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THE EFFECTS OF SECONDARY TASKS ON NATURALISTIC DRIVING PERFORMANCE

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16. Abstract

Data from 36 drivers involved in a naturalistic driving study were analyzed to determine the frequency and conditions under which drivers engage in secondary behaviors and to explore the relationship these behaviors might have with driving performance. A random selection of 1,440 five-second video clips of the drivers' faces was coded for the occurrence of specific secondary behaviors and the frequency and duration of glances. Corresponding performance data from the instrumented vehicles was used to calculate variability of steering angle, mean and variability of lane position, mean and variability of throttle position, and variability of speed. Contextual factors were also examined, including road type, road curvature, and road condition.

Drivers were observed engaged in secondary behaviors in approximately 34% of the clips. Conversation with passengers was the most common secondary behavior (15.3%), followed by grooming (6.5%) and using cellular phones (5.3%). Younger drivers were most likely to engage in secondary behaviors overall (42%). All categories of secondary behavior were associated with significantly higher variability in steering angle. The results for other performance measures were mixed. Cellular phone use, eating/drinking and grooming, resulted in increased steering variance, but did not affect lane position or speed variance. Cellular phone use was associated with the smallest percentage, and shortest mean duration, of glances away from the forward scene, but fewer glances could negatively affect scanning of the roadway environment. However, conversations with passengers showed higher variability in steering angle, increased deviation for both lane position and distance from center of the lane.

In general, secondary behaviors are neither equal in frequency of occurrence nor in their effect on driving performance. Drivers appear to perform differently when taking part in different tasks, and appear to engage selectively in secondary behaviors according to traffic/roadway conditions. In naturalistic conditions, when drivers can freely choose whether or not to engage in secondary tasks, drivers may be performing secondary tasks when their driving skills are least needed and the traffic environment tends towards being less challenging based upon a driver's own assessment. These findings highlight the importance of conducting naturalistic studies, as it appears that controlled studies cannot always account for the full effects of driver choice and perceived risk associated with immersion in actual traffic/roadway environments.

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CONTENTS

INTRODUCTION

A large body of evidence suggests that driving performance degrades when drivers engage in secondary behaviors, such as cellular phone use, and even conversation with passengers. The distraction caused by such secondary behaviors is a well-studied phenomenon, having been demonstrated in both simulator and controlled on-road or test track driving, and subsequently published widely throughout the open literature. However, to date, no published data exists which examines the effects of secondary tasks on driving performance measures under naturalistic conditions (drivers using instrumented vehicles in their daily lives), and few have examined the relative frequency with which these secondary behaviors even occur. Nonetheless, there is a growing public concern with driver distraction due to secondary behaviors—including state and local laws that impose penalties for engaging in distracting behaviors while driving. Yet there remain lingering questions as to how participation in secondary, or "nondriving," behaviors specifically affects driving safety, particularly with regard to driving performance measures such as lane keeping and speed fluctuation in naturalistic conditions. On the other hand, this report does not address the effects of secondary behaviors on drivers' cognitive performance or their reaction time to urgent events. However, the latter of these two is the subject of a continuing investigation by the authors using data similar to that analyzed in the current report. The effect of secondary behaviors on driver cognitive abilities is outside the scope of the existing investigation, and cannot substantively be addressed using the data available to the authors.

Previous Research

While studies that have examined this issue differ in their methodological approaches and the specific hypotheses tested, there is nonetheless a growing consensus among researchers that driver distraction associated with performing secondary tasks leads to increased risk for crashes. Several articles, most notably Caird et al. (2004) and Horrey and Wickens (2004), have closely examined the results from numerous controlled studies and performed meta-analyses, in an attempt to comprehensively evaluate the effects of secondary tasks—in particular the use of cellular phones and conversation with passengers. The studies included in the meta-analyses covered a wide variety of dependent and independent variables. However, for purposes of this report only driver performance variables related to vehicle control are discussed.

While studies that have been conducted to date offer much useful data, it remains the case that far less is known about how frequently drivers undertake secondary tasks and what effect these tasks might have on performance during their normal everyday driving experience. This is partly because there are many inherent difficulties in obtaining naturalistic data. Short of installing cameras and data recorders systems in personal automobiles, self-reports of drivers' secondary behavior patterns are the only alternative currently available. How frequently drivers take part in secondary behaviors is critical to furthering our understanding of the actual risks to which drivers are exposed. So, for example, how often do drivers talk on cellular phones or eat while they drive? Do drivers typically choose to engage in secondary behaviors more often on specific types of roads, at particular times during the day, or road conditions? What effect do different secondary tasks have on driving performance (e.g., is having a conversation with a passenger equivalent to talking on a cellular phone when it comes to staying in your lane or maintaining speed)?

Only recently have large-scale, multi-vehicle, naturalistic studies been conducted on U.S. roadways. One example of this was a two-phase project funded by the AAA Foundation for Traffic Safety (Stutts, Reinfurt, Staplin, & Rodgman, 2001; Stutts et al., 2003). In Phase II of the project, the authors developed a driving log methodology to quantify how often specific secondary tasks occurred in vehicles. Video cameras (directed inside the cabin) were installed in vehicles that were given to participants for one week each. Approximately three hours of naturalistic driving video for 144 participants was recorded, and the video of 70 participants was analyzed for the frequency and duration of distracting events/secondary behaviors, as well as contextual variables such as the time of day, whether the vehicle was in motion, the traffic conditions, whether the drivers' eyes were directed inside the vehicle cabin or outside, whether the drivers' hands were on the wheel, and so forth. The results from this study yielded a refined taxonomy of common distracting behaviors, as well as the first solid indications of when and where drivers choose to engage in secondary behaviors. However the data were collected over a relatively short period of time, and they did not include the associated vehicle performance data.

In short, Stutts et al. (2003) reported that, overall, drivers were engaged in secondary, and potentially distracting, tasks when the vehicle was moving, excluding conversations with passengers, 16% of the time. When conversations with passengers were included, this increased to 31%. The second most common distracting task observed was eating/drinking (4.6%), followed by internal distractions such as reaching for, or manipulating, vehicle controls (3.8%) and external distractions and smoking (1.6% each). Drivers were only observed taking part in cellular phone activities 1.3% of the time the car was in motion.

With regard to driver performance measures, the findings of the two meta-analyses of controlled studies conducted by Caird et al. and Horrey and Wickens are quite consistent as they pertain to the effects of cellular phone use both on reaction time to critical events and driving performance measures such as lane position and speed variation. Specifically, driver reaction times to critical events are affected more than are driver performance measures when drivers are engaged in the use of cellular phones. But both studies report that driving performance measures are also, though perhaps nonsignificantly, affected by cellular phone use. Again, however, these outcomes are exclusively based on the results from controlled studies (desktop tracking tasks, fixed-based simulators, closed course and accompanied on-road testing) as opposed to naturalistic driving.

Caird et al. address the differences in findings in driver distraction studies associated with the variety of experimental approaches. Specifically, at least as it relates to cellular phone use, the strongest effects are observed in the laboratory as compared to on-road or simulator studies. Both Caird et al. and Horrey and Wickens concluded that cellular phone use in particular hampered driver response to critical events and ability to maintain vehicular control, and that other driving performance variables, including lane position and headway, showed smaller effect sizes. Horrey and Wickens state that this is likely due to differences in the way continuous perceptual-motor tasks (i.e., lane keeping and speed maintenance) and discrete events (i.e., emergency braking to avoid collision) "depend on separate attentional resources and are differently affected by concurrent task demand than are discrete measures of hazard response" (p. 3).

Horrey and Wickens go on to state that the results of their meta-analysis on the impact of cellular phones on driving performance are largely manifested in response time to critical events on the roadway. Horrey and Wickens also state that driving performance is negatively influenced regardless of whether the cellular telephone is hand-held or hands-free, and that intense conversations with passengers in the vehicle have the same effect as intense conversations via cellular phone.

Given that very little research has been performed on the frequency with which certain secondary tasks are undertaken, and a lack of any public literature on naturalistic driving performance related to vehicle control that is associated with secondary tasks, this report takes advantage of a large naturalistic dataset to address two elements critical to understanding the risks posed by driving while performing secondary tasks: How frequently secondary tasks are undertaken, and their effect on driver performance in the form of vehicle control.

The Present Study

Field operational tests (FOTs) represent yet another alternative to evaluating the effects of secondary behaviors on driver performance. FOTs provide a mechanism whereby a host of naturalistic measurements can be made within a relatively large sample of the general driving population. An FOT involves lay drivers using an instrumented research vehicle as their own personal car for some period of time, during which extensive data is collected on driver behavior. An FOT vehicle conforms to the "ideal" world in that it quite literally has a set of video cameras and data recording systems installed on-board, albeit usually in the context of evaluating some other driver assistance or in-vehicle technology. Yet, because FOT drivers can typically drive wherever, whenever, and however they choose, the data are derived from the personal mobility needs of the individual subject rather than by any direct experimental manipulations. The recording equipment within the vehicle allows continuous measurements to be made on a variety of variables, including those related to the state of the driver (e.g., facial expressions, glances away from the forward scene, etc.) as well as performance measures such as speed, lane position, and geographical location. While several FOTs that have been carried out by UMTRI have been designed to investigate the use of driver assistance technologies, collectively they have also allowed a vast amount of naturalistic driving data to be stored and analyzed.

This report focuses on data derived from one such FOT, the Road Departure Crash Warning Field Operational Test, or RDCW FOT (Leblanc et al., in preparation). The RDCW FOT (not including development or data analysis phases) was conducted between May 2004 and February 2005 and represents 82,773 miles (133,290 km) of naturalistic driving data from 78 lay drivers from Southeastern Michigan. The present study used data from the RDCW FOT to examine the frequency of various secondary behaviors, and how these behaviors affected several standard measures of driving performance related to vehicle control. A brief description of the RDCW

FOT is presented below in order that the context in which the data were collected is clearly conveyed, however a far more comprehensive description can be found in LeBlanc et al. (2005). This is followed by a summary of how the dataset for the present study was obtained. Finally, the driving performance measures are defined and the results of several analyses are discussed.

The purpose of the RDCW FOT was to evaluate the suitability of a road departure crash warning system for widespread deployment among passenger vehicles. The system consisted of two crash warning functions: Lateral Drift Warning (LDW), which was intended to warn the driver of inadvertent and potentially dangerous lane- and road-departure events, and Curve Speed Warning (CSW), which was intended to warn the driver that the vehicle speed may be too great for safe and comfortable travel through an upcoming curve. A fleet of 11 identical Nissan Altimas were equipped with LDW and CSW, and were provided to 78 randomly selected licensed drivers from Southeast Michigan. Figure 1 shows the FOT vehicle fleet.

Each driver was given an RDCW vehicle for a total of 26 days, and was instructed to use the vehicle as they would their own car during that period. For the first six days of their experience the RDCW system was inactive (i.e., from the driver's perspective the vehicle behaved exactly as a regularly purchased Nissan Altima). This allowed the researchers to obtain a baseline measure of driving for each test subject. The remaining 20 days were spent with RDCW active. With the RDCW system active, warnings were issued to the driver via a driver-vehicle interface (DVI) that utilized visual icons on the instrument panel, auditory warnings presented through the vehicle's speakers, and haptic seat vibrations. At the end of the 26 days, the driver returned to UMTRI and attended a debriefing session, during which they filled out questionnaires and discussed their experience.

As mentioned previously, each vehicle was equipped with video cameras. One camera was mounted on the inside of the vehicle's windshield, behind the interior rear-view mirror, and provided a forward view of the driving scene. Another camera was mounted to the inside of the vehicle's A-pillar, which captured an image of the driver's face at specific intervals and varying frame-rates. Figure 2 shows how the inside of the vehicle appeared to the driver. The "face" camera is circled in the figure.

Figure 1. Full fleet of 11 RDCW FOT vehicles.

Figure 2. Inside an RDCW FOT vehicle. One camera was retrofitted to the A-pillar (circled in the figure).

Driving in the FOT took place primarily in the lower peninsula of Michigan with minor amounts in Ohio, Indiana, and Illinois. Automatic onboard data collection was accomplished using a data acquisition system (DAS) built specifically for the project. Over 500 channels of data were collected, some at a rate of 20 Hz and others at 10Hz. While a complete description of the final FOT dataset is beyond the scope of this report, measures that were used in the present study are described in following sections.

METHOD

Participants

The analyses in this report are based upon data from a subsample of drivers who participated in the RDCW FOT. Recruitment for the FOT began with a randomly generated list of 6,000 licensed drivers from nine counties within Southeast Michigan obtained through the Michigan Secretary of State Office, the state's driver licensing bureau. From this list, smaller random samples of names were selected to receive informational postcards that briefly described the study and contained an "800" telephone number to call for additional information. A total of 1,963 postcards were mailed resulting in 238 people (12.1%) calling to inquire about the study. A research assistant provided these callers with an overview of the study and screened all interested persons. A minimum-annual-mileage threshold was required for a driver to qualify. The qualifying mileage criterion was for a potential participant to report average mileage not less than 25% below the year 2001 National Personal Transportation Survey reported average for his/her particular age and gender category. In addition the following were grounds for excluding individuals from participating in the FOT, several of which were confirmed by examining the participant's driving record:

- They had been driving for less than two years.
- They were unable to drive a car equipped with an automatic transmission without assistive devices or special equipment.
- They had been convicted of any of the following in the past 36 months:
    a. Driving while their operator's license is suspended, revoked, or denied.
    b. Vehicular manslaughter, negligent homicide, felonious driving or felony with a vehicle.
    c. Operating a vehicle while impaired, under the influence of alcohol or illegal drugs, or refusing a sobriety test.
    d. Failure to stop or identify under a crash (includes leaving the scene of a crash; hit and run; giving false information to an officer).
    e. Eluding or attempting to elude a law enforcement officer.
    f. Traffic violation resulting in death or serious injury.
    g. Any other significant violation warranting suspension of the license.
- They acknowledged the need for, but fail to use, corrective devices such as eyeglasses or hearing aids.
- They were taking drugs or substances that may have impaired their ability to drive.

