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Identification of Cognitive Load in Naturalistic Driving

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EXECUTIVE SUMMARY

Over the last decade, naturalistic driving studies have provided significant insight into issues pertaining to the roles of distraction, inattention, and drowsiness in crash risk. New techniques have been developed for coding naturalistic data, mining it, and analyzing it. The application of these techniques has begun to deepen our understanding of how different types of secondary tasks may vary in their effects on crash risk. However, one methodological gap that still remains in the field concerns techniques for identifying periods of cognitive load within streams of naturalistic driving data. Cognitive load is a critical element of current concerns about driver distraction, particularly with regards to intentional tasks of listening and conversing while driving, but also as related to spontaneously occurring processes like daydreaming and becoming lost in thought, which may also take place while driving.

The research reported here was undertaken to develop a methodology for identifying epochs of cognitive activity occurring while driving by using indicators of cognitive load that are based on eye behavior. It furthermore set out to test the ability of these metrics, when used together as part of a model or algorithm, to discriminate pre-identified epochs of cognitive task load from "just driving" baselines drawn from naturalistic driving data. To accomplish these goals, the project mined an existing naturalistic driving database to extract the following types of driving epochs: those containing conversation, which was operationally defined as involving cognitive load; those containing visual-manual interaction; and those containing just driving. Data from these epochs were augmented with new measures related to three hypothesized cognitive load indicators. The measures which were explored as behavioral markers of cognitive load included the following and were derived from the acquired naturalistic data: (a) very long glances to the forward road, coupled with (b) increased concentration of glances to the forward road, (c) reduced breadth of active scanning, and (d) changes in blink rate relative to other types of task loads as well as just driving baselines.

Results of mixed-model analyses confirmed that cognitive epochs corresponded with the hypothesized patterns on two of the four indicators. However, the analysis revealed a surprising finding on all metrics: the "just driving" baseline epochs behaved as if they, too, contained significant amounts of cognitive load, perhaps in the form of daydreaming or mind-wandering. This finding complicated the modeling effort, which, although completed, yielded inconclusive results. The logistic regression approach showed much promise as a technique, but the predictor variables in the final model were difficult to interpret, and again seemed consistent with the notion that the just driving baselines, which were intended to serve as comparison epochs, were instead similarly composed of cognitive load periods. These latter epochs' cognitive loads were simply of a different type—namely, daydreaming, thinking, or mind-wandering activity. This finding, while unexpected, has several important implications, both for future efforts toward the development of algorithms used to identify types of task load from naturalistic data, and for the use of baselines in epidemiological risk estimation.

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LIST OF KEY TERMS AND DEFINITIONS

Inattention. Inattention is defined as "…diminished attention to activities critical for safe driving in the absence of a competing activity" (Lee, Young and Regan, 2008).

Distraction. Distraction is one of several types of inattention. It is defined as "the diversion of attention away from activities critical for safe driving *toward a competing activity*, which may result in insufficient or no attention to activities critical for safe driving" (Regan, Hallett, and Gordon, 2011).

Secondary Tasks. Secondary tasks are goal-oriented activities undertaken by drivers while operating the vehicle. Often, they are done concurrently with driving. They are called secondary because they are of lower priority than the elements of, and not critical to, the primary driving task itself, which consists of controlling the vehicle and avoiding hazards/conflicts. They are often considered discretionary, or optional, tasks, and are done at the driver's initiative. It is important to note that the workload of secondary tasks varies widely. It is also important to distinguish secondary tasks from distraction, as not all secondary tasks interfere with driving and give rise to distraction. In other words, *only some secondary tasks* divert attention to such an extent that they interfere with safe driving results.

Task Load. The concept of task load, or task loading, refers to the amount and type of resources that are demanded of, or required from, a human operator to perform a task. Resources that may be demanded by a task include sensory/perceptual input resources such as vision, auditory input, etc., manual manipulation and voice output resources, and cognitive resources, including working memory, long-term memory, and attentional resources.

CHAPTER 1. INTRODUCTION

The integration and use of new technology in modern vehicles over the last decade has raised concern about the role of distraction, inattention, and drowsiness in crash risk. Naturalistic driving studies have provided significant insight into these issues and into activities that are undertaken by real drivers on the road, including how and when they engage in secondary activities—such as talking with a passenger, listening to music, using phones and devices, consulting maps, and eating snacks—and become involved in crashes. Methods have been developed for using the video records of naturalistic driving events to code many driver behaviors, including glance patterns and activities involving hands-on devices. And most importantly, methods have been developed for the coding of all behaviors in the period prior to a crash.

However, a gap still remains in techniques for identifying *cognitive load* within streams of natural driving data. Cognitive load is a critical area of concern with regard to driver distraction, particularly as related to tasks of listening and conversing, but also as related to spontaneously occurring processes like daydreaming and becoming lost in thought, which may occur especially often on long drives. Some researchers have questioned whether identifying periods of cognitive load from natural driving data is even possible. Recent scientific findings have, however, emerged suggesting that there are behavioral markers that could perhaps be used to identify cognitive load in data already logged from naturalistic studies. The capability to identify epochs of cognitive load during naturalistic driving could advance the field by making it possible to further clarify or substantiate findings regarding the contribution of cognitive load to distraction-related crash risk. This might also yield future contributions toward engineering solutions that assist drivers in maintaining attention to the road, or toward mitigating inattention-related risks.

As a result of the gap in techniques for identifying cognitive load from streams of natural driving behavior, a project was initiated in July 2010 with the purpose of exploring whether behavioral markers or metrics associated with cognitive activity in the scientific research literature could be applied to naturalistic driving data in order to identify epochs of cognitive load during driving. This project was originally conceived as consisting of three phases; it is the first phase that was funded and which is described within this report.

OBJECTIVES

The objectives of this project were to:

1. Identify and develop a methodology for identifying epochs of cognitive activity during driving using eye behavior, already present in the stream of data from naturalistic studies, as an indicator of cognitive load.
2. Test the utility of these indicators for identifying epochs of cognitive load during driving.

SETTING THE STAGE: WHAT IS COGNITIVE LOAD?

For the purposes of this research, the term “cognitive load” can be defined as any workload imposed on a driver’s cognitive processes. In other words, cognitive load includes any operations carried out by cognitive processes or affected by cognitive processes. In this research, interest focuses on periods of time while driving—referred to as driving epochs—during which cognitive load is measurably present above a baseline, or background, level associated with a normal awake state.

Unfortunately, the term cognitive load has often been interpreted more narrowly to refer only to the task load on working memory. However, working memory is only one component of a driver's cognitive processes, and therefore, interpreting cognitive load solely in terms of "working memory load" provides only a portion of the picture. As a foundation for this research, we use the broader and more encompassing definition of cognitive load provided in the first paragraph. At the same time, we recognize that in order to make progress in early research on this topic, it may become necessary to develop more specific operational definitions of cognitive load that can be practically applied. These will be described later in the Methods section.

Since the term cognitive load refers to work done by a human operator's cognitive processes, it is important to describe what those processes are. Many different theoretical frameworks have been developed to do this, and despite their differences, nearly all frameworks contain a small number of common small processes. These core cognitive processes include memory and attentional systems, which are described as follows.

Working Memory

Working memory refers to the cognitive system that enables the storage, manipulation, and maintenance of transitory task-relevant information during the performance of a task (Baddeley and Hitch, 1974; Daneman and Carpenter, 1980; Shah and Miyake, 1999, p. 1). Working memory is often conceived of as serving as a "workspace" or "blackboard" for executive attention, or as the area where information is assembled, ideas are put together, calculations are performed, decisions made, etc. Different components or types of working memory have been identified by various researchers and include spatial working memory (i.e., "maps" of familiar areas which aid navigation), verbal working memory (i.e., words that are being spoken), and even kinesthetic working memory (i.e., sequences of movements to be performed). In the brain, those areas that have been identified as crucial for working memory function are the frontal cortex, parietal cortex, anterior cingulate, and parts of the basal ganglia.

Long-Term Memory

Long-term memory is the part of memory in which knowledge can be stored for long periods of time and from which knowledge and procedures are retrieved to perform tasks. While information in short-term and working memory persists for only about 20 to 30 seconds, or perhaps a little longer, information can remain in long-term memory indefinitely. Retrievals from long-term memory can be demanding of attentional resources, and holding information from long-term memory in working memory can be similarly attention demanding.

Central Executive Attention and the Attentional Networks

Central executive attention is a flexible system or network, often referred to as cognitive control, which is responsible for the control and regulation of cognitive processes, including working memory. Its functions are associated with management of cognitive processes, which, in addition to working memory, include reasoning, task management (e.g., task interleaving and task switching), problem solving, planning, and execution. The central executive is also responsible for resolution of response conflicts and for the scheduling of attention to competing perceptual inputs. Table 1 lists some of the key functions of central executive attention (from Groeger, 2000).

Table 1. Key functions of central executive attention (adapted from Groeger, 2000; used with permission from the author).

Functions	Brain Areas Primarily Involved
Setting attention to a goal	Dorsolateral prefrontal cortex
Sustaining preparedness (vigilance)	Right lateral mid-frontal
Maximizing activation of current goal	Anterior cingulated with reciprocal connections to dorsolateral frontal cortex – or circuit connecting midline thalamo, cingulated, and supplementary motor areas
Suppressing/inhibiting task-irrelevant stimuli and goals	Bilateral orbitofrontal areas
Sharing attention across goals or schemata	Orbitofrontal and anterior cingulated
Switching attention between goals, tasks, etc.	Dorsolateral frontal regions of either hemisphere and also more diffuse areas

Note: Although there are generally thought to be three attentional networks—the arousal network, the orienting network, and the executive network (Posner and Fan, 2008)—for simplicity in this report, these will be grouped under a single heading of "Central Executive Attention and the Attentional Networks." For this discussion, it is important to emphasize that the central executive network is the network providing control and regulation of other cognitive functions. However, orienting attention and the arousal network also play important roles for cognition. They are simply not described in detail here.

When working memory, long-term memory, central executive attention, or the attentional networks are loaded by tasks or activities over a period of time, this would constitute cognitive load.

TYPES OF COGNITIVE LOAD

There are several types of scenarios where cognitive load may occur during, and therefore affect, driving. These include:

1. Cognitive load imposed by secondary tasks undertaken while driving. These are usually goal-oriented in nature. Among these are:

a. **Language-generation tasks—**Generating conversation involves generating ideas/content, sequencing them in working memory, formulating their expression in words in verbal working memory, and generating speech sequentially, all of which also draws upon central executive attention. Examples include generating conversation with a passenger in the vehicle, or over a cell phone, and singing, either to a song that is playing in the vehicle or from memory.

b. **Language-comprehension tasks—**Attending to and comprehending language involves taking in the auditory input, parsing it, understanding it, which may also involve retrievals from long-term memory, and then linking ideas in working memory across "chunks" of the conversation or linguistic input. Examples include listening to conversation, listening to broadcasts over radio channels, listening to audio books or other media, etc.

c. **Memory tasks—**This involves working memory, retrievals, and sometimes executive attention. Examples include remembering errands, remembering a sequence of operations, recalling turns on a route, etc.

d. **Other tasks that impose cognitive load—**Additional secondary tasks may also involve cognitive load, including visual-manual tasks if, for example, there is significant sequencing of operations involved, or memory components involved.

2. **Cognitive load that is associated with activity internal to the driver.** These are classified as activities, not tasks, since they are generally not goal-directed. These activities involve working memory, long-term memory retrievals, and the central executive. These activities can include:

   a. **Daydreaming or mind-wandering**
   b. **Thinking or being lost in thought**
   c. **Planning activities related to daily life**
   d. **Mentally solving problems from daily life**

   The activities of daydreaming, mind-wandering, and thinking while driving deserve special note. These activities constitute a unique area of study within neuroscience and behavioral science and have only recently been studied in the context of driving. However, Smallwood and Schooler (2006) report that between 15% and 50% of an individual's time is spent in mind-wandering activity, such as daydreaming, or lost-in-thought activity, across a variety of tasks. Based on the findings of He et al. (2011), this may be true for the task of driving as well. Neuroscientists have identified that the "default network" of the brain (i.e., those areas of the brain that are more active during rest than during active task performance) is involved in mind-wandering (Christoff et al, 2009), and have hypothesized that when mind-wandering is present, the executive control shifts away from other "primary" tasks (Smallwood and Schooler, 2006). He et al. (2011) have observed that mind-wandering has effects on glance patterns and blink rates that are similar to those observed for periods of cognitive secondary task load. During mind-wandering, there is an increased concentration of gaze on the forward road with concomitant narrowing of scanning, lengthened glances on the forward road, and changes in blink rate.

3. **Cognitive load that arises from the driving task itself.** These activities variously involve working memory, long-term memory retrievals, the central executive, and/or orienting attention. Among these are:

   a. **Planning a route** or a sequence of stops on a trip.
   b. **Situation awareness**, which at the highest level involves forecasting or projecting what will happen next on the road or within traffic.

c. **Resolving response conflicts**, or contention scheduling that arises while driving, such as having to decide whether to brake or steer when a lead vehicle stops suddenly.
d. **Attention shifting** between secondary task and primary task demands.

For the research undertaken here, the first of these categories—cognitive load imposed by secondary tasks while driving—was explored, focusing specifically on tasks that involved language generation or language comprehension. These are described more fully in the Methods section.

REVIEW OF PRIOR LITERATURE

In a project focused on applying behavioral indicators of cognitive load to naturalistic driving data, it is important to understand the prior literature pertaining to measurement and identification of cognitive load. A review of this literature revealed three major categories of work: (1) attempts to identify or measure cognitive load, (2) efforts to develop or test algorithms for identifying epochs of cognitive load, and (3) evaluations of the consequences of cognitive load on driving or simulated driving. The first two categories have immediate salience for this project.

Measures of Cognitive Load

The research literature documents several types of measures that are associated with periods of cognitive load. These are described below.

Glance-Based Measures

<u>Concentration of long glance lengths on the forward roadway.</u> Prior research has shown that secondary tasks which impose cognitive load lead to a high percentage of glances on the forward road and to glances on the forward road that are unusually long (for example, longer than ~5 seconds). These two metrics together have been found to be uniquely indicative of cognitive loads (Angell et al., 2006; Victor et al., 2005). In the Angell et al. (2006) study, drivers gazed at the road about 7% more during cognitively loading auditory-vocal tasks than during just driving comparison tasks, and 40% more than during visual-manual tasks.

