iPod Distraction: Effects of Portable Music-Player Use on Driver Performance

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ABSTRACT

Portable music players such as Apple's iPod have become ubiquitous in many environments, but one environment in particular has elicited new safety concerns and challenges — in-vehicle use while driving. We present the first study of portable music-player interaction while driving, examining the effects of iPod interaction by drivers navigating a typical roadway in a driving simulator. Results showed that selecting media on the iPod had a significant effect on driver performance as measured by lateral deviation from lane center; the effect was comparable to previously reported effects of dialing a cellular phone. In addition, selecting media and watching videos had a significant effect on car-following speed, resulting in speed reductions that presumably compensated for impaired lateral performance. Given that iPod interaction has become increasingly common while driving, these results serve as a first step toward understanding the potential effects of portable music-player interaction on driver behavior and performance.

Author Keywords

Driving, iPod, driver distraction, mobile computing.

ACM Classification Keywords

H.1.2 [Models and Principles] User/Machine Systems – human factors; H.5.2 [Information Interfaces and Presentation] User Interfaces – Input devices and strategies, evaluation/methodology; K.4.1 [Computers and Society] Public Policy Issues: human safety.

INTRODUCTION

Portable music players have exploded in popularity in recent years, garnering attention from the general public and researchers [e.g., 3, 10] alike. Apple's iPod, with a roughly 75% market share [21] and over 50 million units sold [21, 22], is by far the most popular device on the market, with other devices like the newly-announced Microsoft Zune [23] joining the fray in this expanding market. While these devices offer benefits of entertainment and information, use of these devices has become increasingly common in one particularly dangerous situation: while driving a vehicle. A recent survey of American drivers [24], polling 5,288 licensed drivers from all 50 states, found that a significant percentage of drivers have used an iPod while driving, particularly younger drivers aged 18-24: within this age group, the study reports that 20% of drivers have selected songs on an iPod while driving. Such statistics, not to mention the abundance of in-vehicle accessories sold explicitly for connecting iPods to automobile stereo systems, strongly suggest that drivers are interacting with iPods and similar devices while driving.

Surprisingly, even with the plethora of research on driver distraction, there have been no studies to date of how interaction with a portable music player such as an iPod may affect driver performance. Of course, the many studies of driver distraction have painted a rich picture of how interaction with various secondary devices can impair performance. For instance, the many studies of cell-phone interaction [e.g., 1, 2, 7, 9, 11, 15] have demonstrated effects of phone dialing on drivers' ability to maintain a central lane position, to maintain a stable lateral (side-to-side) velocity, and to brake for sudden emergency situations. Other studies have focused on common in-vehicle tasks such as interaction with radios [e.g., 18] and navigation devices [e.g., 20]. However, none have focused on portable music players, and given their burgeoning use in driving environments, the research community and the public alike would benefit greatly from further understanding of their effects on driver performance.

In this paper we describe the first study of portable music-player use while driving, focusing on interaction with an iPod while driving in a typical highway environment. In an experiment, participants drove in a driving simulator while occasionally performing tasks on an iPod. The tasks included searching and "consuming" (listening or watching) three types of media available on the iPod, namely musical songs, informational "podcasts," and videos; video media is likely less common in real-world driving, but was included as a point of comparison with the other non-visual types of media. The study aimed to provide an initial exploration into the effects of these tasks and media on driver performance.

METHOD

Driving Setup and Task

The experiment was conducted in a fixed-base driving simulator at Drexel University. The simulator includes the front half of a Nissan 240sx with standard steering and pedal controls. These controls connect via a hardware interface to a Macintosh desktop computer that runs the simulation and data collection software. The simulation, implemented in the OpenGL graphics package, is projected onto an 8-foot wide screen immediately in front of the simulator vehicle, resulting in a roughly 48° field of view.