- They were unable to commit to being the only individual to drive the research vehicle
- They were unable to schedule a four-week period of driving predominantly within the CSW coverage area, particularly during the first week of their exposure.

This process resulted in a final set of 78 participating drivers (a balanced number of males and females equally divided into three age groups: 20-30, 40-50, and 60-70). Of these 78 drivers, a subsample of 36 was selected for the following analyses. The mean ages of these 36 drivers were 25.1, 45.6, and 64.2 years old for the younger, middle and older age groups respectively. Other characteristics of the 36 drivers, as well as the rationale behind why and how they were selected, are presented in the next section.

Procedure

To the extent that road departure crash warnings potentially affected the driving performance measures under consideration, a filtering mechanism was used to find times when the driver was not receiving either lateral drift or curves speed warnings. One such mechanism emerged from a portion of data analyses that were conducted during the FOT.

Whenever the vehicle was on (i.e., the engine was running) the data acquisition system captured a five-second “exposure” video clip (at 10 frames/second) every five minutes from cameras mounted in the vehicle, regardless of what the driver was doing. The first of these exposure clips was collected five minutes after a trip began, and clips continued to be recorded at five-minute intervals until the engine was turned off (i.e., the trip ended). As part of the original FOT data analysis, a random sample of these exposure video clips was selected and analyzed for evidence of secondary behaviors. The specific intent was to examine whether drivers engaged in more secondary behaviors with or without the driver assistance systems available. The outcome of this analysis is provided in Leblanc et al. (2005). However, because the exposure clips represented instances of natural driving with no RDCW alerts, these data were also well suited for examining what is characterized as relatively normative driving performance.

The analysis began by generating a sample of exposure video clips that would be representative of the FOT data, but not so expansive that the coding process fell outside of the scope of the RDCW FOT project. For example, it would not have been feasible to code all of the video clips for each driver (a total of 18,281 exposure clips were generated during the RDCW FOT). Establishing a data set for the present analyses therefore involved a number of steps, including several filtering criteria. The first criterion for qualifying an exposure clip, aside from it not being associated with any RDCW alerts, was that it had to represent a period of driving in which the speed exceeded 11.18 m/s (25 mph) during the clip. This constraint was not necessary for the present study but was relevant to the original RDCW FOT analysis.

An additional criterion was that drivers had to have at least ten qualifying exposure video clips per week to be included in the pool of candidates (this is equivalent to at least 50 minutes of driving per week). This ensured that each driver included in the analyses had a sufficient number of clips to analyze. However there were 18 drivers who failed to meet this criterion, reducing the total number of potential drivers for the present analysis to 60.

After nonqualifying exposure clips and drivers were removed from the data set, a random selection, without replacement, was performed of six drivers from each of the six gender-by-age group combinations, resulting in a final set of 36 drivers. Ten exposure clips per week per driver were then selected at random, for a total of 40 video clips per driver (10 clips from the period of baseline driving and 30 clips during weeks 2-4, when the RDCW system was active). In sum 1,440 exposure clips were ultimately reviewed: 360 randomly selected exposures from each of the four weeks that the drivers had the FOT. The average mileage of the 36 drivers included in this analysis was 1,914.4 km (1,189.8 miles) over the course of the four-week exposure, with a standard deviation of 635.2 km (394.8 miles).

Before continuing with the analyses, it was necessary to consider whether the RDCW system had an effect on the overall frequency of secondary behaviors from week to week, thus representing a confounding variable. A comparison of the baseline period (week 1, during which the RDCW system was inactive) to the following three weeks (during which RDCW was active) showed very little difference in how often the 36 randomly selected drivers engaged in secondary behaviors (see Figure 6 in the Results section). As such, it was deemed appropriate to include data from all four weeks of the drivers' experience in assessing the overall frequency and effects of secondary behaviors on driving performance.

Video analysis and coding. Coding of the exposure video for evidence of secondary behaviors was performed using a custom data visualization tool created in Visual Basic. A screenshot of this application is provided in Figure 3. Note the two windows of video data, one forward camera and one face camera. The application allowed researchers to query a relational database which included the video and vehicle-based performance measures using SQL programming language, and to write to a table within the database to further record what secondary behaviors were observed in the video clips. The application also allowed the researchers to play the video frame-by-frame, at various speeds, enabling measurements to be made regarding, for example, how often, and for what duration, the driver's direction of gaze was not toward the forward scene. Each video was played multiple times, as a researcher coded what, if any, secondary behavior(s) were observed.

Figure 3. Screen shot of video coding application.

Two research assistants were responsible for reviewing and coding the sample of 1,440 exposure video clips. Prior to coding the entire set of video clips, an inter-rater reliability procedure was conducted in which the same 50 video clips were independently coded by each of the two research assistants. The results of this initial coding were then compared to see how much coding discrepancy existed between the two reviewers. A criterion of at least 80% agreement across all 50 exposure clips was established for each item coded (e.g., the time the driver's gaze was away from the forward scene, whether the driver was engaged in a secondary behavior, etc.). After meeting this criterion, the research assistants then examined the specific cases in which there remained disagreed. For each case in which there was a discrepancy between their ratings, the two research assistants together reviewed the video again to reach consensus. After the inter-rater reliability procedure was completed, the remaining 1,390 exposure clips were equally divided between the two researchers for coding.

Independent Variables

As can be seen in Figure 3, the exposure clips were coded on nine different contextual variables (e.g., precipitation, road condition, etc.). Detailed descriptions of these fields can be found in Appendix A. Out of the nine variables, a few especially relevant ones were selected as focal points for the following analyses. These included a list of observed secondary behaviors, as well as measures of how long the driver's eyes were away from the forward scene (the four "TimeAwayFromForward" fields). While the former category identifies what behavior the driver was engaged in, the latter measure provides further context about the focus of the driver's attention. It should be noted, however, that glances away from the forward scene do not necessarily imply driver distraction, as glances away from the forward scene may be inherently necessary to the driving task (i.e., checking the mirrors).

The researchers used a set of categories and subcategories to code secondary behaviors. These included cellular phone behavior, eating (low and high involvement), drinking (low and high involvement), conversation with passengers, in-car system use, a variety of smoking behaviors, grooming behavior (low and high involvement), and "other" or multiple behaviors (i.e., cases in which the driver was performing behaviors that did not fit any other category, or performing multiple secondary behaviors). The distinction between a "low involvement" and "high involvement" behavior for the eating, drinking and grooming categories was guided by agreed-upon examples of cases that would fall into each category. Appendix A contains descriptions of how each category and subcategory of behavior was defined and identified in the video coding process. For example, under the broad category of cellular phone behavior, researchers coded whether the driver was involved in conversation on the cellular phone, was dialing a number, or reaching for the phone.

It should be noted that audio information was not associated with the video clips. If a given behavior seemed ambiguous some interpretation by the researchers performing the coding was required. This was most evident when the driver's mouth was moving because it was not always clear whether this signified a conversation with a passenger, singing, talking to one's self, or even highly-involved chewing (singing and chewing gum were not considered secondary behaviors in the following analyses). The face camera was positioned such that a limited view of the vehicle cabin was available in an attempt to protect the identity of unconsented passengers. Therefore it was not always possible to determine, for example, where the driver's hands were or whether there were passengers present. Finally, it is worth noting that the driver did not have to be engaged in a given secondary behavior for the duration of the 5s clips to be coded as such; even if the behavior ended shortly after the first frame of video, the event was coded as having that behavior present.

In addition to the secondary behaviors and glances away from the forward scene, other measures were used to examine the conditions in which secondary behaviors were likely to occur. These included the video coding of road condition (dry vs. wet/snowy) and measures that were obtained from the vehicle's on-board sensors, such as whether the driver was in a curve, whether the driver had applied the brakes during the clip, whether the clip occurred during the day or night (calculated from solar zenith angle), and what type of road the driver was on (e.g., limited access road vs. minor surface road, etc.).

Dependent Measures

Data from the instrumented vehicle's on-board sensors made possible the examination of several common measures of driving performance. Among them were variability of steering wheel angle, mean and variability of lane position, variability of speed, and mean and variability of throttle position. Steering wheel angle and lane position represent measures of latitudinal control while throttle and speed represent measures of longitudinal control. All vehicle-based data was recorded at 10 Hz. Thus, for each five-second exposure video clip, there were 50 individual data points for every measured variable. Details regarding the sources and resolution of the vehicle-based data can be found in LeBlanc et al. (2005). Means of driving performance measures were calculated over the duration of a five-second clip, such that each of the individual 1,440 clips had an associated mean value. In addition to calculating the standard deviations of these measures (a commonly used measure of driving performance), we also applied statistical models to them, hoping to derive measures of variability that were more descriptive and robust.

Because time-series data such as these often exhibit autocorrelation (i.e., each observation tends to be highly correlated with immediately preceding observations, violating the assumption of independent observations), the raw observations for each driving performance measure were fit with autoregressive models. A procedure known as autoregressive integrated moving average (ARIMA) that can model a data series' autocorrelations and general trends over time, was implemented. The "random" error variance in these models is typically considered noise that the researcher wishes to eliminate from time-series analyses so that general trends can be seen more clearly. However, in the present case, the random error from these models is precisely what was to be examined. This is because the error term theoretically consists of any variance in the driving performance measure that is not part of the "smooth" or intentional driving process, but rather originates from relatively random driving corrections, such as might occur when the driver is distracted or simultaneously engaged in another behavior.

An example of this is presented in Figures 4 and 5. Both figures represent the raw observations of throttle position (percentage) for exposure durations of five seconds. What is interesting about these two data series is that the standard deviation of throttle position is actually higher for the data in Figure 4 (34.3 compared to 25.2 for the data in Figure 5). However, the data in Figure 4 are highly autocorrelated. It is rather the type of variation exhibited in Figure 5 that was of primary interest in the present study. After fitting the autoregressive model for throttle position, the variance in Figure 5 was considered higher than in Figure 4, which more readily allows modeling the association between secondary behaviors and "random" variance.

For each driving performance measure, a series of different ARIMA models were fit to the data to select the most appropriate model. Because all measures included cases in which the data were nonstationary (i.e., exhibited a trend over time), each data series was differenced such that the change in the measure from observation-to-observation was modeled instead of the series itself. The ARIMA model selected for most measures was a second-order differenced autoregressive model, or ARIMA(2, 1, 0). For lane position variance, a third-order differenced autoregressive model ARIMA (3, 1, 0) proved to be the best fit to model the autocorrelation. After the best models were fit for each measure, the percent of autocorrelation still present in the data ranged from 8% to 15%, depending on the fit of the model to the individual measure.

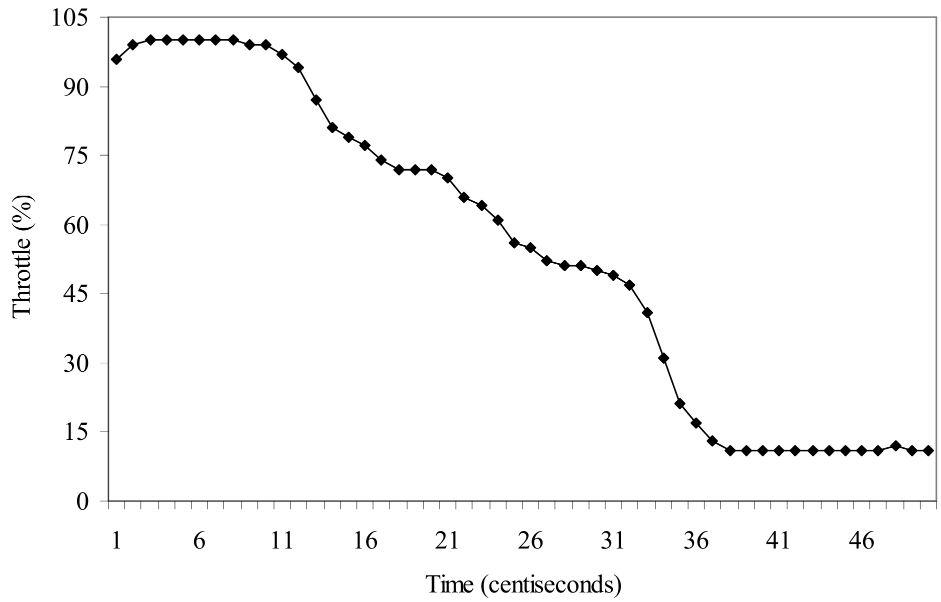

Figure 4. Smooth movement of throttle position.

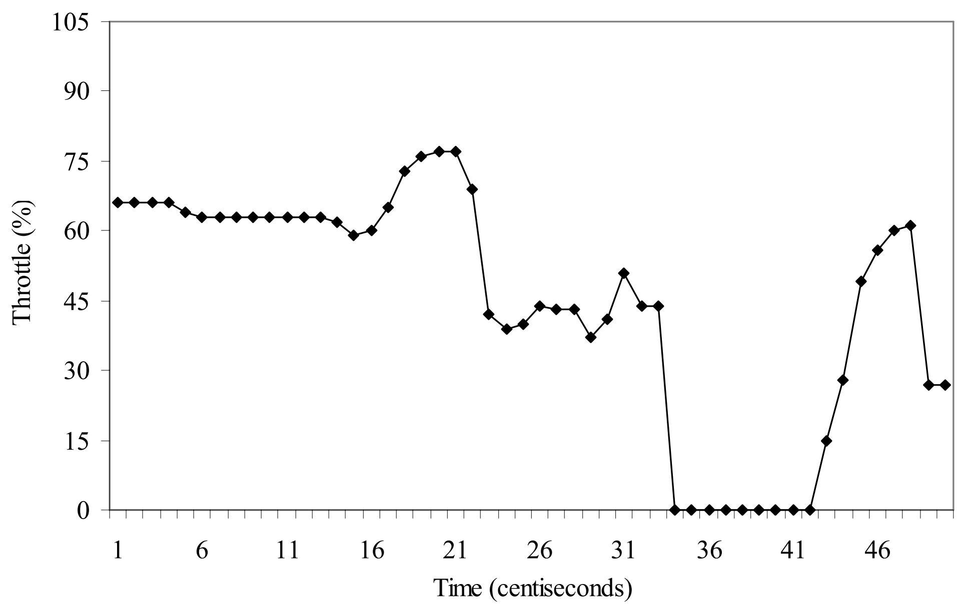

Figure 5. More jagged or “random” movement of throttle position.

