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ABSTRACT

Driver distraction, defined here as engaging in a secondary task or activity that is not central to the primary task of driving, has been shown to be a contributing factor for many crashes. The secondary tasks and other activities in which drivers choose to engage while driving is also known to be highly varied, including very complex activities(e.g., text messaging on a cellular device) to very simple activities (e.g., selecting a radio preset).

Several important distinctions affect the relative risk of engaging in these tasks. Recent data from large-scale instrumented vehicle studies (i.e., "naturalistic" driving studies like the recently released "100 car study" (1)) have begun to provide data where the relative risk, in terms of crash and near crash involvement, can be directly assessed for differing secondary tasks. These data have provided some important insights into the features that create risk.

For example, these data have shown that engaging in a task that is at least "moderately complex" can significantly elevate crash/near crash risk compared to driving while performing no secondary tasks. A moderately complex task in this case is operationally defined as one where the driver must take their eyes off of the road in at most two glances to complete. However, the same data show that simple tasks, defined as requiring no more than a single glance or simple control manipulation to complete, do not significantly increase crash/near crash risk. It is important to note that simple tasks include those that require only "cognitive" attention, defined here as any task that does not require the driver to take their eyes off of the road or hands off of the wheel.

These results have significant implications for the design of driver-vehicle interfaces, as well as the need for future integration of nomadic devices into the driver-vehicle interface in a manner which will minimize crash risk.

INTRODUCTION

It has long been known that secondary task induced driver distraction degrades driving performance. Dingus, Antin, Hulse and Wierwille (1989)(2) in one of the first instrumented vehicle studies of inattention and distraction, were able to show the degree to which important performance and behavior variables including eye glance, lane keeping and speed maintenance measures were impacted by a wide variety of in-vehicle tasks. Since that time, many studies have been conducted utilizing instrumented vehicles, test tracks and simulators that have allowed the relative comparison of differing levels and types of distraction on driving performance. These studies have provided valuable insight into the ordinal effects of differing levels and types of distraction

However, none of these studies have been able to assess distraction in terms of "crash risk" because empirical research has necessarily relied upon "surrogate" measures of safety. That is, the only "ground truth" measures of safety in this context are actual (i.e., not simulated) crash frequency and crash severity. However, since crashes are very rare events, and it would be unethical to involve human subjects in actual crashes, empirical research per se can never practically use real crashes as measures.

This is not to say that estimates of crash risk have not been made with respect to driving distraction. The National Highway Traffic Safety Administration has estimated, using a variety of epidemiological data sources, that roughly 25% of crashes have secondary task distraction as a primary causal factor (3). These data generally rely upon police-reported crashes, which provide limited information in the case of secondary task distraction. For example, many state databases do not provide a categorized list of distraction types.

While empirical and epidemiological studies have allowed researchers to gauge the risk associated with secondary task distraction from an ordinal perspective, or at a general level, none have been able to provide a reasonable estimate of crash risk for drivers engaged in a variety of secondary task types or specific tasks.

Fortunately, advances in video, computing and data storage technology has recently made it possible to instrument large numbers of vehicles over long data collection periods. This has led to a type of study that is "naturalistic" in the sense that a driver's own vehicle is instrumented with an unobtrusive system. In these studies, drivers are not given any instructions and often there are also no specific evaluations (1, 4, 5, 6, 7, 8).

It is important to note that while these studies capture a large number of crash events, there has yet to be a single study large enough to capture a statistically significant number of crashes. To overcome this limitation several studies (1, 4, 5, 6, 7, 8) have utilized "near crashes" in combination with crashes. Near crashes, in this case, are defined as having all of the elements of a crash with the exception that the driver implements a successful evasive maneuver. Since the success of an evasive maneuver depends upon factors such as timing and skill, it has been hypothesized that near crashes are predictive of crashes,

Several studies (4, 5) over the past 15 years have used near crashes as safety surrogates. The 100 Car Study showed that near crash involvement is correlated with crash involvement across differing drivers (1). Thus, there is a growing body of evidence that combining crash and near crash events provides a valid measure of overall crash risk.

MAIN SECTION

METHOD – Data analyses were conducted utilizing the "100 car" naturalistic driving database (1). These data were specifically analyzed for the purpose of assessing secondary task distraction. For the 100 car study, 102 vehicles were instrumented for a period of 12-13 months. Approximately 42,000 hours of driving constituting 2,000,000 vehicle miles were collected. From these data, an "event" database of crashes and near crashes was created with 830 crashes, minor collisions and near crashes. Among the variables recorded through kinematic analysis and video review of the driver and driving context were:

- Pre-event maneuvers,
- Precipitating factors,
- Event types,
- Contributing factors,
- Associative factors,
- Avoidance maneuvers.