The environment used as the experimental driving task was a simulated highway environment. Drivers navigated the middle of three lanes of highway, where construction cones discouraged the driver from moving toward or into the outer two lanes, as shown in Figure 1; in our previous experiences with this environment [e.g., 12, 15], we have found that the construction cones helped to keep drivers diligent in maintaining a central position in the lane. In front of the driver's vehicle, a lead vehicle maintained a steady speed of 55 mph (~88 kph). Drivers were asked to maintain a reasonable distance behind the lead vehicle. In addition, another automated vehicle trailed behind the driver's vehicle at a reasonably short distance (in the range of 30-70 ft or 9-21 m) and was visible in the rear-view mirror, thus providing a realistic impetus not to fall far behind the lead vehicle.

Figure 1. Driving simulator screen shot and interior with in-vehicle iPod mounting.

iPod Setup and Tasks

An Apple iPod with both audio and video functionality was used for the iPod tasks (5th-generation 60GB video iPod; see Figure 2). The device has a prominent scroll wheel that enables the user to rapidly scroll down a list of menu items. Of the five buttons on the front of the device, the center button triggers the selected item, either playing the selected media or accessing a submenu within the information hierarchy. There is also a "Menu" button at the top of the scroll wheel with which the user can return to higher-level nodes in the hierarchy.

Figure 2: Apple iPod. [from www.apple.com]

The tasks studied here involved searching for and playing three types of media: music, podcast, and video. Music has clearly been a centerpiece for iPod use, in all environments including in the car. Podcasts include a wide range of audio media, typically loaded from the Internet and moved onto the iPod for eventual listening; we use the term here to indicate informational programs, such as news highlights or talk-radio broadcasts, where spoken voice is the primary audio content. Video playback is a relatively new feature on the iPod that enables a wide variety of video media from short features to longer content to be viewed (e.g., the iTunes Music Store allows purchase of full TV episodes); while we imagine that music and podcasts represent the more common media in the context of vehicle use, video has become an option in the vehicle, and the precedent of DVD-playing video monitors within many existing vehicles certainly makes video a potential source of distraction and thus a type of media worth further analysis in our study.

Content was selected with the intention of having a representative sample of the most common media. Music content was compiled from a collection of current songs and artists from different genres. Four songs were selected from songs representing a total of 99 artists, where the songs were distributed roughly evenly in terms of their placement within the artist and song lists. Five podcasts and five videos were selected and downloaded from the iTunes Music Store such that the items complemented one another as a diverse set of available media. From these five podcasts/videos, one was used as the test media for training and the other four were used during the experiment.

All content was loaded onto the iPod and cropped to have a playing time of 30 seconds. Podcast and video files were shortened to a 30-second segment such that the segment

Selecting a Song…	Selecting a Podcast…	Selecting a Video…
Press button for "Music" Scroll down 1 item to "Artists," press button Scroll down *Na* items to desired artist, press button Scroll down *Ns* items to desired song, press button to start playing	Press button for "Music" Scroll down 4 items to "Podcasts," press button Scroll down *Np* items to desired podcast, press button Press button to start playing	Scroll down 2 items to "Videos," press button Scroll down 1 item to "Movies," press button Scroll down *Nv* items to desired video, press button to start playing

Notes: Each variable above represents one of four values corresponding with each of the four trials for that media type. Expressing the values as pairs d/l, where d represents the scrolling distance (in items) and l represents the total scrolling distance for the entire list (from the topmost item, i.e., list length – 1), the values were as follows: *Na*: a_1=48/99, a_2=96/99, a_3=22/99, a_4=72/99; *Ns*: s_1=8/16, s_2=3/11, s_3=7/10, s_4=0/0; *Np*: p_1=1/4, p_2=4/4, p_3=0/4, p_4=3/4; *Nv*: v_1=3/4, v_2=1/4, v_3=2/4, v_4=0/4.

