Evaluation of Driver Distraction Using an Event Detection Paradigm

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ABSTRACT

The effects of eight in-vehicle tasks on driver distraction were measured in a large, moving-base driving simulator. Forty-eight adults ranging in age from 35 to 66 and fifteen teenagers participated in the simulated drive. Hand-held and hands-free versions of phone dialing, voicemail retrieval and incoming calls comprised six of the eight tasks. Manual radio tuning and climate control adjustment were also included to allow comparison with tasks that have traditionally been present in vehicles. During the drive the participants were asked to respond to sudden movements in surrounding traffic. The driver's ability to detect these sudden movements or events changed with the nature of the in-vehicle tasks that were being performed. Driving performance measures such as lane violations and heading error were also computed. The performance of the adult group was compared to the performance of the teenage drivers. Compared with the adults, the teens were found to choose unsafe following distances, have poor vehicle control skills and to be more prone to distraction from hand-held phone tasks.

INTRODUCTION

The potential negative effect of cellular phones on traffic safety has long been recognized (*1*,*2*). An analysis of nearly 700 drivers who had cellular phones and were also involved in crashes appears to implicate cellular phone conversation in increased crash risk (*3*). One result of these findings is that the use of hand-held cellular phones while driving is now illegal throughout much of Europe, Asia and South America as well as in New York State in the US. Legislation to ban hand-held phones is pending in over 40 additional states in the US as of mid 2002. Hands-free phones remain legal to operate while driving in virtually all jurisdictions.

More recently, Strayer (*4*) has reported that conversation on hands-free phones caused subjects to miss traffic signals at the same rate as conversation on hand-held devices. Burns (*5*) has compared driving under the influence of alcohol (0.08 BAC) with the use of hands-free phones and other devices and concluded that hands-free conversation interfered with traffic sign recognition even more than alcohol impairment. Lee(*6*) reported that use of a hands-free speech-based email system resulted in a 30% increase in reaction time as compared to a baseline condition of no email use during simulated driving.

It is difficult to assess the magnitude of the on-road problem from these studies. Young (*7*) conducted an analysis of over 8 million actual hands-free phone calls placed over a period of five years and found only two confirmed cases of crashes that occurred during phone use. Stutts (*8*) investigated five years of data from the Crashworthiness Data System and found that distraction from cellular phones occurred less frequently in the crash data than distraction caused by outside objects, radios or eating inside the vehicle.

Our goal in this study was to quantify the effects of distraction caused by hands-free and hand-held phones using an event-detection method as well as traditional measures of driving performance. Parkes (*9*) reported using an event detection paradigm to evaluate driver situation awareness during cellular phone use. However, that study used abstract events (green and red squares superimposed on the driving scene) whose relevance to actual driving is not clear. Lee's study (*6*) used lead vehicle braking as the detection event. However, they set car following time headway to 1.8 seconds in the simulator by adjusting lead vehicle speed in response to speed changes by the driver. No speed variation data are provided. This has the effect of making the distance between vehicles vary in proportion to vehicle speed. Because a typical response to increased workload is for the driver to reduce speed, this type of experimental design may cause the event stimulus to become more apparent as workload increases.

METHOD

In the present study drivers were asked to note severe lane violations made by other cars during simulated highway driving. These events could occur both in front and behind the driver. The violations were severe enough that approximately 50% of the swerving vehicle was outside of its lane boundary at the peak of the 4-second event. The events were dramatic and the impression was that the driver of the swerving car had almost lost control of their vehicle. Drivers were instructed to use their turn signals to note their observance of the event.

By comparing the observed detection rate for these events during normal driving (no secondary task) and while performing in-car tasks we can quantify the interference between the in-car tasks and the driver's ability to pay attention to critical movements in surrounding traffic. Our belief is that these detection rates are an important measure of the distracting effect of in-vehicle tasks.

The VIRTTEX Driving Simulator

The study was conducted on Ford's VIRtual Test Track EXperiment (Figure 1), a large, 6 degree-of-freedom (DOF) moving base driving simulator. VIRTTEX is designed to accommodate a full-size, interchangeable vehicle cab. Vehicles as large as a full-size SUV can be accommodated but for the current experiment a 2000 Ford Taurus was used (Figure 2). The cab includes a steering control loader for accurate feedback of road and tire forces to the driver.

VIRTTEX uses a front-projection display system. The display surface is a spherical section with a radius of 3.7m. A high-gain (4.5:1) coating has been used to ensure brightness and contrast. Five CRT's project the driving scene on the display surface. Three projectors in the forward field of view cover 180° x 39° and two rear projectors cover 120° x 29°. Each channel is driven from a PC-based image generator running at a fixed rate of 60Hz. The front three channels have a resolution of 1600x1200 pixels each and the two rear channels each have a resolution of 1280x1024 pixels.

The VIRTTEX motion system is a hydraulically powered six-DOF hexapod (*10*). The motion system allowed sufficient movement for lateral forces to be presented to the driver with a scale factor of 0.6 for the duration of the experiment. This was possible because of the large motion envelope of the VIRTTEX motion system (Table 1).