<u>Reduced breadth of scanning in the periphery.</u> Prior research has also shown that under cognitive task load, there is some reduction in the breadth of visual scanning, or in other words, a narrowing of the spatial extent of scanning (Angell et al., 2006 and others). This is typically reflected in slightly fewer glances to locations where mirrors are located, the speedometer, and areas peripheral to the road center. In the Angell et al. (2006) study, scanning to the mirrors dropped by about 3% under cognitively loading tasks relative to the just-driving comparison segments. A larger drop of 7% occurred during visual-manual tasks.

Blink-Based Measures

Blinking is a visual behavior that is captured in video footage recorded for most naturalistic driving studies, and which has been identified in the scientific literature as a potential indicator of cognitive load. Blinking more generally serves the function of keeping the tissues of the eye moist by spreading tears from the lacrimal glands across the surface of the eye. Blinks, which typically average in length from 300 to 400 ms for alert humans, however, actually obscure vision for a short time. Therefore, their semi-automatic occurrence and timing is controlled by the brain and is influenced by several factors, including the nature of task activity in which a person is engaged.

A review of the literature reveals that a reduction in blink *rate* has often been correlated with increased mental processing; this measure is sometimes used in aviation applications as an indicator of higher internal cognitive processing workloads. This contrasts with blink *duration,* which instead correlates with fatigue. In fact, closures in excess of 1,000 ms are often defined as microsleeps. Natural blink rates during tasks are in the range of approximately 10–11 blinks/minute. Reductions associated with elevated cognitive processing loads are very slight—perhaps only 1 blink per minute under baseline. Comparatively, conditions involving visual load tend to elevate blinking by 2–4 blinks per minute. Table 2 contains data from an illustrative study on blink rates for high- versus low-workload tasks (reprinted from Himebaugh et al., 2009), to show the range of effects. The difference between blink rates for the two high- versus the two low-workload tasks in this study was significant at $p < .04$, with the two high-workload tasks showing a reduced blink rate.

Table 2. Illustration of cognitive load effects on blink rate.

Workload	Task	Blinks/minute (SD)
High	Play computer game	9 (7)
High	Identify changing letters	9 (5)
Low	Watch movie	14 (11)
Low	Look straight ahead	11 (6)
	Overall	11 (8)

Other research in the literature (e.g., Holland and Tarlow, 1975) has similarly shown that the rate of blinking decreases during tasks that require concentration and intense cognitive activity, such as solving mental math problems or silently counting backwards. Blinking decreases as the load on working memory increases, with fewer blinks as the number of items in memory increases. Rate of blinking decreases during daydreaming, and blinking may be inhibited during very focused or extended mental activity.

Interestingly, it has been found that blinking may itself interfere with activity in visual processing areas of the brain. For example, blinking may interfere with mental imagery, or visualization, of complex geometric shapes, and people tend to suspend blinking when trying to generate complex images in their mind, which is an instance of using spatial working memory. This is consistent with a reduction in blink rate with increased cognitive load. In contrast, blinking increases when a person is unfocused, and it increases during rapidly changing internal states such as emotional excitement, frustration, anxiety, and disorientation (Kanfer, 1960; Ponder & Kennedy, 1927).

Blinking may also be controlled during transitions in processing, occurring, for example, at punctuation marks during reading, at the ends of sentences, and at meaningful breaks in processing. For example, a person engaged in conversation or making a speech will “punctuate” his talk by blinking between phrases and at the ends of sentences (Hall, 1945). In visual tracking tasks, blinks tend to occur before individuals expect tracking to start and then tend to resume immediately after the tracking task ends (Poulton and Gregory, 1952). Blinking also appears to occur at moments of cognitive change; people tend to not blink during the process of trying to retrieve a name from long-term memory and then resume blinking when they remember the name.

Blinking also causes a sudden change in visual input and can be disruptive for visual processing. Thus, relationships between blink rate and visual processing tend to be somewhat complex. As mentioned previously, blinks have been shown to interfere not only with visual sensory input but also with more central visual memory and imaging, and therefore may be inhibited to avoid disturbing cognitive processes that use visuo-spatial storage areas. This fact makes it difficult to predict blink rates for tasks which require *combined* visual and cognitive processing, as driving does.

Liang (2009) examined blink rates during simulated driving when drivers were multitasking. Drivers performed each of several types of secondary tasks, including a task that was primarily visual in nature, one that was primarily cognitive, and one that combined visual and cognitive loads, and also engaged in a just-driving period without multitasking. Liang found that the cognitive and combined tasks led to an *increase* in blink rate relative to the visual task and baseline condition. This finding runs contrary to the prior research's predictions, but that may be due to the fact that the task loading occurred in combination with driving, which is an intensely visual task.

Further, Liang (2009) examined the blink rate before, during, and after each secondary task during multitasking. Results showed differential effects, based on task type. For the visually loading task, blink rate increased in the period *after* the task. However, for a task combining cognitive load with visual load, blink rate remained high following the task, while it decreased back toward baseline levels after the cognitive-only task. See Figure 1 for a graphic depiction of these findings. It should also be noted that the blink rates observed by Liang (2009) during simulated driving are much higher than those previously reported for tasks done in the laboratory or simulator. Rates shown in Figure 1 are between ~0.28 Hz and 0.40 Hz, which translate to approximately 16–24 blinks per minute, well above the range reported for other tasks.

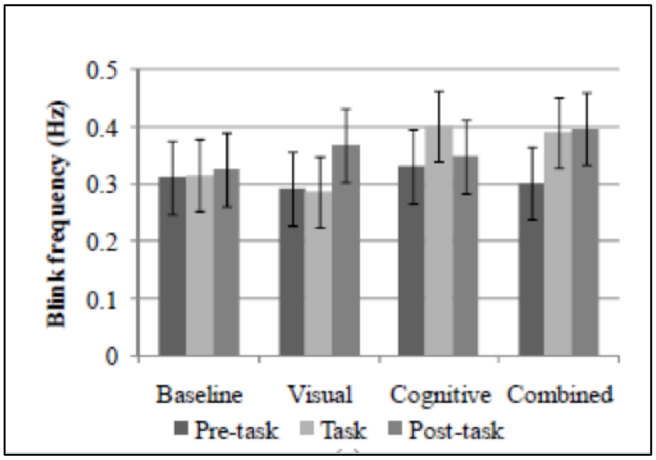

Figure 1. Bar chart. Findings from Liang (2009) on blink rate for different task loading types. Reprinted from panel (a) of Figure 28 of Liang (2009), showing blink rate in pre-task, task, and post-task periods. Used with permission from the author.

These results, while suggesting that blink frequency can be sensitive to cognitive load, also indicate that the effect direction is not a straightforward application of prior laboratory or simulator findings to driving settings. Laboratory results suggest that blink rate should *decrease* during cognitive activity. However, it instead *increased* when cognitive load occurred in the presence of a heavily visual task like driving. Further, Liang's (2009) results suggest that the use of blink rate as a metric may depend not only on type of task loading, but also on temporal aspects of ongoing activity. That is, it may be important to obtain measurements at key transition points in the flow of task activity—for example, before, during, and after potential periods of load. Or, to put it differently, blink rate may serve as an indicator of transitions in task loading or task activity. This arises from Liang's observation that blink rate changes occurred at transitions between before, during, and after-task periods for at least some types of tasks. Finally, Liang (2009) found that extended periods of intense visual secondary activity during driving had an influence that persisted beyond the completion of the secondary task.

Liang (2009) additionally noted that while blink rate was associated with task type during multitasking periods, it had very little impact on variance in steering error or lane position (only 4% and 2%, respectively). Thus, while blink rate might be of some use as an indicator of task loading and type of task loading during driving, it does not lead to observable degradations in vehicle control performance, at least not for alert drivers.

Thus, although blink rate appears promising for use as an indicator of cognitive load, the range over which it varies is quite narrow. Questions also remain about whether it offers sufficient sensitivity when extracted from real-world data acquired from a complex task like driving wherein there are inherent temporal variations in driving task load. Furthermore, during driving, epochs of cognitive load occur concurrently with heavy visual processing of the driving scene itself. This complicates predictions about the effects on blink rate for epochs of cognitive load, since it is not clear whether the combination of cognitive load with visual processing of the driving scene would lead to an overall reduction or elevation of blink rate over just driving baseline rates. The one study that has explored the use of blink rate in driving (Liang, 2009) found that blink rate increased rather than decreased, as all prior studies suggested, during epochs of cognitive load. In addition, prior research has demonstrated that there are significant temporal patterns of variation in blink rates at meaningful points in cognitive processing, further complicating the issue of how the blink rate measure should best be analyzed. Summarizing blink rate with a mean over an epoch may obscure important information, and more temporally nuanced blink rate metrics may be more appropriate. Finally, blink rate data from prior research indicates variability between individuals, raising the question of how best to analyze blink rate data in light of individualized patterns. Therefore, even though blink rate seems to be a promising indicator of cognitive processing, there are measurement issues that may affect how successfully it can be applied in discriminating different types of task loading during driving. Nonetheless, it remains a promising indicator for use in exploratory research.

Physiological Measures

Although various physiological measures have been studied in the identification of cognitive load states, they are not reviewed here. This is because during naturalistic driving, most drivers typically are not wearing physiological sensors. This is at least not the case in the current era, when wearable technologies such as watches, which may be equipped with biometric sensors, are only beginning to be embraced. It should, however, be noted that physiological measures, such as heart rate and skin conductance level, tend to increase as cognitive task load increases (Mehler, Reimer, et al., 2010).

Performance-Based Measures

Measures of driving performance have also been examined as indicators of cognitive load, and distinct patterns have been identified. Periods of cognitive load have been associated with reductions in lane position variability, fewer lane exceedances, and slightly increased speed variability (Angell et al., 2006, Carsten et al., 2005). Lengthening of headway to lead vehicles has also been noted in some studies. However, the research done within this project is initially seeking to find measures that could be applied separately from performance measures. It is possible that performance measures could be utilized as a validating set at a later stage of research and development.

Algorithms to Identify Epochs of Cognitive Load

Some initial research has been done toward the development of algorithms that might be used for identifying periods of driving during which different types of task loading are occurring. The majority of this research was initially focused on identifying visual demand, or epochs of visual or visual-manual task loading (e.g., Engström and Mårdh, 2007; Victor, Engstrom, Harbluk, 2009; Donmez, 2007; Liang, 2009; Kircher, Ahlstrom, and Kircher, 2009). A few algorithms have also been developed to identify cognitive load. Most of this work has emanated from a small group of investigators, some of whom, listed as follows, began working together within a federally funded project called SAVE-IT: Zhang et al. (2004); Liang, Reyes, et al. (2007); Liang, Lee, et al. (2007); and Liang (2009). Each effort has contributed new findings to the area. Zhang et al. (2004) used a decision tree approach to estimate drivers’ cognitive workload from eye glances and driving performance. Liang, Reyes, et al. (2007) used a support vector machine approach to detect cognitive distraction from eye movements and driving performance summarized over a 40-second window with 95% overlap between windows, and obtained 91.6%

accuracy in the structured predictions to which the model was applied using non-naturalistic data. Liang, Lee, et al. (2007) used Bayesian network models and found that they could identify cognitive load reliably for simulator data with an average accuracy of 80.1%, and also found that dynamic Bayesian networks (DBNs) gave a better performance than static Bayesian network models. They found that blink frequency and eye fixation measures were particularly indicative of cognitive task workload in structured experimental data. Liang (2009) used a hierarchical layered algorithm, which incorporated both a DBN and a supervised clustering algorithm, to identify feature behaviors when drivers were in different cognitive states. At the lowest level of this algorithm, three groups of performance measures were used: (1) eye movement temporal measures (blink frequency, fixation duration, etc.), (2) eye movement spatial measures (spatial location of gaze in x, y, z), and (3) driving performance measures (steering error, steering wheel standard deviation, lane position standard deviation). The performance measures were summarized across 30-second time windows, with no overlap between windows. This work offers insight on metrics that may be useful to apply to naturalistic data, as well as potential modeling approaches that might be tried at later stages of research.

Evaluations of the Consequences of Cognitive Load on Driving

Although a range of studies have been conducted in an effort to evaluate the consequence of cognitive load on driving, this domain of study continues to be dominated by scientific debate. In part this is because the vast majority of studies have been performed in simulators, rather than in the field or under naturalistic settings, and the generalizability of findings from simulation studies has often been limited by the restricted range of tasks and conditions studied as well as the limitations of simulators with respect to realistically portraying the consequences of a real-life crash. Generally, the findings from well-controlled studies performed on the road on tasks that are real human-machine interface (HMI) tasks or that resemble real HMI tasks have shown that effects of cognitive load on driving have measurable effects on glance patterns. Results show more gaze time on the forward road along with less scanning to peripheral regions. Small effects are shown on event detection, with results indicating that detection of events remains high, and misses and slowing of latencies is much smaller and more limited than for visual-manual tasks. Small to negligible effects are shown on vehicle control performance, with lane position and lane position variability improving slightly, and speed variability increasing slightly. However, shown results are often not discernibly different from those found in just driving. Key references for these types of findings include He, Becic, Lee, & McCarley (2011) and Recarte & Nunes (2000, 2003), among others. Unfortunately, few studies have been done under natural driving conditions due to the absence of measurements that can be applied to naturalistic data to identify periods of cognitive load. This is one of the gaps that this study hopes to help fill.

THE APPROACH TAKEN FOR THIS PROJECT

Based upon the review of prior research, an initial set of measures for identifying cognitive load (i.e., a “cognitive load protocol”) was identified for exploratory application to naturalistic driving data. This initial set of measures was based both on the review of the literature and also on practical considerations, such as whether the measures were available from data that had been acquired from naturalistic driving studies, or could be derived from those data. The initial set of measures which were selected were all related to eye behavior, and the original intent was to explore their use together as a set, or in combination, in the form of a hybrid measure, on naturalistic driving data for the purpose of identifying periods of cognitive load. These measures included the following:

1. **Blink rate –** Initially, it was hypothesized that results would show reduced blink rates, below the average rate of 10 glances per minute. The updated hypothesis (based on Liang, 2009) was that results would show increased blink rates, above the average rate for baseline.

2. **Concentration of long glance lengths (>5 s) on the forward road –** This was operationalized in terms of measures of average glance length to the forward road, and total cumulative duration of glances to the forward road. The hypothesis was that both metrics would show elevated values for cognitive epochs, relative to comparison epochs, which were baseline as well as epochs of visual-manual task load.

3. **Reduced breadth of scanning in the periphery –** This was operationalized in terms of total glance duration to non-forward driving-related areas. The hypothesis was that less cumulative time would be spent scanning, or looking at, these peripheral areas.

