Cars, Calls, and Cognition: Investigating Driving and Divided Attention

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ABSTRACT
Conversing on cell phones while driving an automobile is a common practice. We examine the interference of the cognitive load of conversational dialog with driving tasks, with the goal of identifying if there are better and worse times for conversations during driving. We present results from a controlled study involving 18 users using a driving simulator. The driving complexity and conversation type was manipulated in the study, and performance was measured for factors related to both the primary driving task and secondary conversation task. Results showed significant interactions between the primary and secondary tasks, where certain combinations of complexity and conversations were found especially detrimental to driving. We present the studies and analyses and relate the findings to prior work on multiple resource models of cognition. We discuss how the results can frame thinking about policies and technologies aimed at enhancing driving safety.

Author Keywords
Driving, attention, dual task performance

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Driving automobiles is often perceived as a fluid, nearly automatic process, and drivers often engage in secondary activities while driving [1, 6, 7, 28, 29]. Although some peripheral tasks are rapid and require only momentary shifts in attention from the primary driving task [9], other secondary activities may require more time and effort, and can lead to prolonged periods of divided attention [12, 22].

With the proliferation of mobile devices and people’s desire to remain connected, talking on the phone, reviewing email, and even composing email messages and texting while driving have become commonplace. The cognitive, visual, and physical demands of such tasks can compromise the primary task of driving. Users may often overestimate their ability to divide their attention with secondary tasks because of the sense that driving is near automatic and can thus be safely shared with secondary tasks. However, it may be difficult to switch full attention back to driving in a timely manner so as to observe and respond appropriately when driving challenges arise, and such attentional problems can result in accidents [16].

The data linking the use of phones while driving to boosts in accidents and fatalities has sparked legislation aimed at limiting cell phone usage during driving to hands-free configurations. However recent research has shown that using devices in a hands-free manner is no less harmful than the use of handheld devices [13]. Thus, phone use would have to be stopped to avoid the challenge they make to driving safety. Unfortunately, people are unlikely to give up phone conversations while driving, and complete bans of phone use in this setting are unlikely.

Our goal is to better understand the interference between the cognition tapped for phone conversations and for driving. Enhanced insights about such potential interference would help to characterize better and worse times for phone conversations during driving, highlighting when drivers could more safely engage in phone conversations. As a first step, we set out to understand how different types of cell phone conversations during varying levels of driving engagement affects driving performance, as well as performance on the call itself. From a more theoretical perspective, we sought to understand the interactions between cognitive resources used in driving and in handling common secondary tasks associated with phone conversations.

We conducted a controlled study with 18 participants driving within a high-fidelity driving simulator. The participants drove on routes composed of segments that posed different types of navigation challenges. While driving, the participants would occasionally have to respond to a cell phone call, pushing a button to initiate a hands-free interaction. The cell phone calls were one of three kinds of engagement: listen (assimilate), answer questions (retrieve) and provide directions (generate). In addition, for each driving trial, we asked drivers to either focus mainly on their driving, on the conversation, or do their best to both drive and handle the phone-based tasks.
Not surprisingly, we found that simpler routes are safer than complex routes when drivers are engaged in phone tasks. Drives on the simpler routes were associated with a lower incidence of collisions, sudden braking, and missed turns. We also found that specific types of phone conversations interfere more significantly with driving, presumably because the tasks associated with the calls interfere with cognition that is relied upon for driving. We shall review how certain tasks may steal attention from the driving task and/or make demands in other ways on the cognitive resources that are used in controlling and navigating a car.

**RELATED WORK**
We shall first discuss research exploring how humans use cognitive resources to address concurrent tasks. We turn to prior research and reflection within cognitive psychology on the allocation of attention in dual-task settings.

**Divided Attention and Dual-Task Challenges**
From the perspective of Multiple Resource Theory (MRT) of cognition [34], humans harness varying quantities of different kinds of limited cognitive resources (e.g., short- and long-term memory, attention, reasoning, etc.) to solve problems. In dual-task settings when there is contention for cognitive resources, reallocation of resources from one task to another can improve the performance on the second task [24, 25, 35], and as the difficulty of one task increases, the performance on the other decreases [39]. MRT further suggests that, for concurrent tasks, performance on both may be maintained if the tasks are in separate processing stages (response selection versus perceptual cognitive activities), or involve different processing mechanisms (spatial and analog information versus verbal and linguistic information) [34, 35]. Finally, the theory of automaticity proposed by William James over a century ago, suggests multiple processes can go on simultaneously, as long they are habitual, with minimum of direct conscious control [15]. While automaticity can be obtained through training and practice [21, 30], its success also depends on consistency [11].

