

NHTSA's RESEARCH PROGRAM ON WIRELESS PHONE DRIVER INTERFACE EFFECTS

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ABSTRACT

Studies have shown that wireless phone use while driving contributes to crashes [1]. To address this phenomenon the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) designed research to assess the impact of wireless phone use on driving behavior and performance. This research focused on the examination of the effects of interface type (i.e., hand-held versus hands-free) on driving performance. Unconstrained, on-road research examined drivers' wireless phone use in a real-world setting. Research using the National Advanced Driving Simulator (NADS) examined the effects of wireless phone use on driving performance in a controlled environment.

Research findings highlighted the impact of wireless phones on driving performance and behavior. The results of the on-road study indicated that phone use alters drivers' attention, as evidenced by changes in patterns of eye glance behavior. However, the variability of driving conditions observed in this study hindered the identification of specific patterns of degraded driving behavior. Although hands-free interfaces allow drivers to steer using both hands, in practice drivers were observed to steer using two hands quite infrequently during routine driving as well as during hands-free phone use. In the more controlled laboratory study, we found that phone use degraded driving performance, including measures of vehicle control and car following. There were also differences between interfaces. Specifically, hand-held phone interfaces were shown to interfere with steering and lane position variability more than hands-free interfaces, however the hand-held interface was associated with faster dialing times and fewer dialing errors than the hands-free interfaces.

INTRODUCTION

Studies have shown that use of wireless phones while driving contributes to crashes [1]. The crash-related

effects of wireless phone use while driving is a controversial issue, and has been under public scrutiny in recent years. Across the United States and in other countries, numerous efforts are underway to pass legislation that allows only hands-free wireless phone use while driving. This move is based on the assumption that any technology that reduces the visual-manual demands of wireless phone use must be safer, since the driver can keep both hands on the wheel and both eyes on the road when using a hands-free system.

To gain insight as to how phone use might be impacting crash rates, the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) performed research to assess the extent and nature of the impact of wireless phone use on driving performance. NHTSA's research used instrumented vehicles for on-road testing and the National Advanced Driving Simulator (NADS). The on-road research examined drivers' wireless phone use in a more naturalistic setting. The NADS research allowed the study of drivers' actions while using wireless phones in a tightly controlled environment. Through these research programs, the effects of interface type and phone task (i.e., dialing, answering, conversing) on driving performance and eye glance behavior were examined.

This paper describes the types of research performed to examine driver distraction due to wireless phone use with different interfaces while driving. This paper also discusses drivers' preferences regarding phone interfaces and compares them to objective phone use data.

ON-ROAD WIRELESS PHONE STUDY

This research examined the effects of wireless phone interface type on driving performance and wireless phone usage behavior. Naturalistic (an observational method involving no specified route or commanded

tasks), on-road data collection with instrumented vehicles was conducted to examine patterns of drivers' use of wireless phones as a function of phone interface type (i.e., hand-held vs. hands-free) under real-world conditions. Specifically, driver eye glance activity, driver-vehicle performance measures, and wireless phone use were examined. This comparative analysis examined the response measures to better understand how wireless phones change the driver's behavior and performance.

The objectives of this research were: 1) to assess the effects of wireless phone use while driving on driving performance as a function of wireless phone interface type (i.e., hand-held, hands-free headset, and hands-free with voice dialing), and 2) to observe patterns of phone use while driving including the frequency and duration of phone use. Additionally, the study sought to examine the types of driving situations associated with phone use. More specifically, this research was intended to identify differences in driving performance during hand-held wireless phone use versus during hands-free phone use.

Method

The experimental design for this study was a one within, one between mixed factor design. The within-subjects (i.e., repeated) measure in this study was type of in-vehicle wireless phone. The three wireless phone interface conditions were: hand-held (manual phone dialing and talking), hands-free headset (manual dialing, hands-free conversation), and hands-free with voice dialing (AutoPC voice controlled dialing, hands-free conversation). The between-subjects factor was frequency of wireless phone use (self-reported: moderate or frequent) while driving. Gender was balanced across experimental conditions.

The vehicles were programmed to record vehicle control inputs (steering, brake activity) and driving performance measures (headway, lane position). Dependent variables relating to vehicle motion and operation included lane position, number of lane exceedences, longitudinal acceleration (g), number of steering reversals, degree of throttle application, time headway (ft), and vehicle speed (mph). Video cameras were unobtrusively installed in the test vehicle to capture driver eye glance behavior during each phone conversation as well as during baseline episodes. Video data were reduced to obtain eye glance information including glance location, glance duration, and glance frequency. Phone call information including number of calls, dialing duration, conversation duration, and traffic density

surrounding the vehicle during phone use were also obtained from video data.