The intent of this project was to explore whether epochs of cognitive load could be identified in streams of data from already-collected naturalistic driving data by applying these measures within a specially tailored study design. As an initial step toward examining the issue of cognitive load using naturalistic data, the project proceeded in a retrospective manner by using a sample of drivers from an existing naturalistic driving database. Then, a set of task activities was pre-identified as having involved cognitive load. These task activities were operationally defined as engaging in conversation or singing and/or listening to conversation. Epochs of such tasks were located within streams of naturalistic data for each driver within the naturalistic study. These cognitively loading task epochs were then examined for the presence of hypothesized cognitive load markers in the associated eye data, and compared to baseline epochs of several types in order to understand whether one type of epoch could be discriminated from the other on the basis of these behavioral markers. Thus, tasks that imposed primarily cognitive load, such as conversation or listening, were first identified in each driver's trips along with a set of comparison tasks that included visual-manual as well as baseline driving epochs of similar length. Then these task epochs were re-scored using a new scoring methodology called the Cognitive Load Protocol as well as with an existing Fatigue/Sleepiness Protocol.[1] Analyses of the newly scored data were then undertaken to determine whether the behavioral markers hypothesized for cognitive load were, in fact, more often associated with cognitive tasks than with non-cognitive tasks and baseline driving epochs. Analyses also examined whether the cognitive load metrics accomplished accurate discrimination of task type.

[1] These data were collected to explore in a preliminary way whether drowsiness or arousal level is in any way associated with cognitive epochs.

CHAPTER 2. METHOD

This project utilized naturalistic data that had already been collected, but developed and applied new data coding protocols designed to enable analyses of whether periods of cognitive load could be identified and discriminated from other types of driving epochs. These methods are described below.

DATABASE USED

This project used a set of naturalistic data called the Naturalistic Skill and Acquisition Database. It was selected because its data encompassed driver engagement in a wide range of secondary activities, including conversation and cell phone interactions, and many of these had already been previously scored for glance locations, and thus could be leveraged for use in this effort.

The Naturalistic Skill and Acquisition study was a small one, and is in Angell, Perez, and Hankey (2008), and Perez, Angell, and Hankey (in press). It utilized two instrumented vehicles, and a total sample of 17 drivers, aged 27 to 57, participated. Each participant was asked to drive one of the instrumented vehicles, using it as if it were their own vehicle, during their daily routine for a period of approximately four weeks. The instrumentation package in each vehicle resembled that used in the 100-Car Naturalistic Driving Study (Klauer et al., 2006). It recorded data on a wide range of kinematic and driving performance variables, as well as 30-Hz video of the forward and rear driving scene, the driver's face and eyes, and an over-the-shoulder view of the driver's hands interacting with devices and objects in the vehicle interior. The final data set included 694 hours of driving and 30,371 vehicle miles. At the time the study was performed, analysts coded eye-glance behavior and secondary tasks performed during driving to answer the original questions for which the study was designed. In using the data toward the goals of this project, additional data coding was necessary.

DATA CODING PROTOCOLS APPLIED

A set of rigorous processes was developed for data extraction and coding. This effort began by reviewing trips within the database, and defining the types of epochs that were to be coded. This is described in the next section. Then, for each epoch to be coded, specific data coding protocols were defined for scoring secondary activities, glances, and blinks. In addition, an existing drowsiness protocol was applied to the data based on eye closure, using percent eye closure (PERCLOS) criteria. These protocols are briefly described below.

Secondary Activities Coding Protocol

All secondary task activities during the selected driving epochs were coded in terms of their start and end times, and in terms of their type or identity even if the activity did not impose cognitive load. This was done to allow "clean" periods of cognitive load and baseline driving to be identified and used in analysis. In other words, if a non-cognitive period of activity occurred in the middle of a cognitive epoch, it was coded, so that it could be removed or ignored in the subsequent analysis, such that only clean periods of cognitive load—periods where no secondary tasks were present—entered into analysis.

Glance Coding Protocol

Glance locations and durations had been previously scored for all interactions in the database, and these data were available for use in this research. Glance coding done previously was scored manually from video using frame-by-frame analysis. Using this methodology, the locations of glances were attributed to over 15 different regions or locations, or annotated as indeterminate due to obstruction of the eyes, and the duration of each glance was also recorded. Glance locations included such areas as Forward Road/Path, Right Windshield, Left Windshield, Rearview Mirror, Left Window + Mirror, Right Window + Mirror, Over-the-Shoulder (left or right), Shifter (E-PRNDL), Center Stack, Down to Instrument Cluster, Passenger, etc. However, for the purposes of this study, previously scored glance locations were grouped into four larger regions of interest. These were:

- Glances forward (toward the road or forward path)
- Glances to driving-related areas that were not forward (non-forward, driving-related)
- Glances to areas that were neither forward, nor driving-related (e.g., passenger, phone, food, cup holder, purse, etc.)
- Glances to the center stack (e.g., radio, CD player, etc.)

Drowsiness Coding Protocol (PERCLOS)

An existing drowsiness scoring protocol was also applied to the video data. This protocol was administered by analysts manually scoring the video in a frame-by-frame manner and was done to allow assessment of alertness/drowsiness during periods of cognitive load and the other types of driving epochs. This protocol was based on a measure known as PERCLOS (Wierwille et al., 1994). PERCLOS is the fraction of time over a specified interval (typically between 1 and 6 minutes) that the eyelids are 80%-100% closed. For example, if a subject’s eyes are 80%-100% closed for a total of 12 seconds over 1 minute, then the PERCLOS-1 score is 0.2 (12/60). In this video scoring protocol, each frame of video is assigned one of three codes, in order to code the frame as follows (Figure 2):

o: Eyes Open. This code was used whenever the eyes were visible AND were less than 80% closed.

c: Eyes Closed. This code was used whenever the eyes were visible AND were 80%-100% closed. The pupil was used as a rough guideline for the 80% mark. Both eyes had to meet the 80%-100% closed criteria to record this condition.

n: Eyes Not Visible. This code was used whenever the eyes were not visible and the analyst was thus unable to determine whether they were open or closed. This occurs when drivers turn their heads from the forward roadway (e.g., checking blind spot), when they are engaged in a secondary task (e.g., leaning to reach for something out of the camera’s view), or when something is blocking the view of the eyes (e.g., glasses or sunglasses, sun visor, etc.). If only one eye was visible, scoring was based on the condition of that eye.

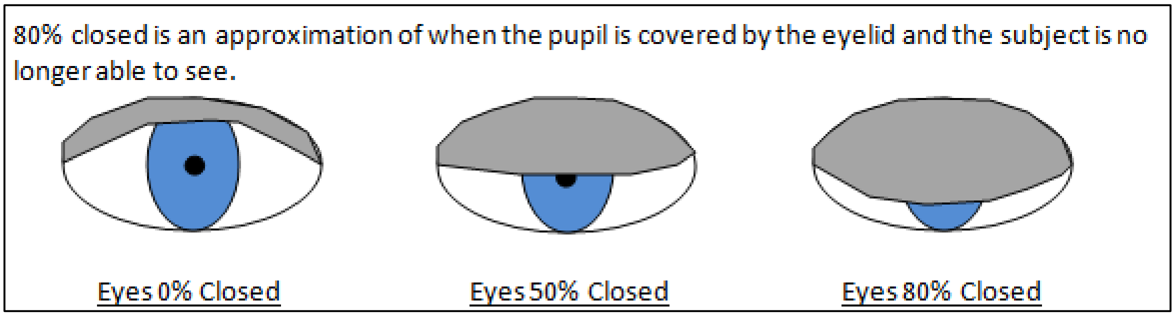

Figure 2. Diagram. Illustration used to guide analysts in application of PERCLOS protocol.

Blink Coding Protocol

Both the frequency and duration of blinks were also scored from video and viewed in a frame-by-frame manner. Quality control checks were administered on 100% of the files, due to the difficult nature of scoring blinks. A blink was defined as the time period during which the eyelids were 80%-100% closed, but with the further caveat that normal blinks are rapid and occur every few seconds. To manually analyze blinks, a modified version of the drowsiness protocol was applied. Analysts simply recorded the frames for which the eyes were 80%-100% closed, and coded them as closed for a blink. All other frames were coded as open under the blink coding protocol.

TYPES OF DRIVING EPOCHS EXTRACTED FROM DATABASE

Six types of epochs were selected for extraction from the naturalistic database for coding and analysis. These included three types of epochs that reflected specific, observable secondary tasks or activities that could be reliably identified from the video record and three types of baseline driving epochs (reflecting just driving) which were drawn in different ways for comparison with the secondary task epochs. These six types of driving epochs are described in more detail below, and then summarized in short form in Table 3.

Description of Types of Driving Epochs

While there are many types of secondary tasks that impose cognitive load on drivers, in this initial exploratory study there was a need for epochs of task activity that could be ascertained ahead of time as involving cognitive activity. It was decided that language-generation activities, including engaging in natural conversation, either over the cell phone or with passengers, were a good candidate. Many studies in the psycholinguistic literature have established the significant role of cognitive processes in language production as well as in language comprehension, making these activities appropriate candidates. In addition, during natural driving, there are times when drivers engage in singing—either along to music or from memory—which was considered to be an instance of language production as well. Further, sometimes drivers are observed talking to themselves rather than to another person in the vehicle or on the phone. This activity also was considered a language-production activity. Thus, for purposes of testing whether behavioral indicators could identify periods of cognitive load, this study utilized as cognitive epochs those during which a driver was observed to be engaged in talking or listening as part of a conversation or singing. This category of activity was divided into two subtypes of epochs: those that involved a cell phone, and those that did not. This was in the event that the use of the cell phone in some way altered the nature of the task loading, and hence the identifiability of the cognitive load through the use of the proposed behavioral markers. Thus, the three types of secondary task loading epochs that were extracted from the database were:

1. **Cognitive Epochs (On Cell Phone):** These consisted of epochs of driving during which conversation (talking and listening) was observed to occur over the cell phone. The epochs were defined to exclude any visual-manual interaction activity, such as dialing. They included only talking and listening activity.
2. **Cognitive Other Epochs (Not on Cell Phone):** These consisted of epochs of driving during which both talking and listening components of conversation were observed that did NOT involve the cell phone, but were carried out with a passenger or with self, as well as epochs with singing.
3. **Visual-Manual Epochs:** These consisted of epochs of driving during which visual-manual interactions were observed. While visual-manual interactions undoubtedly involve some level of cognitive processing, they were identified for inclusion in the visual-manual category because the demands on visual and manual resources of the driver are prominent. In addition, these interaction types were categorized separately so that analyses could determine whether this type of interaction would show any differing pattern on the behavioral markers hypothesized to identify cognitive load. Visual-manual interactions included radio tuning, changing CDs, etc.

Baseline epochs extracted from the database for comparison were all matched in length to their corresponding comparison epochs from the categories above. The baseline epochs fell into the following categories based on length of epoch:

1. **Cognitive Cell-Phone Baselines:** These were epochs consisting of just-driving activity without any secondary tasks at all, which were matched in length to cell phone conversations.
2. **Cognitive Baselines for Non-Cell-Phone Epochs (also called Full Baselines):** These were epochs consisting of just driving without any secondary tasks at all, which were at least one-minute long to match cognitive epochs.
3. **Visual-Manual Baseline Comparison Epochs:** These were epochs consisting of just driving without any secondary tasks at all that were matched in length to visual-manual tasks.

These six types of driving epochs are summarized in Table 3. A total of 312 epochs were extracted from the database and coded for use in analyses.

Table 3. Types of epochs and baselines included in study.

Type of Epoch	Type of Baseline
1. **Cognitive Cell Phone Epochs (On Cell Phone)**. These epochs contained conversation on a cell phone.	1. **Cognitive Cell Phone Conversation Baselines**. These baselines consisted of just-driving epochs ***without any secondary tasks at all*** matched in length to cell phone conversations. Also referred to as Cognito Cell Baseline.
2. **Other Cognitive Epochs (Not on Cell Phone)**. These epochs contained talking, listening to passenger or self, and singing.	2. **Full (Just Driving) Baselines.** These baselines consisted of just driving ***without any secondary tasks at all*** (at least 1-minute long to match cognitive epochs).
3. **Visual-Manual Task Interactions**. These epochs contained dialing, radio tuning, changing CD, etc.	3. **Visual Manual Baseline Comparisons**. These baselines consisted of just-driving epochs ***without any secondary tasks at all*** matched in length to visual-manual tasks.

DEPENDENT MEASURES

For all epochs, 64 eye-glance-related variables were reduced. Table 4 lists all of these metrics, and their operational definitions. All metrics were based on the epochs from which they were extracted and represent a summary for the epoch.[1] The epochs varied widely in length, and their duration was recorded in the data set using the variable name, "duration of trigger," which appears next to last in the Table 4 list. In Table 4, the eye-glance-related variable name conveys the eye behavior, eye-glance measure, or metric, and glance direction, if applicable. Different types of eye behaviors included glances, blinks, or eyes open. As described in Table 4, eye glance metrics could be counts, wherein the count was made throughout the duration of the epoch; percentages, wherein a percentage is calculated from a total based on the entire epoch; rates, wherein the rate per unit time is based on the length of the whole epoch; or sums, wherein durations of glances are cumulated across the length of the epoch. Glance directions included particular areas of interest: forward view, non-forward but driving-related, non-forward and non-driving-related, or center stack.

[1] Although there are known temporal variations as a function of task load for some of the metrics, such as blink rate, the use of summary measures was seen as an initial analysis step. If results using summary measures to distinguish types of task loading are null, consideration can be given to the application of approaches more sensitive to temporal variations and patterns, such as moving window analyses.

Table 4. Eye-glance-related variables and operational definitions.

Eye-Glance-Related Variable Name	Operational Definition
Number of Glances Forward	Count of glances made to the forward road/path during the epoch.
Number of Glances Non-Forward Driving Related	Count of glances made during the epoch that were to driving-related areas other than the forward region—such as mirrors, left or right windshield.
Number of Glances Non-Forward Non-Driving Related	Count of glances made during the epoch that were not related to driving and that were made to areas outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.
Number of Glances Center Stack	Count of glances made to center stack during the epoch (where radio/infotainment systems were located).
Percent Number of Glances Forward	Out of all glances made during epoch, the percent which were made to the forward road/path during the epoch.
Percent Number of Glances Non-Forward Driving Related	Out of all glances made during epoch, the percent which were made to driving-related areas other than the forward region—such as mirrors, left or right windshield.
Percent Number of Glances Non-Forward Non-Driving Related	Out of all glances made during epoch, the percent which were made to areas that were both unrelated to driving and which were in areas outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.
Percent Number of Glances Stack	Out of all glances made during epoch, the percent which were made to the center stack during the epoch (where radio/infotainment systems were located).
Glance Rate Forward	Glances per unit of time made to the forward road/path during the epoch.
Glance Rate Non-Forward Driving Related	Glances per unit of time made during the epoch that were to driving-related areas other than the forward region—such as mirrors, left or right windshield.
Glance Rate Non-Forward Non-Driving Related	Glances per unit of time made during the epoch that were not related to driving and that were made to areas outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.
Glance Rate Center Stack	Glances per unit of time made to center stack during the epoch (where radio/infotainment systems were located).
Total Duration of Glances Forward	Total sum of all glance durations (cumulative) made to the forward road/path during the epoch.
Total Duration of Glances Non-Forward Driving Related	Total sum of all glance durations (cumulative) made during the epoch that were to driving-related areas other than the forward region—such as mirrors, left or right windshield.
Total Duration of Glances Non-Forward Non-Driving Related	Total sum of all glance durations (cumulative) made during the epoch that were not related to driving and that were made to areas outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.

