

Effects of Passenger and Cellular Phone Conversations on Driver Distraction

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The distracting effects of a simulated conversation with passengers and those of a conversation over a hands-free cellular phone were compared. The conversation was also analyzed to determine if passengers modulated their conversations as driving demands changed. Eighty participants were randomly assigned to one of three conditions: driving alone, driving with a passenger, and driving with a cellular phone. Drivers drove through residential and urban traffic environments in a fixed-based driving simulator in which a variety of events occurred, such as pedestrian activity, oncoming vehicles, and intersections. The results indicated that lane and speed maintenance were influenced by increased driving demands. Response times to a pedestrian incursion increased when the driver was driving and talking compared with those detected when the driver was not talking at all. Contrary to what some researchers have assumed, there was little practical evidence that passengers adjusted their conversations to changes in the traffic environment. The workload was rated higher when the driver was driving and talking and was also rated higher by drivers than by nondrivers. The discussion focuses on future research and implications for driver safety and training.

Research has shown that talking on cellular phones and with passengers distracts drivers (1-6). Distraction occurs when attention is withdrawn from the driving task, which results in delayed responses to driving events, increased perceptions of workload, and in some cases, disruptions of speed and lane maintenance [see the report by Goodman et al. (4) for a review]. Both handheld and hands-free cellular phones are distracting (6), suggesting that in addition to holding and manipulating the phone, the conversation itself can interfere with the task of driving. Some researchers have claimed that talking with passengers is less hazardous than talking on a cellular phone, since the passenger can see the driving situation and adjust the conversation accordingly (4, 7). To date, few studies have explicitly tested this assumption. The goal of this study was to compare the distracting effects of a simulated conversation with passengers and those of a conversation over a hands-free cellular phone and determine if passengers modulated a conversation as driving demands changed.

The distraction produced by conversations differs as a function of the driving and conversation tasks. Brookhuis et al. had participants

converse using a handheld or hands-free cellular phone while driving an instrumented vehicle in light, heavy, and city traffic (1). The conversation task was a paced serial-addition task. The participants made more steering wheel movements in city traffic when they were simultaneously conversing using a cellular phone than when they were driving alone or driving and conversing in light or heavy traffic. Irwin et al. compared the response times to a braking event for four levels of conversation difficulty and driving alone (5). No differences in response times were found as a function of conversation difficulty, but response times were slower when participants were engaged in a cellular phone conversation than when they were driving alone. Strayer and Johnson had participants converse with a confederate using a hands-free or handheld cellular phone while simultaneously completing a visual-pursuit tracking task (6). Those in both cellular phone conditions took longer to react to a simulated light change than those driving alone did.

A limited number of studies have examined how cellular phone conversations compare to passenger conversations on measures of driver distraction. Fairclough et al. had participants drive an instrumented vehicle on a predetermined route while negotiating with a confederate via a hands-free cellular phone or as a passenger (2). Participants took longer to drive the experimental route, rated the subjective workload higher, and had higher heart rates when they were conversing; but no differences between the cellular phone and passenger conditions were found. Gugerty found that cellular phone and passenger conversations degraded performance equally on several measures of situation awareness, including response time; the ability to recall nearby car locations; and the ability to identify distant, nearby, and sudden hazards (3). Passengers also had more extremely long word durations than the nondrivers in the cellular phone condition, suggesting that passengers may have paused more often between words.

Taken together, these studies suggest that cellular phone and passenger conversations distract drivers. Higher driving demands worsened the distracting effects of talking while driving (1), and both realistic and artificial conversations could distract the driver (1, 3, 5), suggesting that a natural dialogue is not required to simulate the distracting effects of talking while driving. Some support was found for the claim that passengers regulate a conversation (3), but this was measured by using only one index of conversation rate and was not evaluated as a function of driving difficulty.

PRESENT STUDY

This research focused on conversations with passengers and via hands-free cellular phones as an important source of distraction for drivers. Distraction was measured by using lane and speed maintenance variables, perception response time (PRT) to driving events,

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and perceptions of workload. The conversation was analyzed in terms of speech rate, word complexity, linguistic frequency, and conversation errors. It was hypothesized that conversations with a passenger and over a cellular phone would disrupt lane and speed maintenance as well as the times of response to driving events. Passengers were expected to reduce speech rates and word complexity but increase linguistic frequency as driving demands increased. The subjective workload was predicted to be higher for drivers when they were driving and talking than when they were driving alone and was also predicted to be higher for drivers than for nondrivers.

METHODS

Participants

Eighty students from the University of Calgary (46 men and 34 women) participated in the experiment. Their ages ranged from 18 to 27 years, with an average of 20.61 years. Each participant had a valid driver's license, drove an average of 14,633 km/year [standard deviation (*SD*) = 9,690 km/year], and had an average of 0.65 accidents (*SD* = 0.86 accidents) during the previous 5 years. The mean education level was 14.88 years (*SD* = 1.53 years), and participants had been driving an average of 4.34 years (*SD* = 2.03 years).