TASK SELECTION

We had several goals when choosing the types of tasks to consider. We wanted to construct cellular phone tasks that could be implemented in both a hand-held and hands-free environment so that we could compare hands-free and hand-held devices. The primary phone task involved retrieval of voicemail messages from a queue and response to a particular message. Voicemail retrieval with a hand-held phone is a currently available application – drivers may use any mobile phone to retrieve voicemail while driving and informal surveys have suggested that many business users do access voicemail from their cars. Hands-free voicemail retrieval is considered a likely application for first-generation telematics solutions.

Placing a phone call to the remote voicemail server is a required step in retrieving messages so phone dialing (hand-held and hands-free) was also included. As an additional task, incoming phone calls were answered with both hand-held and hands-free equipment.

It is important to place distraction caused by in-vehicle activity in the context of currently accepted driving behavior. It is not enough to measure the effect of distraction – we must also have some means of determining whether the effects we measure are likely to have an impact on driver safety. An accurate estimate of crash probability from our data is not possible. Therefore, we included in the task set two in-vehicle activities that can occur in every modern vehicle: radio tuning and climate control adjustment. These traditional tasks form a baseline that allows us to compare the distraction caused by vehicle communication and telematics systems with distraction present in existing vehicles.

All of the identified tasks have relatively short durations. Voicemail retrieval is the longest task in the test set with an average completion time of less than 3 minutes (although a significant number of drivers took up to 5 minutes to complete this task). The tasks are also well structured in that there is a clear goal for each transaction (e.g. "retrieve and respond to Bill's message"). These short, structured transactions map well onto the kinds of phone calls that drivers report actually making: 80% of reported calls are less than 5 minutes in duration (*11*). We also believe that these tasks are representative of many of the first-generation telematics applications, which are also short, structured information retrieval tasks (e.g. stock quote retrieval, weather or traffic updates).

TASK DESCRIPTIONS

Each driver wore a commercially available hands-free headset during the drive. The headset was only used during the hands-free tasks listed below. The nomenclature used to refer to each secondary task in the rest of the paper is given next to the task name in parenthesis:

1. **Radio Tuning (radio):** This involved using only the TUNE rocker switch on the radio to locate a specified FM radio station (Figure 3). The radio was then reset to 98.7 FM after this task had been timed.
2. **Climate Control Adjustments (hvac):** For this task, the participant was asked to adjust the fan speed up one setting, the temperature dial to the maximum heating position, and the directional dial to the defrost setting. The driver then reset these dials after the task had been timed.
3. **Incoming calls (incHF or incHH):** The driver was instructed to answer incoming phone calls using the hand-held or hands-free cellular phones while driving. After the caller identified who they were and why they were calling, the driver was instructed to tell the caller that they could not talk at the moment because they were on the road. At this point they were instructed to end the call. Hands-free (HF) calls were answered by pressing the phone button located below the rearview mirror (Figure 4). Hand-held (HH) calls were answered by picking up a commercial hand-held phone (Sprint CDM9100SP) mounted on a holder near the center stack (Figure 5).
4. **10-digit dialing (dialHF or dialHH):** The dialing task always took place prior to the voicemail interaction and was used to access the voicemail server before beginning the voicemail retrieval task

described below. The driver was not required to memorize the number of the voicemail server. Text containing the voicemail access number was affixed to the steering wheel and could be used by the driver during the task to remind them of the number. In the hand-held case the driver would pick up the phone from its holder and dial each digit manually. No memory presets or other dialing shortcuts could be used. In the hands-free case the driver would press the phone icon on the mirror. This would connect to a commercial (Sprint PCS) voice-recognition service. The driver would then speak the phone number and be connected to the voicemail server. The task ended as soon as the voicemail server connection was established.

5. **Retrieving and responding to voicemail (vmHF and vmHH):** The driver was prompted to retrieve a voicemail message from a specific person using either the hand-held or hands-free phone. The act of dialing into the voicemail server was timed and recorded separately and is considered part of the dialHF or dialHH tasks. After connecting to the server the driver would use the phone buttons (vmHH) or voice commands (vmHF) to login to the server and find the message and listen to it. Each message asked the driver for some simple piece of factual information (e.g. home address, model year of the driver's personal car, etc.). The driver would then use the voicemail system to reply to the message and leave the requested information as an attached voicemail.

The voicemail server used in the vmHH and vmHF tasks was modified from its commercial implementation in only one respect. Each voice prompt was re-recorded to allow the option of using a voice command instead of a key press. A prompt that would normally be presented as "To get messages, press 2" was changed to "To get messages, press 2 or say 'get messages'". Since the server did not support voice-recognition, the experimental team implemented hands-free operation of the server using a 'wizard of oz' technique.

The test participants were prompted by the experimenter to begin each task. For most tasks, timing started at the end of the voice prompt and stopped when the driver returned their hand to the steering wheel. For the dialing tasks, the task was considered complete when the voicemail server connected. Similarly, for the voicemail tasks, the task was taken to begin when the voicemail server connection was started.

For these experiments, driving the vehicle safely, maintaining speed and headway comprised the primary task; performing any of the in-vehicle tasks comprised the secondary task.