Eye-Glance-Related Variable Name	Operational Definition
Total Duration of Glances Center Stack	Total sum of all glance durations (cumulative) made to center stack during the epoch (where radio/infotainment systems were located).
Percent Duration of Glances Forward	The percent of the total epoch's duration which was spent glancing at the forward road/path.
Percent Duration of Glances Non-Forward Driving Related	The percent of the total epoch's duration which was spent glancing at driving-related areas other than the forward region—such as mirrors, left or right windshield.
Percent Duration of Glances Non-Forward Non-Driving Related	The percent of the total epoch's duration which was spent glancing at areas that were not related to driving and that were outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.
Percent Duration of Glances Center Stack	The percent of the total epoch's duration which was spent glancing at the center stack (where radio/infotainment systems were located).
Average Duration of Glances Forward	The average duration of individual glances made to the forward road/path.
Average Duration of Glances Non-Forward Driving Related	The average duration of individual glances made to driving-related areas other than the forward region—such as mirrors, left or right windshield.
Average Duration of Glances Non-Forward Non-Driving Related	The average duration of individual glances made to areas not related to driving and that were outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.
Average Duration of Glances Center Stack	The average duration of individual glances made to the center stack (where radio/infotainment systems were located).
Standard Deviation Duration of Glances Forward	The standard deviation of individual glance durations made to the forward road/path.
Standard Deviation Duration of Glances Non-Forward Driving Related	The standard deviation of individual glance durations made to driving-related areas other than the forward region—such as mirrors, left or right windshield.
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	The standard deviation of individual glance durations made to areas not related to driving and that were outside of the forward/road area—such as glances at the passenger, the cell phone, purse, cup holder, etc.
Standard Deviation Duration of Glances Center Stack	The standard deviation of individual glance durations made to the center stack (where radio/infotainment systems were located).
Percent Over 2 Seconds of Glances Forward	Percent of all glances made to the forward area that were longer in length than 2 s.
Percent Over 2 Seconds of Glances Non-Forward Driving Related	Percent of all glances made to non-forward driving-related areas that were longer in length than 2 s.
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	Percent of all glances made to non-forward non-driving-related areas that were longer in length than 2 s.
Percent Over 2 Seconds of Glances Center Stack	Percent of all glances made to the center stack that were longer in length than 2 s.
Longest Duration of Glances Forward	The longest glance made to the forward area out of all those made to that area during that epoch.

Eye-Glance-Related Variable Name	Operational Definition
Longest Duration of Glances Non-Forward Driving Related	The longest glance made to non-forward driving-related areas out of all those made to those areas during that epoch.
Longest Duration of Glances Non-Forward Non-Driving Related	The longest glance made to non-forward non-driving-related areas out of all those made to those areas during that epoch.
Longest Duration of Glances Center Stack Glance	The longest glance made to the center stack area out of all those made to that area during that epoch.
Number of Eyes Open	Number of frames that the eyes were open more than 80% during the epoch.
Number of Blinks	Number of blinks during the epoch.
Number No Info	Number of frames for which no blink information could be coded during the epoch due to eyes not being visible.
Percent Number of Eyes Open	Percent of frames during the epoch during which the eyes were open more than 80%.
Percent Number of Blinks	Percent of frames during the epoch which were coded with blinks.
Percent Number of No Info	Percent of frames during epoch for which no information could be coded on blinks due to eyes not being visible.
Blink Rate	Blinks per unit of time (per minute).
Total Duration of Eyes Open	Total cumulative time during epoch for which eyes were coded as open more than 80%.
Total Duration of Blinks	Total cumulative time during epoch for which eyes were coded as blinking.
Total Duration of No Info	Total cumulative time during epoch for which no information could be coded due to eyes not being visible.
Percent Duration of Eyes Open	The percent of the total epoch’s duration for which the eyes were coded as being open more than 80%.
Percent Duration of Blinks	The percent of the total epoch’s duration for which the eyes were coded as blinking.
Percent Duration of No Info	The percent of the total epoch’s duration for which no information could be coded from the eyes due to eyes not being visible.
Average Duration of Eyes Open	The average duration for which the eyes were open during the epoch.
Average Duration of Blinks	The average duration of individual blinks during the epoch.
Average Duration of No Info	The average duration for which no information could be coded from the eyes for the epoch.
Standard Deviation of Duration Eyes Open	The standard deviation of durations for which the eyes were open during the epoch.
Standard Deviation of Duration Blinks	The standard deviation of individual blink lengths during the epoch.
Standard Deviation of Duration No Info	The standard deviation of durations for which no information could be coded from the eyes for the epoch.
Percent Over 2 Seconds of Eyes Open	Percent of eyes-open periods that were longer in length than 2 s.
Percent Over 2 Seconds of Blink	Percent of blinks that were longer in length than 2 s.

Eye-Glance-Related Variable Name	Operational Definition
Percent Over 2 Seconds of No Info	Percent of no-information periods that were longer in length than 2 s.
Longest Duration of Eyes Open	The longest period of eyes open out of all those occurring during that epoch.
Longest Duration of Blink	The longest blink out of all those occurring during that epoch.
Longest Duration of No Info	The longest period of no-information out of all those occurring during that epoch.
Number of Transitions	Number of transitions (or movements) made by the eyes between locations during the epoch.
Duration of Trigger	Length of the epoch.
Transition Rate	Number of eye movements per unit time during the epoch.

CHAPTER 3. ANALYSIS, RESULTS, AND DISCUSSION

MIXED-MODEL ANALYSES

To analyze the data, a mixed-model analysis with repeated measures was applied, using a condition term referring to the six types of driving epochs that were available for analysis, each containing a different type of task loading, and a random effect for the driver. This mixed-model approach was applied in three independent analyses of each of the key variables hypothesized to be of interest for identifying periods of cognitive load within streams of naturalistic data. The independent variable of Driving Epoch Type had six levels corresponding to the six categories of epochs shown in Table 3: (a) Cognitive/Conversations on Cell Phone, (b) Other Cognitive (Conversation/Singing with Passenger/Self), (c) Visual-Manual Interactions, (d) Baselines for Cell Conversations, (e) Baselines for "Other" Conversations/Singing (with passenger/self), and (f) Baselines for Visual-Manual Interactions. The three key dependent variables were total duration of glances to the forward road, average length of glance durations to the forward road, and blink rate. In these models, the six cognitive categories, in dummy variable format, and the driver identification variable were used to predict each of the three dependent variables. Each of the models found significant effects for Driving Epoch Type. Bonferroni post hoc tests using an adjusted *p* value were applied to the means to explore which conditions differed, and hence were most likely to contain epochs of cognitive load while driving.

FINDINGS

There were multiple significant differences, and importantly, the talking and listening conditions that involved cognitive load were significantly different from the baseline conditions and from the visual-manual comparison conditions on key measures. Due to the small sample size, the post hoc tests may not give a full picture of the true differences, so graphical depictions of the data can be relevant and therefore are provided here.

Total Duration of Glances to the Forward Road

Analyses were performed on the total summed duration of all glances made to the forward road during an epoch. This measure can be thought of as a close associate of measures showing concentration of gaze on the forward road during an epoch of task activity. As shown in Figure 3, both types of cognitive secondary task epochs, which are circled in red, led to longer mean Total Summed Duration of Glances to the Forward Road during epochs than all other epoch types—which appear below the red line—longer than visual-manual interactions, as well as longer than all types of baselines.

The mixed-model analysis confirmed the graphically evident results, and revealed that the factor of "Driving Epoch Type" was significantly associated with total duration of glances forward to the road ($F = 18.95$, $p \leq .0001$). Post hoc Bonferroni *t* tests provided additional insight and revealed the following conditions to be significantly different from each other (these are marked as A vs. B in Figure 3):

- Cell Phone Talking/Listening vs. Visual-Manual Interaction ($p < .0001$)

- Talking, Listening, Singing with Passenger/Self vs. Visual-Manual Interaction ($p < .0001$)
- Cognitive Cell Baseline vs. Visual-Manual Interaction ($p < .0023$)

The other pairwise comparisons did not reach a level of significance, though statistical power to detect significant differences was low in these statistical tests due to small sample size.

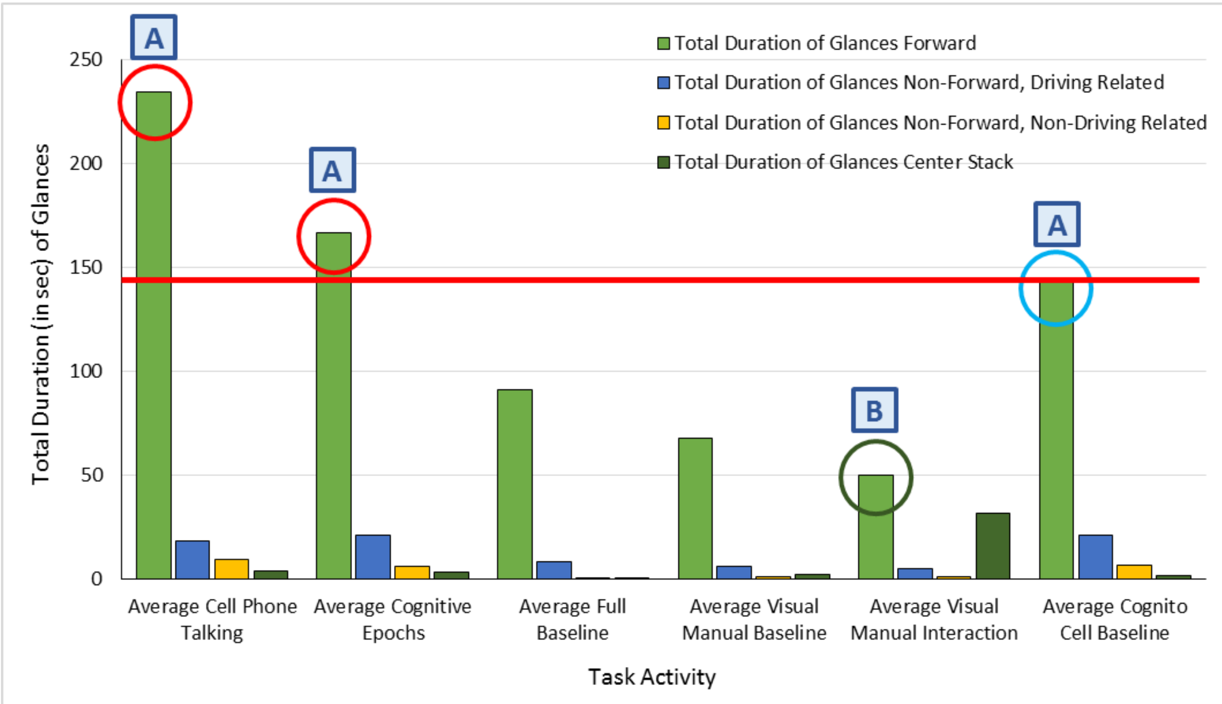

Figure 3. Bar chart. Cognitive epochs of both types are distinguished by "total duration of glances forward to road."

Average Duration of Glances Forward to Road

Analyses were also performed on the average duration of individual glances to the forward road. The means for this variable are graphically depicted in Figure 4. Interestingly, as predicted, the length of glances to the forward road during the two types of cognitive epochs was indeed longer than those made during visual-manual interactions (the red circled bars vs. the green circled bar). They exceeded the value of 5 seconds or longer originally hypothesized to be associated with cognitive load based on prior empirical findings in the literature.

However, what was interesting and unexpected was the fact that similarly long average glance durations to the forward road were also found for just-driving baseline epochs, with two of the three baseline types producing even longer glance durations than the cognitive secondary task epochs. This may indicate that cognitive activity was also present in the baseline driving epochs. While this was not predicted, or anticipated to be at this level, it is understandable in terms of findings reported by He et al. (2011) and others. These results may indicate that there is substantial daydreaming or lost-in-thought activity occurring during the periods of driving that were extracted as baseline just-driving epochs. Certainly, the glance durations for the full just-driving baselines and the just-driving baselines which were drawn for comparison with visual-manual tasks are notably longer, at greater than 11 seconds in length, than previously reported glances to the road for just driving. For example, Angell et al. (2006) found glances to the forward road to be approximately 5 seconds in length for just driving.

This finding is very interesting but reveals a possible difficulty for validating a cognitive load indicator. If baseline driving contains frequent epochs of cognitive load in the form of daydreaming or being lost in thought, then just driving baselines cannot be used to test whether epochs containing cognitive load from a secondary task can be discriminated from periods free from cognitive load or from periods containing a contrasting type of task loading. If it is the case that just driving contains the very type of cognitive activity that a new cognitive load algorithm or hybrid measure is trying to detect, then just-driving epochs will not be discriminable from epochs of cognitive secondary task load, if both daydreaming and the cognitive task load have similar effects on key indicator variables. As mentioned in the introduction, daydreaming and thinking do, in fact, lead to effects on glance metrics and blink rates similar to cognitive secondary task loads. Thus, this finding from the study is critically important for future work on algorithm and hybrid measure development in the cognitive load domain. This issue will be raised again in the modeling and general discussion sections.