Table 1. Procedures for selecting a song, podcast, and video.

remained a self-contained unit (i.e., did not include strange onsets or interruptions of the story line). Songs were not shortened as files but instead were stopped by the experimenter after 30 seconds of playing time.

Once on the iPod, all content was available in the device's default menu structure. The necessary procedures for selecting a song, podcast, and video are detailed in Table 1. Selecting a song is by far the hardest of the three types, because it requires two potentially long-distance scrolling steps to select the desired artist and song. Selecting a podcast or video also requires two or three scrolling steps, but the distance to be scrolled is no more than four items. The scrolling distances for the various selection procedures are detailed within the table and accompanying note.

When practicing with the iPod (as described below), participants could hold the iPod in hand and use it naturally in the normal manner. When driving, the iPod was placed on a hands-free device holder (designed for cellular phones but a perfect fit for the iPod as well, as pictured in Figure 1) to eliminate holding of the device as a possible source of distraction, as done in many cell-phone studies. The iPod in its holder was positioned within easy reach and easy view of the driver: the left edge of the iPod was typically two inches to the right of the steering wheel, and the front side of the iPod was within an inch of the front plane of the steering wheel; however, drivers were allowed to move the steering wheel and the holder from this default setting to wherever they felt most comfortable.

To ensure that drivers were in fact paying attention to the content while driving, we developed questions for each podcast and video to be asked after listening to podcasts and viewing videos. For each podcast, one question was used to test knowledge about the topic covered by the podcast. For each video, two questions were used — one to test knowledge about the audio portion of the video, and one to test knowledge about the visual portion of the video. In all cases, questions were not intended to be very difficult to answer, but rather written with the intent that if the driver paid reasonable attention to the content, s/he would be able to answer the question with high probability. The overall rate of correct responses in the experiment was 84%, and thus participants were indeed paying attention to and understanding the played media content.

Procedure

At the beginning of the experiment, participants were given a rough overview of the experiment and asked to rate their frequency of iPod use: never, infrequent (a few times used to monthly use), or frequent (weekly to daily use). They were also asked to rate their frequency of iPod use while driving on the same scale.

Next, in a practice session, participants were introduced to the video iPod and allowed to practice finding and playing each media type. (Even those participants with experience interacting with the iPod were in most cases not familiar with the new video iPod.) The experimenter showed the participant the device's menu structure and the participant was allowed to practice until s/he felt comfortable navigating the content. This practice only involved finding and selecting media content; the participant was asked not to play any content, as this was reserved for the driving session. After the participant expressed that they were comfortable selecting media, s/he was asked to find and play the practice video clip. The participant was then asked two questions to get a feel for how the test questions would be asked. As the last step in the practice session, the participant drove in the driving simulator (with no secondary tasks) for a few minutes until s/he felt comfortable navigating the roadway.

In the main data-collection session, the participant drove in the simulator and occasionally was asked by the experimenter, sitting in the passenger seat, to find and play a certain media item. In particular, participants were asked to find "Artist <*artist*>, Song <*title*>" for songs, "<*title*> podcast" for podcasts, and "<*title*> video clip" for videos. Each request was made to the participant 30 seconds after

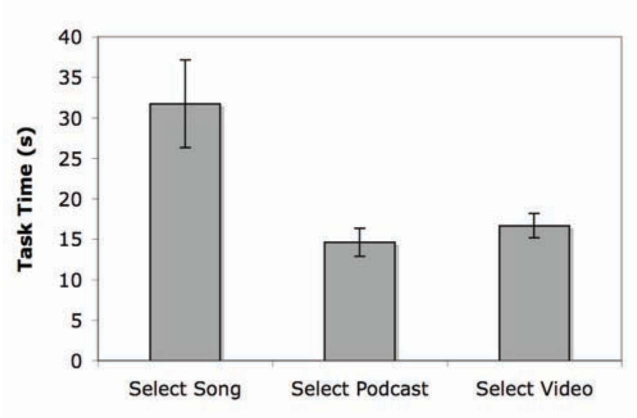

Figure 3. Task times for selecting media. (Error bars here and elsewhere represent standard errors.)