SCENARIO

The drive took place on a simulated section of a US interstate during daylight conditions on dry road. The simulated road was topographically mapped from a section of actual interstate along I-94 in Michigan. Lane widths, lane divisions, elevation changes and road curvature all match the actual roadway. Drivers were instructed to drive in the right lane only and to follow a lead vehicle at a self-selected 'safe following distance'. The lead vehicle was a typical compact Sport Utility Vehicle traveling at approximately 105 kilometers per hour. The lead car varied its speed by approximately ±10% over a 30-second period.

A sub-compact vehicle was also traveling in the right lane in front of the lead car. This vehicle was used for the front detection events. During most of the drive the lead car obscured this vehicle. During the detection events the vehicle appeared to swerve suddenly out of its lane either onto the right shoulder or into the left lane.

An intermediate-size sedan was following in the right lane and was clearly visible in the driver's rearview mirror. This vehicle was used for the rear detection events. During rear detection events this vehicle would swerve in a manner identical to that of the sub-compact vehicle in front of the lead vehicle.

In addition to road roughness, random wind disturbances affected the driver's car. These wind gusts were designed to cause heading errors that would require the drivers to make corrections to avoid lane violations. Without steering input from the driver a lane violation would occur in approximately 4 seconds when driving on a straight section of roadway.

A stream of fast-moving, overtaking traffic was present in the left lane, traveling at approximately 129 kilometers per hour. The road was divided from oncoming traffic by a median or concrete barrier for the length of the drive. A stream of opposing traffic was present on the divided side of the road but did not interact with the simulator driver in any way. Traffic density was fairly light with 15 to 20 vehicles present in the scene at any time.

DETECTION EVENTS

During each secondary task performance a single detection event occurred. The event occurred either in front of or behind the driver. Drivers were instructed to use their turn signals when they saw a lane violation by another car. The direction of the turn signal indicated the direction of the lane violation. Between secondary tasks (except between dialing and voicemail which happen contiguously in time) at least one detection event occurred. More detection events could be scheduled at the discretion of the experimenter if the time between tasks would allow. On average, each participant was exposed to 29 events during the course of the drive. The detection events that occur between tasks are referred to as 'post-task events' and denoted as **PostEvt** in the analysis.

DESIGN AND PROTOCOL

The experiment involved a total of 63 test participants. Forty-eight of the participants ranged in age from 25 years to 66 years. The remaining 15 participants were teenagers who had been recently licensed to drive. They ranged in age between 16 and 18 years (only one participant was 18). Gender was evenly divided within the 25-66 year old age group of test participants; the teenage group comprised 8 males and 7 females. Table 2 summarizes the participant demography. The teenage participants were drawn from local high schools, and were paid for their time. All other participants were employees of the Ford Motor Company, primarily from sales, marketing, finance and human resources organizations. None of the test participants had prior technical knowledge of or familiarity with the VIRTTEX simulator, and participated in the experiments during regular business hours.

Participants had normal (or corrected to 20/40 or better) vision, normal peripheral visual fields, and normal color perception, as tested with an OPTEC 2500 vision tester. Hearing acuity was not tested, but all participants indicated that they had normal hearing in both ears.

Each participant received training in the secondary tasks that lasted between 30 minutes and 1 hour. Training was considered complete when a participant could demonstrate at least one unaided, error-free performance of each secondary task. Additionally, the participants were shown examples of the front and rear detection events and practiced signaling in response to the events during the first five minutes of the simulation drive. They were told that events would occur during the drive but were given no information about when or how often to expect them.

Secondary tasks were balanced using a Latin Squares design with the constraint that hand-held voicemail was always preceded by hand-held phone dialing and hands-free voicemail was always preceded by hands-free phone dialing. Each participant performed each of the secondary tasks twice during the drive. The in-task detection event and first post-task detection event were also balanced to achieve an even distribution of rear and front, left and right detection events for each secondary task. Additional post-task events were inserted at the experimenter's discretion. The total length of the simulation drive was approximately 50 minutes.

RESULTS

The average secondary task performances ranged in duration from a low of 8.5 seconds for the climate control (hvac) task to over 170 seconds for the vmHH task (Table 3). There is a trend toward longer task durations with increasing age. This increase in task duration becomes especially apparent for the oldest age group. The hands-free tasks generally show less variation with age than the hand-held tasks, primarily because the dialing and voicemail hands-free systems enforce a steady pacing.

Analysis of detection events

When a detection event occurred during the drive the simulation computers recorded the state of the turn signal stalk. Activation of the turn signal within ten seconds of the start of an event was classified as a detection if the direction of the turn signal indication was in the same direction as the event. For example, if the event consisted of a car swerving to the right and the driver responded by signaling right the driver was considered to have correctly detected the event. The number of missed events due to direction errors was extremely small during the experiment (< 2% of the events categorized as missed were because of direction).

Front Events

The front event detection percentages are shown in Table 4. Drivers correctly detected over 96% of the front events when no secondary task was in progress. The results for the 48 adult drivers are plotted in Figure 6. The detection responses were fit to a logistic model with secondary task as the independent variable and 'PostEvt' (no secondary task) as the reference level. Phone dialing, incoming hands-free and hand-held voicemail were significantly different from no secondary task ($p<0.05$).

