

On-Road Comparison of Driving Performance Measures When Using Handheld and Voice-Control Interfaces for Mobile Phones and Portable Music Players

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ABSTRACT

This study presents an on-road evaluation of driver performance when controlling in-car technology via a handheld or voice-controlled interface. Participants drove with an experimenter on public roads while making mobile phone calls, having brief phone conversations, and playing tracks from a portable music player using both types of interface. The test vehicle was an instrumented 2010 Mercury Mariner equipped with the Ford SYNC® system, which allows for voice control of mobile phones and portable music devices. Twenty-one participants were tested, including 12 younger (19-34) and 9 older (39-51). All participants were owners of a vehicle equipped with the voice-control system, and all used the system regularly for phone calls and music playback.

Results indicated that handheld dialing and music track selection tasks were of longer duration and were associated with more frequent and longer glances to the interior of the vehicle, more total glance time to the interior of the vehicle, higher steering variance and maximum steering wheel velocity, and higher subjective mental demand than when using voice control for the same tasks. These differences were not found for conversation tasks. All tasks had higher mental demand than baseline driving. Further, older drivers had more difficulty maintaining vehicle tracking when dialing and playing tracks using handheld controls, as seen in steering variance and maximum steering velocity data. These findings suggest that voice control of in-vehicle devices may allow drivers to keep their eyes on the road longer, track their course more consistently, and have lower mental demand than when these devices are controlled manually.

INTRODUCTION

Driver distraction caused by in-car technology is currently a topic of much debate in the scientific community, as well as a subject of growing concern to the government and public. The rapid advance of personal technology has allowed an increasing number of devices to become commonplace in modern automobiles, including mobile telephones, portable music players, navigation systems, and the like. As researchers have yet to reach a consensus on what aspects of in-car technology pose the highest risk to driving [1,2,3], there is not currently a clear path to counter potential distractions. State governments have enacted a patchwork of regulations banning various aspects of in-car technology (focusing primarily on mobile telephone use), while automobile manufacturers have taken differing paths in attempting to increase the safety of devices used in their vehicles.

Several on-road studies of driver behavior have found that the visual demand associated with manipulating in-car devices poses a substantially greater risk than task-related cognitive distraction. In a long-term naturalistic study of driving behavior, Klauer et al. (2006) found that dialing a handheld mobile phone significantly increased the odds of being in a crash, but engaging in a conversation using a handheld mobile phone did not [4]. Further, Mazzae et al. (2005) found that hands-free dialing was associated with more eyes-on-road time than handheld dialing [5]. Finally, Sayer et al. (2005) found that the use of mobile phones was associated with higher steering angle variance than baseline driving; however, they concluded that these effects were minor and that drivers tended to modulate device use based on environmental and road conditions [6]. In a driving simulator,

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Chisholm et al. (2007) found that searching for tracks on a portable music device significantly increased steering variance and glance duration to the interior of the vehicle [7].

If it is the case that handheld manipulation of in-car devices poses an increase in risk, technologies such as hands-free dialing, voice control and speakerphones may provide a way to maintain safety while retaining the benefits of in-car devices. This paper investigates driving behavior while participants operated devices using a voice-control system and traditional handheld controls. Dependent measures included task duration, eyeglance analyses, steering variance and maximum steering wheel velocity, and subjective mental demand. Klauer et al. (2006) found that glances over 2 s away from the forward roadway significantly increased the odds of a crash in naturalistic driving [4], and Wierwille & Tijerina (1998) modeled increasing risk of crash with increasing task visual demand [8]. Steering variance and related measures have also been commonly used as an indicator of driver inattention [9,10,11].

Participants familiar with the voice-control interface drove on public roadways while using both types of controls to call contacts, have telephone conversations, and play music tracks from a portable music player. Participants used their own mobile phones and music players to ensure device familiarity. It was predicted that tasks completed using the voice-control system would be of shorter duration, result in fewer and shorter glances to the interior of the vehicle, have less total time spent looking to the interior of the vehicle, have less steering variance and lower maximum steering wheel velocities, and have smaller subjective mental workload ratings than tasks using handheld controls. Further, it was predicted that these effects would be larger for older participants than for younger participants. If these hypotheses were supported, it would suggest that risk related to the tested tasks is lower when using a voice-control system than when using a handheld interface for the same task.