The prior work on dual-task challenges provides a useful framing for research on performance tradeoffs in the setting of driving a car while talking on the phone or interacting with an in-vehicle system [14, 20]. For example, while a seasoned driver may show an overriding automaticity in piloting a vehicle, the driving task demands resources associated with visual perception, spatial working memory, and motor responses and coordination [18, 36, 38]. Attempts to solve secondary tasks may draw on resources used during driving [23], and this may lead to performance degradations in one or both tasks.

Introduction of a second task has been shown to impact performance in many dual-task contexts. Basic research on performance in rarified dual-task settings has been done with studies of shared attention in visual search [1]. However, it is not clear whether results demonstrated on low-level dual-task challenge problems, formulated and studied in psychology labs, holds for switches between higher-level and more complex tasks (e.g., switching from driving to attending to a cell phone call) and how well attention can be selectively allocated, or divided across these two tasks. Pursuing such an understanding is the main thrust of this work.

We study commonplace dual-task situations that people face when they engage in phone conversations while driving. Different types of conversations may engage different mixes of cognitive, spatial, and verbal resources that may compete in different ways with the challenges of driving. Rather than attempting to characterize the detailed cognitive requirements associated with different types of conversations, we shall study the interaction of classes of conversational tasks that we characterize broadly as assimilation, retrieval, and generation. Our goal is to understand how these different types of conversational tasks conflict with driving and to identify whether certain combinations of driving challenge and conversation tasks are associated with increased or diminished risk.

**Effects of performing secondary tasks while driving**
Dual-task scenarios of driving and performing secondary tasks such as conversing on the phone, texting, interacting with in-vehicle controls have been an area of active research. Studies have shown that dialing or answering the phone, adjusting the radio or interacting with music players have negative influences on driving, [6, 7, 29], as well as reasoning and conversing during driving [8].

Phone usage during driving has been shown to have catastrophic effects in many studies. For example, drivers with phones have slower braking reaction time [1, 19], have impaired steering control [7], and are more likely to have an accident [27, 32]. Moreover, no value of moving from hand held to hands free phones has been found, debunking beliefs that removing the need to physically hold phones reduces distraction during driving [27, 31]. These findings reinforce the hypothesis that cognitive demands of multitasking play a more important role in distracting drivers than manual manipulation [26, 31].

In order to understand the effects of cognitive demands on driving, researchers have looked at performance on various secondary tasks known to cause memory load in prior psychology studies. These include working memory tasks [1], mental arithmetic tasks [6], and reasoning tasks [8]. Although not entirely representative of conversations that one may have over the phone, these tasks were chosen as they may replicate the cognitive demands placed on drivers while participating in more natural conversational settings. Performance on driving was reduced in all cases.

We reexamine the influence of phone conversations on driving, and explore how phone conversations are affected by driving. We compare performance across different types of conversation while driving on courses with different levels of difficulty. Although conversation types and driving difficulty have been separately explored in prior research, we look at both together. Also, we investigate how varying levels of attention allocation across driving and phone con-
aversations affect performance. While others have investigated several of these factors or partial combinations, prior research has not explored the interactions in a joint manner within a single experiment as we do here.

**Strategies for interleaving secondary tasks with driving**

Given that people can perform two tasks concurrently [34], researchers have recently looked at opportunities to interleave secondary tasks with driving. Brumby et al. investigated how interleaving a phone dialing task with driving impacted lane keeping and the dialing time under conditions of prioritizing either driving or dialing [9]. Results showed that when asked to prioritize the secondary task, users use chunk boundaries to switch back to driving to maintain driving performance, and while focusing on driving, the secondary task is slowed down. In another study, Brumby et al. showed that the fastest strategy for selecting a song on a music player while driving was to scroll in one contiguous block without returning attention to the primary task of driving. For the safest strategy, more time needs to be given to the driving task, at the cost of longer response times for the secondary task, and correspondingly longer stretches of times for the dual-task scenario [10].