It is worth noting that the vmHF task was not significantly different from driving with no secondary task but that dialHF was different. One difference between these tasks is that dialHF had a component of visual demand associated with reading the voice server phone number from the text affixed to the steering wheel. The vmHF task had no such visual demand component. A video review of the driver's face during the 5 missed detection events in the dialHF case shows that in 3 cases the driver was clearly reading the phone number from the steering wheel when the event took place. In one of the remaining two cases, it was not possible to tell where the driver was looking and in the last case the driver was looking directly at traffic when the event occurred. To the extent that hands-free dialing of an unfamiliar number might require a visual aid (note card or scrap of paper) in real-world driving these results are realistic. However, they do not demonstrate cognitive interference with event detection due to hands-free dialing.

The relatively high missed rate for incoming hands-free calls compared with incoming hand-held calls is also interesting. A video review was conducted of the 6 missed events in the incHF case to determine where the driver was looking when the events took place. In each case, the driver had pressed the phone icon to answer the call and had turned visual attention back to the driving scene when the events occurred. In spite of the fact that these drivers were looking directly ahead when the events occurred, they failed to respond.

The 15 teenage drivers show a different pattern of response (Figure 7). Here only the dialHH task was statistically different from the no secondary task case ($p<0.05$). The size of the effect, however, is startling. The teen drivers missed 53.8% of the front events when dialing a hand-held phone. This, combined with the high speed at which teens completed the dialing task, indicates that they may be employing a different strategy than more experienced drivers. Many of the teens appear to give the dialing task equal or higher priority than scanning the driving scene. The low sample size for teen drivers may account for the lack of statistical significance in the other secondary tasks.

Rear Events

The rear detection event data for the 48 adults shows a somewhat different pattern (Table 5). Just over 60% of rear events were detected when no secondary task was in progress. This reflects the lower priority that drivers allocate to the rearview mirror while driving. Again, the results were fit to a logistic model. Hand-held dialing, incoming calls (both hand-held and hands-free) and climate control adjustment (hvac) were significantly different from driving with no secondary task (Figure 8).

No significant results were found for teen drivers when analyzing the rear events, possibly because of the small size of the teen sample group.

Analysis of driving performance

Lane violations were counted during the secondary task performances. A lane violation was defined as a lane exceedance large enough to move one of the vehicle's tires completely outside the left or right lane markings.

Other continuous driving performance measures were analyzed during the drives including following distance and heading error. These results were analyzed using a univariate, repeated-measures ANOVA with age and secondary task as independent variables. Age was coded as a categorical variable with the age groups defined as in Table 2. For the performance measures, the two normal driving replicates were taken to be the two longest driving intervals between secondary tasks for each driver.

Lane Violations

Lane violations were rare throughout the experiment. This is quite different from many fixed-base simulator experiments where lane violations are commonly observed (*12*). We attribute the low rate of lane violations in this testing to the presence of accurate lateral motion cues that allowed the drivers more realistic and precise control of the simulated vehicle*.

The number of lane violations by task is shown in Figure 9 broken out for adults and teens. The vast majority of the lane violations occurred during the vmHH task. The only other task with more than a single lane violation was hand-held phone dialing (dialHH). The high number of lane violations for teen drivers is of concern since there were only 15 teens in the study and 48 adults. If we divide the number of lane violations while performing the vmHH task by the total time required by all drivers to complete the task we can determine a lane violation rate for hand-held voicemail retrieval. The resulting rate is 2.5 lane violations per hour for adults but it is 3.9 lane violations per hour for the teen drivers.

Following Distance

The following distance or headway was defined as the straight-line distance from the center of the driver's car to the center of the lead car. The drivers determined their own headway – their only instructions were to follow at a 'safe' distance. The mean following distances computed over the secondary tasks are shown in Figure 10. The age effect on following distance is significant ($p<0.01$) and a Tukey HSD comparison shows that 45 to 54 and 55 to 64 year old groups are both significantly ($p<0.04$) different from drivers in the 35 to 44 year old group and younger. The hand-held voicemail (vmHH) task was significantly (<0.01) different from all other tasks.

The following distances for teen drivers correspond to a time headway of 1.3 seconds. For drivers in the 45 to 54 year old group this rises to 2.2s. Although this is not a measure of distraction it does point out that younger drivers leave little room for error when choosing a 'safe' following distance. Coupled with the high rate of missed events during hand-held phone dialing that was observed for teen drivers this situation leaves teens especially vulnerable to the effects of hand-held phones.

The rise in mean following distance during the vmHH task is evidence that drivers are not able to maintain speed during this task since the lead vehicle did not change its behavior. This 'falling back' behavior is commonly observed during real-world driving during periods of heavy distraction.

Heading Error

Heading error is defined as the difference between the instantaneous roadway tangent and the current vehicle heading measured in degrees. There are many ways to summarize this measure over a given secondary task performance. We can choose an average value, a peak value, a median and so on. Averages tend to discount the effect of a momentary, severe error and peak values give too much weight to such disturbances. The summary statistic analyzed here is the 90^{th} percentile heading error denoted HE90. The value of HE90 computed over any secondary task is the value of heading error that was exceeded 10% of the time. It is more sensitive to large transient errors than an arithmetic mean but not as sensitive as a peak value.