Procedure

Ten participants drove an instrumented vehicle unaccompanied on public roads for a total of six weeks. Since only six test vehicles were available for use, the data were collected in two, 6-week phases. Participants drove for two weeks with each of three types of wireless phones: hand-held, hands-free headset, and hands-free with voice dialing. Participants were instructed that the study sought to assess a state-of-the-art data acquisition system and also gather drivers' opinions about new in-vehicle technologies. At the beginning of their 6-week phase, participants were instructed in the use of the in-vehicle computer system. This system provided phone, phone book, radio control, and other functions. Every two weeks, the phone interface configuration was altered and participants were instructed on the use of the wireless phone interface that would be present in the vehicle for that period. Drivers were instructed that they were free to use the wireless phone provided to them (rather than their own personal phone) and the test vehicle in their normal, daily routine. Thus, the test vehicles were to take the place of participants' normal vehicles during the course of their participation in the study.

Observation over a period of time during normal, unrestricted driving provided the gathering of naturalistic driving data with a minimum of experimental artifacts. This method also provided insights into frequency of use, duration of use (e.g., conversation), and driving situations during use as a function of the technology. However, this unrestricted driving led to highly variable driving conditions that complicated data analysis.

Results

The following is only a brief summary of the results from this study. The complete results are documented in [2].

Drivers in this study engaged in 2.25 calls per hour (7 calls per 100 miles) on average. The average call (conversation) duration was 2.4 minutes (SD =3.5 min.). Calls were involved in 5-9 percent of driving time observed, depending on the phone interface.

One important question this research sought to answer was whether drivers would make more calls and longer calls with a hands-free phone than with a hand-held phone due to presumed increased ease of

use. Drivers in this study did not make more calls or longer calls with hands-free wireless phones than with hand-held wireless phones. In fact, the hand-held wireless phone interface used in this study was associated with more calls and calls of longer duration. This could be attributable to increased familiarity with hand-held phones, as well as poor performance of the voice recognition system used for the hands-free with voice dialing interface. Anecdotal evidence based on video data suggests that some drivers had considerable difficulty in voice dialing using the hands-free with voice dialing wireless phone interface supported by an in-vehicle computer (AutoPC). More than half of calls made in the hands-free with voice dialing condition were dialed manually. Drivers ignored instructions to use hands-free (voice) dialing, suggesting drivers found voice dialing difficult to use. The hand-held wireless phone was associated with shorter dialing periods.

Drivers engaged in fewer wireless phone calls when driving in conditions of high traffic density, particularly when using the hands-free phone interfaces. Ninety-two percent of calls were made when there were less than 10 vehicles present in the vicinity of the participant's vehicle. Seventy-five percent of calls were conducted in the presence of five or fewer surrounding vehicles. The mean number of surrounding vehicles was highest during hand-held calls (4.5 vehicles) and lowest during hands-free with voice dialing calls (3.2 vehicles), suggesting drivers may have felt more comfortable engaging in calls using the hand-held phone interface.

Significant trends that would distinguish the effects on driving performance of hands-free wireless phone use from hand-held wireless phone use were not found. However, some interesting findings were obtained relating to glance behavior during wireless phone use:

--Drivers spent proportionately less time looking at the roadway ahead while dialing (40-50%), relative to baseline driving (70%). Hands-free dialing was associated with a modest increase in the percentage of time spent looking at the forward roadway (50%), relative to manual dialing (40%). Hands-free dialing thus allowed drivers to recover approximately one-third of the 30% decrement in time spent looking at the forward roadway associated with hand-held dialing.

-- During phone conversation, drivers made fewer glances of longer duration relative to baseline

driving, suggesting a decrease in situational awareness while engaged in phone conversation. Drivers spent almost 90% of the time during phone conversation looking straight ahead when using the hand-held interface, versus approximately 77% for the hands-free interface and 70% during baseline driving.

-- For conversations of 2 minutes or longer, the percentage of time spent looking at the forward roadway increased across successive 30-second segments. At the same time, the percentage of time looking inside the vehicle decreased, as did the percentage of time spent looking left and right. The results suggest that drivers gradually became less attentive to the immediate driving situation as the phone call continued.

-- During baseline driving, participants steered with both hands for 13.4% of the time. The corresponding percentages for hands-free conversation were 13-16% versus less than 1% for hand-held conversations. Thus, while hand-free phone use allows drivers to keep their hands on the wheel, the present results suggest that they most often choose to drive with less than two hands on the wheel.