Fifty-three participants reported that they had owned a cellular phone for an average of 2.47 years (*SD* = 1.41 years). Cellular phone owners used their phone an average of 17.67 min/day (*SD* = 16.22 min/day), 87% indicated that they used their phone while driving, and 93% of phones were handheld.

All participants had corrected or uncorrected visual acuity of 20/30 or better and normal contrast sensitivity and reported that English was their first language. Eleven participants reported taking medications at the time of testing, but none indicated any side effects that would interfere with learning, memory, or vision. Pairs of participants, described below, did not know each other, and all participants received partial course credit for their involvement in the study.

Apparatus and Materials

Driving Simulator

Driving scenarios were created and managed using the University of Calgary Driving Simulator (UCDS). UCDS is a fixed-based simulator that projects a detailed and realistic driving environment on three data projector screens for a total field of view of 150 degrees. A fully instrumented Saturn SL1 automobile is connected to five networked workstations that control graphics presentation, equations of motion, and development software (HyperDrive, version 1.6.1). More information on UCDS can be found in the work by Edwards et al. (8). A JVC Super VHS ET videocassette recorder was used to record the drivers' and passengers' faces as well as the simulated conversation. To ensure that the intensities of the conversations were equivalent, the speaker volume in the cellular phone condition was set at 60 dB, which is the intensity for normal person-to-person conversations (9).

Driving Environment

Two driving scenarios that were 4,000 m (2.48 mi) in length and that lasted approximately 5 min were developed. One of the scenarios simulated driving in a residential area (i.e., an easy driving condi-

tion), while the other simulated driving in an urban area (i.e., a difficult driving condition). The scenario in the residential area involved a two-lane, bidirectional road that measured 18 m (59 ft) wide, including both the left and the right parking lanes and a two-way left-turn lane. The scenario in the urban area involved an 11.2-m (36.7-ft)-wide, two-lane, bidirectional road with left and right parking lanes but no left-turn lane. All scenarios used daytime dry pavement driving conditions with good visibility.

Driving difficulty was also manipulated by varying the amount of oncoming traffic and the numbers of road signs, pedestrians, and parked vehicles. Forward traffic was excluded because this would have influenced average speed and reactions to driving events. To determine a realistic number of parked cars, pedestrians, road signs, and oncoming traffic for both the residential and the urban scenarios, two raters analyzed video footage of residential and urban scenes in Calgary, Alberta, Canada. The minimum values were used for the residential scenario, and the maximum values were used for the urban scenario.

Participants drove each scenario twice, once from each direction, so that each drive shared the same road characteristics (i.e., the numbers of intersections, pedestrians, parked cars, and traffic signs and the amount of oncoming traffic). Therefore, drivers were exposed to four different routes over the course of the study (i.e., two easy routes and two difficult routes). Each route contained five intersections and required participants to make two right turns and two left turns. Route information (e.g., "please turn right") was presented on the forward screen when the simulated vehicle reached a distance of 150 m (491.8 ft) before the relevant intersection. The speed limit for all routes was 50 km/h (31 mph).

Driving Events

To avoid priming responses to the driving events (10), drivers responded to only two events. Each driving event was encountered only once in both the residential (i.e., easy) and the urban (i.e., difficult) scenarios. This resulted in participants responding to one event for each route traveled. Four route orders were created, whereby easy and difficult routes alternated. Each route had an equal probability of being first, second, third, or last in the order. The driving events were then counterbalanced across each route order. Each event is described in more detail below.

Intersection Light Change

The traffic lights for all intersections were green for the driver's direction of travel. For the one intersection where participants had to travel straight ahead, the light changed from green to yellow to red (Figures 1a and 1b). The participants were given 3.5 s to stop without encroaching into the intersection. This gave each driver the same time in which to respond, even though they may have been driving at different speeds.

Pedestrian Incursion

A pedestrian originated on the right-hand side of the road from behind a parked vehicle and proceeded across the road at a speed of 5 km/h (3.1 mph). The pedestrian proceeded one-third of the way