The values of HE90 are show in Figure 11. Higher values of HE90 correspond to larger heading errors while driving. The effect of age is significant ($p<0.01$). A Tukey HSD comparison of age groups shows that the 25 to 34 age group is significantly different from the teen group ($p<0.01$) and from the 55 to 65 year old group ($p<0.02$). There is a general trend towards slightly worse lateral control with increasing age beginning with the 25 to 34 year old group. The teenage group does not appear similar to their slightly older peers. Instead teen drivers were observed to have lateral control skills comparable to the oldest drivers tested.

As with the following distance measures, the age effect is not a measure of distraction. However, it does point out that teen drivers are still learning basic vehicle control skills. They have not completely mastered the skills required for lane discipline.

The effect of secondary task is also significant ($p<0.01$). The tasks fall into 3 significance groups. Normal driving, hands-free dialing (dialHF) and hands-free voicemail (vmHF) form one group. Radio tuning, incoming calls (both

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* The authors conducted a simple experiment to test this hypothesis. At the end of the trials outlined in this paper, 6 test subjects were run through the exact same protocol except that the lateral motion scale factor was set to zero. The lane violation rate for these drivers was found to be 6.6 times higher than the rate observed during the main experiment where the lateral scale factor was set to 0.6.

hand-held and hands-free), climate control adjustment (hvac) and hand-held voicemail (vmHH) form another group ($p<0.03$). Hand-held phone dialing (dialHH) is the most interfering task by this measure and falls in a group by itself ($p<0.01$).

CONCLUSIONS

Table 6 summarizes the five measures (front detection rate, rear detection rate, lane violations, following distance and heading errors) for the adults in the study. We have not attempted to combine these measures into a single figure of merit for each task. However, it is clear that hand-held voicemail retrieval and hand-held phone dialing presented significant levels of distraction to the adult drivers. In particular, the large lane violation rate for the vmHH task is alarming and drivers who engage in this or similar tasks that require a large number of key presses on a hand-held phone would be well advised to stop their vehicles before proceeding.

Hands-free incoming calls generated significant results in three of the five measures. The front event missed detection rate for this task was nearly the same as for hand-held dialing. We found that the missed events could not be attributed to increased visual demand associated with pressing the phone button located on the rearview mirror. Drivers were actually looking out the windshield and still failed to detect events occurring directly in front of their vehicle. We also note that this did not occur when answering incoming calls with the hand-held phone. Hand-held incoming calls were not innocuous, however. They were responsible for both heading errors and missed rear detection events, although at a level that was very similar to those seen while performing the climate control task.

Hands-free dialing generated a significant number of missed front detection events. However it is important to remember that the majority of these missed events can be accounted for by the visual demand required to read the voicemail phone number affixed to the steering wheel. In the absence of these events the hands-free dialing task would not have generated a significant distraction result by any measure. Our result should be seen in the specific context present in the experiment – using a hands-free phone to dial a number while using a written memory aid. It is not clear that the result will apply in the case of a well-known number that does not require the driver to look to a note or other prepared text.

Manual radio tuning was responsible for a large heading error, but not for lane violations. This indicates that the errors were transient and were quickly corrected before a large error in lane position could occur. The level of distraction indicated by the front and rear detection events did rise during radio tuning but not enough to reach statistical significance during this test.

Finally, the hands-free voicemail retrieval task did not reach significance in any of the five distraction measures. The dramatic contrast between this result and the result for the same task performed with the hand-held phone is a powerful example of the benefits of a hands-free interface for specific applications.

We observed two different types of effects due to driver age. The first is that the teen drivers exhibit behaviors that may place them at higher risk even when no distraction is present. The teens choose small following distances and time headways (1.3-seconds) that leave little room for error. They also generate relatively high heading errors, indicating that they have not fully learned the basics of vehicle control.

The second effect on teen drivers is that distraction from the secondary tasks was more pronounced with this group. The lane violation rate for the hand-held voicemail task (vmHH) was 56% higher for teens than for adults (3.9 lane violations/hour for teens vs. 2.5 lane violations/hour for adults). The front missed event rate for the hand-held dialing task was even more dramatic: 53.8% for the teens and 13.6% for adults.

The combination of poor judgment in following distance, poor vehicle control skills and more severe distraction seen in teen drivers is a serious cause for concern. Cellular phones, pagers and other devices are popular among teens. The results of this study indicate that, at a minimum, driver education curricula should be revised to address the use of communication technology while driving. The use of hand-held phones by teens, in particular, should be strongly discouraged.

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Figure 5 Radio, climate-control and hand-held phone locations. Drivers removed the phone from its holder during use.