METHOD

APPARATUS

The test vehicle for this study was a 2010 Mercury Mariner equipped with the Ford SYNC voice-control system. With this system, users initiate voice commands for mobile phones and portable music players via steering wheel-mounted buttons (Figure 1A) followed by voice commands (e.g. “Call Jessie Jessie”). Feedback from the voice-control system is presented both aurally (e.g. “Calling Jessie Jessie”) through the vehicle speakers, and visually in a display on top of the vehicle center stack (Figure 1B). Although the interface requires physical interaction in addition to voice commands, for convenience it will be referred to as the “voice-control” system throughout this paper.

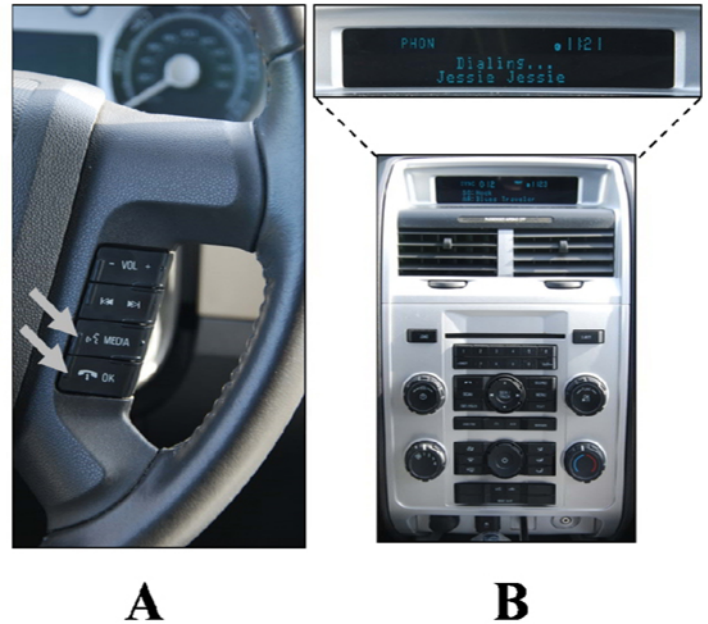


Figure 1. Control and feedback locations for voice-control system.

The voice-control system accessed a Motorola mobile phone via Bluetooth and a SanDisk flash drive through a USB interface to provide phone and music functionality. The flash drive contained an alphabetically varied selection of music tracks. Participants brought their personal mobile phones and portable music players to the session to ensure familiar handheld controls; these devices were not connected to the voice-control system. Of the telephones used, 10 had standard numeric physical keyboards, 7 had touch screens as primary input, and 4 had full QWERTY keypads. Of the portable music players, 12 were Apple iPods with click-wheel interfaces, 4 had touch-screen interfaces (including 2 Apple iPhones and 1 iPod Touch), and 5 had other interface configurations.

An onboard data acquisition system (DAS) collected steering wheel position from the vehicle network. In addition, the vehicle was equipped with cameras monitoring the driver's face, the steering wheel and instrument cluster, the center stack, and the forward roadway. A white 1999 Ford Contour was used as a lead vehicle to guide participants to the testing area, and for certain scenarios occurring after the testing presented here, which will be analyzed at a later time.

PARTICIPANTS

Participants were recruited so as to attain a sample of drivers who were familiar with the voice-control interface and owned both a mobile phone and a portable music player (telephones with integrated music players were permitted). Twenty-one participants were tested in two age groups. The number of participants in each group is shown in Table 1.