The prior results suggest that for automatized tasks like driving, it may be possible to formulate strategies to perform other tasks without significantly compromising the primary task. Successful dual-task scenarios will depend on the availability and requirements of cognitive resources for the secondary task in light of resource consumption by the primary task. We explore performance in these scenarios by generating phone calls with different cognitive demands during driving situations of different difficulties. We seek to probe the interaction of cognitive resources for driving and handling calls via the proxy of measuring how performance is affected on both the driving and phone call tasks. We provide recommendations on the timing and nature of conversations that conflict the least with driving and propose strategies for minimizing interference.

**OVERVIEW OF STUDY**

Our goal was to explore if and when opportunities exist during driving when phone conversations can be carried on without reducing driving performance, what conversations cause the most interference with driving, and how increasing driving difficulty affects the degree of conflict.

Understanding performance of driving on conversation has not been well studied. We also investigated how well users can carry out the conversation and how much they can recall afterwards. We addressed the following questions:

1. How is driving performance affected by participating in phone conversations where the driver has to interact in varying levels of engagement? How do these effects vary with changes in driving difficulty?
2. How are phone conversations influenced by concurrently driving, and how do these effects vary with changes in the levels of driving difficulty?
3. How does the performance vary with different loci of attentional focus (driving, conversation or both)?

To answer these questions, we conducted a controlled study using an driving simulator (see Figure 1). Using the simulator, users engaged in driving a realistic route, with a realistic steering wheel, pedals, and controls. Custom software allowed researchers to design driving scenarios and log relevant parameters during driving. To simulate a hands-free phone call environment, phone calls were presented through a peripheral system including a loud speaker and a microphone, and a ‘respond’ button on the driving console.

**Experimental Design**

The study was designed as a 3 (driving complexity) X 3 (call type) X 3 (focus) repeated measures within subjects design. Possible effects of order were countered by blocking the factors on a fully balanced Latin square design.

**Users**

18 people participated in our study (F=3), recruited through a call sent out to randomly selected people from the entire employee pool of our organization. The mean age of participants was 33.2 years, (S.D. = 8.2) with a mean of 16.8 years of driving experience (S.D. = 9.41). All participants reported to be comfortable talking on the phone while driving.

**Driving Task**

Participants drove routes comprised of multiple 30s segments, each segment having either of the following 3 levels of complexity: simple, complex and unexpected occurrences. An example of a simple segment is a single stretch of driving on a relatively empty road. A complex segment involves driving with many cars on a road, and requires changes of speed or lane changing. A segment with unexpected occurrences involves a sudden onset of an unexpected event, e.g. a car in front suddenly braking, a pedestrian stepping into the road, or an object rolling in front of the car. The segments with unexpected occurrences include time for the driver to recover and resume safe driving. The routes were about 10 minutes long.

Drivers were asked to follow the route straight on, unless there were instructions to turn left or right. Instructions appeared in large banners in the front view of the driver and were easy to see if drivers were looking at the road.

![Figure 1: The STISim driving simulator. It hosts a console with a steering, turn signals, and buttons that can be mapped to external functions. The three 47” screens, placed at roughly 45°, generate a convincing impression of driving a vehicle.](image)
To preserve the order of driving complexity as dictated by the Latin square design, we randomly chose segments where users would receive phone calls. Complexities would be assigned to these segments according to the Latin square. Complexities to the remaining segments were then assigned randomly. This procedure reduced the probability that users would be able to predict phone calls on any given segment.

Phone Tasks
As participants were driving they would occasionally receive phone calls through the peripheral system. Pressing the respond button on the system would mark the beginning of the conversation. The phone task was selected according to the design and launched. Participants had 30 seconds to perform the task after which the call would cut off.

Phone tasks belonged to one of the three categories: assimilation, retrieval, and generation (table 1). The categories were designed based on prior studies looking at decrements of performance in driving while drivers engage in secondary tasks (see, e.g., [31]). In distinction to the prior work, we designed the tasks so as to resemble conversations that one typically may have over the phone.

For the assimilation task, the participant listened to a 15-20 second news headline. The choice of this task was motivated by Strayer and Johnston’s [31] book-on-tape task, where participants were instructed to listen so that they could answer post-experiment questions. For the retrieval task, participants were asked to answer two demographic/survey questions, similar to what one may get from a telemarketer. For the generation task, participants were asked to provide driving directions between two points of interest. The first two tasks were designed to exploit verbal and linguistic/semantic resources. The third task adds more obvious spatial reasoning requirements to the mix.