RESULTS

Descriptive Statistics

Drivers were engaged in secondary behaviors in about one-third of the reviewed clips (486 out of 1,440 exposure clips). The most frequently observed secondary behavior was "conversation" with a passenger. This was present in 220 of the clips, or 15.3%. "Grooming" was the second most common secondary behavior, 6.5% of the clips, and using a "hand-held cellular phone" was the third most common, 5.3% of the clips. It should be noted that the frequency of these three particular behaviors as observed in the present study is consistent with the previously published findings of Ervin, et al (2005) and somewhat similar to the findings of Stutts et al. (2003) as it relates to the relative frequency of conversation with passengers.

Based on initial frequency-counts, some low-frequency behaviors were collapsed together in order to form groups that could be compared more readily. For example, low and high involvement behaviors for each category were collapsed together: Hands-free cellular phone use ($n = 2$) was grouped with hands-held cellular phone use ($n = 18$); eating ($n = 18$) and drinking ($n = 10$) were grouped; smoking behaviors ($n = 9$) were collapsed into "other" behaviors; and multiple behaviors were separated into its own group. This led to a final frequency distribution, shown in Table 1. Frequency counts of non-collapsed behaviors (e.g., low and high involvement) can be found in Appendix A. Because the category of "multiple behaviors" often included one or more of the categorized behaviors, the rightmost column in Table 1 provides the frequency with which each individual behavior was observed within "multiple behaviors." Out of all of the behaviors, "grooming" was most often observed concurrently with another behavior.

Table 1
Secondary behaviors exposure review counts.

Observed Behavior	*f*	%	Multiple behaviors (*f*)
No secondary behavior	954	66.2	
Conversation	219	15.3	21
Grooming	96	6.5	26
Cellular phone	76	5.3	10
Eating/Drinking	28	1.9	2
Multiple behaviors	31	2.2	-
Other	36	2.5	5
Total	1,440	100	64

Appendix B provides a breakdown of these observed behavior frequencies by driver, as well as the total mileage of each driver over the course of the four-week FOT. All drivers had at least four or more cases of observed secondary behaviors among their exposure clips, and the average per driver was 14 (SD = 6.2). It is worthwhile to note that 24 of the 76 observed "cellular phone" exposure clips (32%) came from just two drivers.

Driver Age and Gender. Table 2 shows the percentage of clips in which each type of secondary behavior was observed for each age group and gender. Notice that the occurrence of secondary behaviors generally decreased with age, with the largest difference among age groups seen in cellular phone use. Two notable exceptions to this trend included the following: The proportion of clips with "conversation" was somewhat lower for younger drivers, with little difference between middle and older age groups. In addition, the middle-age group had the highest percentage of "multiple" behaviors.

Females were observed to have generally higher rates of secondary behaviors than males, with the exception of "grooming" and "cellular phone" use. The largest difference between males and females was seen for "conversation," in which females were observed conversing in 17.8% more of their exposure clips than males.

Table 2
Percentage of exposure clips containing secondary behaviors by age group and gender.

Secondary behavior	Age group			Gender	
	Younger	Middle	Older	Male	Female
Conversation (n = 219)	29.2	35.6	35.2	41.1	58.9
Grooming (n = 96)	37.5	35.4	27.1	54.2	45.8
Cellular phone (n = 76)	55.3	36.8	7.9	53.9	46.1
Eating/Drinking (n = 28)	46.4	32.1	21.4	42.9	57.1
Multiple (n = 31)	38.7	41.9	19.4	45.2	54.8
Other (n = 36)	47.2	41.7	11.1	41.7	58.3
Mean percentage:	42.4	37.3	20.3	46.5	53.5

Period of Exposure. Figure 6 shows the percentage of clips that had secondary behaviors for each of the four weeks that the drivers had the vehicle. The relative frequency changed very little by week. Week 2 saw the highest percentage of secondary behaviors (present in 36% of the exposures) while week 4 had the lowest percentage at 32%. The higher percentage present in Week 2 consisted mainly of more clips with "conversation" in them (19% in Week 2 compared to 15% average over all weeks). Because Week 2 corresponded to when the RDCW warning system became active, the higher frequency of conversations may have been caused by the drivers' enthusiasm to explain the RDCW system to passengers.

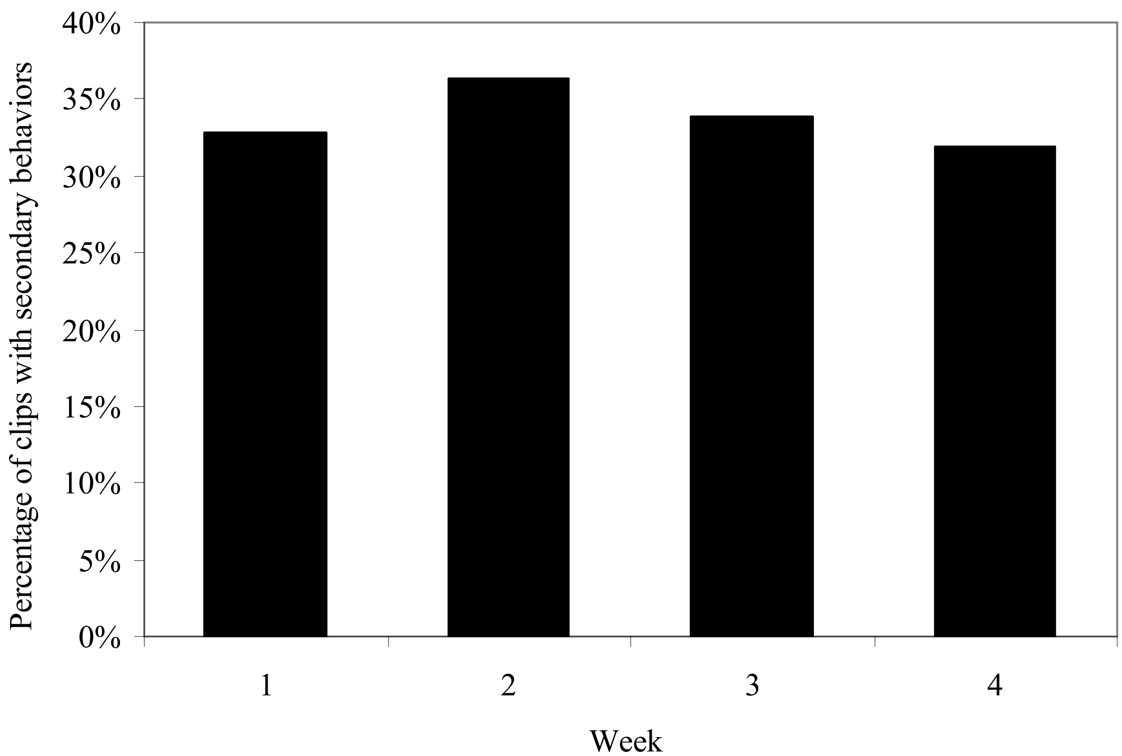

Figure 6. Secondary behavior percentages by week.

Road Type. Secondary behaviors by road type was initially analyzed by four categories of road type: Limited access (freeway), major surface roads, minor surface roads, local roads (such as residential or subdivision roads), and ramps (entrance, exit, or transition). Figure 7 compares the observed frequencies of all secondary behavior clips (collapsed) and nonsecondary behavior clips by road type. Notice that most of the driving (across all exposure clips) occurred on limited access roads. Further, local streets and ramps together only accounted for a small portion (roughly 8%) of the 1,440 exposure clips. It should be noted that in nine cases, the road type could not be identified; these cases were therefore excluded from all analyses by road type.

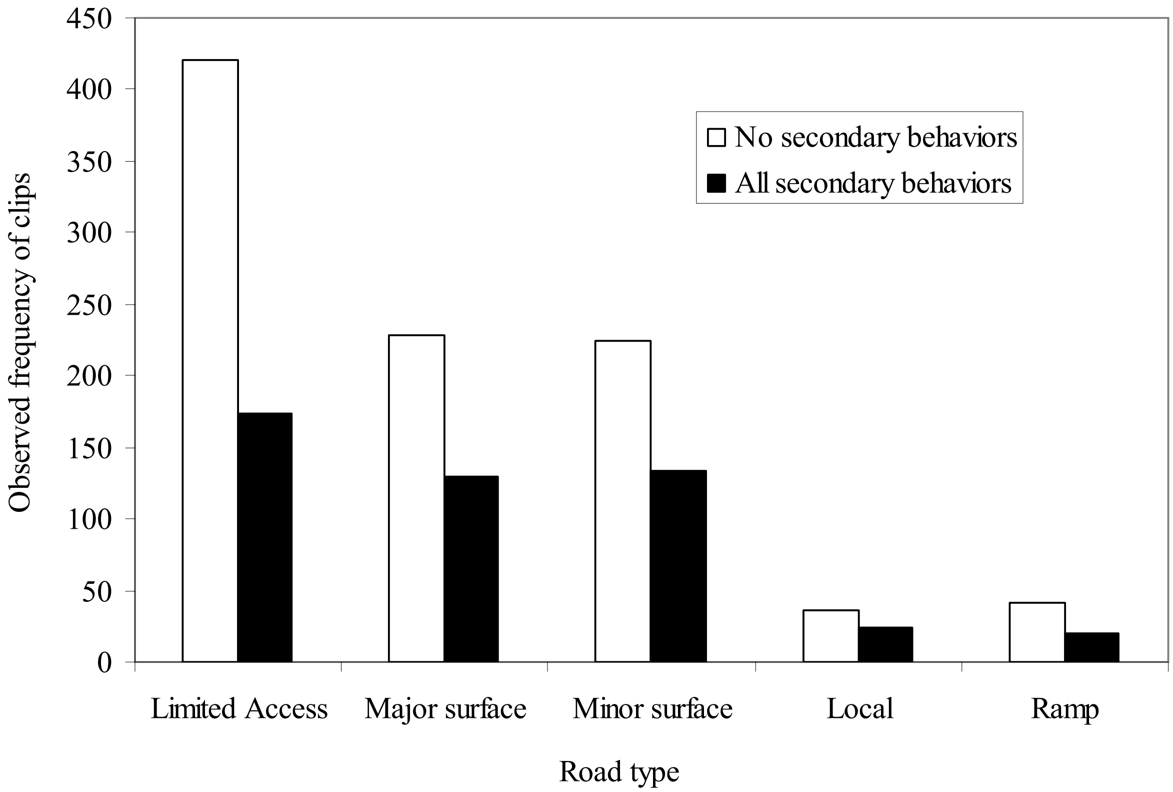

Figure 7. Observed frequencies of secondary and nonsecondary behavior clips by road type.

To illustrate on what types of roads drivers typically chose to engage in secondary behaviors, Figure 8 shows the same data as Figure 7 in a slightly different format. In this figure, the observed frequency of each type of secondary behavior is presented as a function of road type. Note that this figure omits those clips in which no secondary behaviors were observed. While drivers engaged in most types of secondary behaviors more on limited access roads (e.g., conversations, grooming, multiple behaviors, and "other" behaviors), notice that cellular phone use occurred mostly on major surface streets, and eating/drinking occurred mostly on minor surface streets. None of these differences in observed frequencies, however, was particularly large. Because of this, and the fact that there were relatively few exposure clips that took place on local streets and ramps, later analyses compare only limited access roads to all other road types combined.

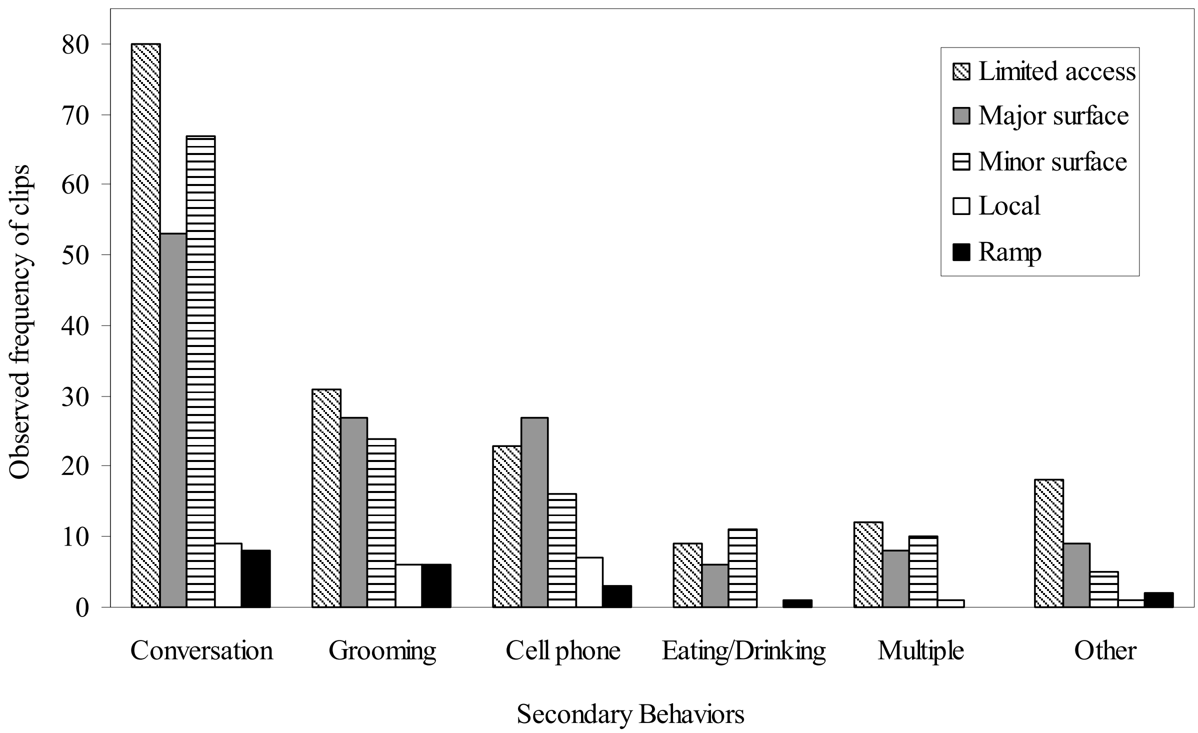

Figure 8. Observed frequencies of each secondary behavior by road type.