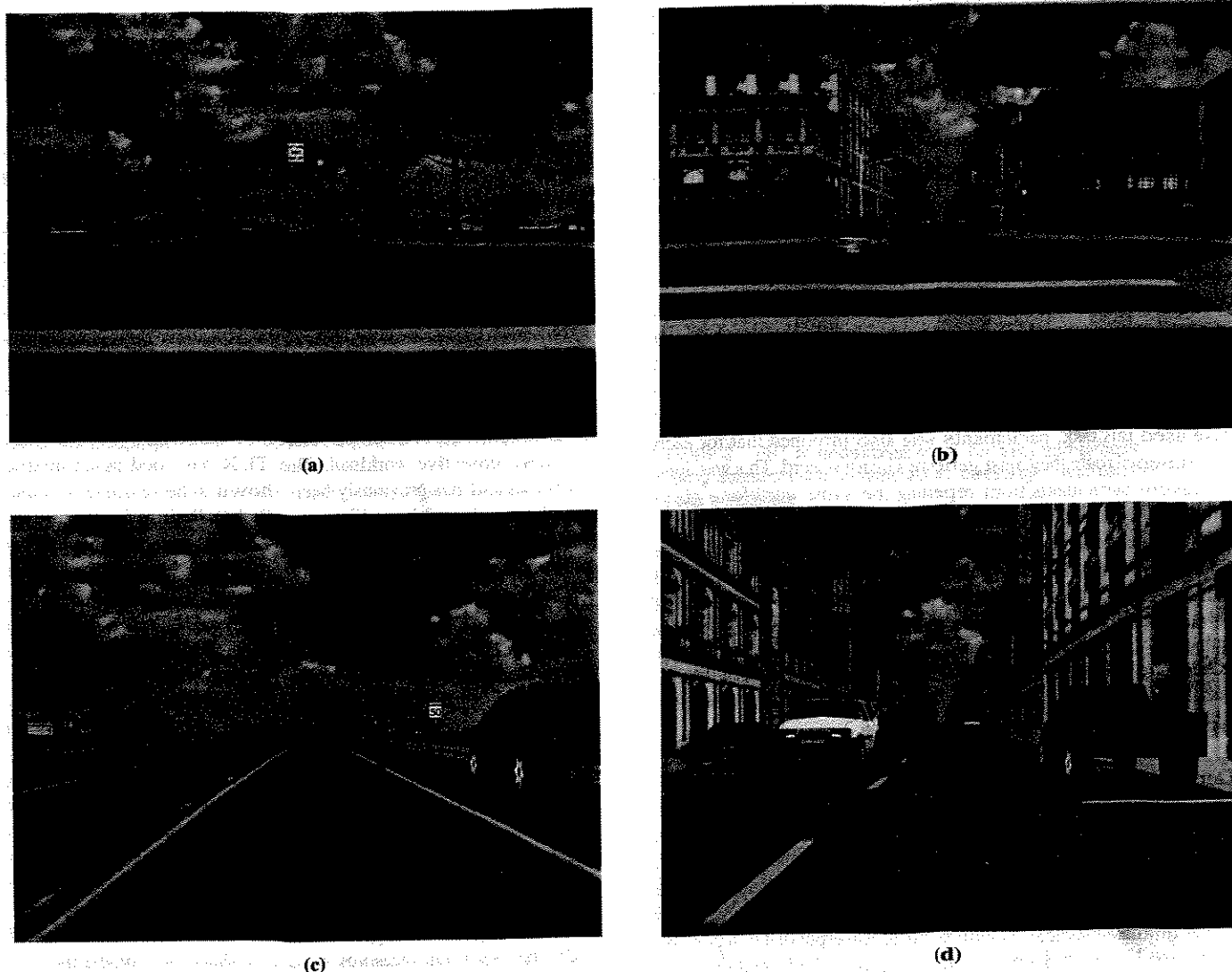


FIGURE 1 Driving events used in the study: (1) intersection light change event for (a) residential (easy) and (b) urban (difficult) driving conditions and (2) pedestrian incursion event for (c) residential (easy) and (d) urban (difficult) driving conditions.

into the driver's lane, and participants were given 2.5 s to respond (Figures 1c and 1d). The incursion occurred at a randomly chosen location for each route.

Procedure

On arrival at the laboratory, the participants were briefly introduced to the study and asked to sign an informed consent document. They then completed a simulator sickness questionnaire. If participants responded "yes" to any of the questions, they were encouraged not to continue. Although 38 participants responded "yes" to at least one question, all agreed to participate. A Snellen Visual Acuity Chart was then used to assess visual acuity, and the Vistech Contrast Test System was used to measure contrast sensitivity. All participants were required to possess nearly normal or corrected-to-normal levels of visual acuity (better than 20/30) and normal contrast sensitivity.

A 5-min, 4,000-m (2.48-mi) practice scenario allowed participants to familiarize themselves with the handling characteristics of the

driving simulator and both the residential and the urban environments. The residential and urban sections in the practice scenarios contained the same number of pedestrians, parked cars, oncoming traffic, and road signs as the respective experimental scenarios. During the practice scenario, when participants traveled 10 km/h (6.2 mph) above or below the speed limit, a message appeared on the forward screen telling them to slow down or speed up, as appropriate.

Each participant was then randomly assigned to the cellular phone, passenger, or driving alone condition. Those in the cellular phone and passenger conditions were tested in pairs, with one member of the pair being randomly assigned to the role of driver and the other being the nondriver (passenger or cellular phone user). Passengers sat in the passenger seat, while nondrivers in the cellular phone condition talked to the driver from behind a curtain using a headset. Drivers heard the cellular phone conversation through a speaker located on the passenger seat. Before the experimental routes were started, the drivers were told that they would not be given feedback about maintaining the posted speed. Drivers then completed one of the four route orders, counterbalanced across participants.