the previous secondary task was completed, allowing for 30 seconds of regular driving time between tasks. The experimenter held a keyboard on which he keyed the start of each iPod task (immediately after speaking the instruction) and the end of the finding stage (after the participant pressed the final button to start play). (Note that the end of the playing stage occurred 30 seconds after the end of the finding stage, since all media content was pruned to this length.) After each iPod task was completed, the participant again focused on driving, and the experimenter reset the iPod to its initial state at the topmost level of the menu structure. During this process, if any abnormalities were noted, such as playing wrong clips or mishearing instructions, the experimenter used a special key entry to flag that task for omission in the final analysis.

A total of 17 participants (3 female) ran in the study. One participant had significant difficulty driving the simulator; another two participants experienced malfunctions with the steering hardware; and two participants had never before used an iPod. We excluded these participants and focused our data analysis on the 12 remaining participants (1 female), all of whom reported at least some experience using an iPod. Of these 12, one reported frequent use of the iPod while driving, another reported infrequent use while driving (approximately once per month), while all others reported never using an iPod while driving.

RESULTS

Task Times. As a first estimate of task difficulty for the three media types, we examined the time needed to select the desired song, podcast, or video. These times and their standard errors are shown in Figure 3. We performed a repeated-measures ANOVAs to analyze the effect of task type while driving, namely comparing the three conditions of selecting a song, selecting a podcast, and selecting a video. This analysis (detailed statistical results shown in Table 2) revealed a significant main effect of task type; the differences between song and podcast, and song and video, were significant, whereas the difference between podcast and video were not. Thus, selecting a song took significantly longer than selecting either a podcast or video, which in turn required roughly the same amount of time. These results are not surprising given that song selection required two complex scrolling steps, as noted earlier, while podcast and video selection were very similar in terms of the number and complexity of steps.

<u>Task Time Results</u>

Main effect: $F(2,22) = 12.24, p<.001$
Select song vs. podcast: $F(1,11) = 12.64, p<.01$
Select song vs. video: $F(1,11) = 15.32, p<.01$
Select podcast vs. video: $F(1,11) = 1.52$, *n.s.*

<u>Lateral Deviation Results</u>

Selection Tasks
Main effect: $F(3,33) = 8.34, p<.001$
Select song vs. baseline: $F(1,11) = 24.21, p<.001$
Select podcast vs. baseline: $F(1,11) = 7.49, p<.05$
Select video vs. baseline: $F(1,11) = 6.84, p<.05$

Playing Tasks
Main effect: $F(3,33) = 2.49$, *n.s.*
(All task conditions vs. baseline also *n.s.*)

<u>Speed Results</u>

Selection Tasks
Main effect: $F(3,33) = 5.46, p<.01$
Select song vs. baseline: $F(1,11) = 8.12, p<.05$
Select podcast vs. baseline: $F(1,11) = 9.15, p<.05$
Select video vs. baseline: $F(1,11) = 3.69$, *n.s.*

Playing Tasks
Main effect: $F(3,33) = 2.97, p<.05$
Play song vs. baseline: $F(1,11) = .004$, *n.s.*
Play podcast vs. baseline: $F(1,11) = .08$, *n.s.*
Play video vs. baseline: $F(1,11) = 5.68, p<.05$

Table 2. Results of repeated-measures ANOVAs for task time, lateral deviation, and speed across task conditions (where baseline represents driving with no secondary task).