Time of Day and Weather Condition. The great majority of the exposure video clips (both with and without secondary behaviors) captured daytime driving on dry roads. This is illustrated in Table 3, which shows the percentage of clips that occurred during daylight hours versus nighttime, and the percentage that occurred on dry versus wet/snowy roads. The distinction between day and night was defined using solar zenith angle (measured via a global positioning system installed on the vehicles). "Night" began at *civil twilight*, or at 96° solar zenith angle, and "day" was defined as any time when the solar zenith angle was below 96°. While a higher proportion of the clips sampled occurred during daylight, the likelihood of observing drivers taking part in secondary behaviors was actually slightly higher at night. Notice, however, that eating and drinking occurred almost exclusively during the day. In addition, it is interesting to note that 100% of the observed cases of "multiple" behaviors occurred only on dry road conditions.

Table 3
Percentage of exposure clips by time of day and road condition.

Secondary behavior	Time of day		Road condition	
	Day	Night	Dry	Wet/snow-covered
None (n = 954)	80.0	20.0	88.1	11.9
Conversation (n = 219)	68.5	31.5	84.9	15.1
Grooming (n = 96)	79.2	20.8	90.6	9.4
Cellular phone (n = 76)	67.1	32.9	90.8	9.2
Eating/Drinking (n = 28)	96.4	3.6	89.3	10.7
Multiple (n = 31)	71.0	29.0	100.0	0.0
Other (n = 36)	80.6	19.4	91.7	8.3
Mean percentage:	77.5	22.5	90.8	9.2

Road Curvature and Brake Application. Table 4 is similar to Table 3, but shows the percentages of exposure clips in which the driver was negotiating a curve or using the brake pedal during any portion of the clip. A "curve" was defined as any curvature in the road with a radius less than or equal to 1,000 meters. Brake pedal use did not have to begin or end within the clip duration to be considered "braking." Rather, if any portion of the exposure clip contained any amount of braking, then that driver was "braking" during the clip. Recall that all of the clips were associated with velocities of 11.18 m/s (25 mph).

Table 4
Percentage of exposure clips by curvature and brake use.

Secondary behavior	Curvature		Brake use	
	Curve	No curve	Brakes	No brakes
None (n = 954)	11.7	88.3	13.0	87.0
Conversation (n = 219)	13.2	86.8	16.9	83.1
Grooming (n = 96)	17.7	82.3	19.8	80.2
Cellular phone (n = 76)	6.6	93.4	13.2	86.8
Eating/Drinking (n = 28)	14.3	85.7	28.6	71.4
Multiple (n = 31)	6.5	93.5	22.6	77.4
Other (n = 36)	13.2	86.8	8.3	91.7
Mean percentage:	11.7	88.3	17.5	82.5

Notice that the majority of exposure clips included times when the driver was neither in a curve nor using the brakes. The categories of "cellular phone" and "multiple" behaviors were observed least in curves, whereas "eating/drinking" and "multiple" behaviors were associated with the highest proportion of braking events. In other words, it appears that drivers may be choosing to engage in certain behaviors less often when they were negotiating curves, but that taking part in other behaviors are more likely to require use of the brakes. This may reflect a perception of higher risk associated with some behaviors, and thus the drivers exercised a greater degree of caution.

Glance Frequency. Table 5 provides a summary of the frequency and duration of glances away from the forward scene by secondary behavior type. The two major columns of data refer to the first and second glances in relation to the first frame of the five-second video clips. Overall, at least one glance away from forward was observed in about 61% of the exposure clips, with fewer second glances. Notice that the relative frequency of first glance away from the forward scene was lower during clips in which a cellular phone was being used relative to any other category, including when no secondary behaviors were taking place. This trend can also be seen for second glances, and differs from all other secondary behaviors (which were associated with a greater relative frequency of glances away from forward). Furthermore, cellular phone use was associated with the shortest durations for glances away from the forward scene, for either first or second glance. Glance duration is more formally addressed in a following section.

Table 5
Glance frequency and duration (sec) of away from the forward scene by behavior type.

Secondary behavior	First glance			Second glance		
	f	%	Mean duration	*f*	%	Mean duration
None (*n* = 954)	531	55.7	0.70	315	33.0	0.85
Conversation (*n* = 219)	133	60.7	0.73	79	36.1	0.78
Grooming (*n* = 96)	59	61.5	0.82	32	33.3	0.72
Cellular phone (*n* = 76)	41	53.9	0.55	23	30.3	0.58
Eating/Drinking (*n* = 28)	19	67.9	0.64	12	42.9	0.88
Multiple (*n* = 31)	18	58.1	0.80	12	38.7	0.62
Other (*n* = 36)	24	66.7	0.87	16	44.4	1.12
Means:	117.9	60.6	0.73	69.9	37.0	0.79

Inferential Statistics

Linear mixed-effects models were fit on each of the seven driving performance measures. The mixed-effect model is a broader form of the general linear model, and this type of analysis was chosen for several reasons. First, because the structure of the data represent a within-subjects design (i.e., there were potentially multiple observations of the same conditions on the same driver), a repeated-measures analysis was required. However, because of the observational nature of the data, there were largely unequal *n*'s among the levels of the independent/predictor variables. That is, the data were unbalanced. More traditional forms of the general linear model (such as the ANOVA) exclude entire cases from the data set if an observation on one variable is missing. Further, using mixed-effects models allow one to model the variance/covariance structure of the data, a feature that can lead to more accurate parameter estimates and test statistics.

For each analysis, models were initially fit using a two-level factor of secondary behavior: No secondary behavior versus all types of secondary behaviors combined. This was done to reduce the degrees of freedom and to determine whether secondary behaviors in general had an overall effect on the dependent/outcome measures. The models were then refit using a seven-level factor of secondary behavior (i.e., no secondary behavior and six individual types of behavior) to see if any specific behavior had a unique relationship to the outcome variables.

Unless otherwise specified, all models initially included the factors of age group (three levels), gender (two levels), secondary behaviors (two or seven levels), road type (two levels: limited access vs. all other roads), road condition (two levels: dry vs. wet/snowy), road curvature (two levels: curve vs. no curve), and brake use (two levels: brake application vs. no brake application). The method of model selection used for all analyses was a "backwards" selection in which all main effects were initially included. Each model was then refit multiple times, each time excluding the main effect that was least significant. When only significant main effects remained, the model was refit again to include those main effects and their interaction terms. Finally, the nonsignificant interactions were removed to obtain the final model for each analysis.

Each analysis also included random effects of "driver" and "driver by within-subject factor" interactions. In other words, the random variance between drivers was included as a parameter within each model. Thus, if the effects of between-subjects variables (e.g., age or gender) or within-subjects variables (e.g., secondary behaviors) were not significantly greater than random variance among drivers, they would not reach statistical significance in the model.

In the following summary of results, graphs depict predicted parameter estimates (i.e., least square means) from the mixed-effects models. These estimates were calculated such that they represent unweighted means, but have estimated standard errors that account for the covariance structure in the model. This resulted in predicted means that were very close to the observed means, but more accurately reflect the random variance among drivers and correlations among repeated measurements on the same driver. This also allowed appropriate 95% confidence intervals to be constructed for each set of means.

Glance Duration. Two mixed-effects models analyses were performed, one on the mean duration of first glances away from the forward scene, and one on the mean duration of second glances away. While the first model found no significant effects, the model for second glances contained a significant main effect of secondary behaviors, $F(6, 479) = 2.52$, $p < .05$ (see Table 5 for the observed means). While the difference between no secondary behaviors and the "cellular phone" category failed to reach significance when Bonferroni corrections were used for multiple pairwise comparisons, glance durations away from the forward scene were actually at their shortest when drivers were using the cellular phone. This was true for both second and first glance durations. The longest mean glance duration was associated with "other" behaviors, and had the greatest influence on the statistical significance of the factor.

Steering Angle Variance. Examination of the steering angle variance data revealed a substantial outlier among the 1,440 observations. While the median value of all the other steering angle data points was 0.13°, the value of the outlier was 24.9°. A review of the associated video clip revealed that the driver had just turned into a shopping center driveway and repeatedly turned the steering wheel back and forth to extreme angles. To avoid excessive influence on model parameters from this case it was excluded from the following analyses.

A mixed-effects model was fit on steering angle variance using the aforementioned between- and within-subjects factors, including the two-level factor of secondary behaviors (all secondary behaviors versus no secondary behaviors). The main effect of secondary behavior was significant, $F(1, 33.1) = 10.6$, $p < .01$. Secondary behaviors were associated with greater variance in steering angle.

Because the effect of secondary behaviors in the first model was significant, a second mixed-effects model was fit using the seven-level factor of secondary behavior. In this model, the effect of secondary behavior just failed to reach significance (p = .053). However, each secondary behavior was associated with a higher mean steering angle variance. This can be seen in Figure 10, which displays the estimated means. The error bars represent 95% confidence intervals.

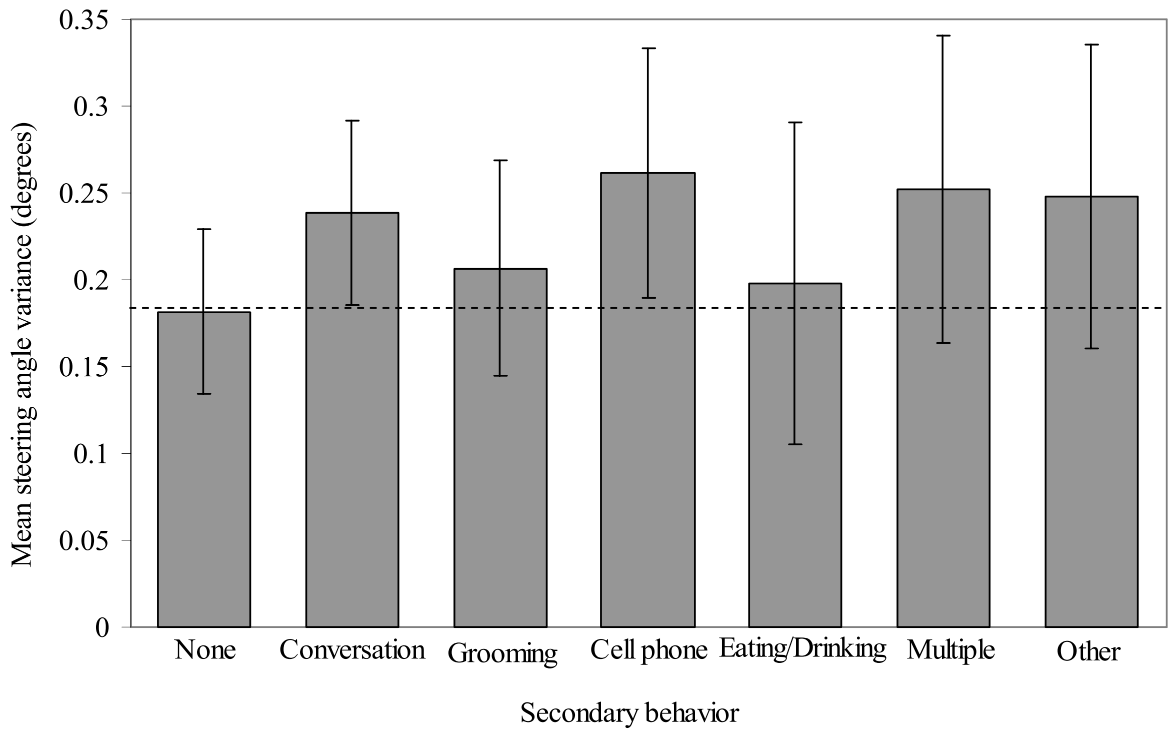

Figure 10. Mean steering angle variance (degrees) for each type of secondary behavior.

Notice that cellular phone use was associated with the highest mean steering angle variance. Steering angle variance associated with "eating/drinking" was not as high, although the error was larger (presumably because of the low *n* in this group). It is plausible that the larger standard error in the last three categories of secondary behavior was a factor in the nonsignificant main effect. It is worth noting that an analysis of the more conventional measure of steering angle variability (i.e., the standard deviation of steering angle) yielded very similar results as the ARIMA-fitted measure, except that the effect of secondary behavior was somewhat weaker. This may suggest that the more "random" variance described by the ARIMA-fitted measure has the potential to better capture the relationship under investigation. The standard deviation of steering angle by secondary behavior can be found in Appendix C (Figure C-1).

There were no significant effects of age group or gender on steering angle variance. However, the main effect of brake use was significant, $F(1, 44.4) = 9.6$, $p < .01$. Steering angle variance was higher in those clips in which the driver was using the brakes than when the brakes were not active (estimated mean variance of 0.29° and 0.18°, respectively).

There was also a significant interaction between road type and road curvature on steering angle variance, $F(1, 37.4) = 14.1$, $p < .001$. Again, error bars represent 95% confidence intervals of the mean. Most noticeable is the large mean steering angle variance associated with curves on surface (non-limited access) roads. This is not altogether surprising, considering that surface roads and ramps typically have sharper curves than limited access roads. Both of the main effects in this interaction were significant as well: $F(1, 19.6) = 28.5$, $p < .0001$ for road curvature, and $F(1, 48.9) = 22.3$, $p < .0001$ for road type. In other words, steering angle variance was generally lower on limited access roads, and was generally lower when the driver was not negotiating a curve.