Drivers and nondrivers in the cellular phone and passenger conditions completed a simulated conversation task while driving. The conversation task was a word game in which the drivers and nondrivers generated words based on what each other said (3, 6). The experimenter began each route by saying a word (e.g., "character"), and then the nondriver or driver said a word that began with the last letter of the previous word. The driver and nondriver then took turns saying words based on the last-letter rule. Participants were told to respond to the words as quickly and as accurately as possible, but the driver was instructed not to compromise the safe operation of the vehicle. The word game was chosen because it has been shown to distract drivers in visual pursuit tracking tasks (6) and on measures of situational awareness (3). It also provided a good balance between standardization and realism by facilitating turn taking, ensuring that drivers and nondrivers were attending to the task, and forcing participants to remember what was said (11). Unlike other studies that have used this task, participants were also informed that for each experimental route they must generate a unique word. This was done to prevent participants from repeating the same word for a given letter and to increase the working memory demands of the task.

After each route, participants filled out a modified version of the National Aeronautics and Space Administration (NASA) task load index (TLX), developed by Hart and Staveland (12). At the end of all the experimental routes, participants completed a postsimulator sickness and demographic questionnaire before they were debriefed.

RESULTS

Dependent Variables

The first group of dependent variables related to driver performance. The mean lane position and the variability (*SD*) of the lane position measured lane-keeping behavior. Lane position was calculated as the distance (in meters) from the center of the driving lane to the center of the simulated vehicle. Negative values corresponded to a position to the left of center; positive values indicated a lane position to the right of center. Average speed and variability (*SD*) in speed measured speed control (in kilometers per hour). Speed and lane position were not analyzed for the first 100 m of each route, 100 m before and after intersections where participants turned, and 100 m before and after driving events.

PRT was used to assess responses to driving events and was defined as the time needed for drivers to detect and identify an event, decide on an appropriate course of action, and initiate a response (10). PRT was collected from the onset of each driving event to the moment that the driver made a response (i.e., acceleration, steering, or braking). For the pedestrian event, swerving and braking responses were analyzed. For the light event, acceleration, braking, and release of the accelerator were analyzed. A steering response was defined as a change in wheel deflection of 5 degrees or greater. A brake response was defined as any increase in brake position from the default zero value. An acceleration response was defined as a change in accelerator input value of 2% or greater (where 100% means that the accelerator was fully depressed). A response in which the participants released the accelerator occurred when the accelerator input value changed to zero and remained as such until the event was passed. In cases in which more than one response was made (i.e., steering and braking), the fastest of the response types was taken as the PRT for the event.

The second group of dependent variables related to the conversation. A transcript of the conversation was analyzed separately for the driver and the nondriver by using four measures: speech rate, word complexity, linguistic frequency, and errors. Speech rate was calculated by counting the total number of syllables and dividing the result by the total time. Word complexity was measured by counting the total number of syllables and dividing the result by the total number of words. Linguistic frequency was calculated by using the norms of Kucera and Francis (13), in which higher numbers represent more commonly used words. In cases in which more than one word matched the word uttered by the participant (e.g., "ant" versus "aunt"), the word with the higher linguistic frequency was used. Errors were separated into two types: the first when participants repeated a word that was said previously and the second when the last-letter rule was not obeyed.

The last category of dependent variables corresponded to perceptions of workload. A modified version of the NASA TLX was used to assess subjective workload. The TLX has good psychometric properties and has previously been shown to be sensitive to attentional demands in driving-like tasks (2, 14). Ratings for the six subscales of the NASA TLX were based on a 10-point anchored rating scale and were combined by using equal weighting to produce an overall NASA TLX score (14).

Data Reduction

All dependent variables were aggregated across valid routes for both the easy and the difficult scenarios. This means that although participants drove each scenario twice (i.e., once from each direction), the data for both routes were averaged to produce one datum point for both the difficult and the easy scenarios. Routes were considered valid when the participants did not miss a turn. The participants missed only eight turns (zero in the driving alone condition, four in the passenger condition, and four in the cellular phone condition), resulting in a loss of only 4.2% of the data. With the exception of PRT, the dependent measures were calculated only on the basis of the available routes. For the PRT data, if the turn was missed after the event occurred, the data were included.

In seven cases, participants (three driving alone, two with passengers, and two with cellular phones) were either braking, accelerating, or swerving at the onset of the driving events, which represented a loss of 3.6% of the PRT data. It is not known whether this occurred because of coincidence or whether the participants were anticipating the events. To avoid decreasing the power in the omnibus analyses, group means were replaced by the missing PRT values. Although other approaches to dealing with missing data exist (15), the use of group means is a relatively conservative method since the mean for the distribution as a whole does not change, and with a small number of missing values to be substituted, the reduction in the within-group variance is minimized.