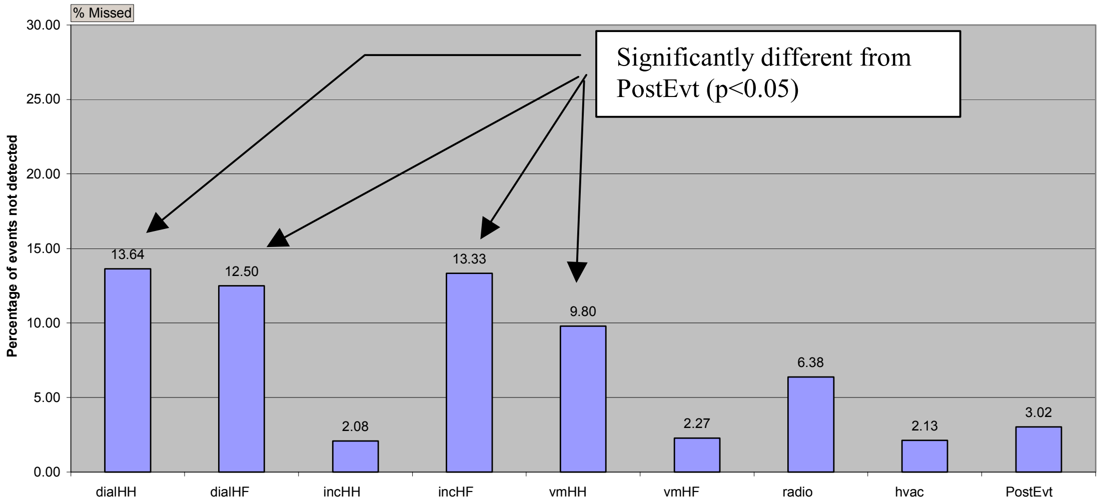

Figure 6 Percentage of front events not detected by adult drivers, grouped by secondary task. 'PostEvt' corresponds to events where no secondary task was in progress.

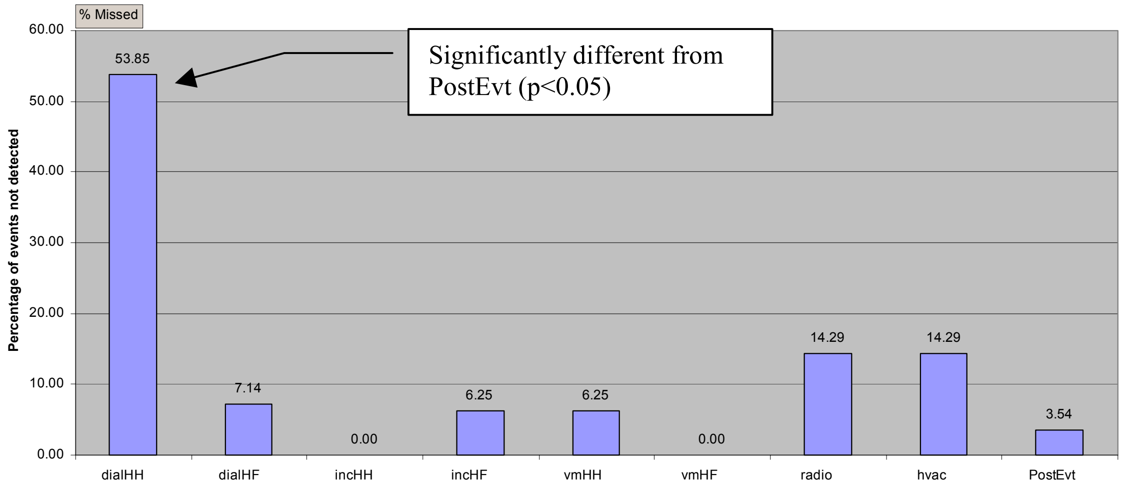

Figure 7 Percentage of front events not detected by teen drivers, grouped by secondary task. 'PostEvt' corresponds to events where no secondary task was in progress.

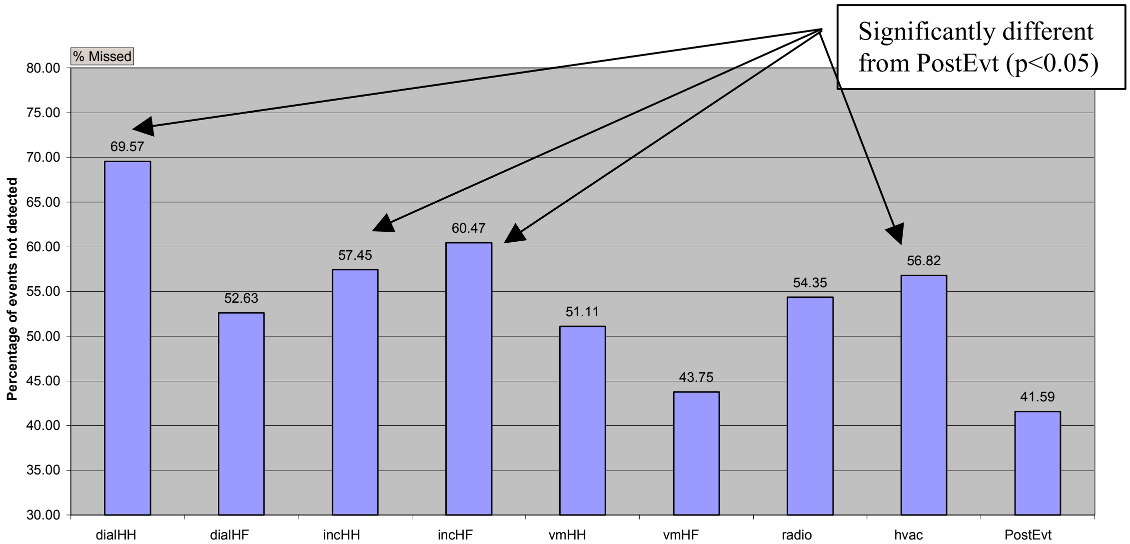

Figure 8 Percentage of rear events not detected by adult drivers, grouped by secondary task. 'PostEvt' corresponds to events where no secondary task was in progress.