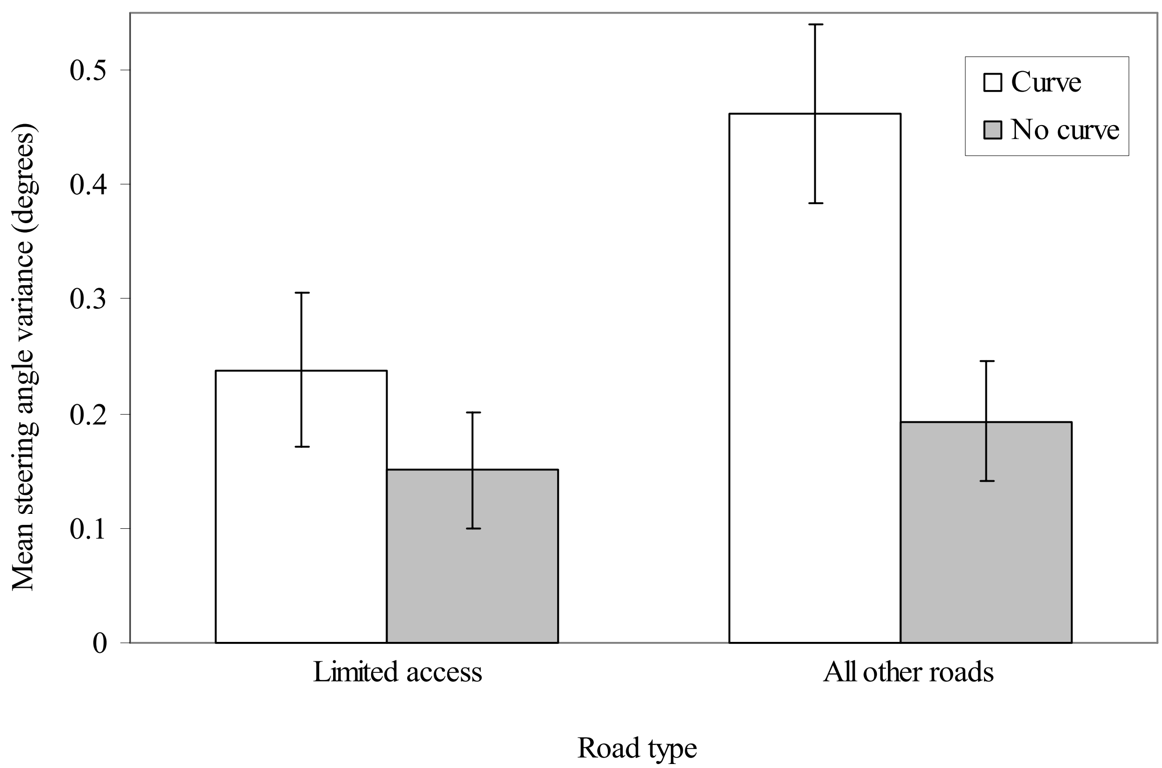

Figure 11. Mean steering angle variance (degrees) by road type and road curvature.

Mean Lane Position and Lane Position Variance. The measurement of lane position was associated with a "confidence" level in the data collection process. The confidence level was calculated based on how well the forward-looking video camera could identify lane markings on the road. This was affected by many factors, such as ground covering (e.g., dirt or snow), the quality and/or presence of the painted lane markings and proper camera calibration. Scatter plots revealed that at levels below roughly 20% confidence, lane position measures were characterized by substantially higher variability. Therefore, for all analyses that included measures of lane position, cases with confidence below 20% (or 201 cases) were excluded. Further, for the remaining cases, the lane position confidence was used as a covariate in every model. This controlled for any influence of the confidence level on the outcome variables.

The distance from lane center (i.e., the absolute value of the lane position) was used to calculate the mean lane position. Thus, no differentiation was made between being off-center to the left or off-center to the right. The mixed-effects model for mean distance from lane center showed two significant effects; on curves, the mean distance from lane center was higher than when not on curves, $F(1, 1233) = 18.3$, $p < .0001$, and mean distance from lane center was also higher on wet/snowy roads than on dry roads, $F(1, 1193) = 8.47$, $p < .01$. There were no significant effects of age group, gender, or secondary behavior. A graph of mean distance from lane center by secondary behavior can be found in Appendix C (Figure C-2).

One could argue that the sampling procedure employed could potentially have affected this outcome measure, as events in which the driver was drifting in his/her lane were less likely to be included in the sample due to the elimination of exposure video clips in which RDCW alerts were issued. However, an analysis of lateral drift warning data did not show much, if any, difference in the occurrence of secondary behaviors between exposure video clips and the RDCW alert events. To illustrate this, Table 6 again lists the observed frequencies of each secondary behavior in the 1,440 exposure clips (as in Table 1). However, the rightmost columns in Table 6 represent the observed frequencies of secondary behaviors for a different sample of videos (exposure videos used in the current analyses and exposure clips containing lateral drift warnings excluded from the current analyses). This latter sample represents 854 randomly selected events in which the driver had drifted sufficiently to prompt a lateral drift warning. In other words, while the left-most columns represent driving while relatively centered in the lane, the right-most columns represent driving while drifting to the left or to the right. Notice that the percentages of observed secondary behaviors are quite similar between the two samples, suggesting that eliminating the exposure clips that included RDCW alerts was unlikely to significantly alter the outcome of the present analyses.

Table 6
Frequencies of observed secondary behaviors for exposures and lateral drift warnings.

Secondary behavior	Exposure videos		Lateral drift warning videos	
	f	%	*f*	%
None	954	66.2	548	64.2
Conversation	219	15.3	147	17.2
Grooming	96	6.5	61	7.1
Cellular phone	76	5.3	37	4.3
Eating/Drinking	28	1.9	12	1.4
Multiple	31	2.2	26	3.0
Other	36	2.5	23	2.7
Total:	1,440	100	854	100

Results for lane position variance were mixed. For the ARIMA-fitted measure, no significant differences were seen among any of the independent/predictor variables. However, the more common measure of standard deviation of lane position showed a number of significant differences. The effect of secondary behaviors on the standard deviation of lane position was significant, $F(6, 326) = 2.2$, $p < .05$. Figure 12 illustrates this effect. No direct relationship seems to emerge from examining the means; conversation, cellular phone and multiple behaviors were associated with greater variability in lane position while other secondary behaviors were associated with lower variability. The pattern, however, seems somewhat consistent with the results for steering angle variance. Bonferroni-corrected pairwise comparison tests did not reveal any significant differences among the levels of the effect, suggesting that these differences were not especially strong.

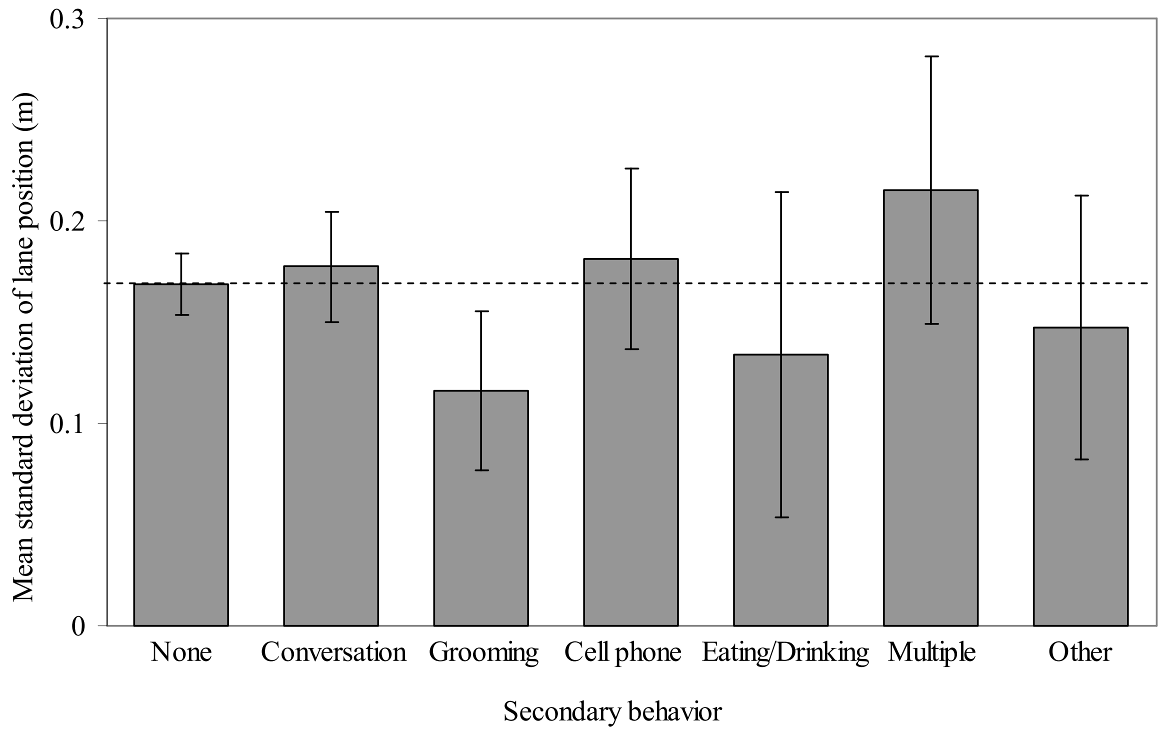

Figure 12. Mean standard deviation of lane position for each type of secondary behavior.

There was also a significant effect of age group on the standard deviation of lane position, $F(2, 40.5) = 4.3$, $p < .05$. This is shown in Table 7. There was higher variability in lane position for the younger age group, while the middle and older age groups showed a similar level of variability. There was no significant effect of gender.

Table 7
Mean standard deviation of lane position by age group.

Age Group	St. dev. (m)
Younger	0.19
Middle	0.15
Older	0.16

Finally, higher standard deviations of lane position were observed when drivers were negotiating curves, $F(1, 142) = 7.9$, $p < .01$. This is not a surprising finding, as drivers often "cut corners" going into curves or are not prepared for them, drifting near or exceeding the lane boundaries. The estimated means were 0.16 m for non-curvature clips compared to 0.22 m for curvature clips.

Mean Throttle Position and Throttle Variance. The mixed-effects model for mean throttle position showed no significant main effect of secondary behavior (for neither the two- nor seven-level factors). The estimated means can be found in Appendix C (Figure C-3). There were, however, two significant effects from this analysis, neither of which were hardly surprising: Brake use was associated with lower mean throttle positions, $F(1, 92.7) = 411.2$, $p < .0001$, and driving on limited access roads was associated with higher mean throttle positions, $F(1, 47.9) = 18.4$, $p < .0001$. Similar to other analyses, there were no significant effects of age or gender on mean throttle position.

The results for mean variance in throttle position were difficult to interpret. Neither of the mixed-effect models analyses (using the two- or seven-level factors of secondary behavior) showed any significant main effects. Nonetheless, it is worthwhile to compare the means of throttle variance by secondary behavior to those of steering angle variance. The estimated means for throttle variance are presented in Figure 13. Notice that many of the behaviors were associated with a higher throttle variance (similar to the findings for steering angle variance), but that a couple of behaviors (noticeably "eating/drinking") were associated with lower mean variances.

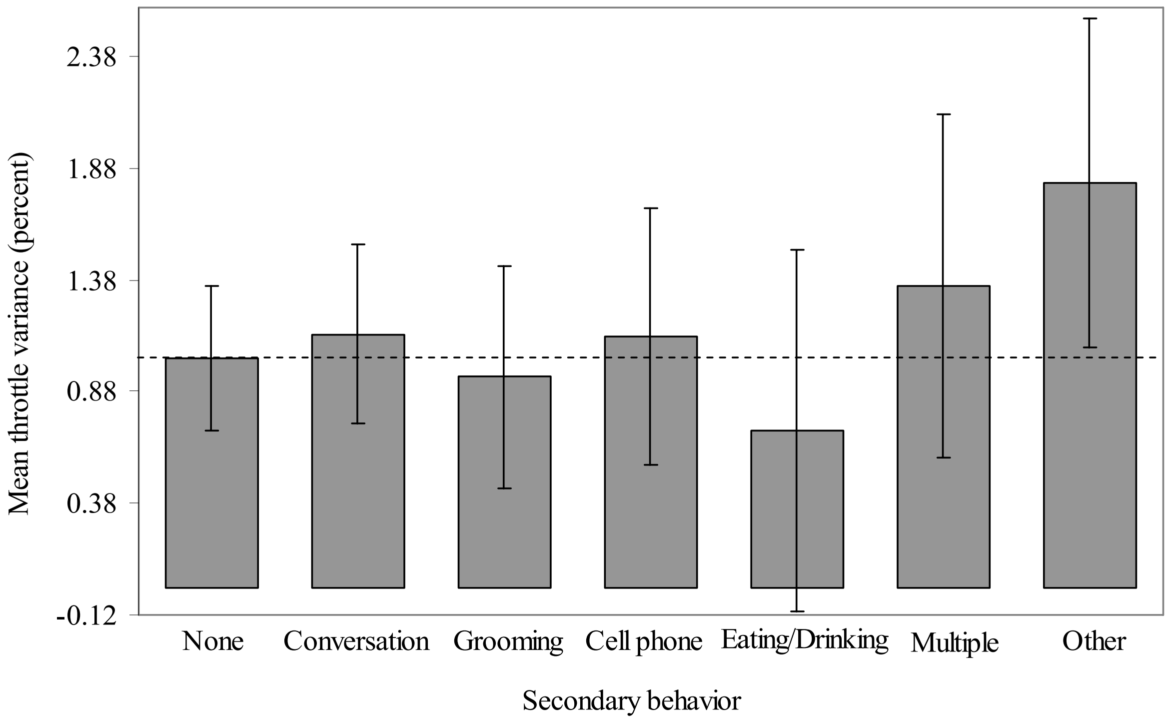

Figure 13. Mean throttle variance (percent) for each type of secondary behavior.

While in one sense it seems that no clear relationship could be seen between secondary behavior and throttle variance, examining the data slightly differently raises an interesting issue. Figure 14, for example, shows the percentage of cases in which either throttle or braking behavior was present as a function of secondary behavior type. In the majority of cases (i.e., in which no secondary behavior was observed), engagement of throttle (by any amount and/or duration) occurred in roughly 90% of the cases, while engagement of the brakes (again, by any amount and/or duration) occurred in 13% of the cases. Notice, however, the respective proportions for "eating/drinking." There were noticeably fewer cases of throttle engagement (a 10.7% reduction) and more cases of braking engagement (a 15.6% increase). In other words, drivers were less likely to use the throttle, as opposed to the brake, while eating or drinking. Thus, while throttle variance is lower in this category, it is not necessarily indicative of lower variance in longitudinal control of the vehicle. Therefore, variance in speed may more accurately capture longitudinal control in certain circumstances. Finally, it is worth mentioning that no significant effects were found when the more conventional measure of the standard deviation of throttle was examined.