It is unclear whether the difference in time spent driving with two hands on the steering wheel between hand-held and hands-free of approximately 12 percent relates to a significant difference in drivers' ability to operate the vehicle safely. However, statements arguing that "hands-free lets you keep your hands on the wheel" appear less significant when considering the finding of this study that drivers may only be steering with two hands 13 percent of the time when not using the phone.

Conclusions from This Study

In summary, while some differences were found between phone interfaces for dialing duration and conversation durations, significant differences in driving performance were not found for the specific measures examined. Significant differences in driving performance during conversation versus driving performance during baseline driving were also not distinguishable based on data collected in this study. However, the robustness of eye glance data provided useful information regarding drivers' glance behavior during conversations and how this glance behavior can change as the conversation progresses in time. While drivers were observed steering with two hands on the wheel 12 percent more during hands-free conversation than during

hand-held conversation, it is unclear whether this difference relates to a substantial difference in drivers' ability to safely operate the vehicle.

Given that the analyses reported here demonstrated the large amount of variability in driving conditions and based on the fact that many studies have shown performance degradation due to conversation generally, the absence of such effects in this study suggest that the experiment might not have the sensitivity necessary to detect differences in driving performance due to the interface conditions. While the lack of control of driving conditions is inherent in naturalistic studies, this type of research allows for observation of behaviors which drivers might be less inclined to exhibit in a more controlled setting.

EXAMINATION OF THE DISTRACTION EFFECTS OF WIRELESS PHONE INTERFACES USING NADS – FREEWAY STUDY

This research investigated the effects of wireless phone use on driving performance and behavior. The study had two primary objectives: (1) to assess the distraction potential associated with the use of wireless phones while driving, and (2) to determine whether distraction potential was related to the specific phone interface used. In particular, the experiment addressed the question of whether hands-free operation substantively affected the distraction potential associated with wireless phone use while driving. In addition, the experiment investigated whether voice-activated dialing affected the distraction potential associated with using a phone while driving. The secondary objective was to determine whether the distraction potential associated with phone use varies with driver age.

This research was conducted by NHTSA using the National Advanced Driving Simulator (NADS) in collaboration with NADS staff at the University of Iowa. The experiment was one of the first to use the NADS' capabilities for developing complex driving scenarios.

Method

Fifty-four subjects drove a freeway route scenario on the NADS with each of three different wireless phone interface types: hand-held, hands-free headset, and hands-free speaker kit with voice dialing. Phone conversations consisted of a verbal interactive task involving judging whether sentences made sense and later recalling words from each sentence.

Each driver completed a single session of participation in which the same scenario route was driven three times, once per phone interface. The order of presentation of interface conditions was varied systematically. Each traversal of the route involved one incoming and one outgoing call, for which the presentation order was balanced.

The route consisted of a four-lane divided freeway with a 65-mph speed limit with traffic present. The route generally consisted of four straight segments of nearly equal length joined by right-side interchanges requiring exiting and merging behavior. The treatment drives were approximately 15 minutes in length and required participants to drive three segments of the divided freeway route. The route segments corresponded, respectively, to the incoming phone call, outgoing phone call, and baseline (no call) periods. Each route segment involved a series of interactions between the driver and the scenario vehicles (i.e., events). Events included a sudden lead-vehicle cut-in, sudden braking by the lead vehicle, a car following event, and a merge. Each traversal of the route was associated with a different order of events. The intention of the scenario design was to overlap the events with the 3.5-minute conversation task periods. Each participant also experienced a brief final event involving a more critical lead vehicle-braking event.

A more thorough description of the methodology used for this study is contained in [3].

Results

The following is only a brief summary of the results from this study. The complete results are documented in [4] and [5].

Results showed that the simulated phone conversations used in this experiment impaired aspects of driving performance. The car-following events provided the strongest demonstration of performance impairment effects due to phone conversation. Phone conversation was associated with increased delay in responding to lead-vehicle speed changes, which indicates significant cognitive impairment due to phone conversation. Steering entropy (error) was also found to increase during phone conversation in car-following events, reflecting an increase in high-frequency steering corrections. Phone use was associated with elevated steering reversal rates during car following, which reflect the increased workload associated with the combination of car following and phone conversation.