Methodology
On arrival to the lab, participants were first taken through a 15-20 second news headline. The choice of this task was motivated by Strayer and Johnston’s [31] book-on-tape task, where participants were instructed to listen so that they could answer post-experiment questions. For the retrieval task, participants were asked to answer two demographic/survey questions, similar to what one may get from a telemarketer. For the generation task, participants were asked to provide driving directions between two points of interest. The first two tasks were designed to exploit verbal and linguistic/semantic resources. The third task adds more obvious spatial reasoning requirements to the mix.

Prior studies have shown that asking users specifically to focus on one task over another in dual-task experiments involving driving can yield different outcomes [9, 20].

The experimental session lasted about 1.5 hours. Users came back for two more sessions, where the experimental factors were varied according to the Latin square design to correct for ordering effects. In summary, each participant drove 9 routes and answered 81 phone calls over 3 sessions.

Measures
Performance for both driving and the phone tasks were measured for route segments when users were answering a phone call while driving. For driving performance, we measured the number of collisions, missed turns, and sudden braking (as a measure of how users attempt to self modulate driving safety), and driving speed while talking on the phone. We also recorded the same measures when users were driving while not engaged in a phone call, as a way of measuring baseline performance. The values were automatically recorded by the simulator.

For performance on the phone task, we measured the ability to correctly identify topics in the phone conversation. As an indicator of how users attempt to modulate the conversation to ensure driving safety, we also tracked the time participants took to respond to the ringing of an incoming phone call, and analyzed the prosodic information such as mean length of pauses and silent segments in their utterances.

RESULTS
For the baseline condition, each user provided 3 data points per phone task, totaling 9 data points per user. For the experimental condition, each user provided 3 data points for each of the (Driving complexity (3) X Call type (3) X Focus (3)) conditions, totaling 81 data points per user and a grand total of 1,620 data points.

Effects on driving
For driving performance, we compare performance across moments when the driver was involved in a phone call while driving, and moments when they were driving with

<table>
<thead>
<tr>
<th>Phone task type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation</td>
<td>A 16 year old in NY recently was texting while walking and fell into an open manhole.</td>
</tr>
<tr>
<td>Retrieval</td>
<td>When did you last change oil in your car?</td>
</tr>
<tr>
<td>Generation</td>
<td>Please give directions from your home to the nearest grocery.</td>
</tr>
</tbody>
</table>

Table 1: Examples of phone based task categories
no phone distractions. Note that the overall rates of occurrences of these events (collisions, missed turns, sudden braking etc) are low, as not all distractions result in catastrophic outcomes in real life, and it was no different in the simulation. This is similar to findings described in [31]. However, we sought to investigate the extreme cases of when such events occur, and how much they are affected by the factors (focus, driving complexity, and call type) explored in this experiment.

Collisions
A collision was registered whenever the driver hit a car, an object, or a pedestrian. Overall, for the 18 users, the rate of collisions/minute in the experimental conditions (with phone calls) was significantly higher than in the baseline condition (no phone calls) (t(17)=5.19, p<0.0001). For the experimental routes, overall, the number of collisions were low, 53 out of 1458 phone calls (excluding the baseline phone calls). There was a significant main effect of driving complexity (F(2, 1431)=13.55, p<0.0001), and interaction effects between focus and call type (F(4, 1458)=3.42, p<0.009) on the number of collisions (see Figure 2(a)).

Post hoc Bonferroni tests showed that while driving on simple route segments, the number of collisions while engaged in a phone call (M=0.002) is significantly lower than while driving on a complex route (M=0.06, p<0.0001) or when an unexpected event occurs (M=0.047, p<0.0001). This suggests that regardless of the call type, simple segments are more conducive for phone conversations than driving on the other two kinds of segments.

We now investigate the interaction between the focus and the call type. We report only on significant differences, and all these results are independent of the driving complexity. When drivers focused more on driving, assimilation caused significantly more collisions (M=0.056) than generation (M=0.006, p=0.044). When drivers focused more on phone conversations, there were no significant differences in the number of collisions across the different call types. However, when focusing on both, retrieval resulted in more collisions (M=0.068), compared to assimilation (M=0.012, p=0.018). Although generation caused less collisions (M=0.025) than retrieval, the difference was not significant.

Both of these results are interesting, albeit counterintuitive findings. One might assume that the verbal nature of the assimilation and retrieval tasks should conflict less with the spatial/manual task of driving [31]. As an explanation, we hypothesize that drivers may consciously modulate driving when they are engaged in a task where there are obvious difficulties in generating an answer (visio-spatial directions task). This could manifest through reductions in speed or managing to hit the brakes in time, to be explored shortly.