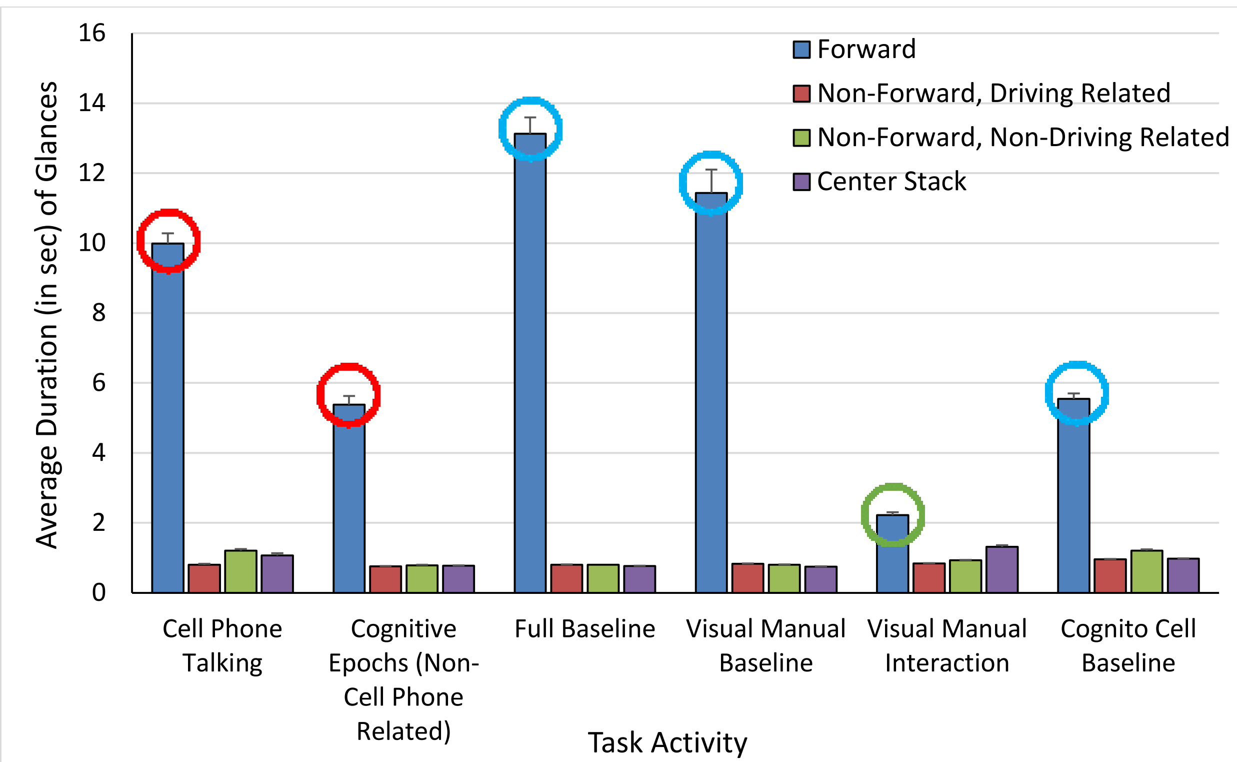

Figure 4. Bar chart. Cognitive epochs (of both types) are distinguished from visual-manual tasks by "average duration of glances forward to road" but not from baselines.

Formal analysis using the mixed model confirmed the findings shown in Figure 4. The Driving Epoch Type variable was found to be significantly associated with average duration of glances forward to road (F = 29.15, $p \leq .0001$). When comparing means for the various types of epochs using the Bonferroni post hoc, adjusted *p* value, and *t* tests, the following conditions were significantly different from each other. These findings are represented by different colored circles in Figure 4.

- Cell Phone Talking vs. Cell Baseline ($p < .0001$)
- Cell Phone Talking vs. Other Cognitive Epochs (Talking/Listening/Singing to Passenger, Self) ($p < .0001$)
- Cell Phone Talking vs. Visual-Manual Interaction ($p < .0001$)
- Other Cognitive Epochs vs. Visual-Manual Interaction ($p < .0001$)
- Other Cognitive Epochs vs. Full Baseline ($p < .0216$)
- Cell Phone Baseline vs. Full Cognitive Epoch Baseline ($p < .0144$)
- Cell Baseline vs. Visual Manual-Interaction ($p < .0453$)
- Full Cognitive Epoch Baseline vs. Visual-Manual Interaction ($p < .0001$)

Blink Rate

Formal analysis using the mixed-model analysis revealed that the Driving Epoch Type variable was significantly associated with blink rate ($F = 8.72$, $p \leq .0001$, Figure 5). The Bonferroni post hoc, adjusted *p* value, and *t* tests revealed that the following conditions were significantly different from each other:

- Cell Phone Talking vs. Cognito Cell Baseline ($p < .0001$)
- Cell Phone Talking vs. Visual-Manual Interaction ($p < .0001$)
- Average Cognitive (Passenger) vs. Cognito Cell Baseline ($p < .0254$)
- Average Cognitive (Passenger) vs. Visual-Manual Interaction ($p < .0117$)

The test results are displayed graphically in Figure 5. The blink rate is presented for each task activity and the boxed letters at the top of each column represent significantly different results.

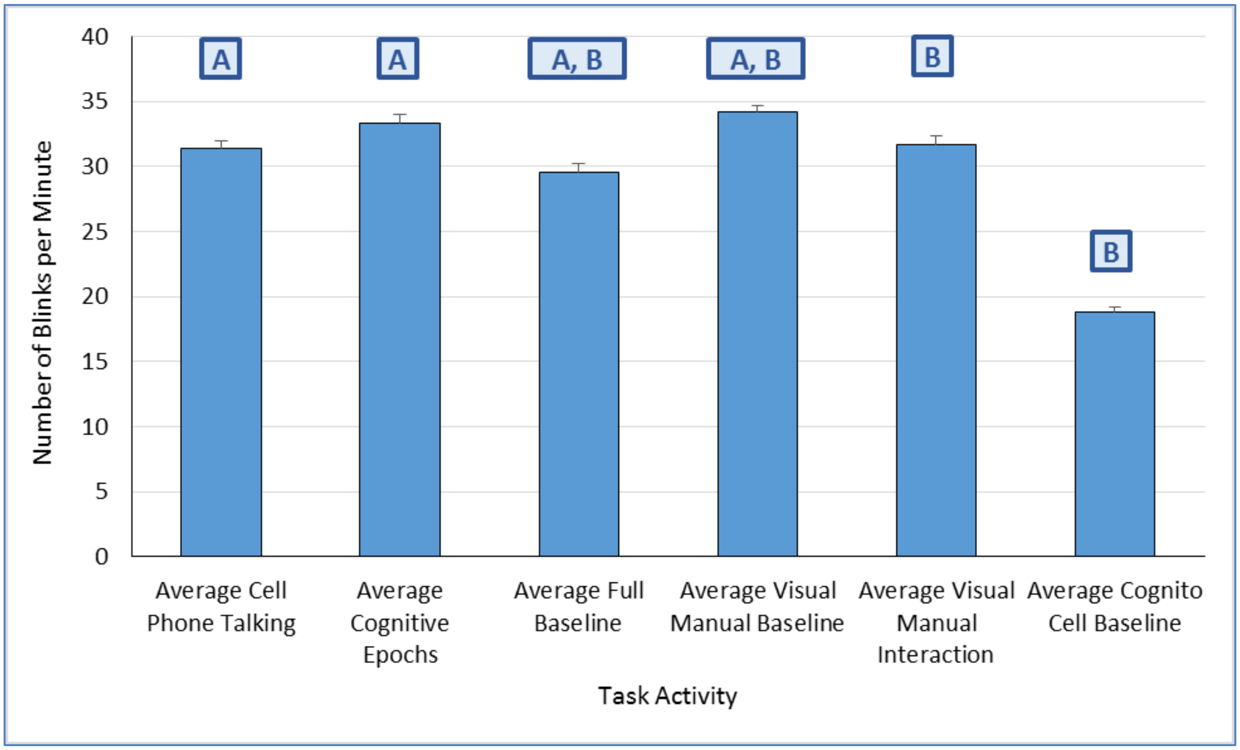

Figure 5. Bar chart. Blink rate <u>not successful</u> in distinguishing cognitive epochs.

The mean results for blink rate, shown in Figure 5, did not follow either the initially hypothesized pattern, based on the literature, in which blink rate is predicted to drop during periods of cognitive load, or the most recently found pattern (from Liang, 2009), in which periods of cognitive load combined with driving showed an elevation of blink rate relative to all other conditions. Furthermore, in this study, blink rates were much higher than observed in any other prior study. The rates are closer to those reported for simulated driving by Liang (2009) than to those reported in non-driving studies, where resting rates of blinking average 10-11 blinks per minute. This study reported over 30 blinks per minute for most conditions. This could be due to the fact these rates were obtained from, and may be the first reported blink rates from, naturalistic driving. Finally, the highest blink rates were found in conditions for cell phone conversation, other cognitive epochs, full baselines (which may have contained daydreaming and lost-in-thought activity), visual-manual baselines, and visual-manual interaction epochs. This last finding showing the similarity of blink rates between the cognitive task epochs and the other types of epochs presents the greatest puzzle in interpreting the results for this variable. Even finer-grained, temporal analyses are unlikely to overcome the fact that blink rate was very high in all conditions analyzed, with the exception of one baseline condition.

Total Cumulative Duration of Glances to Non-Forward Areas

Finally, an analysis was undertaken to examine whether the hypothesized narrowing of scanning was observed for periods of cognitive load relative to just driving. Figure 6 graphically depicts the means for total duration of glances to both driving-related and non-driving-related non-forward areas. The observed findings were contrary to the hypothesized effects. It was expected that under cognitive load a reduction of glances to areas peripheral to the forward view would be observed, along with a concomitant drop in total time looking at these areas. Instead, an increase relative to just driving was observed. It is not clear what could explain this unexpected outcome since a narrowing of scan under cognitive load has been robustly established by a number of prior studies.

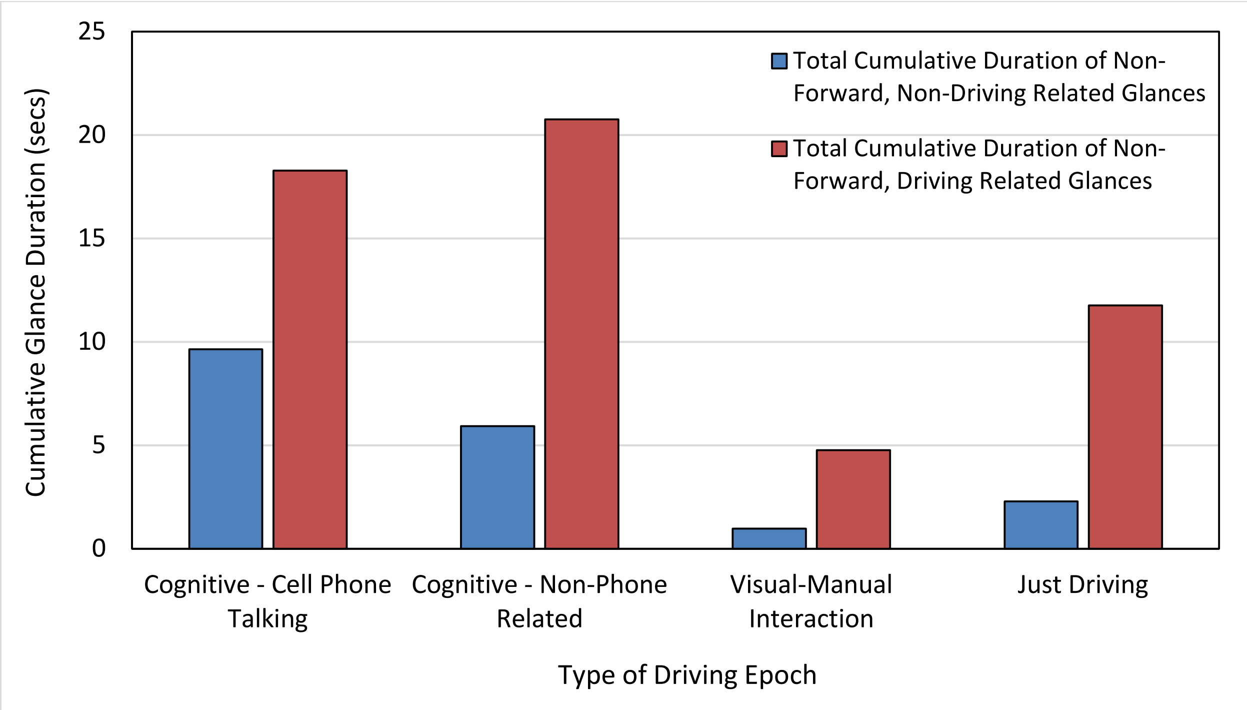

Figure 6. Bar chart. Differences in total duration of glances on non-forward areas by driving epochs.

DESCRIPTIVE STATISTICS

Descriptive statistics were calculated for each of the original eye-glance variables for each of the three types of task loadings or driving activities. These task loading types were defined by grouping the six types of driving epochs into three groups, as follows:

1. A category of epochs consisting of just-driving activity. This contained baseline epochs of all types, which were grouped together into this one category.
2. A category of epochs consisting of Cognitive Task Load, which contained all epochs from the two categories of cognitive load epochs.
3. A category of epochs consisting of Visual-Manual Task Load, which contained the visual-manual task epochs.

In Appendix A, Table A1 displays the mean and standard error for each variable of the original eye-glance variables that were reduced from the data. Appendix A additionally contains Tables A2 through A10 with descriptive statistics across the three task loading levels and tables with descriptive statistics across the different driving epoch categories as defined by triggers in the data streams.

MODELING

Following the main analyses, additional work was undertaken to develop a model with the hope that it might provide a foundation for the eventual development of an algorithm that could crawl naturalistic data streams and identify periods of time-history data during which cognitive load was present rather than some other type of task-loading or driver activity. It should be noted that the development of such an algorithm is a very complex undertaking that would typically first progress through several more modest stages of development. Therefore, the modeling effort that was completed for this project was intentionally designed as a preliminary first step. It was structured to take advantage of the fact that the epochs in this study had been intentionally pre-identified as either containing cognitive load associated with a secondary task such as conversation or singing, or as representing just driving. The initial challenge for this stage of model development was to determine whether it was possible to predict the identity of each epoch (cognitive or just driving), based on measured variables reduced from the naturalistic data. Thus, the intent of the model was to predict whether a given epoch was a cognitive epoch or a just-driving baseline epoch. For this analysis, those epochs which were entered into the analysis included all epochs comprised of conversation on a cell phone *as well as* all epochs from the cognitive other category, which included conversations with passenger and self, and also singing. Included in a contrasting category were all baseline epochs. All baseline epochs of all types were included together. Excluded from the modeling effort were the epochs containing visual-manual secondary task activities.[1]

The first step in modeling was to select which predictor variables would be included in the modeling effort. To do this, the means of each measured variable for all cognitive epochs and all baseline epochs were plotted and then compared to determine if a difference in mean values between cognitive and baseline epochs appeared to exist for each variable. Statistical tests were not used for two reasons: (1) lack of power arising from the small sample size and (2) the risk of Type 1 errors due to the large number of comparisons that were to be made. Therefore, as a precaution, all those measured variables that appeared to differ between baseline and cognitive epochs were selected for inclusion in the modeling effort. These are shown in Table 5.