The results provided some support for the hypothesis that hand-held phone use would degrade driving performance more than the hands-free interface conditions during car-following events. Specifically, steering entropy was highest in the hand-held condition. In addition, lane position variability was greater in the hand-held condition than in the other interface conditions, also presumably reflecting the physical conflict. These two results presumably reflect the physical conflict between holding the phone and steering, both of which require use of the hands. However, the interpretation of these results was complicated by the overall finding that phone use generally was associated with decreased lane position variability during car-following events, which suggests improved lane tracking performance while drivers were engaged in phone conversation.

The results for steering holds, which represent periods of steering inactivity and are assumed to reflect increasing neglect of steering due to the demands of other tasks, were contrary to predictions, reflecting better performance during the simulated phone conversation. Specifically, the baseline condition was associated with higher steering hold rates than the hands-free or hand-held conditions. Finally, the observed decrease in modulus (gain) during car following indicates more conservative responses when drivers were engaged in conversation, and may be interpreted as an attempt to compensate for the increased demands of car following and phone conversation.

Beyond the car-following events, there was only modest evidence consistent with predictions of performance impairment due to phone conversation. Neither the lead-vehicle braking nor lead-vehicle cut-in events exhibited the predicted slowing in accelerator release and brake response times. The merge event provided one piece of evidence of impairment due to phone use. Specifically, while engaged in the phone conversation task, drivers devoted less visual attention to planning for an upcoming merge event. They made fewer glances toward the traffic stream and spent proportionately less total time looking in that direction relative to the baseline condition. This suggests that drivers diverted attentional resources from merge planning to manage the phone conversation task.

Results suggested that the drivers may have compensated for phone conversation by increasing their time headways, but at the same time, they were likely to have diverted attention away from speed monitoring, which led, unintentionally to increased average speeds.

There were modest differences between interface conditions during conversation for the other events. First, there was some evidence that the hand-held interface interfered with steering and lane control, as would be expected since both tasks require use of the hands. Second, there was some evidence that the hands-free speaker kit interface was associated with faster speeds, relative to the other interfaces. In particular, speeds for the hands-free speaker kit interface were fastest at the beginning of the cut-in events and also at the end of the merge events. Hands-free speaker kit calls were associated with more slowing at the very beginning of the merge and more increase in speed at the end of the merge. One interpretation is that while engaged in hands-free speaker kit calls, drivers felt safer and thus paid less attention to speed control.

Differences among interfaces conditions were stronger for dialing and answering than those associated with conversation. Specifically, the hand-held interface was associated with consistently faster dialing times and fewer dialing errors (i.e. repeated attempts) than the other interface conditions. Voice dialing times exceeded hand-held dialing times by 84 percent for hands-free speaker kit and by 51 percent for hands-free headset. The hands-free speaker kit interface was associated with significantly faster answering and hang-up (call termination) times than the other interfaces.

Several differences among age groups were found. Young drivers were more aggressive in their car following, as reflected by higher modulus scores. Older drivers exhibited more steering reversals during car following, indicative of higher workload for this group. Drivers in the middle age group were faster than younger drivers at the beginning of the LV cut-in event. In the merge event, relative to the other age groups, older drivers made proportionately more glances leftward before the merge event and spent more time looking left to plan the merge. Older drivers also maintained greater following distances than younger drivers.

Analysis of the final event scenario revealed significant differences for some dependent measures. Hypothesized effects related to phone interface were complicated by significant interactions between phone interface and age. For first response to the final brake event, participants in the hand-held condition responded significantly faster than those in the hands-free and no-phone conditions, contrary to hypothesis. These results appear to agree with results of the previously mentioned on-road study [2] that

showed that drivers looked forward more with hand-held than with hands-free.

Although participants rated the hand-held interface to be most difficult to use, this interface was associated with the fewest dialing errors (in terms of the number of attempts per dialing trial). Participants' feelings that the hand-held interface was the most difficult to use were also not supported by dialing time results, which showed that the hand-held interface was associated with significantly faster dialing times than the other two interfaces for all three age groups. Shorter dialing times for the hand-held interface may be attributable to participants' prior experience with hand-held wireless phones, which was approximately 6 years on average. However, it should be noted that the length of time required to perform voice digit dialing depends on the interface being used. This study used the Sprint PCS Voice Command system, since it was assumed that a system-based voice-dialing interface would be more likely to have better voice recognition capability than phone-based voice dialing. Some newer phone designs feature integrated voice digit dialing capability that may allow shorter dialing times. Use of voice "tags" for dialing may also afford shorter dialing times; however, voice digit dialing was chosen for implementation in this study since it provided the most direct comparison between manual and voice dialing.

Conversation task performance did not differ as a function of phone interface. Age was the only examined variable significantly related to phone task performance, with younger individuals performing better than older individuals.