Failing to follow instructions to turn
We explored how users noticed changes in the driving route made in real time via road signs, appearing both during phone conversations and when there were no phone calls in progress. Overall, across the 18 users, 8.2% of the turns (61/742) were missed or wrongly taken (e.g. taking a left turn instead of a right and vice versa), resulting from failing to properly notice the road signs instructing the turn. For our 18 users, the rate of missed turns during phone calls were significantly higher than the rate of missed turns during the baseline condition of no phone calls (t(17)=8.357, p<0.0001). A univariate ANOVA analysis with Missed Turns as the dependent factor showed that Focus (F(2, 717)= 56.54, p<0.0001), Driving Complexity (F(2, 717)=15.89, p<0.0001), and Call Type (F(2, 717)=17.873, p<0.0001) – all significantly impacted the number of missed turns. There was also significant interaction effects between the pairs Focus-Driving Complexity (F(4,717)=20.89, p<0.0001), Focus-Call Type (F(4, 717)=16.68, p<0.0001) and Driving Complexity-Call Type (F(4, 717)=4.35, p<0.002). See Figure 2 (b).

We performed Post hoc Bonferroni analysis to understand the main and interaction effects. Again, we will only report on the significant differences, see figure 2(b) for details. Overall, when participants were asked to focus more on driving, having a phone conversation caused users to miss significantly more turns (M=0.453) than when asked to focus on both (M=0.052, p<0.0001), and to focus more on the phone conversation (M=0.274, p<0.0001). Being asked to focus more on the phone conversation also caused users to miss more turns than when asked to focus on both (p<0.0001). This finding alludes to the potential difficulty of switching attention back and forth between one task to the next, when focused primarily on one or the other.

When focused more on driving and an unexpected event occurred, generation caused users to miss significantly more turns compared to retrieval (p<0.043). When focused more on phone conversations, regardless of the driving complexity, assimilation caused most missed turns (p<0.0001 for both retrieval and generation). When focused on both and driving on a simple segment, retrieval caused significant more missed turns than both assimilation (p<0.004) and generation (p<0.0001). While driving on a complex segment, generation caused more missed turns than both assimilation and retrieval (p<0.0001 for both). When focused on both and an unexpected even occurred, the number of missed turns were not significantly different across the different call types.

Overall, differences in missed turns across varying levels of focus indicate difficulties in switching attention from one task to the other, but no other clear patterns emerged across various combinations of focus, driving difficulty and call type. However there appears to be unique structural conflicts across certain combinations. For example, when driving in complex conditions, generation (a visual/spatial task) caused the highest number of turns to be missed. This suggests that there may be a contention between the use of cognitive resources by driving and keeping an eye on turn instructions. However, it is difficult to draw conclusions from this set of results about resource conflicts and further exploration in this direction is needed.
The rate of sudden brakes during phone calls was significantly higher than in the baseline condition ($t(17)=5.154$, $p<0.0001$). There were a total of 96 sudden brakes across the 18 users, and 55 of them happened during a phone call. As with collisions, there was a significant effect of Driving complexity ($F(2, 1431)= 43.418$, $p<0.0001$). There was also an interaction effect between Focus and Call type ($F(4, 1431)=3.375$, $p<0.009$) on the number of sudden brakes. Figure 2(c) shows the details.

As expected, facing an unexpected condition while driving caused majority of the sudden brakes (49/55). This was significantly higher than both brakes during simple and complex driving ($p<0.0001$ for both).

As before, we report only the significant differences for the interactions between Focus and Call type. Though trends were as expected (see Fig 2(c)), only when focused more on driving, generation resulted in significantly more sudden brakes ($M=0.074$) than retrieval ($M= 0.012$, $p<0.007$). This could be based in the difficulties of rapidly switching spatial resources while giving directions as the user tries to focus on driving. Whether this is accompanied by a corresponding speed reduction will be explored shortly.

Driving Speed
We examined driving speeds in the phone call and no phone call conditions. Overall, average speed during phone calls were significantly lower than the average speed when there were no phone calls ($t(17)=3.45$, $p<0.003$). A univariate ANOVA on speed showed main effects of all three factors - Call type ($F(2,1421) = 4.51$, $p<0.011$), Focus ($F(2,1421)=21.85$, $p<0.0001$) and Driving complexity ($F(2,1421)= 225.1$, $p<0.0001$). There were also significant interaction effects between all three factors.