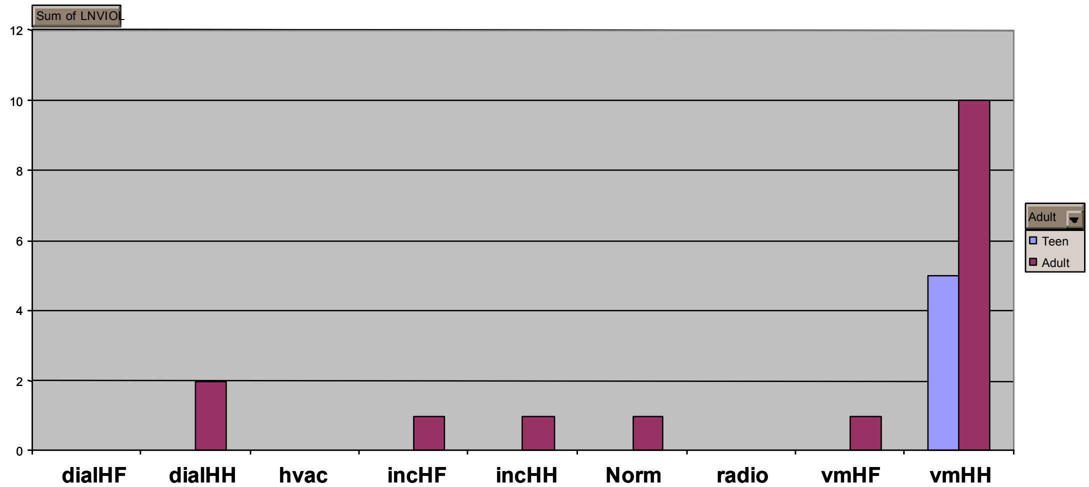

Figure 9 Total lane violations by task for teens and adults

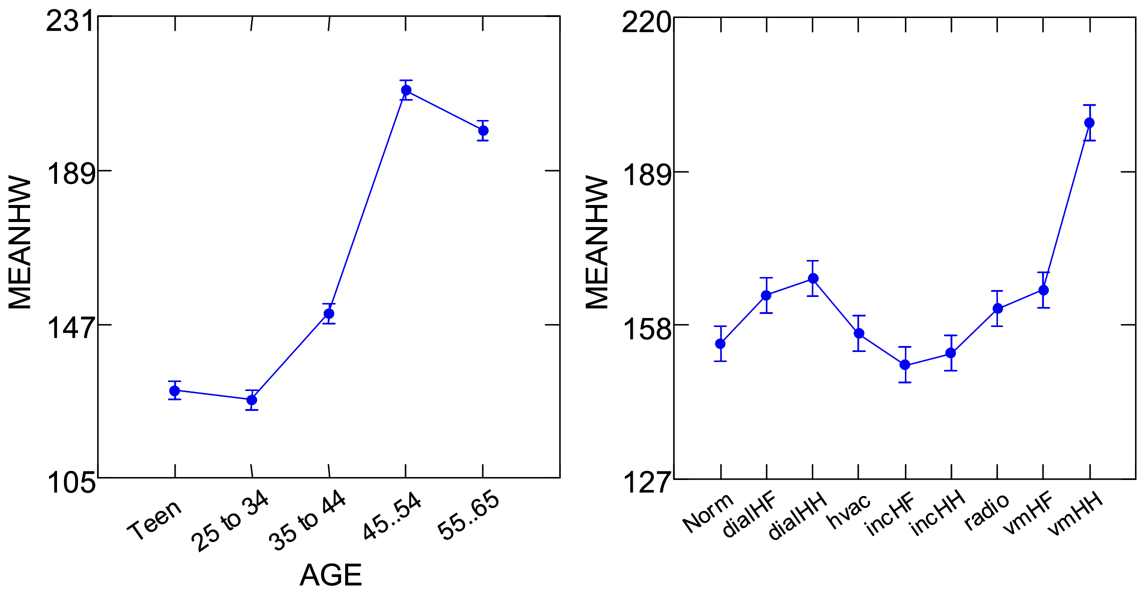

Figure 10 Following distance (mean headway) in feet

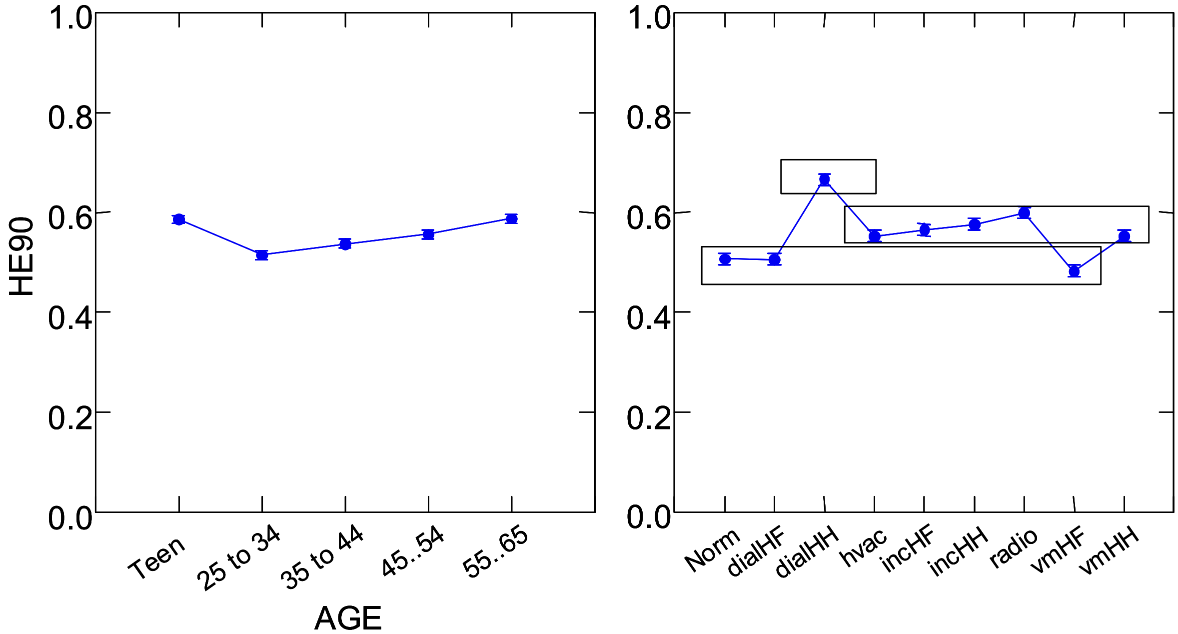

Figure 11 90th percentile heading error. The boxes on the task plot indicate significance groups

TABLES

	Accleration	Velocity	Displacement
Longitudinal/Lateral	>0.6g	>1.2 m/s	±1.6m
Vertical	1.0g	1.0 m/s	±1.0m
Pitch/Roll	> 200 deg/s^2	>20 deg/s	±20deg
Yaw	> 200 deg/s^2	>20 deg/s	±40deg

Table 1 VIRTTEX Motion System Limits

	Teen	25 to 34	35 to 44	45..54	55..65	Total
male	**8**	**6**	**5**	**7**	**6**	32
female	**7**	**6**	**7**	**5**	**6**	31
Total	15	12	12	12	12	63

Table 2 Participant age and gender distribution

Average of TSKDUR	CAT$							
age group	dialHF	dialHH	incHF	incHH	vmHF	vmHH	radio	hvac
Teen	43.91	24.88	13.98	17.46	147.61	154.19	13.90	7.55
25 to 34	35.81	26.48	16.49	20.12	145.25	157.57	14.79	7.86
35 to 44	35.95	30.50	17.84	21.90	152.27	168.13	17.49	8.28
45 to 54	38.01	31.77	18.04	20.93	153.11	170.31	16.78	8.93
55 to 65	50.11	42.02	18.03	22.58	162.61	212.88	22.34	10.31
Overall Mean	40.97	30.74	16.73	20.45	151.99	171.74	16.91	8.54

Table 3 Secondary Task Durations (seconds)

	dialHF	vmHF	incHF	hvac	radio	dialHH	vmHH	incHH	No Task