Table 5. Variables that changed in mean value across cognitive epochs/baseline epochs.

Variable Name
Total Duration of Glances Non-Forward Driving Related
Total Duration of Glances Non-Forward Non-Driving Related
Total Duration of Glances Center Stack
Percent Duration of Glances Center Stack
Percent Over 2 Seconds of Glances Forward
Percent Over 2 Seconds of Glances Center Stack
Longest Duration of Glances Center Stack Glance
Number of Eyes Open
Number of Blinks
Total Duration of Eyes Open

[1] Should future research be possible, there are several additional modeling efforts that would be interesting to apply that would make use of the category of visual-manual epochs in addition to the epochs of cognitive load and just driving.

Variable Name
Total Duration of Blinks
Number of Transitions
Number of Glances Forward
Number of Glances Non-Forward Driving Related
Number of Glances Non-Forward Non-Driving Related
Number of Glances Center Stack
Percent Number of Glances Non-Forward Driving Related
Percent Number of Glances Non-Forward Non-Driving Related
Glance Rate Non-Forward Driving Related
Glance Rate Non-Forward Non-Driving Related
Glance Rate Center Stack
Total Duration of Glances Forward

Following the selection of variables, logistic regression was run to derive the model. In this procedure, a backwards regression technique was applied such that on any given model run, the variable with the highest probability value was removed before the next subsequent run of the model. Then the model was rerun and the methods repeated until only statistically significant variables remained in the model. This technique produced a model that could predict whether a given epoch of driving was likely to represent a cognitively loaded or baseline period of activity.

The resulting model was a function of six variables, which were:

- percent glances non-forward non-driving related
- total duration of glances non-forward driving related
- total duration of glances non-forward non-driving related
- number of eyes open
- total duration of blinks
- number of transitions

The six variables are different from those which were initially hypothesized to be the key variables in identifying epochs of cognitive load, but do include two that are close associates of the originally hypothesized predictors. The model does not define cause and effect; rather, it identifies significant associations and relationships between the variables and the classification of driving epochs as cognitively loaded or just driving (baseline). Table 6 provides additional information from the model, including estimated effects and confidence limits.

Table 6. Predictor variables and estimates for final model

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Squared	Pr > ChiSq
Intercept	1	-0.0790	0.3868	-0.8372	0.6792	0.04	0.8381
Percent Number of Glances Non-Forward Non-Driving Related	1	0.0927	0.0356	0.0229	0.1625	6.77	0.0093
Total Duration of Glances Non-Forward Driving Related	1	-0.1961	0.0633	-0.3201	-0.0721	9.60	0.0019
Total Duration of Glances Non-Forward Non-Driving Related	1	-0.1051	0.0366	-0.1769	-0.0333	8.23	0.0041
Number of Eyes Open	1	0.0461	0.0156	0.0155	0.0767	8.73	0.0031
Total Duration of Blinks	1	-0.2293	0.8280	-0.3915	-0.0671	7.67	0.0056
Number of Transitions	1	0.0709	0.0262	0.0196	0.1221	7.33	0.0068

A particularly interesting feature of the model is that it can predict whether an epoch is one that reflects cognitive load or just driving rather than giving only a one-sided prediction. In other words, each variable in the model makes bidirectional predictions. This means that increases in the values of a given variable within the model will be associated with one classification outcome, and decreases in the value of that variable will be associated with the other classification outcome. In this context, the classification outcome corresponds to a prediction about whether a given epoch of driving is a cognitive epoch or a just-driving epoch.

Thus, the bidirectional predictions for each of the variables in the final model are as follows:

- **Total duration of non-forward driving-related glances**

  Increases in the value of this variable increased the predicted probability that an epoch was a **just-driving (baseline) epoch**. Longer cumulative glance time to non-forward locations, such as glances to mirrors, and glances to right and left sides, were associated with tasks/activities other than cognitively loading ones.

  Decreases in the value of this variable increased the predicted probability that an epoch was a **cognitive epoch.** This is more easily understood when it is reframed slightly. When there are decreases in the total duration of non-forward driving-related glances within an epoch, it necessarily means that the total cumulative duration of glances to other regions increases. Among these other regions is the forward region.

- **Total duration of non-forward non-driving-related glances**

  Increases in the value of this variable increased the predicted probability that an epoch was a **just-driving (baseline) epoch**. Longer cumulations of glances to areas that were both non-forward and non-driving-related (e.g., glances specifically to things such as radio, food, beverage, passengers, pets, and objects brought into the vehicle) were more often associated with just-driving epochs.

  Decreases in the value of this variable increased the predicted probability that an epoch was a **cognitive epoch.** Like the variable above, this is more easily understood in terms of the variable which is its complement or mirror image. The complement of "total duration of non-forward, non-driving related glances" is "total duration of glances to all other areas besides non-forward and non-driving areas," or in other words, to "forward driving-related areas." As total time spent looking to forward driving-related areas increases, the predicted probability of a cognitive epoch increases. This finding is consistent with original predictions for cognitive epochs, namely that when cumulative gaze time on forward driving-related areas increases, it tends to indicate a period of cognitive load.

- **Percent of glances to non-forward non-driving-related areas**

  Increases in the value of this variable increased the predicted probability that an epoch was a **cognitive epoch**. These would be glances to locations like the radio, cup holder, purse, passenger, carried-in devices, etc. This predictor is difficult to interpret and seems a spurious outcome.

  Decreases in the value of this variable increased the predicted probability that an epoch was a **just-driving (baseline) epoch.** A decreased percentage of glances to non-forward, non-driving-related areas would correspond with an increased percentage of glances forward, driving-related areas and this would be associated with just-driving baseline epochs. This predictor is difficult to interpret, and seems to move opposite the direction that would be expected.

- **Number of transitions between locations**

  Increases in the value of this variable increased the predicted probability that an epoch was a **cognitive epoch**. Increases in the number of transitions between locations are an indicator of visual-manual task activity. This predictor is difficult to interpret and seems opposite to the expected direction.

  Decreases in the value of this variable increased the predicted probability that an epoch was a **just driving (baseline) epoch.** This predictor is difficult to interpret and seems opposite to the expected direction.

- **Number of frames of eyes open during the epoch**

  Increases in the value of this variable increased the predicted probability that an epoch was a **cognitive epoch**. Increases in the number of frames of eyes open during the epoch are an indicator of alertness and arousal. This predictor is difficult to interpret and unusual as a main predictor of type of load.

Decreases in the value of this variable increased the predicted probability that an epoch was a **just-driving (baseline) epoch.** This predictor is difficult to interpret and unusual as a main predictor of type of load.

- **Total duration of blinks**

  Decreases in the value of this variable increased the predicted probability that an epoch was a **cognitive epoch**. Decreases in the total **duration** of blinks are an indicator of arousal. This predictor is difficult to interpret and unusual as a main predictor of type of load.

  Increases in the value of this variable increased the predicted probability that an epoch was a **just-driving (baseline) epoch.** This predictor is difficult to interpret and unusual as a main predictor of type of load.

Summary of Model Predictions Across Variables

For predicting cognitive load epochs, the findings from the model were not easily interpreted as a whole. However, they can be summarized as follows. The probability that an epoch of driving contains cognitive load tends to increase when the following occur:

- The total cumulative duration of forward driving-related glances during the epoch increases.

- The number of frames of eyes open during the epoch increases. This is an indicator of alertness and arousal. It is difficult to interpret and is surprising as a main predictor of a cognitive load epoch. Though there are some hypotheses that could be offered, they are speculative in nature without further analysis to support them.

- The total duration of blinks decreases. Shorter blinks tend to be associated with alert states, in contrast to drowsiness, which is associated with long-duration blinks. This finding is difficult to interpret and is surprising as a main predictor of a cognitive load epoch. If the finding were understood in terms of arousal, then it might become interpretable. Some research on cognitive load has noted elevations in physiological measures of arousal and stress under higher levels of cognitive load (Mehler, Reimer, et al. 2010). Stern et al. (1984) indicate that blink rate increases with arousal and workload levels and that blink rate and blink duration are correlated. And thus, while it is hard to interpret the model prediction, the possible relationship between shorter blinks and higher blink rates is noted, as well as the possible relationship to higher levels of cognitive load and arousal/stress.

- The percentage of glances to non-forward, non-driving related areas increases. These glances would be to locations such as the passenger, carried-in devices, cup holder, purse, briefcase, etc. This result is difficult to interpret, and seems to be the opposite of what would be expected, unless it is attributable to the nature of the conversation component of interactions examined here (i.e., to looking at the person with whom a conversation is occurring for cues on turn-taking, comprehension, etc.) and/or associated with glances to the cell-phone location during the talking/listening epoch. Such glances would not be associated with cognitive load per se, but instead with the social and pragmatic conventions that accompany conversation, and/or with the necessities that accompany speaking over a cell phone.

- The number of transitions between locations increases. This result is likewise difficult to interpret and surprising. Typically, an increase in number of transitions, or eye movements between locations, is an indicator of visual-manual task activity, so to see it emerge as a main indicator of cognitive load is difficult to explain.

Implications of these findings are discussed more fully under the General Discussion section.

Inter-Correlations Between Predictor Variables

As a final type of analysis performed during this research effort, correlations between predictor variables were examined. It is important to note that some of the eye-glance variables included in the original model were correlated with each other and their exclusion from the model does not mean they are not associated with cognitive load. The correlations between all eye-glance variables included in the original model can be found in Tables 8 and 9, with the corresponding parameter number labels in Table 7 for reference. One example of a variable in the final model being highly correlated with other variables is Percent Number of Glances Non-Forward Non-Driving Related. According to the tables below, this variable is correlated with Number of Glances Non-Forward Driving Related (ρ = 0.59), Total Duration of Glances Non-Forward Non-Driving Related (ρ = -0.60), and Number of Transitions (ρ = -0.68). Several other correlated variables can be found in the tables. Cells highlighted in yellow and marked with an * are those in which correlation values exceed r = 0.71, which indicates that the corresponding R^2 value would exceed 50%, and more than 50% of the variance in the relationship would be accounted for.

Table 7. Initial model eye glance variable and parameter number for reference in correlation matrices.

Parameter Number	Variable Name
Prm1	Intercept
Prm2	Number of Glances Non-Forward Driving Related
Prm3	Number of Glances Non-Forward Non-Driving Related
Prm4	Number of Glances Center Stack
Prm5	Percent Number of Glances Non-Forward Driving Related
Prm6	Percent Number of Glances Non-Forward Non-Driving Related
Prm7	Glance Rate Non-Forward Driving Related
Prm8	Glance Rate Non-Forward Non-Driving Related
Prm9	Glance Rate Center Stack
Prm10	Total Duration of Glances Forward

Parameter Number	Variable Name
Prm11	Total Duration of Glances Non-Forward Driving Related
Prm12	Total Duration of Glances Non-Forward Non-Driving Related
Prm13	Total Duration of Glances Center Stack
Prm14	Percent Duration of Glances Center Stack
Prm15	Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related
Prm16	Percent Over 2 Seconds of Glances Center Stack
Prm17	Longest Duration of Glances Center Stack Glance
Prm18	Number of Eyes Open
Prm19	Number of Blinks
Prm20	Total Duration of Eyes Open
Prm21	Total Duration of Blinks
Prm22	Number of Transitions

For those variables that were correlated, the patterns are meaningful. For example, Parameters 4, 9, 13, and 14 were all correlated above 0.71. These variables all are related to glances made to the center stack, including number, rate, total duration over the epoch, and percent duration over the epoch made to the center stack. In addition, Parameter 22 (Number of Eye Transitions between Locations) was correlated with Parameter 2 (Number of Glances to Non-Forward Driving-Related Areas). Parameters 18 and 19 were nearly perfectly correlated in a negative direction; the Number of Frames with Eyes Open decreased as the Number of Blinks increased. Parameter 10 (Total Duration of Eyes Forward) showed a negative correlation with Parameter 20 (Total Duration of Eyes Open) such that as the amount of time the eyes were forward increased, the total amount of eyes open time across the epoch decreased. This relationship is difficult to understand, unless a decrease in eyes open is seen as a surrogate for an increase in blinking, which is perhaps suggested by the near-perfect correlation in the negative direction between number of blinks and number of eyes-open frames. Parameters 12 and 15 were highly correlated; the Total Cumulative Duration of Glances to Non-Forward Non-Driving-Related Glances, which might include the total time spent looking at passengers and phones, etc., was correlated with Long Glances to these areas, where long glances were those over 2 seconds.

Table 8. Correlation matrix for variables 1–22 by variables 1–12.

Estimated Correlation Matrix												
	Prm1	**Prm2**	**Prm3**	**Prm4**	**Prm5**	**Prm6**	**Prm7**	**Prm8**	**Prm9**	**Prm10**	**Prm11**	**Prm12**
Prm1	1.00	0.35	0.26	0.03	-0.72*	-0.19	-0.06	-0.03	-0.18	-0.06	0.31	-0.12
Prm2	0.35	1.00	0.59	0.11	-0.43	-0.19	0.03	0.16	0.08	-0.13	-0.23	0.03
Prm3	0.26	0.59	1.00	0.23	-0.23	-0.22	0.15	-0.23	-0.10	0.09	0.12	-0.60
Prm4	0.03	0.11	0.23	1.00	0.05	0.07	-0.07	-0.09	-0.89	-0.16	0.30	-0.28
Prm5	-0.72	-0.43	-0.23	0.05	1.00	0.21	-0.51	0.03	0.00	0.03	0.10	-0.11
Prm6	-0.19	-0.19	-0.22	0.07	0.21	1.00	-0.04	-0.68	-0.16	0.10	0.02	-0.22
Prm7	-0.06	0.03	0.15	-0.07	-0.51	-0.04	1.00	-0.24	0.04	0.27	-0.36	0.07
Prm8	-0.03	0.16	-0.23	-0.09	0.03	-0.68	-0.24	1.00	0.23	-0.20	-0.13	0.37
Prm9	-0.18	0.08	-0.10	-0.89*	0.00	-0.16	0.04	0.23	1.00	0.00	-0.32	0.33
Prm10	-0.06	-0.13	0.09	-0.16	0.03	0.10	0.27	-0.20	0.00	1.00	-0.13	-0.17
Prm11	0.31	-0.23	0.12	0.30	0.10	0.02	-0.36	-0.13	-0.32	-0.13	1.00	-0.28
Prm12	-0.12	0.03	-0.60	-0.28	-0.11	-0.22	0.07	0.37	0.33	-0.17	-0.28	1.00
Prm13	0.15	0.12	-0.02	-0.91*	-0.08	0.00	-0.03	0.05	0.81	0.15	-0.14	0.14
Prm14	0.02	-0.17	-0.01	0.84*	0.10	0.18	-0.03	-0.22	-0.96*	0.03	0.23	-0.24
Prm15	0.10	-0.17	0.43	0.35	0.15	0.13	-0.06	-0.37	-0.44	0.22	0.34	-0.80
Prm16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prm17	-0.36	0.17	0.12	0.00	-0.16	-0.26	0.34	0.13	0.23	-0.08	-0.42	0.19
Prm18	-0.03	-0.12	0.03	-0.04	0.03	0.27	0.17	-0.30	-0.11	0.42	-0.05	-0.23
Prm19	-0.03	0.10	-0.05	0.03	-0.02	-0.23	-0.10	0.27	0.12	-0.32	0.00	0.25
Prm20	-0.16	0.08	-0.19	0.04	-0.03	-0.24	-0.03	0.34	0.12	-0.89*	-0.14	0.35
Prm21	0.36	0.11	0.11	0.06	-0.19	-0.11	-0.27	0.06	0.01	-0.59	0.26	-0.11
Prm22	-0.36	-0.97*	-0.68	-0.16	0.44	0.26	-0.08	-0.14	-0.04	0.12	0.06	0.01

* Cells highlighted in yellow and marked with an * are those in which correlation values exceed r = 0.71, thus indicating that the corresponding R^2 value would exceed 50%.