Primary Analyses

The primary analyses looked for mean differences for each dependent variable as a function of the experimental condition. For the driving performance data, 3 (task conditions, i.e., driving alone, driving with a cellular phone, and driving with a passenger) \times 2 (driving difficulty, i.e., easy and difficult) split-plot analyses of variance (ANOVAs) were computed. For the conversation data, 2 (task conditions, i.e.,

with a passenger and with a cellular phone) $\times 2$ (driving difficulty, i.e., easy and difficult) $\times 2$ (role, i.e., driver and nondriver) split-plot ANOVAs were conducted. Because role was nested in the cellular phone and passenger conditions, two analyses were performed for the subjective workload data. The first compared the workload for the driver by a 3 (task condition, i.e., driving alone, driving with a cellular phone, and driving with a passenger) $\times 2$ (driving difficulty, i.e., easy and difficult) split-plot ANOVA. The second examined the workloads for drivers and nondrivers by using a 2 (task condition, i.e., driving with a cellular phone and driving with a passenger) $\times 2$ (driving difficulty, i.e., easy and difficult) $\times 2$ (role, i.e., driver and nondriver) split-plot ANOVA. In all the analyses, a Geisser-Greenhouse correction was used to correct for violations of sphericity; however, the reported analyses show the degrees of freedom associated with the uncorrected test. Follow-up tests were conducted by using a Bonferroni adjustment (16), and the omnibus error term was used when appropriate.

Driver Performance Data

On average, the drivers drove to the left of center but were farther to the right (i.e., closer to the center of the lane) under difficult driving conditions [mean (M) = -0.24 m; SD = 0.13 m] than under easy driving conditions (M = -0.36 m; SD = 0.18 m) [$F(1, 45)$ = 35.69 ; p < $.001$]. The main effect of task condition and the condition-by-difficulty interaction were not significant (p > $.69$).

Consistent with the lane position data, participants showed less variability in lane position when they were driving the difficult scenario (M = 0.11 m; SD = 0.03 m) than when they were driving the easy scenario (M = 0.21 m; SD = 0.05 m) [$F(1, 45)$ = 183.39 , p < $.001$]. However, the main effect of task condition and the condition-by-difficulty interaction were not significant (p > $.12$).

Participants drove more slowly under difficult driving conditions (M = 49.47 km/h; SD = 2.74 km/h) than under easy driving conditions (M = 53.09 km/h; SD = 2.61 km/h) [$F(1, 45)$ = 105.66 , p < $.001$]. However, no differences were found as a function of task condition, and the interaction was not significant (p > $.15$).

No differences in speed variability were found between difficult and easy driving scenarios or between driving alone and the two conversation conditions (p > $.17$). The interaction was also not significant (p > $.20$).

Under easy driving conditions, all participants responded to the light signal change event, whereas in the difficult scenario three participants did not respond (one participant driving alone, one participant driving with a passenger, and one participant driving with a cellular phone). PRT was analyzed for those participants who responded to the light signal changes under both the easy and the difficult driving scenarios. No differences were found between the easy and the difficult driving scenarios or driving alone, driving with a passenger, and driving with a cellular phone conditions (p > $.26$). The task condition-by-difficulty interaction was also not significant (p > $.50$).

Under both the easy and the difficult driving conditions, one participant did not respond to the pedestrian event. Of the participants who responded to the pedestrian event, PRTs were marginally faster under the difficult driving conditions (M = 1.26 s; SD = 0.28 s) than under the easy driving conditions (M = 1.36 s; SD = 0.31 s) [$F(1, 42)$ = 3.01 , p = $.09$] (Figure 2). The main effect of task condition was also significant [$F(1, 42)$ = 3.25 ; p = $.049$]. Follow-up tests showed that when the driver was talking with a passenger

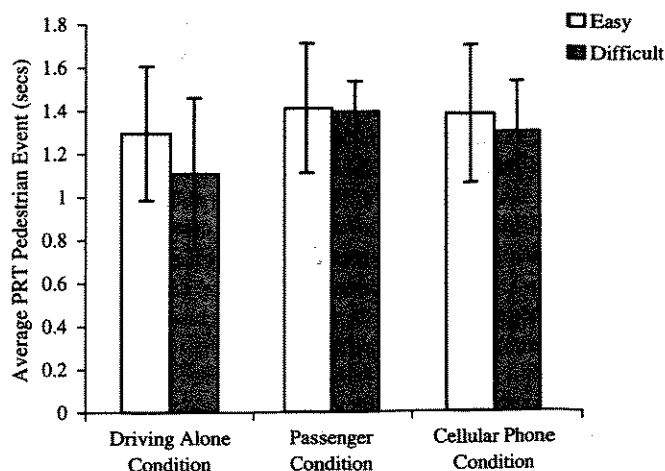


FIGURE 2 PRT to pedestrian event for easy and difficult driving scenarios and driving alone, passenger, and cellular phone conditions.