When users focused more on driving, users drove faster while doing generation ($M=41.8$) than while doing retrieval ($M=36.59$, $p<0.0001$) and assimilation ($M=37.85$, $p<0.004$). When users focused more on conversations, they drove slower ($M=33.4$) when doing generation than retrieval ($M=38.5$, $p<0.0001$). Users also drove slower while doing assimilation ($M=35.5$) than while doing retrieval ($p<0.028$).

When users focused on both driving and the conversation, they drove slower during both retrieval ($M=31.4$, $p<0.0001$) and generation ($M=31.1$, $p<0.0001$), compared to assimilation ($M=39.1$). These results are aligned with findings in [31] that show that listening has a lesser impact on driving.

When users were more focused on driving and an unexpected event happened, users slowed down the most ($M=30.82$), compared to driving in the complex condition ($M=37.14$, $p<0.0001$), and driving in the simple condition ($M=48.33$, $p<0.0001$). Conversing and driving in the complex condition also resulted in lower driving speeds compared to conversing and driving in the simple driving conditions ($p<0.0001$). Similar results were found when users were focused on both driving and conversing (fig 2(d)). When focused more on the phone conversation, the unexpected event while talking caused users to have significantly lower speeds than both the simple and complex driving situation ($P<0.0001$ for both cases).
These numbers allude to the difficulty in dividing attention across the verbal tasks of conversing and often visual task of generating content according to a mental visualization of a given route, the visual-spatial task of driving and the skillful maintenance of speed. However, as discussed before, perhaps the act of being engaged in a complex secondary task that obviously conflicts with the driving task, users self-modulate driving speed to attempt to ensure safe driving.

Influence of driving on conversations and related tasks

We also studied effects of driving on the performance of the conversations and actions associated with them. Since this was a dual-task scenario where the phone task would likely be foregrounded, we wanted to understand how driving concurrently in the background influenced performance.

Time to respond to calls

Time to respond to calls was measured as the time between the initiation of the phone ringing and the time the user hit the button, depending on how difficult it was to switch attention from driving to the phone call. The time to respond to a phone call while driving was significantly higher (M=2.5s), compared to the baseline condition (M=1.52s, F(1,1608)=55.37, p<0.0001). These differences indicate the difficulty in switching attention from driving to responding to the phone call, where users often attempted to reach a safe state in driving before initiating the call.

A univariate ANOVA showed main effects of Focus (F(2, 1431)=53.3 , p<0.0001), and Driving complexity (F(2, 1431)=18.32, p< 0.0001) on Response time (Fig. 3). There were no interactions between the two. We ignore Call types for this analysis as the user did not know before responding to the call what type of conversation it would entail.

As expected, when focused more on driving, response time was highest compared to focusing on both (p<0.0001) and more on phone calls (p<0.0001). Response time for when the focus was more on phone calls were lower than when the focus was on both driving and phone calls (p<0.0001).

These results are in line with the expected difficulties associated with disengaging from driving to respond to the call; when focused more on driving, it took more time to switch than when prioritizing the cell phone conversation. Interestingly, prioritizing both results in response times not as high as when focused more on driving, nor as low as when prioritizing phone calls, indicating that there is some tradeoff in rapidity of response in order to ensure safer driving.

For driving complexity, response times while facing an unexpected event while driving was significantly higher than when driving on a simple route (p<0.0001) and on a complex route (p<0.05). Response times when driving on a complex route was also significantly higher than when driving on a simple route (p<0.0001), yet again demonstrating difficulty in disengaging from a cognitively demanding situation (complex or unexpected event) to take the call.

Recalling information from conversations

As a measure of how effectively users were able to pay attention to the phone conversations while driving, we analyzed how much they could recall information about the conversations in a questionnaire presented to them right after finishing driving each route. The questionnaire asked them to identify from within a set of distracters keywords presented in the news headlines, topics addressed in the demographic questions, and start and end points of the directions they were asked to provide in the conversations.