Secondary task distraction as a general category, as well as a specific, detailed type of distraction, was included as a contributing factor if there was evidence that the driver's perception, decision making or response was degraded as a result of the secondary task engagement.

In addition to the event database, a baseline database was created from the remaining data to allow for an exposure estimate. This baseline database included 5,000 randomly selected epochs of non-event driving stratified across all of the drivers who had crash and near crash involvement. Part of this baseline database was the categorization of any secondary tasks that the driver was performing. This essentially provided a database of the frequency of secondary task involvement. The creation of this baseline allowed the calculation of crude odds ratios to provide an estimate of crash/near crash risk.

The odds ratio is commonly employed to measure the association between the presence of "cases" (i.e., crash and near crash involvement) and controls (i.e., baseline driving epochs). In this case, the odds ratios are providing an approximation of relative crash/near crash risk for each of the distraction categories and tasks.

The basic odds ratio equation used for the analyses in the next section was:

Odds Ratio = (A X D)/(B X C), where:

A = the number of crashes/near crashes where the driver was engaged in a secondary task

B = the number of crashes/near crashes where the driver was attentive

C= the number of baseline epochs where the driver was engaged in a secondary task

D = the number of baseline epochs where the driver was attentive

To interpret odds ratios, a value of 1.0 indicates a crash/near crash risk that is equivalent between secondary task and attentive driving. A value above 1.0 indicates greater risk for secondary task involvement and a value below 1.0 indicates less risk for secondary task involvement. In addition, the ratio indicates the degree of relative risk. For example, an odds ratio of 3.0 indicates that the secondary task is three times as risky as attentive driving.

RESULTS – Utilizing the data described above, several analyses were conducted. Table 1 shows the odds ratios, along with confidence limits, for a number of representative secondary tasks. It is important to note that only those cases where the range between the confidence limits does not contain 1.0 are significant at the 95% confidence level. It is also important to notice that the confidence limits vary widely depending on the number of times that the secondary tasks were observed, with a larger range indicating a lower frequency of occurrence.

As shown, "reaching for a moving object" showed the highest level of crash/near crash risk with an odds ratio of 8.8. A "moving object" in this case was defined to include a number of smaller categories including something sliding off of the seat or dashboard, something spilling or dripping including food or drinks. This category is probably as high as it is because the driver, in each case, was clearly compelled to respond to the situation immediately regardless of the traffic or environmental circumstances.

Several secondary tasks, including dialing a hand-held device, reading, or applying make-up were roughly equivalent in relative risk with values ranging from 2.8 to 3.4. All of these tasks require the driver to take multiple glances away from the roadway and require at least one hand to accomplish the intended task. Handling and inserting a CD, which also requires glances and manual manipulation, was slightly lower than this group with an odds ratio of 2.3 and was not statistically significant, probably due to the small number of observed occurrences.

The next group, including: eating, talking/listening to a hand-held device, drinking and simple radio tasks (e.g., volume adjustment) were all not significantly elevated in crash risk over baseline driving. It is important to note that this group does not typically require multiple glances or manual manipulation with the possible exception of eating.

Table 1 also shows that talking to a passenger in an adjacent seat resulted in a "protective effect". That is, driving with a passenger results in significantly lower crash/near crash risk than driving alone. This is consistent with other research for adult drivers and probably indicates that drivers are somewhat more cautious in the presence of a passenger. It is also likely that the passenger serves as another set of eyes in identifying potential hazards.

Table 1. Relative risk associated with selected secondary tasks (adapted from Klauer, et al., 2006)(9)

Example Secondary Tasks			
Type of Inattention	Odds Ratio	Lower Confidence Level	Upper Confidence Level
Reaching for moving object	8.8	2.5	31.2
Reading	3.4	1.7	6.5
Dialing Hand-held Device	2.8	1.6	4.9
Applying Make-up	3.1	1.3	7.9
Handling CD	2.3	0.3	17.0
Eating	1.6	0.9	2.7
Talking/listening to Hand Held	1.3	0.9	1.8
Drinking	1.0	0.3	3.2
Adjusting Radio	0.6	0.1	2.2
Passenger in Adjacent Seat	0.5	0.4	0.7

A second analysis was conducted that classified all of the secondary tasks observed as "simple", "moderately complex" or "complex". The operational definitions for these categories was drawn from work by Dingus, Antin, Hulse and Wierwille (2) and are based upon the number of glances away from the roadway and/or the number of required steps or control activations. Simple tasks are defined as those that require no more than one glance away from the roadway and no more than one simple control activation (e.g., button press). Moderately complex tasks are those that require at most two glances away from the forward roadway and/or at most two simple control activations. Complex tasks are those that require multiple steps, glances and or control activations.