Lateral Deviation Effects. While task time is one indication of performance, we are arguably more interested in the effects of the task on driver performance. Interestingly, task time does not always correlate with effects on driving; for example, dialing a cellular phone by saying the entire phone number can require a long time but have no significant effects on driver performance, while dialing by pressing digits on the phone keypad can take less time but produce large detrimental effects on performance [10]. To quantify driver performance in our task, we used a lateral deviation measure that represents the driver's ability to maintain a central lane position and has been common in other driver distraction studies. We computed lateral deviation as the root-mean-squared error of the lateral distance between the vehicle's center and the lane center. We also subtracted out the baseline lateral deviation observed during normal driving to compute the *lateral deviation effect* — the change in lateral deviation from baseline performance due to the secondary task.

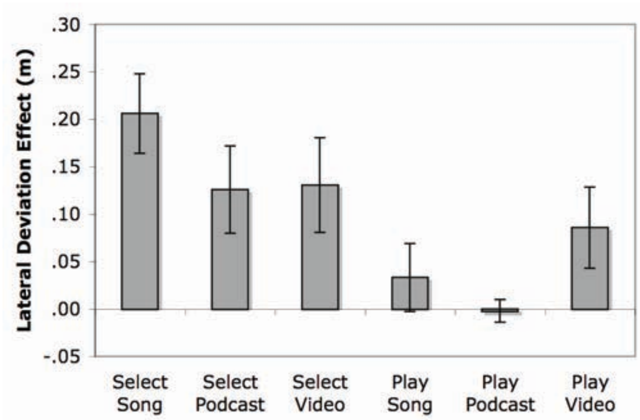

Figure 4. Lateral deviation effects (change in lateral deviation from baseline driving) for selecting and playing media.

Figure 4 shows the lateral deviation effect for both the selecting and playing tasks for each media type. For selection, the main effect of task type (select song, select podcast, select video, and the no-task baseline condition) was highly significant (details in Table 2). In addition, each of the selection tasks was significantly different from the baseline condition (i.e., significantly different from 0 in Figure 4). Thus, selection of all media types had a significant effect on driver performance as measured by lateral deviation. Song selection resulted in roughly double the lateral deviation effect as that for podcast or video selection, due in large part to the more difficult search task of selecting among a larger number of items.

Because one might expect a strong relationship between selection task time and lateral deviation, we examined this relationship more closely by computing the correlation between the two quantities across all participants. However, this correlation, $R = .48$, was not significant, $t(10) = 1.74$, *n.s.* Thus, we did not find a strong relationship between task time and driver performance, corroborating other studies [e.g., 11] that have found that the two measures need not be related.

For playing, the main effect of task type (play song, play podcast, play video, and baseline) was not significant, and the individual comparisons between playing each media type and the no-task baseline condition were not significant as well. These results for playing a song and podcast correspond to generally accepted norms, in that listening to music or spoken voice is not typically considered sources of significant distraction. Perhaps surprisingly, although playing a video yielded a larger increase in lateral deviation than the other media types, the increase was not significant.

As a point of comparison for these findings, we can compare the distraction effects of iPod selection with those from the most commonly studied distracting device, namely a cellular phone. The many studies of phone use in the literature analyze data from many different driving simulators or real-world vehicles, making direct comparison to our data set somewhat challenging.

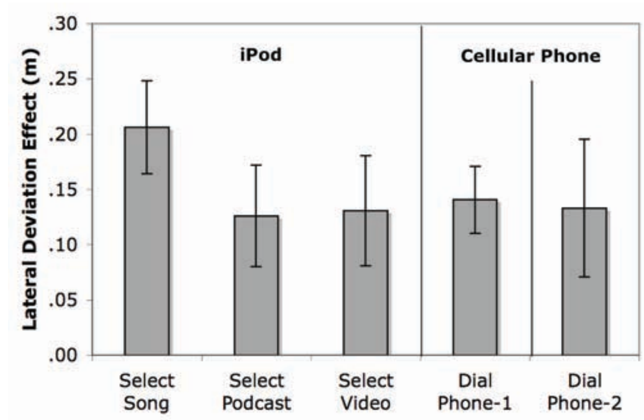

Figure 5. Comparison of iPod lateral deviation effects with those for dialing a cellular phone. ("Dial Phone-1" from [11], "Dial Phone-2" from [15])