(M = 1.40 s; SD = 0.16 s), the PRT was slower than that when the driver was driving alone (M = 1.20 s; SD = 0.25 s) [$t(42)$ = 2.48 ; p = $.009$, one tailed]. PRT was also marginally slower when the driver was talking over a cellular phone (M = 1.34 s; SD = 0.22 s) than when the driver was driving alone [$t(42)$ = 1.75 ; p = $.044$, one tailed]. The task condition-by-difficulty interaction was not significant (p > $.46$).

Conversation Data

Speech rates (total number of syllables per total time, in seconds) were higher for easy routes (M = 0.207 ; SD = 0.041) than for difficult routes (M = 0.202 ; SD = 0.033) [$F(1, 60)$ = 3.48 ; p = $.034$, one tailed]. Speech rates were lower for the passenger condition (M = 0.198 ; SD = 0.036) than for the cellular phone condition (M = 0.212 ; SD = 0.035), but the difference was only marginally significant [$F(1, 60)$ = 2.36 ; p = $.065$, one tailed]. The main effect of role was not significant, nor were any of the interactions (p > $.32$).

Word complexity (number of syllables per word) did not vary as a function of driving difficulty, task condition, or role; and none of the interactions was statistically significant (p > $.09$).

Words with very high linguistic frequencies (i.e., "the" and "and") created a nonnormal distribution. To compensate for this, 95% trimmed means were used for all participants. Linguistic frequency (average linguistic frequency per word) was higher under the cellular phone condition (M = 105.38 ; SD = 46.97) than under the passenger condition (M = 86.00 ; SD = 33.90), but the difference was only marginally significant [$F(1, 60)$ = 3.81 ; p = $.056$]. Linguistic frequency was also higher for nondrivers (M = 105.66 ; SD = 49.04) than for drivers (M = 85.72 ; SD = 30.63) [$F(1, 60)$ = 4.04 ; p = $.049$]. None of the other main effects or interactions was statistically significant (p > $.09$).

Participants repeated fewer words while driving easy routes (M = 0.81 ; SD = 0.79) than while driving difficult routes (M = 1.06 ; SD = 0.88) [$F(1, 60)$ = 3.39 ; p = $.035$, one tailed]. They also made more repeat errors under the cellular phone condition (M = 1.22 ; SD = 0.63) than under the passenger condition (M = 0.66 ; SD = 0.53) [$F(1, 60)$ = 14.44 ; p < $.001$]. The main effect of role was not significant, nor were any of the interactions (p > $.17$).

More last-letter errors were made under the cellular phone condition ($M = 1.95$; $SD = 1.07$) than under the passenger condition ($M = 1.50$; $SD = 0.94$), but the difference was only marginally significant [$F(1, 60) = 3.11$; $p = .083$]. A marginally significant difference was found between the number of last-letter errors made under the easy driving condition ($M = 1.58$; $SD = 1.20$) and the number made under the difficult driving condition ($M = 1.86$; $SD = 1.34$) [$F(1, 60) = 2.18$; $p = .075$, one tailed]. However, the main effect of role was not significant, nor were any of the interactions ($p > .10$).

Subjective Workload Data

The overall subjective workload was calculated by averaging the responses on the six subscales of the NASA TLX and was analyzed in two ways. First, workload was examined for drivers as a function of driving difficulty and task condition. Workload was rated higher under the difficult driving condition ($M = 4.38$; $SD = 1.44$) than under the easy driving condition ($M = 3.96$; $SD = 1.40$) [$F(1, 45) = 11.11$; $p = .001$, one tailed], and the main effect of task condition was significant [$F(2, 45) = 3.79$; $p = .013$]. It appeared that workload was rated higher for the passenger ($M = 4.20$; $SD = 1.50$) and the cellular phone ($M = 4.83$; $SD = 1.08$) conditions than for the driving alone condition ($M = 3.47$; $SD = 1.11$). These main effects were, however, qualified by a significant interaction between driving difficulty and task condition [$F(2, 45) = 4.08$; $p = .024$]. Follow-up tests showed that drivers in the driving alone condition rated the workload higher for the difficult scenario ($M = 3.94$; $SD = 1.39$) than for the easy scenario ($M = 3.00$; $SD = 1.00$) [$t(45) = 4.26$; $p < .001$]. Under the passenger and cellular phone conditions, the drivers did not rate workload differently for the easy and the difficult scenarios ($p > .50$).