It is important to emphasize that this operational definition of secondary task complexity is based upon the requirement to look away from the roadway or manually manipulate a control. "Simple" then includes, by default, all of the tasks that are strictly "cognitive" in nature. In fact, the data from the "100 Car" study (1) shows that it is a rare case that a crash occurs while the driver's eyes are on the forward roadway, regardless of any other "cognitive demand" that they might be engaged in. For example, in 14 of the 15 100 car rear-end crashes observed during the study, the driver had an eye glance away from the forward roadway within 3 seconds of the crash precipitating event (1). It is important to note that several of these cases involved fatigue or glances away that were not secondary task-related. However, none involved a case where the driver was "lost in thought" to the point where they were unable to react to impending crash scenario with a successful evasive maneuver.

Table 2 shows the classification of the secondary tasks into the categories defined above. Combining the secondary tasks from the 100 Car Study in these categories allowed many of the very low frequency tasks (i.e., those not shown in Table 1) to be included. As shown, the simple secondary tasks had an odds ratio of 1.2 but the relative risk was not statistically elevated above baseline driving. In contrast, the odds ratios for moderate and complex tasks indicated a significantly elevated crash/near crash risk and were 2.1 and 3.1 respectively.

Table 2. Relative risk of secondary tasks classified as simple, moderately complex or complex (from Klauer, et al, 2006)(9).

Type of Inattention	Odds Ratio	Lower Confidence Level	Upper Confidence Level
Complex Secondary Task	3.1	1.7	5.5
Moderate Secondary Task	2.1	1.6	2.7
Simple Secondary Task	1.2	0.9	1.6

These data can provide insight into the relative crash/near crash risk of different types of secondary tasks. To illustrate this application, we have evaluated all of the tasks that were observed in the 100 Car Study (1) together with all of the tasks that were categorized in the Dingus, et al. (2) study that was the genesis of the operational definitions of simple, moderately complex and complex secondary tasks. The results are shown in Table 3.

As shown, the glance durations, lane deviations and number of glances away from the roadway are presented for the Dingus, et al. (2) data. The number of glances and task steps were used to classify these tasks as simple, moderately complex or complex. Using these two sources of data allows us to begin to understand, in approximate terms, the near crash/crash risk associated with a broad range of secondary automotive tasks. Note also, the number of lane deviations across the three categories. These results from the Dingus et al.(2), study provide corroborative evidence from a lane deviation surrogate measure that supports the categorizations of crash/near crash risk.

TABLE 3. TASK LISTS FROM THE 100 CAR STUDY AND THE DINGUS, ET AL., STUDY (1, 2) CLASSIFIED INTO SIMPLE, MODERATELY COMPLEX AND COMPLEX VARIABLES.

Task	Mean Glance Duration	# of Lane Deviation	Mean # Glance	
Following Traffic	0.75	0	1.31	Simple Secondary Tasks Crash/Near Crash Risk= 1.2 (0.8-1.6)
Report Time	0.83	0	1.26	
Report Speed	0.62	0	1.26	
Adjust Vent	0.62	0	1.83	
Destination Distance +	1.06	0	1.73	
Destination Direction +	1.20	0	1.31	
Tune Signal	0.36	0	0.63	
Adjust Fan	1.10	1	1.78	
Adjust Radio (e.g., volume)				
Adjust other in-vehicle				
Talking to passenger				
Drinking				
Smoking				
Lost in Thought				
Remaining Fuel - computer	1.04	1	1.52	Moderately Complex Secondary Tasks Crash/Near Crash Risk=2.1 (1.6-2.7)
Adjust Tone Controls	0.92	1	1.73	
Talking/ listening hand-held				
Inserting/ Retrieving CD				
Inserting/ Retrieving Cassette				
Combing or fixing hair				
Eating				
Looking at external object				
Correct Direction + Sentinel	1.45 1.01	1 2	2.04 2.51	Complex Secondary Tasks Crash/Near Crash Risk = 3.1 or greater (1.7-5.5)
Adjusting Balance	0.86	2	2.59	
Activate Defrost	1.14	3	2.51	
Activate Heat	1.30	3	2.76	
Activate Info Lights	0.83	3	2.12	
Activate Fuel Economy - Computer	1.14	3	2.48	
Zoom Level +	1.40	4	2.91	
Fuel Range	1.19	5	2.54	
Temp	1.10	8	3.18	
Cross Street +	1.66	8	5.21	
Roadway Name +	1.63	8	6.52	
Roadway Distance +	1.53	9	5.78	
Tune Radio*	1.10	10	6.91	
Insert Cassette Tape	0.80	13	2.06	
Adjust Power Mirror	0.86	21	6.64	
Dialing hand-held				
Answering hand-held				
Operating a PDA				
Reading				
Animal in vehicle				
Reaching - moving object				
Insect in-vehicle				
Applying makeup				
+Navigation Tasks				

*In the Dingus et al. study (2), this was an analog radio that was tuned manually.