Conclusions from This Study

Based on the preceding results, it was concluded that:

1. Phone use while driving degraded driving performance particularly during car following. The simulated phone conversation was associated with a significant delay in responding to lead vehicle speed changes. Phone conversation also degraded vehicle control, as reflected by increased steering error and an increase in one measure of driver workload. Drivers spent less time planning for merge events while engaged in the phone task.

2. Overall, there were modest differences among interface conditions during the conversation task. The hand-held phone interfered with steering and lane position more than the hands-free interfaces.

3. Differences among interface conditions were strongest for dialing and answering. Specifically, the hand-held interface was associated with fastest dialing times and fewest dialing errors. Drivers rated this interface most difficult to use while driving.

4. Neither older nor younger drivers exhibited consistently worse performance due to simulated phone conversation.

EXAMINATION OF THE DISTRACTION EFFECTS OF WIRELESS PHONE INTERFACES USING NADS –ARTERIAL

NHTSA also conducted research to investigate the effects of wireless phone use on driving performance and behavior in an urban arterial driving environment. The urban arterial environment represented required a more active style of driving and employed a more dynamic visual scene.

The main objective of the research was to collect information useful in the assessment of 1) the distraction potential of wireless phone use while driving, and 2) the difference in distraction caused by the use of a hands-free phone interface versus that associated with use of a hand-held interface. Of particular interest was whether using hand-held phone interfaces (e.g., dialing, answering, conversation) while driving degrades driving performance more than does hands-free wireless phones. In addition, the research addressed the question of whether younger and/or older drivers exhibit worse driving performance during wireless phone task components than middle-aged drivers. Lastly, the research examined whether drivers glance away from the forward roadway more when using a hands-free phone interface than they did when using a wireless phone in a hand-held configuration.

Method

Fifty-four participants drove an urban arterial driving scenario on the NADS with each of three difference wireless phone interface types. Like the freeway study, phone conversations consisted of performance of a verbal interactive task involving judging whether sentences made sense and later recalling words from each sentence.

Each participant completed a single session in which the same basic route was driven three times, once with each phone interface. The order of presentation of phone interface conditions was varied systematically. Each traversal of the route involved one incoming call, one outgoing call, and a baseline

period, as well as a unique order of scenario events. The order of presentation of incoming and outgoing calls was balanced.

The route consisted of four-lane undivided arterial roadway with a 45-mph speed limit and other traffic. The route was approximately 15 minutes in length and generally consisted of three segments of equal length. Each segment corresponded to an incoming call, outgoing call, or baseline driving period.

Each segment contained a “between towns” section and an “in town” section. Between town sections were characterized by mild, alternating curves. A visual target detection task was presented during between town sections in which participants had to press the vehicle’s horn button when they spotted a pedestrian wearing a shirt with an “I” on it amongst a number of other similarly dressed pedestrians. In town sections consisted of straight portion of roadway lined with buildings and some vehicles. During in town sections, events were presented including incursions, occasional static vehicles blocking the participant’s travel lane, and changing traffic signals that required drivers to respond to avoid a collision or running a red light.

Dependent measures used to characterize driving performance included reaction time in response to discrete events (i.e., conflict events and traffic lights), as well as reaction time and accuracy of responses for the visual target task. Phone task performance measures included dialing time, number for dialing errors, answering time, and the number of correct judgments and recalled terms for the conversation task. Participants also completed a post-drive questionnaire used to report perceived difficulty of driving and phone tasks, as well as preferences regarding phone interfaces and related features.

Status

Data analysis for this study is scheduled for completion in Spring 2005. Analyses are focused on assessing the impact of phone use on individual measures of driving performance. Analyses will highlight the degree to which phone use affects a driver’s ability to respond to conflict events and objects in their visual environment.

SUMMARY

NHTSA has conducted on-road and NADS studies to examine the effects of wireless phone use on driving performance and behavior.

On-road testing showed that using a wireless phone while driving altered drivers’ eye glance behavior. Although hands-free interfaces allow drivers to steer using both hands, in practice drivers were observed to steer using two hands quite infrequently.

NADS testing showed that phone use while driving degraded driving performance and vehicle control. Differences in phone task performance among interface conditions were determined to be strongest for dialing and answering. Specifically, the hand-held interface was associated with fastest dialing times and fewest dialing errors. Drivers rated this interface most difficult to use while driving. While hand-held phone interfaces were shown to interfere with steering and lane position more than the hands-free interfaces, the hand-held interface tested was associated with fastest dialing times and fewest dialing errors.

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