However, two previous studies in particular [11, 15] have used essentially the same simulator setup, with the same simulator code and vehicle dynamics. (Although there were also differences between the environments — for example, [11] used a one-lane road while [15] used the same construction-zone environment but with an accelerating and decelerating lead vehicle — the core elements were similar enough that we can draw fairly direct comparisons.) Figure 5 shows the lateral deviation effects from phone dialing from these two previous studies alongside those of the current iPod study. The phone-dialing results are most similar to the simpler selection tasks on the iPod, namely selecting a podcast or video. The more complex selection task of selecting a song led to an even greater effect on lateral deviation.

Speed Effects. Since iPod interaction affected driver performance in terms of maintaining a central lane position, we might wonder whether drivers were aware, in some capacity, of these effects and whether they adapted their safety margins accordingly. We explored this issue by looking at one important safety margin under the control of the driver in the experimental driving task: how closely they followed the lead vehicle. Although the distance between the driver's vehicle and the lead vehicle comes to mind as an appropriate measure for this purpose, distance does not closely reflect driver behavior because of the time lag between a driver's reactions and the downstream effects on distance. Thus, we focused instead on the speed of the driver's vehicle as a more responsive measure of behavior. Recalling that the lead vehicle drives at a constant 55 mph, we can measure a driver's average *speed effect* by computing the difference between the speed of the driver's vehicle and that of the lead vehicle.

Figure 6 shows the average speed effect for selection and playing broken down by media type. This figure looks very similar to that for lateral deviation in Figure 4, except inverted: generally speaking, drivers decreased their speed when lateral deviation increased. For selection, the main

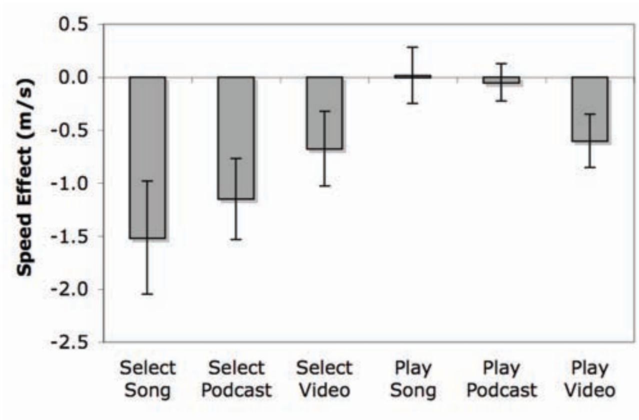

Figure 6. Speed effects (change in speed from baseline driving) for selecting and playing media.

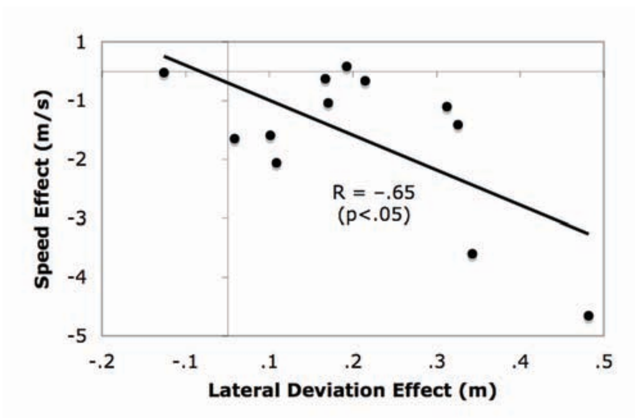

Figure 7. Lateral deviation effects plotted against speed effects for individual participants.

effect of task type was significant (statistical results in Table 2). Selecting a song or podcast yielded significant effects in comparison with the no-task baseline condition, although selecting a video did not. It seems that drivers recognized when they were most distracted and decreased their speed roughly in accordance with their level of distraction.

