtually nonexistent. Nor were significant experience differences in degree of distraction found among any of the individual distractors ($p \geq .67$).

Gender differences were also nonsignificant across all distractions collectively with age and experience held constant (F = 27; df = 4,146; p = .58). Placing calls evidenced marginal significance (F = 2.89; df = 1,146; p = .09) with females showing the least distraction. None of the gender differences for other distractions approached significance ($p \geq .48$).

DISCUSSION

The three tasks associated with use of cellular phones—placing calls, casual conversations, and intense conversations—all led to significant increases in the likelihood of failure to respond to highway traffic situations. As might be expected, intense conversations provided the greatest overall degree of performance decrement—about on par with tuning a radio. The act of placing cellular phone calls and carrying on casual conversation yielded significantly smaller increases in nonresponse. While experience with cellular phones may facilitate their use, it did not appear to lessen the effect of cellular phone use upon responsiveness to highway traffic situations. Nor was gender related to performance, with or without the presence of a distractor.

The greatest overall deficit in ability to respond to highway traffic situations while distracted was experienced by older subjects. The frequency of nonresponse when using the phone in any way was about one-third higher than when not using the phone and significantly greater than the nonresponse evidenced by the two younger groups combined. These results are consistent with research showing older drivers to be deficient in the ability to share attention. (Craik 1973; Parkinson 1980; Temple 1989; Ranney and Pulling 1990). Why older subjects did not exhibit greater performance degradation during intense conversation than in casual conversation or placing calls lacks a ready explanation. It may be that placing calls and casual conversation are sufficiently distracting to older drivers that the intensity of conversations fails to have a noticeable effect.

For subjects under age 50, telephone tasks seem to have had relatively less impact upon the ability to notice and respond to the demands of the highway and its other users. Both the young and mid-age groups did show significant increases in nonresponses when engaged in intense conversation. However, only the youngest group, showing the greatest response rate when undistracted, evidenced a significant decline in responsiveness during casual conversation.

Except among older subjects, the performance decrement associated with phone calls seems to be no worse than that which occurs when tuning a radio and is considerably less distracting than radio tuning for the youngest age group. Yet, the total amount of time that a driver would devote to radio tuning in normal driving is probably far less than the time spent in phone conversation, particularly by those who use cellular phones for business purposes. Incidentally, while the data do not reveal the reasons why the young subjects were particularly vulnerable to distraction from radio tuning, a review of their videotaped performance shows this group lavishing greater attention on tuning the radio than did mid-age and older subjects. The results may reflect differences in interest rather than attention-sharing ability.

One might legitimately ask whether the distraction that results from phone conversations is truly a cellular phone problem. Under the "hands off" type of operation simulated by the present study, phone conversations were really no different from conversations that might be carried on with another passenger. However, accident statistics indicate that drivers operate unaccompanied about two-thirds of the time. Therefore, it seems very likely that introduction of a cellular phone into a vehicle brings about an increase in the number of en route conversations. Moreover, unlike a passenger, the person on the other end of a phone call cannot see when a highway situation requires the driver's full attention, and stop talking (or even warn the driver).

It is clear that the effect of cellular phone use upon operation of automobiles is not confined to the direct interference involved in attempting to handle phone equipment and is therefore not a concern that will disappear with widespread adoption of "hands-free" systems. While the degree of distraction may not entail unacceptable risk on the open road, any activity that draws upon the driver's attention for extended periods of time in situations where attentional demands are high (e.g. heavy traffic), represents a potential hazard. The fact that other activities might be equally distracting does not mitigate the danger.

The results of this study do not give reason to discourage drivers from having cellular phones in their vehicles. While a potential threat to safety, they also offer a safety benefit by providing drivers a way of summoning help in the event of illness or mechanical breakdown without advertising their plight over a CB radio. However, in attention-demanding situations, drivers might lower their accident risk by avoiding calls, particularly those involving intense conversation. Among older drivers, whose attention-sharing abilities might already be in decline, any use of the phone during such situations seems potentially hazardous.

Acknowledgements—This study was conducted under a grant from the AAA Foundation for Traffic Safety, supervised by Samuel Yaksich, Jr. The authors would also like to acknowledge the assistance provided by Julian Urquijo, A. Scott Tippetts, and Marcia L. Williams.

REFERENCES

Brookhuis, K. A.; de Vries, G.; de Waard, D. The effects of mobile telephoning on driving performance. Accid. Anal. Prev. 23:309; 1991.

Brown, I. D.; Tickner, A. H.; Simmonds, D. C. Interference between concurrent tasks of driving and telephoning. Journal of Applied Psychology 53(5):419–424; 1969.

Craik, F. Signal detection and analysis of age differences and divided attention. Paper presented at the Annual Meeting of the American Psychological Association, Montreal, Canada, 1973. Washington, DC: American Psychological Association; 1973.

Parkinson, S. R.; Lindholm, J. M.; Urell, T. Aging dichotic memory and digit span. J. Gerontol. 35:87–95, 1980.

Ranney, T. A.; Pulling, N. H. Performance differences on driving and laboratory tasks between drivers of different ages. Presented to the Transportation Research Board, Washington, D.C. Washington, DC: Transportation Research Board; 1990.

Sextro, D. Analysis: Growing the typical cellular user. Cellular User (newsletter); 1989.

Stein, A. C.; Parseghian, Z.; Allen, R. W. A simulator study of the safety implications of cellular mobile phone use. In: 31st Annual Proceedings of the American Association for Automotive Medicine. Des Plains, IL: American Association for Automotive Medicine; 1987:181–200.

Temple, L. L. Perceptual and cognitive factors affecting driving ability of young and old drivers. Washington, DC: AARP Andrus Foundation; 1989.

Treat, J. R.; Tumbas, N. S.; McDonald, S. T.; Shinar, D.; Hume, R. D.; Mayer, R. E.; Stansifer, R. L.; Castellan, N. J. Tri-level study of the causes of traffic accidents. Vol. 1: Causal factor tabulations and assessments. Vol. II: Special analyses. Final Report on U.S. Department of Transportation Contract No. DOT-HS-034-3-535-770. Indiana University, Institute for Research in Public Safety. Washington, DC: Government Printing Office; 1977.