Overall, users had a higher number of wrong answers for questions from the experimental condition with phone calls (M=0.19) compared to the baseline condition (M=0.12, F(1, 1618)=4.83, p<0.028). A univariate ANOVA on the number of wrong answers showed main effects of Focus (F(2, 1458)=6.82, p<0.001), and Call type (F(2,1458) =7.121, p<0.001 ), but not of Driving complexity. There was however, an interaction effect between Focus and Driving difficulty (F(4, 1458)=4.25, p<0.002) as well as between Focus and Call type (F(4, 1458)= 4.99, p<0.001).
As seen in Fig 4, there is no clearly delineated pattern of wrong answers. However, following up on the interaction effect between Focus and Driving difficulty, Post hoc Bonferroni analysis showed that when focusing on both driving and the conversation and driving on the simple segments, users had significantly more wrong answers (M=0.27) compared to driving on the complex (M=0.13, p<0.001) and unexpected segments (M=0.11, p<0.003). This is a counterintuitive result, contradicting the earlier findings. However, it is possible that while instructed to focus on both, users were able to generate information while driving safely, but retaining information was more difficult while trying to maintain performance on both. No other significant differences were found.

Following up on the interaction effect between focus and call type, we found that when driving was the main focus, users had significantly more wrong answers for assimilation (M=0.33) compared to retrieval (M=0.185, p<0.003) and generation (M=0.22, p<0.039). When users focused on both driving and conversations, users had significantly more wrong answers for generation (M=0.284), compared to assimilation (M=0.136, p<0.003) and retrieval (M=0.086, p<0.0001). No other differences were found.

Prosodic analysis

Finally, we analyzed attributes of the speech of drivers during phone conversations using specialized speech analysis tools. We were particularly interested in the length of pause segments and the length of silent segments in the speech, as an indicator of how users were interleaving attention across the driving task and the conversation. Since for assimilation the user did not have to speak, we exclude phone calls for assimilation in this analysis.

No significance differences across the mean lengths of pause segments were found. However, there was a significant effect of focus on the mean length of silent segments (F(2, 938)=4.04, p<0.018). Post hoc Bonferroni tests showed that silent segments were the longest (M=0.093s) when users were more focused on driving, significantly higher than when the users were more focused on the conversation (M=0.072s, p<0.012). Even though there was no significant differences, the length of the silent segments while focusing on both was higher than when focusing on the conversation, and lower than when focused on driving (fig 5). This finding provides further evidence that while focused on driving, it is more difficult to disengage and switch to a call, and users interleave more (resulting in silence in the conversation) to maintain driving performance.

Summary of results

Overall, our findings show complex interactions between varying levels of focus, driving complexity, and conversation type. However, results suggested that answering a phone call while driving on a simple route results in the least collisions, the least slowing, and the least sudden braking. On the other hand, driving on more complex routes or a route that contains unexpected events results in degraded driving performance—especially when performing a generation task that involves spatial reasoning. On receiving phone calls, users appeared often to attempt to ensure a stable driving situation before initiating a switch of attention. However, the more focused the user is on driving, the more difficult it is for them to make the switch to the phone call. Also, more focus on driving means that users are trying to switch back and forth more between driving and the phone task. This could explain the lengthier silent segments. When attempting to focus on both driving and conversations, retaining information is difficult as shown through lower number of recalls on headline information.

These results provide the first evidence of the complex interplay between focus, conversation type, and driving difficulty. Although no clear winning combination emerged, overall it appears that conversations not requiring many spatial resources during simple routes are likely the least disruptive to the primary task of driving. The quantitative evidence suggests that the effects on performance is common and catastrophic events do happen with non-negligible frequency. Since driving is a safety-critical domain the goal must be to reduce the negative performance as much as possible, as the potential costs are high.

DISCUSSION

We investigated the interplay between driving complexity and conversation types, and allocating varying levels of focus on the driving and the phone call task affects their performance on both. Our findings highlight the difficulties in determining opportune moments for engaging in phone calls, as combinations of certain types of conversation coupled with road conditions can result in performance degradations with severe outcomes. Our findings also show that for a task like driving, which is in the most part automated, users are able to switch attention back and forth if conditions are favorable, and users attempt to do so even when they are asked to focus on the phone conversation.

Apart from understanding the measurable outcomes of the experimental conditions, we wished to understand the underlying cognitive mechanisms underlying the findings. We were in particular interested in understanding how cognitive
demands that the conversation may place on the user (e.g., requiring spatial resources versus requiring verbal resources) conflicted with the oft automatic, spatial-manual task of driving. Our results showed that the generative task of providing directions resulted in the largest degradation in performance during driving. Generative tasks have been shown to result in performance deficits in dual task scenarios (e.g., see [5, 31]). According to the multiple resource theory, an solely verbal cell phone conversation should not interfere with a spatio-visual driving task [6, 34, 31]. However, it is important to consider the details of problem solving associated with the superficially verbal phone conversation. For the generative task of providing directions, the conversation can lead to competing mental spatio-visual analyses which may conflict with the efficient analysis and response to the visual scene of the real-world in which the driver is immersed. This competition and interference may explain the performance degradation when drivers face an unexpected event. The combined resources required for the efficient processing of the spatio-visual tasks associated with the conversation and of driving may exceed the capacity of the resource reservoir [37].