For playing, the main effect of task type was significant. Playing a song or podcast did not yield significant effects in comparison with the no-task condition, but playing a video indeed yielded a significant result. Thus, drivers compensated for the difficulty of watching a video (which requires both visual and aural processing) by significantly reducing their speed.

We explored the relationship between speed and lateral deviation for selection task conditions by plotting the two measures against each other across all participants and computing their correlation, as shown in Figure 7. Unlike the correlation between task time and lateral deviation, the correlation between speed and lateral deviation was significant, $R = -.65$, $t(10) = 2.68$, $p<.05$, such that large lateral deviations corresponded with large speed effects in the negative direction. Thus, individual drivers who experienced large effects in lateral performance seemed to compensate by reducing their speed. Nevertheless, there are clearly other factors at play; for example, drivers who only felt that their performance was affected may have reduced speed even though their actual performance remained good, and vice-versa.

GENERAL DISCUSSION

Study Findings and Limitations

As the first study of iPod use while driving, this study was intended to provide baseline findings that both confirm our expectations about driver distraction from such devices and elucidate interesting aspects of this distraction as a function of interaction with the various media types that such devices offer. The major findings of the study include the following:

- *Selecting media while driving significantly affected driver performance as measured by vehicle lateral deviation from lane center***.** Complex selections involving longer lists of potential items (in our case, songs) showed effects nearly twice as large as simpler selections involving shorter lists (in our case, podcasts and videos).
- *The effects of selecting iPod media on lateral deviation were comparable to previously reported effects of dialing a cellular phone*. Specifically, the lateral-deviation effects from simpler selections were very similar to previous findings for cell-phone dialing, and the effects from more complex selections were even larger than those found for cell-phone dialing.
- *Selecting media significantly affected car-following speed*. Drivers reduced their speed under conditions in which lateral-deviation effects increased. Lateral deviation and speed were significantly negatively correlated across all participants, $R = -.65$.
- *Listening to audio media and watching video media did not significantly affect driver performance as measured by lateral deviation*. The results for songs and podcasts are perhaps not surprising, given that listening to audio media is generally regarded as acceptable while driving. While the lateral deviation effect for watching videos was larger than those for the other media types, lateral deviation was not significantly different from baseline driving.
- *Watching videos significantly affected car-following speed*. While listening to songs and podcasts had no significant effect, watching videos led drivers to significantly reduce their speed, likely helping drivers to alleviate the effects of video watching on lateral deviation.

These findings provide a first indication that interaction with an iPod while driving degrades driver performance. On the one hand, drivers were less able to maintain a central lane position while selecting media on the iPod. On the other hand, we see evidence that, as Lee and Strayer [6] have stated, "drivers are not passive recipients of distracting stimuli": drivers reduced their car-following speed under conditions in which their steering performance was most affected. Future studies could help to further explore these and other aspects of driver behavior, performance, and adaptation during iPod interaction.

Our study has focused on one particular measure of driver performance and distraction, namely lateral deviation of the vehicle from lane center. While this measure has been used widely and effectively to gauge driver performance, there are certainly other measures that warrant exploration; for instance, the driving environment might contain a sudden occurrence (e.g., the lead vehicle suddenly braking) that requires a response from drivers, thus testing their reaction time to unexpected events. In addition, our study used a driving simulator for data collection, a common tool for testing driver performance when safety may be a concern. However, a well-designed on-road test with a real vehicle would clearly benefit our understanding of distraction from such devices, providing behavioral data collected in a realistic, natural context.

Aspects of iPod Interaction

Interaction with an iPod has a number of aspects that could lead to significant distraction, with the visual requirements of interaction standing out as the likely foremost source of distraction. Selecting media with the iPod requires scrolling with a thumb wheel that involves a great deal of visual processing as the screen scrolls downward. For shorter lists, a user could listen for the audio-click feedback generated by the device and count the number of steps down to a desired item, but for longer lists this heuristic would be much less feasible. Thus, for complex selection such as that in our song-selection condition, the driver must share visual resources between driving and iPod interaction and rapidly switch between the two tasks.