The second analysis for the subjective workload data compared drivers and nondrivers as a function of task condition and driving difficulty. Drivers rated the workload marginally higher ($M = 4.52$; $SD = 1.33$) than the nondrivers did ($M = 4.01$; $SD = 1.36$) [$F(1, 60) = 2.32$; $p = .067$, one tailed], and workload was rated somewhat higher under the cellular phone condition ($M = 4.58$; $SD = 1.33$) than under the passenger condition ($M = 3.95$; $SD = 1.33$) [$F(1, 60) = 3.57$; $p = .064$]. No differences as a function of easy or difficult driving conditions were found, and none of the interactions was significant ($p > .10$).

DISCUSSION OF RESULTS

This study had two goals, which were achieved, first, by using multiple measures of driver distraction to compare the effects of conversations with passengers with those of conversations held over hands-free cellular phones, and second, by analyzing the conversation to determine whether the passengers modulated a conversation as driving demands changed. The results are discussed in more detail below.

Driver Performance

Lane position was farther to the right and drivers showed less variability under difficult driving conditions. Drivers also drove more slowly when driving demands were more difficult. These compensatory behaviors are most likely due to differences in traffic flow

patterns between the easy and the difficult scenarios. In the easy scenario, participants had less oncoming traffic to contend with and also had a left-turn lane to buffer them from the approaching vehicles. In contrast, the difficult scenario was constructed to have a constant stream of oncoming traffic, and there was no center turning lane. This resulted in participants driving farther to the right, slowing down, and maintaining a constant lane position to avoid being hit by the approaching traffic.

No differences in lane or speed maintenance were found between drivers who were driving alone and drivers who were conversing. There are two possible explanations for this finding. First, for most drivers, lane maintenance and speed maintenance are well practiced and automated tasks that require little attention (1). Automated tasks are usually unaffected by secondary tasks because they involve consistent mapping between stimulus and responses (17). Second, the conversation may have led to a selective rather than a general withdrawal of attention (4). Selective withdrawal often leads to degraded object and event detection, although vehicle control largely remains unaffected.

The selective withdrawal interpretation is supported by the finding that response times to the pedestrian event were slower when the driver was simultaneously talking and driving. This is consistent with much of the distraction literature, which has shown that talking over a cellular phone or with passengers increases the response times to driving events (3, 5, 6). Therefore, drivers engaged in in-vehicle conversations may be at a greater risk for accident involvement when quick responses are required. The reason that the reactions to the pedestrian event were influenced by both the driving difficulty manipulation and the conversation task, whereas the light event was not, is most likely due to differences in the urgency of the events. Light signal changes do not always require a response, and drivers can often proceed through the intersection without any acceleration or braking response. Consequently, light signal changes may not be suitable events for PRT measurement. In contrast, pedestrian incursions often evoke an urgent emergency response, since failing to brake or swerve could result in a collision and injury. This might make driving events that require urgent responses more appropriate for PRT assessments.

The PRT to the pedestrian was marginally faster when participants drove the difficult scenario. This is most likely because of the increased vigilance accompanied by arousal. Vigilance is important for tasks that require operators (i.e., drivers) to detect and respond to events that occur infrequently over long periods of time. In both scenarios, the probability that the pedestrian occurred was low and relatively unpredictable. However, in the difficult driving scenario, there were more pedestrians and oncoming traffic, and this may have reduced some of the uncertainty surrounding the event and increased arousal. Lower levels of uncertainty and more arousal have been shown to increase sensitivity to event detection in vigilance tasks (18).

Conversation

Unlike many previous studies (2, 5, 6), conversations were analyzed to test the assumption that passengers adjust to changes in the traffic environment. The results indicated that under both task conditions the drivers and nondrivers reduced their speech rates as driving demands became more difficult. However, the difference in speech rates between the easy and the difficult scenarios corresponded to approximately 1.5 syllables during the 5-min drive. Participants in

the passenger condition also had lower speech rates overall compared with those in the cellular phone condition. Thus, being able to see the driving situation seemed to result in some overall allowance for driving demands, but the difference between the two task conditions was 4.2 syllables. Although these differences may be statistically interesting, they are not likely to have much meaning in terms of driver safety or workload. Most importantly, there were no differences in speech rates between the drivers and the nondrivers, particularly in the passenger condition. Thus, unlike what some researchers have assumed (4, 7), nondrivers in the passenger group (i.e., the passengers) did not adjust their speech rates more from the easy to the difficult driving conditions relative to those of the nondrivers in the cellular phone group.

Nondrivers had higher linguistic frequencies than drivers. The authors thought that since the drivers were driving and talking they might compensate for the increased resource demand by using more common words. What appears to have occurred is that because drivers were doing two things at once and they were told to generate words as quickly as possible, they may have generated words without consciously attending to how common they were. Because nondrivers were only completing the conversation task and were talking only half the time, they may have had more resources available to think of words that were more common. A similar argument could be used to explain why participants in the cellular phone condition used more common words than the passenger group. Because the nondrivers in the cellular phone group were completing only the conversation task and could not see the driving environment at all, they had even more resources than the passengers did. Given that passengers were in the car with the driver, their responses may have been influenced by the driving situation.