Users were occasionally found to be able to attend to each task effectively when confronted with one task while asked to focus on the other. For example, even while deeply engaged in a phone conversation, users were also found to make subtle adjustments to their driving (e.g., reducing their driving speed to have more control) to accommodate the conversation without compromising safety. Also, while focusing on driving, users were found to have many more silent segments in their conversations, indicating that perhaps users were switching back and forth between driving and the conversation to ensure that the driving task is not being impacted. Interleaving as such may or may not be an effective strategy [9] because even when users are asked to focus primarily on driving, having conversations often resulted in similar performance degradations than when they were asked to focus on both tasks.

There may be alternate explanations. Kubose [17] showed that talking improves driving performance related to driving in silence, where there was less variability in maintenance of lane position for both easy and difficult driving. Some of our results could be interpreted by taking into account the automaticity aspect of driving, where drivers are able to drive safely without having to exert too much attention. In fact, experts can get worse when they explicitly try to focus on the components of their skills [3, 4].

Our findings also showed differences in response times based on the level of focus the user had. The findings may be based in the user consciously choosing a moment for conversation when there would be less overall cognitive load. Welford’s central bottleneck theorem may explain some of the difficulties in processing both tasks [33]. That work poses central processing (response selection) as serial, where perceptual analysis and response execution can be more parallel when there is no resource conflict. One of the reasons that there was a significant difference in response times to the phone calls is that drivers had to make the decision to respond, whereas afterwards they were able to concurrently continue the tasks while driving.

Our results on response time draw an interesting parallel to Brumby et al.’s [9] findings on how users interleave with driving. They show how drivers use the chunk boundaries in a 10-digit dialing task to switch back to driving to maintain lane keeping. In our experiment, where phone calls appeared at moments of varying levels of driving engagement, we found users to reach a safe state in driving before choosing to respond to a phone ring. Although it may be difficult to determine exact hierarchies and corresponding boundaries during driving, our results further support prior work where users are more comfortable switching tasks when workload is lower, and these moments exist at the completion of a task at some level of granularity [2].

IMPLICATIONS FOR DESIGNING IN-VEHICLE SYSTEMS

Our findings provide recommendations for designing in-vehicle systems that are sensitive towards users’ communication needs while prioritizing driving safety. An intelligent system could combine contextual information such as traffic and road conditions with the driver’s state to determine the complexity of the driving situation. External calls could be routed to the system and callers could specify the general type of their call. Based on the driving complexity and call type, the system could either let the call through or could put callers on hold until the driver had reached a safe driving state. Given the rapid improvement in in-vehicle technology, adding such a component of intelligence cannot be far away. This kind of mediation would lower the potential costs that might arise when drivers try to establish a conversation immediately when phone rings—so as to catch the call before the caller is transferred to voicemail or hangs up.

CONCLUSION AND FUTURE WORK

We conducted a study to understand how different types of phone conversations during driving result in resource conflict and corresponding performance degradation in driving and for the phone conversation. Our findings showed that simple routes with few or no other cars and constant speeds are safest in terms of receiving and engaging with phone calls. Tasks that share processing resources with driving have the most conflict and result in decreased performance. We found that, despite their engagement in phone conversations, drivers subconsciously maintain safety in driving. However, problems with driving may arise when resource demands exceed resource availability, such as when drivers are engaged in conversations involving spatio-visual tasks and simultaneously face a complex or unexpected situation on the road. The findings highlight types of conversations and types of road segments that can be leveraged to allow phone conversations to be carried on while driving. Future work includes developing a prototype system that can incorporate contextual information and intelligent decision making capabilities in order to regulate phone calls, while ensuring they reached users in a timely fashion.
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REFERENCES
15. James, W. Principles of Psychology, New York, 1890.
34. Wickens, C.D. Multiple Resources and Performance Prediction. Theoretical Issues in Ergonomic Science, 3 (2), 159-177.