Table 9. Continued correlation matrix for variables 1–22 by variables 13–22.

Estimated Correlation Matrix										
	Prm13	**Prm14**	**Prm15**	**Prm16**	**Prm17**	**Prm18**	**Prm19**	**Prm20**	**Prm21**	**Prm22**
Prm1	0.15	0.02	0.10	0.00	-0.36	-0.03	-0.03	-0.16	0.36	-0.36
Prm2	0.12	-0.17	-0.17	0.00	0.17	-0.12	0.10	0.08	0.11	-0.97
Prm3	-0.02	-0.01	0.43	0.00	0.12	0.03	-0.05	-0.19	0.11	-0.68
Prm4	-0.91*	0.84*	0.35	0.00	0.00	-0.04	0.03	0.04	0.06	-0.16
Prm5	-0.08	0.10	0.15	0.00	-0.16	0.03	-0.02	-0.03	-0.19	0.44
Prm6	0.00	0.18	0.13	0.00	-0.26	0.27	-0.23	-0.24	-0.11	0.26
Prm7	-0.03	-0.03	-0.06	0.00	0.34	0.17	-0.10	-0.03	-0.27	-0.08
Prm8	0.05	-0.22	-0.37	0.00	0.13	-0.30	0.27	0.34	0.06	-0.14
Prm9	0.81*	-0.96*	-0.44	0.00	0.23	-0.11	0.12	0.12	0.01	-0.04
Prm10	0.15	0.03	0.22	0.00	-0.08	0.42	-0.32	-0.89*	-0.59	0.12
Prm11	-0.14	0.23	0.34	0.00	-0.42	-0.05	0.00	-0.14	0.26	0.06
Prm12	0.14	-0.24	-0.80*	0.00	0.19	-0.23	0.25	0.35	-0.11	0.01
Prm13	1.00	-0.85*	-0.26	0.00	-0.20	0.06	-0.05	-0.14	-0.02	-0.09
Prm14	-0.85*	1.00	0.37	0.00	-0.21	0.12	-0.12	-0.08	-0.07	0.15
Prm15	-0.26	0.37	1.00	0.00	-0.21	0.16	-0.18	-0.36	0.04	0.12
Prm16	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Prm17	-0.20	-0.21	-0.21	0.00	1.00	-0.11	0.14	0.22	-0.05	-0.16
Prm18	0.06	0.12	0.16	0.00	-0.11	1.00	-0.98*	-0.40	-0.30	0.12
Prm19	-0.05	-0.12	-0.18	0.00	0.14	-0.98*	1.00	0.33	0.12	-0.10
Prm20	-0.14	-0.08	-0.36	0.00	0.22	-0.40	0.33	1.00	0.36	-0.07
Prm21	-0.02	-0.07	0.04	0.00	-0.05	-0.30	0.12	0.36	1.00	-0.10
Prm22	-0.09	0.15	0.12	0.00	-0.16	0.12	-0.10	-0.07	-0.10	1.00

* Cells highlighted in yellow and marked with an * are those in which correlation values exceed $r = 0.71$, thus indicating that the corresponding R^2 value would exceed 50%.

CHAPTER 4. GENERAL DISCUSSION

The purpose of this research was to explore, in a preliminary way, whether epochs of cognitive load could be identified in streams of naturalistic driving data by applying a small set of glance-based measures that had shown promise as behavioral indicators. As an initial step toward this, epochs of driving representing different types of task loading were extracted from natural driving trips and compared on a wide set of measures. The formal statistical analyses of key measures confirmed that cognitive load epochs were associated with an elevated amount of time gazing at the forward road region, as had been hypothesized, and with elongated durations of individual glance durations. However, surprisingly, at least one of the baseline just-driving conditions was also associated with these effects. This suggests that the just-driving baseline epochs perhaps contained cognitive activity—daydreaming, thinking, or mind-wandering activity, for example. Also, surprisingly, the hypothesized narrowing of scan, or less gazing at peripheral areas under cognitive load, during periods of cognitive load was not supported by the naturalistic data, at least not relative to the true just-driving epochs. However, if those baseline epochs contained significant, but unexpected, amounts of daydreaming or mind-wandering, then it is possible that the expected relative difference between these conditions would not have been obtained.

The second part of the analytic work done in this project consisted of modeling work based on logistic regression. However, the results from the model were somewhat puzzling. Only two of the four predictor variables that emerged from the logistic regression model were associated with any variables that had been strongly identified with cognitive load in empirical work that had been done in the literature. While two of the predictor variables from the model may be understood as close associates of two of the originally hypothesized variables, the remaining predictors were difficult to understand. Therefore, it is perhaps important to reflect on the fact that the model makes its predictions about the probability of a cognitive epoch as compared to the baseline epochs that were analyzed, and does so in terms of the range of differences in eye-glance behavior that exist in the analyzed set of epochs. In other words, the analysis is necessarily constrained by the range of variability that exists within the categories of driving epochs being analyzed.

Therefore, if it were the case that the baseline periods to which the cognitive epochs were compared also happened to contain periods of cognitive load—for example, in the form of daydreaming or mind-wandering—*and* if this form of cognitive load caused drivers to behave similarly on the key hypothesized glance indicators (increasing the concentration of gaze on the forward road, lengthening glances on the forward road, narrowing scans, and changing blink rates in a similar way), then differences in those eye-glance variables between the two categories of epochs as defined above would *not* be found in the logistic regression analysis. Under such a situation, the model would likely *not* identify those variables as significant predictors.

If, however, daydreaming as a form of cognitive load was present in the baseline epochs but caused drivers to behave *dissimilarly* from talking/listening/singing epochs as a form of cognitive load, the model would then be describing the probability that two different *types* of cognitive epochs could be differentiated through the use of certain predictors (i.e., with some variables identifying cognitive load from talking/listening/singing and other variables identifying daydreaming/mind-wandering). In other words, in this situation, the model may identify the eye-glance behaviors associated with differentiating these *specific* forms of cognitive load.

Unfortunately, it is likely that the baseline set of natural driving epochs actually contained a *mixture* of both active, attentive, daydreaming-free driving periods as well as periods of daydreaming. This type of mix within the baseline just-driving epochs makes it even harder to know how best to understand the modeling results that were obtained. It is difficult to know whether the modeling outcome results indicate that the cognitive epochs and just driving epochs were not discriminable on the hypothesized indicators, and, as a result produced unexpected predictors in the model, or if the model is indicating how two specific types of cognitive load might be differentiated (conversation vs. daydreaming/mind-wandering), or something in between.

However, a major finding emerging from this research is that just-driving baselines may in fact *not* be "just driving." They may instead contain a considerable amount of cognitive activity in the form of daydreaming and lost-in-thought activity. If this is indeed the case, there are several important implications:

1. Traditionally defined just-driving baselines may not be appropriate comparisons against which to evaluate an algorithm for identifying epochs of cognitive load.
2. Instead, some other types of comparison epochs will likely need to be used. For example, epochs which contain markedly less cognitive activity than the traditionally defined just-driving baselines, where daydreaming may be as prevalent as estimated by He et al. (2011), could be used. And either a special study applying a special method to just-driving portions of trips to filter out periods of daydreaming may need to be carried out, using, for example, methods such as those employed in the literature on mind-wandering, or both different comparison epochs and special methods may need to be employed.
3. Just driving is not "just driving." If it is the case that just driving contains frequent cognitive activity in the form of daydreaming and thinking and yet is free from crashes, this may have implications for studies on the estimation of crash risk. Estimates of crash risk based on comparisons of activities to just-driving baselines may need to be reconsidered in light of the possible finding that just-driving baselines may contain the aforementioned frequent cognitive activity.
4. A need for new and different evaluations of the effects of cognitive load on driving performance and safety emerges from this work, since the extent of cognitive load in terms of glance concentration effects and glance lengths to the forward road during baselines and cognitive secondary tasks may be similar. Might this in fact further underscore the possibility that crash risk from cognitive load is low, at least in many scenarios, as recent papers have begun to suggest (Young, 2014)?

New modeling efforts, which would compare cognitive load to different types of resource-loading, may be an important next step in this research. For example, a modeling approach comparing visual-manual task loads to cognitive loads from talking/listening/singing to just-driving epochs, which may contain daydreaming, would provide important information. Such a modeling approach would indicate which eye-glance behaviors are associated specifically with cognitive load, as opposed to those that are primarily visual-manual task loading, and which type of resource-loading is more similar to just driving.

As noted above, in future efforts, it would be ideal to include periods of baseline epochs that represent only active, attentive driving, which are also free from daydreaming or lost-in-thought processing. But at the present time, this would appear to be difficult to do in the context of naturalistic driving. Such an effort would seem to require either physiological measurement or the use of self-report or probe methods, such as those employed by He et al. (2011), in order to define periods of time during driving that are free from mind-wandering. Unless a “true” baseline is included in a modeling effort, it will be difficult to interpret whether differences in glance variables during cognitive load are due to the type of load or are due merely to the lack of visual-manual loading.

Thus, to conclude, there remains much promise for the development of an algorithm or hybrid measure that could be used to identify periods of cognitive load within naturalistic data. However, future research efforts to develop such a technique may benefit from the use of additional types of comparison epochs, beyond the traditionally defined just-driving baseline epochs.

APPENDIX A. DESCRIPTIVE STATISTICS

Descriptive statistics were calculated for each of the original eye-glance variables across three cognitive load levels. For this grouping into cognitive load levels, all baseline epochs were grouped together into one category called Just Driving – No Observable Cognitive Activity. Then the two categories of cognitive load epochs were grouped together into another cognitive load category. The visual-manual task epochs formed the third category. Table A1 displays the mean and standard error for each variable. The appendix contains tables with additional descriptive statistics across the three cognitive load levels and tables with descriptive statistics across the different trigger categories.

Table A1. Mean and standard error of eye-glance variables for epochs of different types.

Eye-Glance Variable	Just Driving (Baseline) - Mean	Just Driving (Baseline) - Standard Error	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Mean	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Standard Error	Visual-Manual Interaction - Mean	Visual-Manual Interaction - Standard Error
Number of Glances Forward	15.31	0.34	36.35	1.74	31.13	0.93
Number of Glances Non-Forward Driving Related	13.72	0.31	26.68	1.40	6.16	0.26
Number of Glances Non-Forward Non-Driving Related	1.92	0.09	7.96	0.46	1.07	0.07
Number of Glances Center Stack	1.08	0.04	4.04	0.26	25.90	0.82
Percent Number of Glances Forward	45.13	0.22	46.63	0.21	47.95	0.08
Percent Number of Glances Non-Forward Driving Related	45.39	0.38	34.94	0.42	10.17	0.35
Percent Number of Glances Non-Forward Non-Driving Related	4.31	0.20	10.66	0.31	1.62	0.10
Percent Number of Glances Stack	4.68	0.21	6.53	0.30	39.66	0.33
Glance Rate Forward	7.67	0.11	9.71	0.20	21.75	0.46

Eye-Glance Variable	Just Driving (Baseline) - Mean	Just Driving (Baseline) - Standard Error	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Mean	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Standard Error	Visual-Manual Interaction - Mean	Visual-Manual Interaction - Standard Error
Glance Rate Non-Forward Driving Related	9.61	0.42	7.94	0.28	3.90	0.13
Glance Rate Non-Forward Non-Driving Related	0.98	0.05	1.92	0.06	0.77	0.05
Glance Rate Center Stack	0.73	0.03	1.52	0.10	18.47	0.44
Total Duration of Glances Forward	102.42	2.00	206.13	8.06	49.83	1.53
Total Duration of Glances Non-Forward Driving Related	11.76	0.29	19.32	0.87	4.76	0.19
Total Duration of Glances Non-Forward Non-Driving Related	2.29	0.13	8.09	0.54	0.97	0.06
Total Duration of Glances Center Stack	0.92	0.04	3.75	0.25	31.36	0.93
Percent Duration of Glances Forward	84.08	0.45	83.48	0.47	54.50	1.00
Percent Duration of Glances Non-Forward Driving Related	12.55	0.42	9.93	0.36	5.15	0.19
Percent Duration of Glances Non-Forward Non-Driving Related	2.17	0.13	3.29	0.14	1.17	0.08
Percent Duration of Glances Center Stack	1.02	0.04	2.58	0.25	38.08	0.96
Average Duration of Glances Forward	10.41	0.26	8.03	0.21	2.22	0.09
Average Duration of Glances Non-Forward Driving Related	0.85	0.00	0.79	0.02	0.84	0.01