These aspects of iPod interaction highlight some important similarities and differences with cell-phone interaction, particularly the task of dialing a cell phone. For the well-studied task of cell-phone dialing, visual attention would typically be used to guide hand and finger movements to buttons on the phone, thus focusing on fixed-location objects — in contrast to the rapidly scrolling items on the iPod display during selection. Also, the buttons on most cellular phones can be navigated by tactile feedback (e.g., feeling around the keys to establish the center and corners of the numeric keypad), thus offering potential to reduce visual demands. Of course, alternate dialing methods such as voice dialing are available to drivers. Arguably the closest relative to iPod interaction involves dialing by selecting from a menu of address-book contacts; in an earlier study, we [15] found that menu dialing actually reduces the visual gaze time to the secondary device, but results in roughly the same lateral deviation effects as manual dialing. The current study corroborates these results in finding similar lateral deviation effects between iPod selection and phone dialing. Overall, the main point is that tasks that demand a high degree of visual interaction are likely to have deleterious effects on driving performance because both tasks contend for vision as a shared perceptual resource.

The comparison between iPod and cell-phone interaction also calls to mind the issue of whether the device is held by the driver or mounted on the vehicle's dashboard — that is, the issue of handheld versus hands-free interaction. We chose to mount the iPod to allow for hands-free interaction, and thus our results speak more to this type of interaction. However, many studies of cell-phone use have found no significant differences between handheld and hands-free devices [e.g., 8]. Nevertheless, more empirical work would be needed to explore the differences between handheld and hands-free interaction for portable music players and related devices.

It is possible that driver distraction from iPod interaction could be mitigated by practice and/or learning. As one example, participants in our study used an iPod with unfamiliar content (and perhaps a different menu structure, with the added video option and considering that the menu structure is customizable). One might imagine that intimate familiarity with the content structure, or limitations of the content to a much smaller database, could mitigate distraction for certain drivers. It is also possible that drivers could improve with frequent practice in iPod interaction while driving; however, given the safety issues involved, this does not seem a desirable option. Interestingly, our one participant who reported frequently using an iPod while driving performed no better than the average participant: this participant's overall lateral deviation effect (.100 m) was almost identical to the overall effect across all participants (.097 m).

Moving Forward: Rapid Evaluation of Driver Distraction

As new handheld/mobile devices are introduced and gain popularity, it becomes critical that we understand the driver distraction potential from these devices and work to alleviate or eliminate distraction as much as possible. One burgeoning area of research that aims to address this issue is exploring new evaluation techniques for "off-the-desktop" computing such as that involved in secondary-task interaction while driving. Empirical studies such as that described in this paper serve as the baseline technique for evaluation, but also require a great deal of monetary resources, time, and effort. In the long term, however, we would also like to build from this empirical work and develop faster, easier, and/or cheaper methods as complementary evaluation techniques.

Recent work has highlighted many new approaches in this direction. Scholtz and Consolvo [17] have outlined a framework for evaluating ubiquitous computing systems using a host of relevant metrics. Other systems have relied on cognitive modeling to predict aspects of user performance; for instance, the CogTool system [4, 5] allows a user to prototype a new device, create task models by demonstration, and generate behavioral predictions that can be used for interface refinement. Such systems rely on higher-level modeling frameworks [e.g., 14, 19] that capture the critical elements of behavior. New systems that focus on driver distraction in particular [e.g., 16] require complex and rigorous models of normal driver behavior and the multitasking behavior that occurs during secondary-task interaction [e.g., 11, 12, 13]. As such systems gain ground on the breadth of potential in-vehicle devices, we hope that a combination of new evaluation techniques and empirical work like that described here can help to better understand and mitigate driver distraction.

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