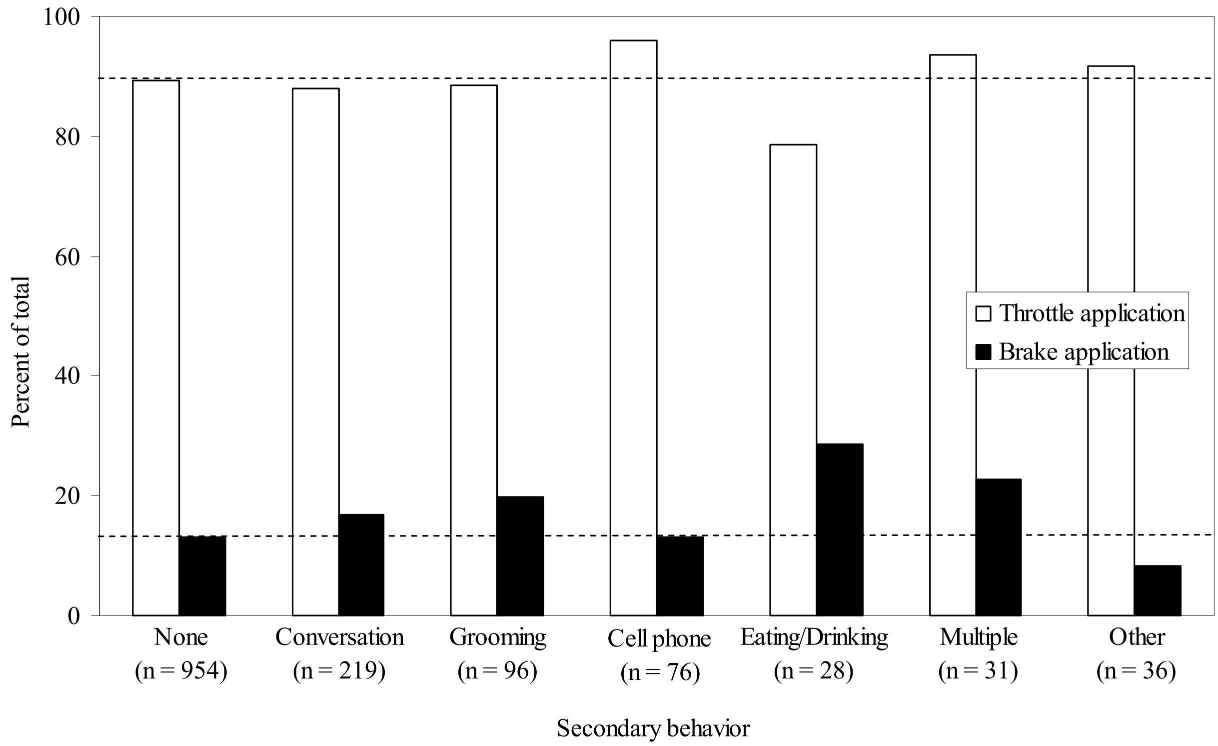

Figure 14. Percent of exposure clips containing throttle or braking application by secondary behavior type.

Speed Variance. Both mixed-effects models of speed variance (including the two-level and seven-level factors of secondary behavior, respectively) showed the same set of significant effects. Results are therefore presented for the seven-level model.

The main effect of secondary behavior on the ARIMA-modeled measure of speed variance was significant, $F(6, 1{,}371) = 3.2$, $p < .01$, and can be seen in Figure 15. For most behaviors, whether braking or not, speed variance was lower when drivers were engaging in secondary behaviors. While it is difficult to interpret this in light of the higher throttle variance findings, it may suggest that drivers were exercising more longitudinal control (and smoother longitudinal movements) while engaging in secondary behaviors, but are making more throttle corrections to achieve this.

There was also a significant interaction effect between brake use and secondary behaviors, $F(1, 1{,}354) = 3.7$, $p < .01$. This is illustrated in Figure 15. Cases not associated with any braking were roughly equivalent in speed variance across secondary behavior types. However, when drivers were braking, their speed variance changed considerably, depending on what type of secondary behavior they were engaged in. That is, the drivers' speeds tended to change more smoothly (i.e., less "random" variance) when they engaged in certain types of behaviors, particularly when using the cellular phone. In fact, overall, there was actually less variance in speed when drivers were using the cellular phone relative to any other behavior.

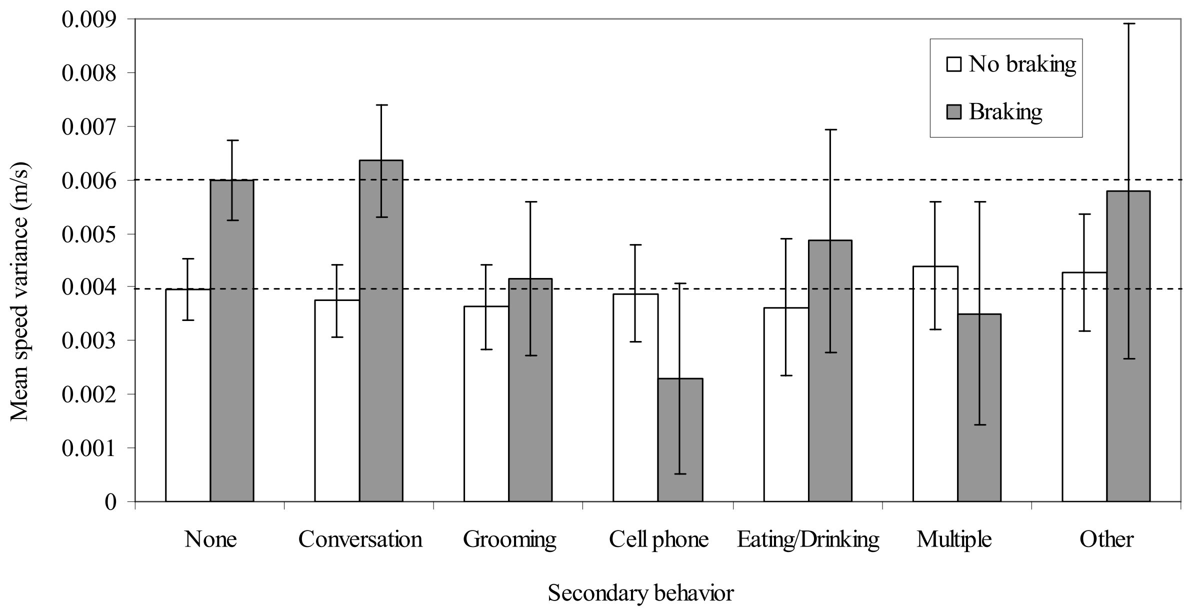

Figure 15. Mean speed variance (m/s), with and without brake application, for each type of secondary behavior.

Admittedly, this is a complicated interaction, made perhaps more difficult to interpret in light of the modified ARIMA-modeled measure of speed variance that was used. For this reason, the same model was fit to the pre-ARIMA measure of speed variability (i.e., the standard deviation of speed over the five-second duration). A reproduction of Figure 15 using this more common measure of speed variability can be found in Appendix C (Figure C-4). The interaction was still significant; the only major difference is seen in the "eating/drinking" category, in which speed variability when braking was higher than braking without secondary behaviors. Otherwise the relationship was quite similar.

Finally, there was also a significant main effect of road type on speed variance, $F(1, 36.3) = 69.1$, $p < .0001$. Surprisingly, drivers had a higher speed variance on limited access roads than on surface roads (estimates of 0.005 m/s versus 0.003 m/s, respectively). It is interesting to note that this effect was reversed in the model that contained the standard deviation of speed. In this latter model, drivers had higher speed variability on surface roads than on limited access roads, $F(1, 1{,}258) = 23.2$, $p < .0001$. Here, the estimates were 0.5 m/s versus 0.3 m/s, respectively. Stated another way, drivers had larger overall changes in speed on surface roads, but these changes were generally smoother and less “random” than on limited access roads.

An illustration may help to conceptualize this relationship. In the top graph of Figure 16, the driver is on a surface road in which there is no road curvature, but he/she is braking. Notice that, overall, the change in speed is substantial, but relatively smooth. Compare this to the data in the bottom graph of Figure 16, which shows a driver on a limited access road in which there is no road curvature or braking. The axes for both graphs contain the same number of units to enable a comparison. Although the overall change in speed is lower for the second driver, the change fluctuates more; it is more “random” and is thus captured as higher variance in the ARIMA modeling.

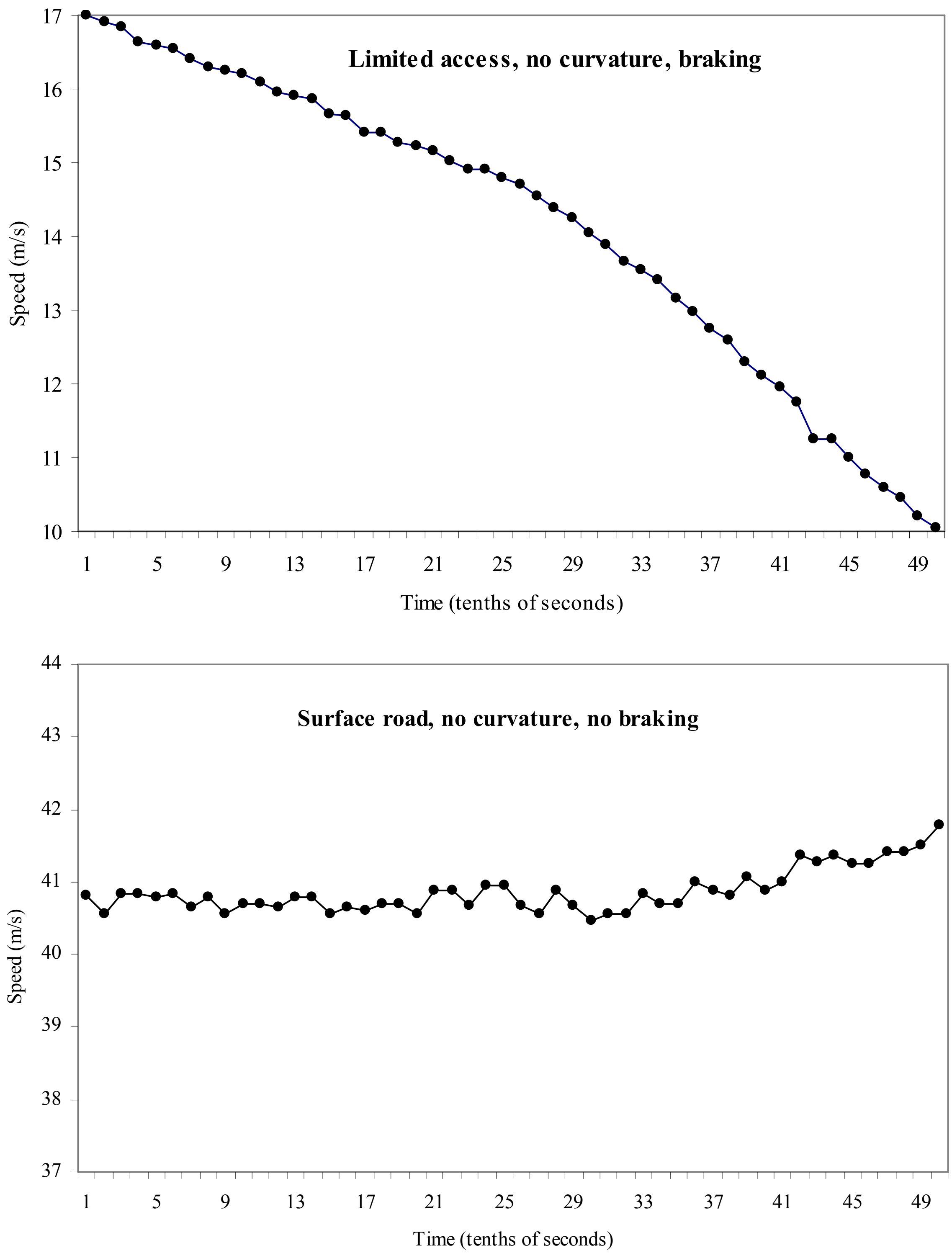

Figure 16. Two examples of variability in speed: limited access road, no curvature, braking (top) and surface road, no curvature, no braking (bottom).

DISCUSSION

Summary

At least on first impression, the results of naturalistic driving performance data suggest that not all secondary behaviors are equal either in their frequency of occurrence or their affect on driving performance. Driver performance is affected differently depending upon the type of secondary behavior the driver is engaged in and the frequency of the behavior, but the frequency with which a driver engages in secondary behaviors is influenced by the roadway environment. It may therefore help to summarize the results by the categories of tasks that were studied.

Conversations with passengers occurred in 15.3% of the clips, followed by grooming (6.5%) and use of a cellular phone (5.3%). Overall, drivers engaged in secondary behaviors in 34.0% of the clips examined, although for younger drivers the mean reached 42.4%. Relative to when and where secondary behaviors tended to occur, it was observed that cellular phone use and multiple behaviors occurred infrequently on curves. Further, eating and drinking occurred almost exclusively during daylight hours, and multiple behaviors always occurred on dry roads.

Cellular phone use was associated with the highest increase in steering angle variance, but was not associated with any differences in mean lane position, and only showed a slight increase in lane position variance. Further, using a cellular phone was not associated with any statistically significant change in mean throttle position or throttle variance, but was rather associated with smoother or less severe braking maneuvers (i.e., less variance in speed when the brakes were applied). Thus, the data do not seem to suggest any strong or consistent connection between cellular phone use and decrements in driving performance related to lane keeping or speed fluctuation. However, the frequency and duration of glances away from the forward scene were at their lowest when the drivers were using cellular phones. It is very likely that the driver's scanning of the traffic environment is thereby reduced, and may be indicative of the differences between continuous perceptual-motor tasks and discrete measures of hazard response (see Horrey & Wickens, 2004).