Missed	11.11	1.69	11.48	4.92	8.20	22.81	8.96	1.59	3.15
Detected	88.89	98.31	88.52	95.08	91.80	77.19	91.04	98.41	96.85
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
N	54	59	61	61	61	57	67	63	444

Table 4 Front detection event percentages by secondary task

	dialHF	vmHF	incHF	hvac	radio	dialHH	vmHH	incHH	PostEvt
Missed	55.77	40.98	59.65	61.40	55.00	68.33	51.72	55.74	38.86
Detected	44.23	59.02	40.35	38.60	45.00	31.67	48.28	44.26	61.14
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
N	52	61	57	57	60	60	58	61	440

Table 5 Rear detection event percentages by secondary task

	Front Event Detection	Rear Event Detection	Lane Violations	Following Distance	Heading Error
Hand-held phone dialing (dialHH)	13.6% missed	69.6% missed	2		.70 deg
Hand-held voicemail (vmHH)	9.8% missed		10	210.1 ft	.56 deg
Hand-held incoming call (incHH)		57.4% missed			.61 deg
Hands-free phone dialing (dialHF)	12.5% missed				
Hands-free voicemail (vmHF)					
Hands-free incoming calls	13.3% missed	60.5% missed			.57 deg
Manual radio tuning (radio)					.63 deg
Climate control adjustment (hvac)		56.8% missed			.57 deg
Normal driving	3% missed	41.6% missed	1	162.8 ft	.5 deg

Table 6 Distraction measures that were different from normal driving (p<0.05) by task (adults only)