DISCUSSION - These results have significant implications for the design of driver-vehicle interfaces, as well as the need for future integration of nomadic devices into the driver-vehicle interface in a manner which will minimize crash and near crash risk. Several of these implications are described in the following paragraphs.

Cognitive-only, or auditory-voice secondary task interfaces will generally be less risky than visuo-manual secondary tasks. From the 100 Car findings (1, 9) and the list in Tables 2 and 3, it is clear that the tasks with the highest crash risk are those that require multiple glances away from the road. Conversely tasks such as talking to a passenger, talking on a wireless device, general "lost-in-thought" were not as risky as many of the multi-glance visual tasks.

Although, it certainly can be argued that cognition drives the engagement of any secondary task, these results provide compelling evidence that it is the location of the driver's gaze at critical times in an imminent crash situation that largely determines the crash/near crash outcome. These results also show that purely cognitive secondary tasks (i.e., not requiring glances away from the roadway) will be inherently less risky than those that have an associated visual demand. The one caveat to this general statement is that there were no highly-complex, multi-step cognitive/auditory interface tasks in any of the studies cited (e.g., using a voice activated entertainment system application).

Hand-held is substantially riskier than "true" hands-free. Similarly, it is clear from these data that operating a complex hand-held device is significantly more risky than a hands-free counterpart. As Table 3 shows, dialing and answering a hand-held phone were both higher risk tasks, even in comparison to the often longer task of talking on a hand held phone. Thus, it is clear that the greatest proportion of risk does not come from the act of holding a phone to one's ear, it comes from the complex task components of dialing and answering that require multiple glances away from the roadway.

Talking on a cell phone is not the same as talking to a passenger. As shown in the tables above, talking to a passenger provides a protective effect for adult drivers. In contrast, talking on a cell phone does not provide a protective effect, and may even elevate crash/near crash risk to some extent. Note that even though the confidence limits for cell phone conversations contained the value of 1.0, it is possible that with a larger sample the results would in fact be statistically significant. It is important for future naturalistic driving studies to consider this possibility, particularly since cell phone use is so frequent in moving automobiles and trucks that even a relatively small elevated risk could lead to a significant number of crashes.

Talking on a cell phone is not the same as driving while under the influence of alcohol. As discussed in the previous paragraph, while cell phone conversations may elevate the crash/near crash risk in the neighborhood of 0 to 30%, contrary to recent driving simulator research (10), it is nowhere close to the crash risk associated with driving at the legal limit for alcohol intoxication. For example, the fatal crash risk associated with driving with a BAC of 0.08% has been estimated in the range of 7.0 or 700% (11).

An "interruptible" task is still risky if it requires eyes-off-road. Recent research indicates that if an in-vehicle secondary task is "interruptible" (12, 13), the driver can manage the task while driving without increasing crash risk. However, the results presented in this paper show no indication of a constant, or nearly constant, crash/near crash risk, for a broad range of in-vehicle tasks given that multiple glances away from the roadway are required. It is clear that a common crash/near crash situation involves an unexpected external event occurring when the driver is not looking in the direction of the event. It would then follow that the crash/near crash risk is greatly influenced by the joint probability of where the driver is looking and the probability of an unexpected event. Therefore, secondary tasks that require the driver to take their eyes off of the road for long and/or multiple periods will have the elevated crash/near crash risk, even if they are more easily managed by the driver.

CONCLUSION

The use of large-scale, instrumented-vehicle, naturalistic studies has allowed us to begin to consider the issue of driver distraction in terms of the relative risk of crashes and near crashes. Historically, these relative risk assessments were simply evaluated in terms of their differences in surrogate measures of performance, with no quantitative link to crash and near crash risk. When considering this relative risk, some aspects of secondary tasks are shown to elevate risk to differing degrees. In particular, eyes-off-road time and/or multi-step visuo-manual tasks greatly elevate crash/near-crash risk. In contrast, cognitive-only or auditory-voice-based tasks elevate crash/near crash risk to a much lesser extent if at all. These results have important implications for the design of vehicle interfaces, for the coherent adoption of laws or administrative rules governing what tasks should or should not be performed in a moving vehicle, and for public awareness of the tasks and circumstances that provide the greatest danger while driving.

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