Eating and drinking similarly did not show any consistent affect on driving performance. While these behaviors were associated with a modest increase in steering variance, they were also associated with a lower standard deviation of lane position. Similar to other behaviors, eating and drinking were not associated with a significant difference in mean throttle position.

Braking behavior was substantially more frequent when drivers were eating or drinking, but while this resulted in a relatively large increase in the standard deviation of speed (compared to braking events in other behavior categories), the ARIMA-modeled variance in speed showed no effect of brake use relative to other behaviors. Glance frequency increased while drivers were engaged in eating and drinking, but the duration of the glances tended to be relatively short. This was particularly the case for initial glances away from the forward scene.

A similar pattern was true for grooming behaviors. There was a slight increase in steering angle variance while grooming, but lower variance (if any change at all) in the other measures of driving performance. Grooming showed the same interesting phenomenon of lower variance in speed, but only during brake use. Glance behavior, relative to the baseline of no secondary behaviors taking place, did not change much either in frequency or duration while drivers were engaged in grooming.

Conversation was associated with higher steering angle variance, and a slight increase in the standard deviation of lane position. Again, mean throttle position and variance were not significantly affected, nor was variance in speed. Here too, glance behavior, relative to the baseline of no secondary behaviors taking place, did not change much either in frequency or duration while drivers were engaged in conversations with passengers.

Multiple behaviors showed the highest increase in the standard deviation of lane position, in addition to increases in steering angle variance. While not statistically significant, multiple behaviors were also associated with increases in throttle variance, and this category of secondary behaviors showed one of the only increases in speed variance when the brakes were not applied. In addition, drivers applied the brakes more often when engaging in multiple behaviors. However, this must be interpreted with caution considering that cases of multiple behaviors only comprised 2.2% of the data. Glance behavior away from the forward scene did not change much relative to the baseline, particularly for initial glances.

"Other" behaviors (e.g., smoking and in-car system use) showed no consistent pattern; they were associated with higher steering angle variance, but a lower standard deviation of lane position. As with all of the behaviors examined, mean throttle position and variance were not significantly affected. However, glance frequency and durations were considerably higher for both first and second glances away from the forward scene.

Conclusions

Meta-analyses by Caird et al. (2004) and Horrey and Wickens (2004) point out two important results pertaining to secondary behaviors, especially cellular phone use. First, cellular phone use appears to be more strongly associated with increases in reaction time to critical events than in decrements in ongoing driving performance measures. Second, the strongest effects of secondary tasks are seen in laboratory studies, with decreasing effect sizes as the study moves towards naturalistic driving (e.g., simulator vs. closed course w/ assigned task vs. on-road). These two results make it very difficult to identify the real effects of secondary behaviors on everyday driving, even though it may seem intuitive that they would affect driving performance. Furthermore, the lack of serious safety consequences to the participant with simulator and laboratory studies may provide even less motivation for participants to exhibit their best driving performance relative to trying to achieve the tasks the experimenter has asked them to perform. In naturalistic conditions when drivers can freely choose whether or no to engage in secondary tasks, at least to some degree one would expect drivers would choose to perform those tasks when their driving skills are least needed and the traffic environment tends towards being less challenging based upon the individual driver's own assessment.

Consistent with these observations, the present study showed relatively little effect of secondary behavior on basic driving performance measures. Steering-angle variance seemed to be most affected by secondary tasks, with cellular phone use, eating and drinking, and conversation all associated with higher steering-angle variance. However, these behaviors were associated with few other differences in driving performance measures. Outside of driving performance, some differences in glance behavior were detected. In particular, cellular phone use was associated with fewer and shorter glances, while eating/drinking was associated with more, but shorter, glances. Unfortunately, it is difficult to determine how glance behavior is associated with performance as the present analysis does not examine the specific locus of the driver's attention when not looking forward. However, this may be the subject of further investigation.

The distribution of conditions (e.g., road type, day/night) under which drivers chose to engage in secondary behaviors might shed some light on the question of whether they select safer conditions to engage in such behaviors. Indeed, cellular phone use occurred more often when not braking and not in a curve, multiple behaviors occurred exclusively on dry roads and eating/drinking occurred primarily during the day. However, other aspects of drivers' choices seem inconsistent with this hypothesis. For example, cellular phone use occurred disproportionately on major surface and local roads, as well as at night. Although these conditions are, on average, more dangerous than limited-access highways and daytime driving, these numbers may reflect a form of exposure that either have not, or cannot, be measured with the available data. That is, drivers may more often feel the need to make phone calls when they are in local areas (as opposed to on a long trip on an interstate), just as they are probably more often hungry in the daytime. If so, they may still be calling only when they judge themselves to be in a less dangerous driving situation, as judged by circumstances not identified in the current analysis (e.g., variations traffic density). However, upon first examination, the results will look as though they choose somewhat more dangerous roads on which to make calls.

These examples are purely speculative, but they illustrate the difficulty of determining the influence of driver choice on when to engage in secondary behaviors. Nonetheless, driver choice in naturalistic conditions is critical to understanding the broad effect of secondary behaviors on driving. The present study suggests that secondary behaviors have limited effects on continuous driving performance measures in naturalistic driving conditions. Perhaps more importantly, this study demonstrates the importance of conducting such a naturalistic study, as controlled studies cannot always account for the effects of driver choice and perceived risk. In this vein, our ongoing investigation of reaction time, response to critical events and specifics of eye glance behavior in naturalistic driving will provide an important complement to the results in this report.

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APPENDIX A: EXPOSURE VIDEO CODING KEY

Precipitation

(Not used for analyses in this report. Precipitation was identified via the forward camera scene, although it was sometimes difficult to know whether a given case of precipitation was rain or snow).

0 = None
1 = Rain
2 = Snow/Sleet

Road Condition

(The condition of road was used for analyses in this report. The category was used to identify whether the road was dry, wet, or covered with snow. Cues came from the forward camera scene, and included reflections on the road, precipitation, windshield wiper state, etc.).

0 = Dry
1 = Wet
2 = Snow covered

Seatbelt

(Not used for analyses in this report. From the face camera scene, the driver's seat belt could usually be seen. However, because the image was black and white, the seatbelt could potentially blend into the color of the driver's clothes, making a determination difficult).

0 = Yes
1 = No
2 = Cannot tell

Location of eyes at first frame

(Not used for analyses in this report. Eye location was coded by what the reviewers could see of the driver's eyes at the first frame. The reviewers coded the location of the driver's eyes even if they could only see one eye, as it was assumed that the driver's eyes moved in parallel. The reviewers needed to be very confident in location of the driver's eyes in order to code as a specific location. There were many instances when the reviewers were confident that the driver's eyes were not looking forward, but could not tell specifically where the eyes were looking. The determination of whether glances were still forward or it they were glances away was also very difficult and subjective. The reviewers agreed upon an area or "box" which they considered to be looking forward, this allowed for slight glances but even many scans across the forward scene were considered glances away. This process defined "looking forward" very narrowly and essentially meant straight forward. Glances toward the right of the forward scene, the right area of the windshield, were glances away and were coded as 8's.)

0 = Looking forward at forward scene
1 = Left outside mirror or window
2 = Looking over left shoulder (The driver's gaze needed to look over the driver's shoulder, though the driver's chin did not necessarily need to cross over the driver's shoulder.)
3 = Right outside mirror or window

4 = Looking over right shoulder (The driver's gaze needed to look over the driver's shoulder, though the driver's chin did not necessarily need to cross over the driver's shoulder.)
5 = Head down, looking at instrument panel or lap area
6 = Head down, looking at center stack counsel area (*Counsel* means the area where the stereo, thermostat, and clock are located)
7 = Driver wearing sunglasses or glasses with glare (The glare prohibited the ability to classify where the eyes are looking. There were instances where drivers were wearing sunglasses but the reviewers felt that they could confidently identify the location of the drivers' eyes. In these instances eye location was recorded.)
8 = Cannot accurately evaluate eye location (An *8* is chosen when the reviewer was unsure of the eye position and/or classification within a reasonable level of confidence though not because of glasses. Typically the reviewer could see the actual eye, but could not determine where the gaze was directed. Eyes in transition were often coded as *8*, as it was unclear where the driver's gaze was at that particular moment.)
9 = Other (For example the driver may clearly be looking at passenger side floor. When a glance was coded as *other*, the location was noted in the notes section. The most common position recorded as *other* was the rear-view mirror.)

<u>Eyes on task at first frame</u>

(Not used for analyses in this report. This category defined whether the driver could be said to be paying active attention to the driving task, evidenced by his/her gaze being directed either toward the forward scene, mirrors, instrument panel, etc.).

0 = No (The classification of *no* was only used when the reviewer could confidently determine that the driver's eyes were off the task of driving.)
1= Yes (The classification of *yes* does not mean looking forward, it means that the driver's eyes were on the task of driving.)
2 = Cannot determine (For instance, the driver was wearing glasses with glare or the reviewer could not see the driver's eyes for some other reason. This classification was also used when the reviewer could not tell if the eye location was on task. For instance, the driver was looking out the window but it was unclear whether the driver was looking at traffic or at a fancy building that was distracting the driver's attention. In any case, the reviewer did not KNOW whether the driver was on task or not.)

<u>Hand location at time first frame</u>

(Not used for analyses in this report. Both hands were not often visible, so the reviewer coded what could confidently be inferred from the scene. At times, playing the video farther helped to determine what was ambiguous in a still frame. For instance, at the first frame there may have been a small blur near the steering wheel. Upon continuation of the video the blur may have moved and come into view as a hand.)

0 = Cannot see the position of either hand or cannot determine the position of either hand (The reviewer coded *0* if a hand could be seen but the reviewer could not tell if it was on the wheel).
1 = At least one hand on steering wheel (This was coded when the position of one hand could not be determine but one could see that at least one hand was on the steering wheel).
2 = Both hands are on the steering wheel.

3 = At least one hand off the steering wheel (This was coded when the position of one hand could not be determine but at least one hand was clearly off the steering wheel.)
4 = One hand on, one hand off the steering wheel. (A *4* was classified when the reviewer could clearly see both hands, and one was on the wheel while the other was off.)
5 = Both hands off the steering wheel. (A *5* was classified when the reviewer could clearly see both hands, and both were off of the wheel.)

Eyes in transition

(Not used for the analyses in this report. This category refers to instances in which the first frame of video included a transition in the driver's gaze from one direction to another).

0 = No
1 = Yes, towards forward scene
2 = Yes, away from forward scene
3 = Yes, both towards and away from forward scene
4 = Cannot tell (*Cannot tell* was selected when the driver was wearing sunglasses or the reviewer could not see the driver's eyes for some other reason; therefore it was uncertain whether they were in transition.)

Time away from forward scene, glances 1-4

(Used in this report. The duration of up to four glances away from the forward scene were coded in tenths of seconds. The "forward scene" was defined in the same manner as for "Location of Eyes at First Frame" (above). If a driver was in the process of directing his/her gaze away from the forward scene and in the first frame of that movement he/she was blinking, the blink was counted as a tenth of a second away. If the driver was always looking forward, then these fields were left null, as that category was not applicable).

Secondary behaviors

(Used in this report. Coding of secondary behaviors

0 = None
10 = Cellular phone: **Conversation, in use** (C*onversation* could include listening, talking, or both while using the cellular phone).
11 = Cellular phone: Reaching for phone (This classification refers to when the driver reached for the handheld phone in order to speak on that phone. If the driver reached for the phone simply to answer the phone, but then commenced speaking while using a headset, then the classification was "*Other*.")
12 = Cellular phone: Dialing phone
20 = Headset, hands-free phone: Conversation (This was selected when the reviewer could tell that the driver was in a conversation on a hands-free phone).
21 = Headset, hands-free phone: Reaching for headset
22 = Headset, hands-free phone: Unsure of activity level (The driver was wearing a headset but it was not clear whether the headset was in use. The driver may have been listening to someone or wearing it in case of an incoming call.)

30 = Eating: High involvement (*High involvement* includes eating a burger, unwrapping food, or other kinds of eating that involve one or both hands off the steering wheel for an extended period of time).

31 = Eating: Low involvement (*Low involvement* includes eating candy, grabbing chips, and so forth, where the driver's hands were not necessarily off the steering wheel for an extended period of time).

40 = Drinking: High involvement (*High involvement* includes situations where the driver was trying to open a straw or bottle, blowing on a hot drink, etc. As with eating, the extent to which the driver's hands were off the steering wheel was also a factor).

41 = Drinking: Low involvement (*Low involvement* includes situations where the driver was sipping a drink, drinking without looking, etc.)

50 = Conversation (The driver and someone in the car are carrying on a conversation. The driver can be listening during the clip, talking during clip, or doing both)

60 = In-car system use (The driver was actively adjusting something within the car, usually on or around the front console. For example, the driver was not just listening to the stereo; the driver was also adjusting the stereo, etc. Using the car cigarette lighter was coded under the smoking section).

70 = Smoking: Lighting (This classification included the in-car lighter or other means of lighting a cigarette, cigar, etc.).

71 = Smoking: Reaching for cigarettes or lighter or ashtray (This classification includes the in-car lighter).

72 = Smoking (Actively smoking).

80 = Grooming: High involvement (*High involvement* includes applying makeup, brushing hair, etc. As with eating and drinking, driver hand location was a factor in determining the level of involvement).

81 = Grooming: Low involvement (*Low involvement* includes scratching, running one's fingers Through his or her hair, etc.)

90 = Other/multiple behaviors, specified in notes section (These included behaviors that did not fit into any of the other categories, or situations in which the driver was engaged in more than one behavior, all of which were then recorded in the "notes" section).

<u>Notes</u>

(A notes section recorded any unusual events or ambiguous situations not covered by categories for a particular question. This section also contains general notes on the clip if there was anything significant taking place that was not adequately covered by the coding process).