More conversation errors were made in the difficult scenario, perhaps because the oncoming traffic increased the ambient noise inside the vehicle. More errors were also made in the cellular phone group than in the passenger group. This likely occurred because participants in the cellular phone group lacked the nonverbal cues that have been shown to assist in conversations. Research has shown that being able to see the person you are speaking with greatly improves communication, particularly when signal quality is low (18).

Subjective Workload

Most researchers view workload as an interaction of task and system demands, operator capabilities, training, experience, and effort (19). In this study, the workload was analyzed to determine if the addition of the conversation task and changes in driving demands would be reflected in subjective performance criteria. The results showed that workload was rated higher when the driver was driving and talking than when the driver was driving alone, but when the driver was driving alone, the driver was better able to discriminate between the easy and the difficult driving demands. This is probably because when drivers were driving and talking, the workload was already elevated, and any additional increases were more difficult to distinguish. The workload data for drivers and nondrivers revealed that, overall, drivers rated workload higher than nondrivers did. This was expected since drivers were performing two tasks, while nondrivers were only conversing. Additionally, the data revealed that the workload for the cellular phone condition was rated somewhat higher than that for the passenger condition. This is consistent with the conversation error data, since participants made more errors, on average, in the cellular phone condition than in the passenger condition.

Limitations and Future Research

In this study, the authors tried to match the frequency that driving events occurred to their frequency in real driving. The authors believed that encountering two light signal changes and two pedestrian incursions was realistic, given the 20 min that participants were required to drive. However, it was difficult to get reliable measures of PRTs from only two responses for each driving event. Participants could have responded to each event several times in one route, but this would have primed subsequent responses to the same event and unrealistically decreased the PRT (10). A compromise between realism and reliability was attempted, but with only moderate success.

The majority of participants (>90%) in this and other studies (20) indicated that they used handheld phones while driving. Although this study and several others (3, 6) point to the importance of focusing on the conversation, manual factors such as dialing, holding, and manipulating the phone should be more thoroughly researched. In fact, few studies have compared handheld and hands-free cellular phone conversations with passenger conversations.

One limitation of the conversation analysis was that the data were averaged for each route. There may have been important changes in the conversation that were not captured when the data were aggregated. During transcription of the conversations, it was noted that some participants paused during turns. Although the authors wanted to analyze the conversation separately for intersections (i.e., during turns) and straight roads, the variable nature of the driving environment was such that not all intersections were equivalent. A future study should compare conversations in scenarios that contain intersections where turns are required and conversations in scenarios that do not require turns.

The fact that no differences in speech rates were found between drivers and nondrivers suggests that the conversation placed fairly low resource demands on the drivers. Modulation may not have been observed because the conversation task was effectively shared with the driving task, and thus, little decrement in driving performance was observed. Future research should consider the use of a more difficult conversation to determine the relationship between conversation difficulty and modulation.

Last, the sample used in this study might also explain why conversations were not modulated. Participants were generally young, with an average of only 4.34 years of driving experience. It is possible that participants lacked the driving experience to know that they should be modulating their conversations. This study should be expanded to include a sample of more experienced drivers over a wider age range. Since older and middle-aged adults have more driving experience, they may be more likely to modulate a conversation. Older adults would also be expected to show more distraction and modulate the conversation to a greater degree, since research has shown that older adults are more influenced by secondary tasks (21) and will shed them when possible (14). Until future research explores the relationship between age, experience, modulation, and distraction, the results of this study should be extended to the general driving population with caution.

CONCLUSIONS

The driving performance data found that while lane and speed maintenance tasks may be shared effectively with a concurrent conversation task, driving events that require urgent responses may be influenced by in-vehicle conversations. To the extent that discrete

driving events are one of the greatest threats to driving safety, drivers should be aware of the distraction caused by conversations either with passengers or via cellular phones. Ideally, drivers would monitor conversations on their own and minimize talking and driving during periods of high driver workload. However, studies suggest that in-vehicle phone use is increasing (4), and drivers are unlikely to curtail their discussions with passengers. Therefore, some thought should go into educating and training drivers about the hazards of conversations both on cellular phones and with passengers.

The findings of the conversation analysis raise some questions about the assumptions that driving researchers have made about the safety of passenger conversations. Although some statistically interesting findings were observed, the study found little practical evidence that passengers modulate a conversation as driving demands changed. Therefore, the fact that passengers are in a position to see the driving environment may not necessarily result in changes in the conversation. The potential exists for passengers to continue talking even when driving demands are high, and this could account for why some studies find that conversations with passengers can be just as distracting as conversations over cellular phones (2, 3). Unlike what some researchers have assumed, modulation may be the exception rather than the rule, and the specific circumstances under which modulation occurs is still unknown.

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