Table 1. Number of Participants (Range;) By Group

	Female	Male
Younger	6 (19-26; 23)	6 (19-34; 27)
Older	4 (40-50, 44)	5 (39-51, 48)

All participants were current owners of Ford or Lincoln vehicles equipped with the SYNC voice-control system. The participants were screened to select individuals who reported using the voice-control system regularly for control of both mobile phones and music players. The Older group reported owning their current vehicle for a mean of 13.2 months, and the Younger group reported owning their vehicle a mean of 16.1 months. All participants were licensed U.S. drivers, scored 20/40 or better on a standard Snellen visual acuity test and were able to read a text message sent to their phone, and were free from any health issues that could impact driving performance or safety.

EXPERIMENTAL DESIGN

Independent Variables

This study was a mixed-factor design, with one between-subjects factor (Age) and two within-subjects factors (Task and Modality). Age had two levels (Younger and Older). Task had four levels (Baseline, Dial, Converse, Play), and Modality had two levels (Handheld and Voice-Control). For Dial tasks, participants were asked to call a contact either using their phone's address book or through the voice-control system, but not have a conversation. For Converse tasks, participants were asked to have a brief phone conversation with an experimenter about a previously determined topic of interest using either their phone or voice control. For Play tasks, participants were asked to play a music track using either their portable music player or voice control. Three baseline measures were taken, one at the beginning and end of the study (Free-Drive Baselines), and one during task completion (Task Baseline). Modalities were presented in a blocked format, so each participant performed all trials in one modality before the other. Within each block, trial orders were counterbalanced across participants to ensure all permutations of task exposure were seen in equal proportions. Each task was presented twice for both handheld and voice-control devices, for a total of 12 trials plus baselines.

Dependent Variables

Several dependent measures were collected for this study from onboard instrumentation, post-hoc video analysis, and subjective report. The test vehicle's onboard DAS recorded steering wheel position directly from the vehicle control network, which was used to calculate steering variance in degrees and maximum steering wheel velocity in degrees/second. Video analysis was conducted by trained reductionists to obtain the number and duration of interior glances for each task, and the total duration of each task.

Subjective mental demand was rated from 1 (Very Low) - 7 (Very High) by the participant after each task and at several baseline locations during the drive. This scale is one of the five NASA TLX scales, and was selected to obtain a measure of demand while minimizing impact of the scale itself on driving or cognitive demand.

Data Reduction

Vehicle and video data for each participant were uploaded from the vehicle DAS to a secure server. Video data were then analyzed to identify start and stop times for each trial and to record eye movements frame-by-frame at a rate of 10 Hz for each event. Start and stop times were defined based on specific actions that occurred in all instances of each task. For example, the start time for Converse trials was coded when the participant's mouth opened to begin the first word of the conversation, and the stop time for handheld Dial and Play tasks was when the participant finished the last control-related manipulation of the device. Task duration was defined by finding the difference between trial start and stop times.

Interior eye glances were defined as fixations to the steering wheel, center stack, interior object (including handheld device), or instrument cluster; these did not include glances to the passenger to avoid experimenter confound. For the baseline measure taken during the task phase of the study (Task Baseline), a segment of driving 18.8 s long (equal to the mean duration of all Dial and Play tasks) was selected when no task was being performed. An effort was made to select a segment with no dialogue between the participant and experimenter for this baseline; in cases where there was not a continuous 18.8 s of silence, the time window with the fewest words spoken by the participant was selected.

Test Route

All roads on the test route were highways and major secondary roads in southwestern Virginia. The primary testing area was a straight stretch of divided secondary road approximately 1.9 miles long, with a speed limit of 65 mph. Turnarounds at each end of the straight allowed participants to remain in the testing area for the duration of the tasks reported in this paper. The route to and from the testing area covered local highways and major secondary roads with speed limits between 45 mph and 65 mph. The drive to and from the testing area took approximately 20 minutes. All testing was done between the hours of 9:00 am and 3:00 pm to ensure daylight and similar traffic conditions; traffic for all participants was light to moderate.

PROCEDURE

After arrival, Institutional Review Board approved consent, and vision testing, participants completed a pre-drive questionnaire. While the participant was completing the questionnaire, the experimenter noted two music tracks from