Table A-1
Non-collapsed secondary behaviors exposure review counts

Observed Behavior	*f*	%
No secondary behavior	954	66.3
Conversation	219	15.2
Grooming: low involvement	95	6.6
Grooming: high involvement	1	0.1
Cellular phone: conversation	72	5
Cellular phone: reaching for	0	0
Cellular phone: dialing	2	0.1
Headset, hands-free phone: conversation	1	0.1
Headset, hands-free phone: reaching for	0	0
Headset, hands-free phone: unsure of behavior	1	0.1
Eating: low involvement	16	1.1
Eating: high involvement	2	0.1
Drinking: low involvement	9	0.6
Drinking: high involvement	1	0.1
In-car system use	5	0.3
Smoking	8	0.6
Smoking: reaching for cigarettes or lighter or ashtray	1	0.1
Smoking: lighting	0	0
Other/Multiple behaviors	31	2.2
Total	1,440	100

APPENDIX B: SECONDARY BEHAVIORS AND MILEAGE BY DRIVER

Driver	Mileage	Secondary behaviors (*f*)						
		None	Conversation	Grooming	Cellular phone	Eating/Drinking	Multiple	Other
1	1,420.6	30	4	3	0	1	0	2
2	1,458.3	26	5	6	1	1	0	1
3	1,629.1	29	5	1	4	0	1	0
4	1,189.4	18	6	8	1	1	5	1
5	1,395.9	26	3	5	2	2	2	0
6	1,762.9	30	9	0	0	1	0	0
7	1,307.1	33	5	0	0	1	1	0
8	1,175.4	36	2	2	0	0	0	0
9	919.1	13	5	6	14	0	2	0
10	1,194.2	31	5	1	0	2	1	0
11	1,573.5	19	13	2	2	0	1	3
12	1,473.7	30	4	3	2	0	1	0
13	1,298.3	33	0	1	2	4	0	0
14	1,181.7	28	4	4	1	0	0	3
15	674.2	24	12	2	0	1	1	0
16	1,537.0	28	6	1	3	0	0	2
17	744.9	27	9	0	0	3	1	0
18	1,478.2	33	0	1	6	0	0	0
19	2,055.1	26	2	4	6	0	1	1
20	885.1	19	10	2	2	3	3	1
21	1,038.7	29	4	2	0	3	2	0
22	1,679.0	11	8	4	10	1	3	3
23	748.9	35	3	2	0	0	0	0
24	1,390.0	31	3	2	4	0	0	0
25	663.7	34	4	1	0	0	0	1
26	696.3	29	5	4	1	0	1	0
27	963.9	15	9	10	3	1	0	2
28	307.6	21	12	0	0	1	1	5
29	1,031.1	28	6	5	1	0	0	0
30	572.9	27	3	7	0	1	1	1
31	1,370.3	27	7	1	3	0	0	2
32	1,603.4	17	11	1	4	0	2	5
33	1,654.8	26	9	1	2	0	0	2
34	854.7	26	13	1	0	0	0	0
35	825.8	29	7	3	0	0	1	0
36	1,078.2	30	6	0	2	1	0	1
Total (*f*):		954	219	96	76	28	31	36
% of participants		100	94	86	61	47	53	47

APPENDIX C: SELECT NONSIGNIFICANT RESULTS

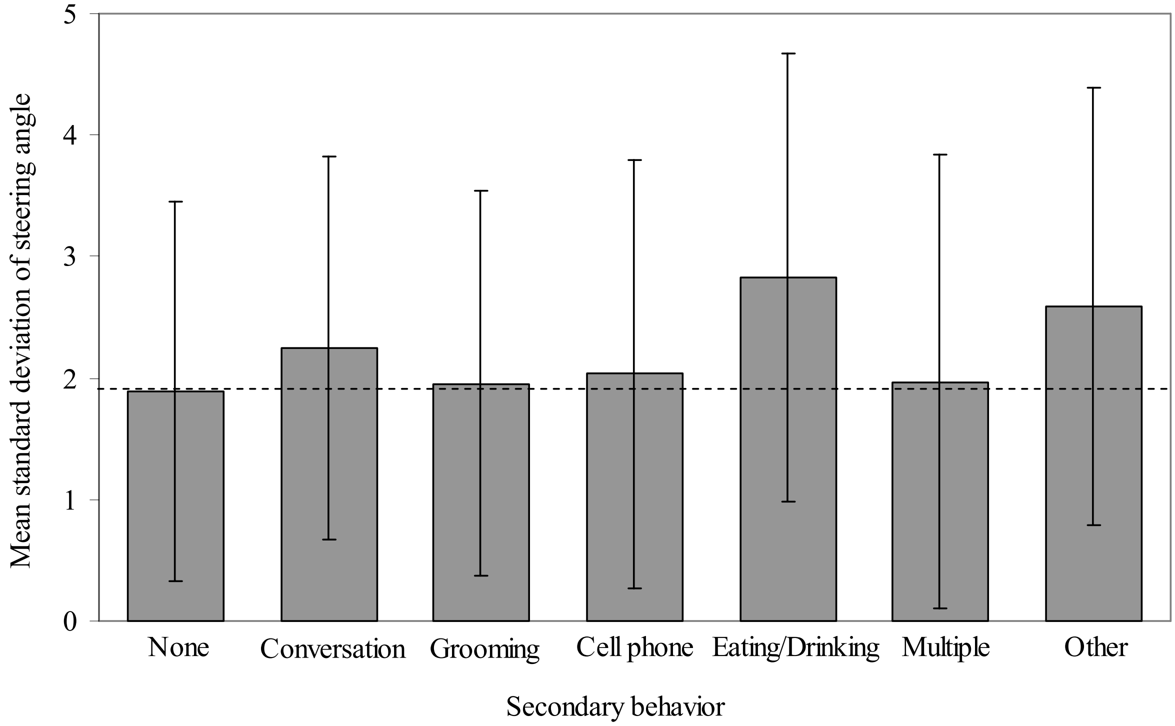

Figure C-1. Mean standard deviation of steering angle for each type of secondary behavior.

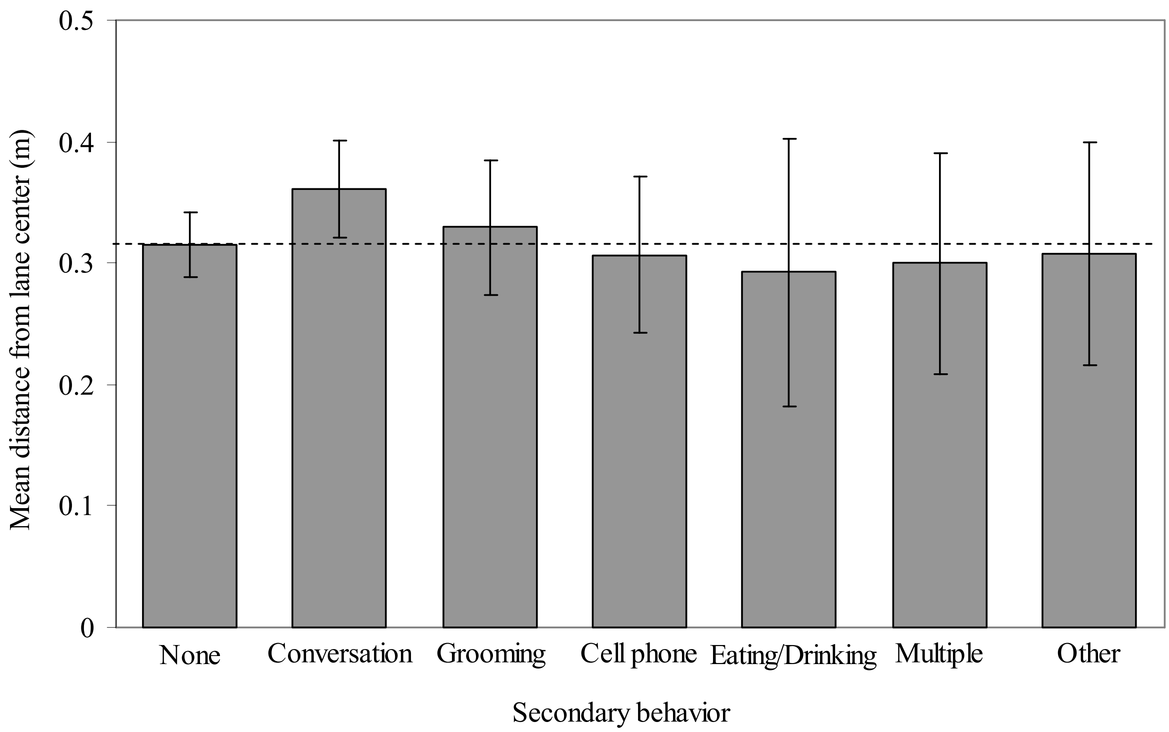

Figure C-2. Mean distance from lane center (m) for each type of secondary behavior.

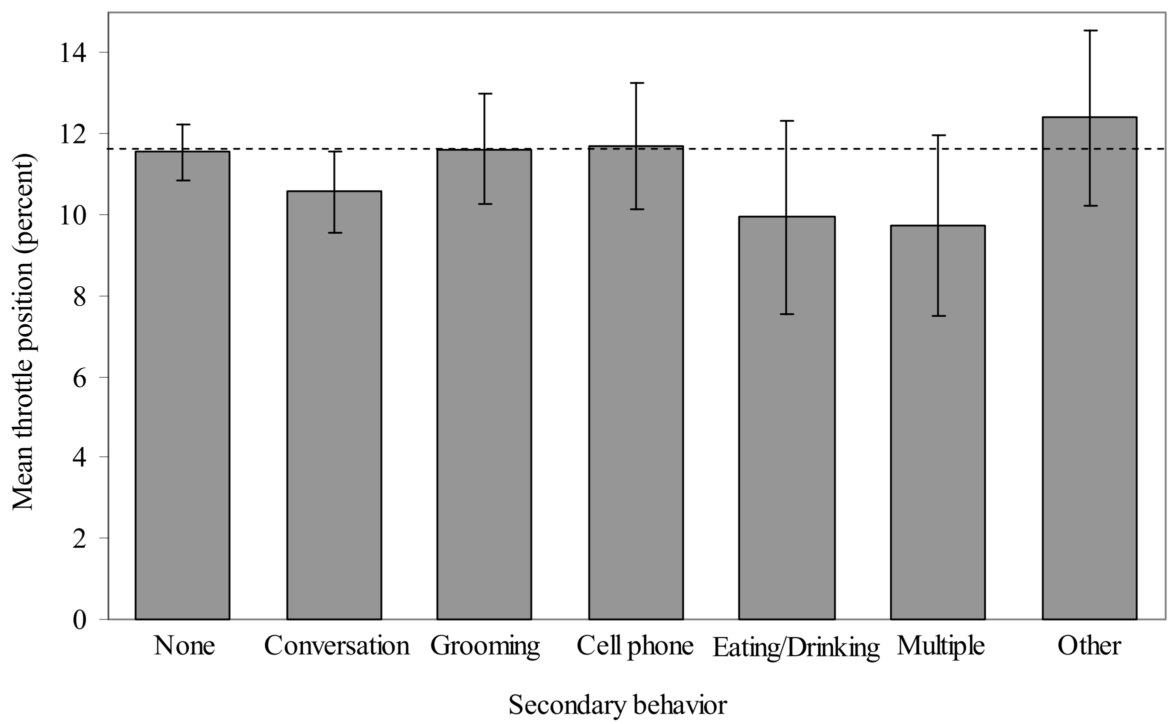

Figure C-3. Mean throttle position (percent of total) for each type of secondary behavior.

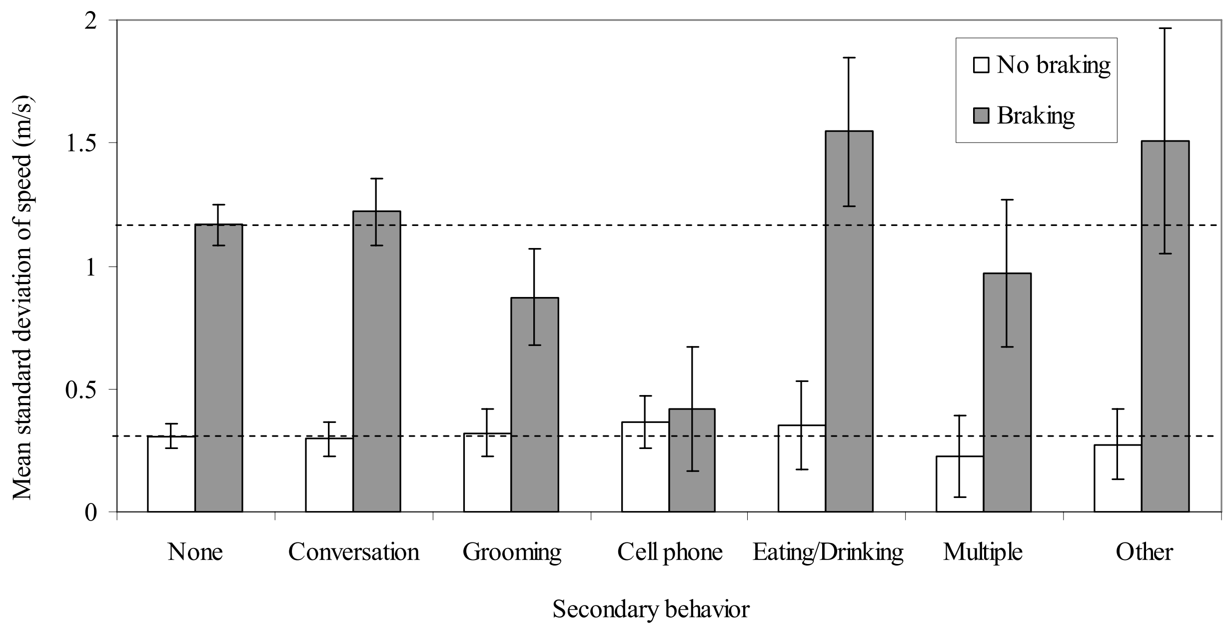

Figure C-4. Mean standard deviation of speed (m/s) for each type of secondary behavior.