Eye-Glance Variable	Just Driving (Baseline) - Mean	Just Driving (Baseline) - Standard Error	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Mean	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Standard Error	Visual-Manual Interaction - Mean	Visual-Manual Interaction - Standard Error
Average Duration of Glances Non-Forward Non-Driving Related	1.06	0.01	1.04	0.02	0.93	0.01
Average Duration of Glances Center Stack	0.87	0.01	0.96	0.03	1.32	0.04
Standard Deviation Duration of Glances Forward	8.03	0.13	9.55	0.27	2.58	0.12
Standard Deviation Duration of Glances Non-Forward Driving Related	0.36	0.01	0.40	0.02	0.31	0.01
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.33	0.01	0.41	0.02	0.19	0.01
Standard Deviation Duration of Glances Center Stack	0.10	0.00	0.34	0.01	0.80	0.05
Percent Over 2 Seconds of Glances Forward	29.56	0.27	28.03	0.32	12.74	0.52
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.55	0.04	0.72	0.06	0.19	0.03
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.15	0.02	0.80	0.08	0.02	0.01
Percent Over 2 Seconds of Glances Center Stack	0.00	0.00	0.54	0.13	4.08	0.28
Longest Duration of Glances Forward	29.81	0.49	34.95	0.86	10.23	0.43
Longest Duration of Glances Non-Forward Driving Related	1.60	0.02	1.79	0.04	1.38	0.04

Eye-Glance Variable	Just Driving (Baseline) - Mean	Just Driving (Baseline) - Standard Error	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Mean	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Standard Error	Visual-Manual Interaction - Mean	Visual-Manual Interaction - Standard Error
Longest Duration of Glances Non-Forward Non-Driving Related	1.51	0.04	1.97	0.09	1.12	0.02
Longest Duration of Glances Center Stack Glance	1.00	0.01	1.56	0.06	3.53	0.19
Number of Eyes Open	59.09	1.46	137.70	5.71	51.03	1.91
Number of Blinks	59.34	1.45	135.52	5.65	51.45	1.91
Number No Info	0.97	0.04	4.03	0.24	0.75	0.07
Percent Number of Eyes Open	49.73	0.04	50.41	0.05	49.70	0.06
Percent Number of Blinks	50.27	0.04	49.59	0.05	50.30	0.06
Percent Number of No Info	1.47	0.07	2.30	0.16	1.38	0.15
Blink Rate	27.42	0.36	32.19	0.45	31.67	0.71
Total Duration of Eyes Open	125.71	2.21	231.39	8.50	83.44	1.44
Total Duration of Blinks	8.46	0.23	15.19	0.62	6.80	0.29
Total Duration of No Info	0.72	0.04	4.47	0.44	0.77	0.09
Percent Duration of Eyes Open	92.84	0.11	91.96	0.15	92.20	0.20
Percent Duration of Blinks	6.25	0.10	6.04	0.10	6.84	0.19
Percent Duration of No Info	0.91	0.07	1.99	0.12	0.96	0.12
Average Duration of Eyes Open	3.18	0.09	2.10	0.04	2.37	0.07
Average Duration of Blinks	0.14	0.00	0.11	0.00	0.12	0.00
Average Duration of No Info	0.58	0.01	0.97	0.03	0.93	0.03
Standard Deviation of Duration Eyes Open	2.72	0.10	1.80	0.04	2.09	0.08
Standard Deviation of Duration Blinks	0.05	0.00	0.05	0.00	0.05	0.00
Standard Deviation of Duration No Info	0.17	0.01	0.64	0.04	0.34	0.04

Eye-Glance Variable	Just Driving (Baseline) - Mean	Just Driving (Baseline) - Standard Error	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Mean	Cognitive Load (Talking/Listening on Phone, with Passenger, or Self, or Singing) - Standard Error	Visual-Manual Interaction - Mean	Visual-Manual Interaction - Standard Error
Percent Over 2 Seconds of Eyes Open	42.23	0.15	39.28	0.21	39.84	0.34
Percent Over 2 Seconds of Blink	0.04	0.00	0.05	0.01	0.09	0.02
Percent Over 2 Seconds of No Info	0.85	0.06	1.23	0.13	0.83	0.10
Longest Duration of Eyes Open	12.03	0.33	9.80	0.20	8.90	0.27
Longest Duration of Blink	0.33	0.01	0.44	0.03	0.30	0.01
Longest Duration of No Info	0.82	0.02	2.21	0.13	1.36	0.09
Number of Transitions	31.17	0.69	74.81	3.58	63.77	1.93
Duration of Trigger	140.03	2.29	254.87	9.11	94.88	1.62
Transition Rate	0.23	0.00	0.30	0.01	0.69	0.02

The next three tables provide descriptive statistics for three category groupings of epochs.

Category 1: All just-driving baselines grouped together.
Category 2: All cognitive task loading epochs grouped together. Both those on the cell phone and those with passengers/self are included.
Category 3: Visual-manual task epochs only.

Table A2. Descriptive statistics for Category 1: All just-driving baselines.

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	15.31	0.34	12.71	0.00	6.75	14.00	21.50	58.00
Number of Glances Non-Forward Driving Related	13.72	0.31	11.89	1.00	5.75	12.00	18.00	60.00
Number of Glances Non-Forward Non-Driving Related	1.92	0.09	3.53	0.00	0.00	0.00	2.25	17.00
Number of Glances Center Stack	1.08	0.04	1.68	0.00	0.00	0.50	1.00	7.00
Percent Number of Glances Forward	45.13	0.22	8.44	0.00	45.60	47.00	48.28	50.00
Percent Number of Glances Non-Forward Driving Related	45.39	0.38	14.52	13.33	34.80	48.52	52.67	100.00
Percent Number of Glances Non-Forward Non-Driving Related	4.31	0.20	7.71	0.00	0.00	0.00	4.98	33.33
Percent Number of Glances Stack	4.68	0.21	8.11	0.00	0.00	0.40	5.52	33.33
Glance Rate Forward	7.67	0.11	4.22	0.00	4.56	7.20	10.27	17.71
Glance Rate Non-Forward Driving Related	9.61	0.42	15.86	1.31	4.52	6.85	9.50	100.00
Glance Rate Non-Forward Non-Driving Related	0.98	0.05	1.78	0.00	0.00	0.00	0.89	7.53
Glance Rate Center Stack	0.73	0.03	1.17	0.00	0.00	0.07	0.84	4.43
Total Duration of Glances Forward	102.42	2.00	75.64	0.00	52.53	87.40	142.00	393.30
Total Duration of Glances Non-Forward Driving Related	11.76	0.29	10.98	0.60	4.35	9.30	15.13	60.20
Total Duration of Glances Non-Forward Non-Driving Related	2.29	0.13	4.85	0.00	0.00	0.00	2.15	23.50
Total Duration of Glances Center Stack	0.92	0.04	1.42	0.00	0.00	0.20	1.23	5.70

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Duration of Glances Forward	84.08	0.45	16.88	0.00	82.30	88.68	91.95	98.13
Percent Duration of Glances Non-Forward Driving Related	12.55	0.42	15.87	1.53	6.23	9.70	13.38	100.00
Percent Duration of Glances Non-Forward Non-Driving Related	2.17	0.13	4.94	0.00	0.00	0.00	1.38	23.02
Percent Duration of Glances Center Stack	1.02	0.04	1.66	0.00	0.00	0.11	1.44	7.01
Average Duration of Glances Forward	10.41	0.26	9.99	2.24	4.72	7.43	12.03	44.30
Average Duration of Glances Non-Forward Driving Related	0.85	0.00	0.18	0.56	0.74	0.82	1.01	1.18
Average Duration of Glances Non-Forward Non-Driving Related	1.06	0.01	0.56	0.40	0.81	0.91	1.13	2.96
Average Duration of Glances Center Stack	0.87	0.01	0.28	0.40	0.70	0.83	0.99	1.60
Standard Deviation Duration of Glances Forward	8.03	0.13	5.06	0.00	4.70	7.34	8.91	26.61
Standard Deviation Duration of Glances Non-Forward Driving Related	0.36	0.01	0.23	0.00	0.23	0.32	0.43	0.95
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.33	0.01	0.54	0.00	0.00	0.20	0.40	2.26
Standard Deviation Duration of Glances Center Stack	0.10	0.00	0.15	0.00	0.00	0.00	0.18	0.45
Percent Over 2 Seconds of Glances Forward	29.56	0.27	10.24	0.00	23.75	28.80	35.48	47.22
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.55	0.04	1.33	0.00	0.00	0.00	0.00	5.65

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.15	0.02	0.93	0.00	0.00	0.00	0.00	5.56
Percent Over 2 Seconds of Glances Center Stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longest Duration of Glances Forward	29.81	0.49	18.46	9.00	16.75	25.80	37.65	101.60
Longest Duration of Glances Non-Forward Driving Related	1.60	0.02	0.87	0.60	1.20	1.35	1.70	5.10
Longest Duration of Glances Non-Forward Non-Driving Related	1.51	0.04	1.44	0.40	0.90	1.25	1.53	6.70
Longest Duration of Glances Center Stack Glance	1.00	0.01	0.33	0.40	0.80	1.00	1.18	1.60
Number of Eyes Open	59.09	1.46	55.11	5.00	28.00	46.00	65.00	273.00
Number of Blinks	59.34	1.45	54.98	6.00	28.00	47.00	66.00	271.00
Number No Info	0.97	0.04	1.54	0.00	0.00	0.00	1.00	5.00
Percent Number of Eyes Open	49.73	0.04	1.38	45.45	49.42	49.61	50.00	54.35
Percent Number of Blinks	50.27	0.04	1.38	45.65	50.00	50.39	50.58	54.55
Percent Number of No Info	1.47	0.07	2.74	0.00	0.00	0.00	1.07	10.87
Blink Rate	27.42	0.36	13.57	2.93	17.43	27.13	35.50	54.53
Total Duration of Eyes Open	125.71	2.21	83.68	9.67	64.32	93.37	174.10	429.00
Total Duration of Blinks	8.46	0.23	8.69	0.50	3.23	6.03	9.73	38.83
Total Duration of No Info	0.72	0.04	1.66	0.00	0.00	0.00	0.55	8.10
Percent Duration of Eyes Open	92.84	0.11	4.03	84.09	90.58	93.41	95.95	99.01
Percent Duration of Blinks	6.25	0.10	3.63	0.61	3.26	5.62	8.53	15.25
Percent Duration of No Info	0.91	0.07	2.53	0.00	0.00	0.00	0.27	12.60
Average Duration of Eyes Open	3.18	0.09	3.47	0.95	1.58	2.11	3.39	20.28
Average Duration of Blinks	0.14	0.00	0.03	0.07	0.12	0.13	0.16	0.24
Average Duration of No Info	0.58	0.01	0.47	0.03	0.20	0.44	0.90	1.62

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Standard Deviation of Duration Eyes Open	2.72	0.10	3.83	0.26	1.01	1.59	2.77	22.58
Standard Deviation of Duration Blinks	0.05	0.00	0.03	0.02	0.03	0.04	0.05	0.19
Standard Deviation of Duration No Info	0.17	0.01	0.32	0.00	0.00	0.00	0.23	1.21
Percent Over 2 Seconds of Eyes Open	42.23	0.15	5.70	27.98	39.67	42.35	46.50	52.17
Percent Over 2 Seconds of Blink	0.04	0.00	0.13	0.00	0.00	0.00	0.00	0.63
Percent Over 2 Seconds of No Info	0.85	0.06	2.12	0.00	0.00	0.00	0.00	8.70
Longest Duration of Eyes Open	12.03	0.33	12.37	1.93	4.90	8.30	13.32	69.77
Longest Duration of Blink	0.33	0.01	0.29	0.13	0.20	0.27	0.33	1.70
Longest Duration of No Info	0.82	0.02	0.90	0.03	0.23	0.67	1.17	3.60
Number of Transitions	31.17	0.69	26.22	0.00	12.75	28.00	45.75	123.00
Duration of Trigger	140.03	2.29	86.39	60.30	72.28	104.70	183.58	470.70
Transition Rate	0.23	0.00	0.15	0.00	0.13	0.21	0.32	0.59

Table A3. Descriptive statistics for Category 2:
All cognitive task-loading epochs (includes talking/listening on cell phone and with passenger/self).

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	36.35	1.74	53.56	0.00	10.00	19.00	37.50	470.00
Number of Glances Non-Forward Driving Related	26.68	1.40	43.13	0.00	7.00	14.00	28.50	399.00
Number of Glances Non-Forward Non-Driving Related	7.96	0.46	14.33	0.00	1.00	3.00	8.00	89.00
Number of Glances Center Stack	4.04	0.26	8.02	0.00	0.00	1.00	4.00	70.00
Percent Number of Glances Forward	46.63	0.21	6.43	0.00	46.64	48.08	48.95	52.94
Percent Number of Glances Non-Forward Driving Related	34.94	0.42	12.84	0.00	28.57	35.00	42.69	100.00
Percent Number of Glances Non-Forward Non-Driving Related	10.66	0.31	9.71	0.00	3.54	8.00	16.64	50.00
Percent Number of Glances Stack	6.53	0.30	9.11	0.00	0.00	2.33	10.58	50.00
Glance Rate Forward	9.71	0.20	6.04	0.00	5.45	8.35	13.07	32.26
Glance Rate Non-Forward Driving Related	7.94	0.28	8.78	0.00	3.55	6.04	9.88	85.71
Glance Rate Non-Forward Non-Driving Related	1.92	0.06	1.97	0.00	0.61	1.47	2.62	11.02
Glance Rate Center Stack	1.52	0.10	3.22	0.00	0.00	0.41	1.91	27.65
Total Duration of Glances Forward	206.13	8.06	248.63	0.00	60.75	119.10	239.65	1532.50
Total Duration of Glances Non-Forward Driving Related	19.32	0.87	26.76	0.00	4.90	10.70	21.90	190.90
Total Duration of Glances Non-Forward Non-Driving Related	8.09	0.54	16.71	0.00	1.00	2.80	8.05	171.30
Total Duration of Glances Center Stack	3.75	0.25	7.76	0.00	0.00	1.10	3.60	67.40

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Duration of Glances Forward	83.48	0.47	14.50	0.00	79.13	87.56	91.21	98.32
Percent Duration of Glances Non-Forward Driving Related	9.93	0.36	11.04	0.00	4.48	7.31	13.39	100.00
Percent Duration of Glances Non-Forward Non-Driving Related	3.29	0.14	4.32	0.00	0.72	2.14	4.29	37.51
Percent Duration of Glances Center Stack	2.58	0.25	7.71	0.00	0.00	0.51	2.58	94.64
Average Duration of Glances Forward	8.03	0.21	6.38	0.95	3.60	6.24	9.55	32.19
Average Duration of Glances Non-Forward Driving Related	0.79	0.02	0.48	0.10	0.63	0.72	0.85	6.37
Average Duration of Glances Non-Forward Non-Driving Related	1.04	0.02	0.77	0.20	0.70	0.82	1.13	7.90
Average Duration of Glances Center Stack	0.96	0.03	0.98	0.40	0.65	0.80	1.00	10.60
Standard Deviation Duration of Glances Forward	9.55	0.27	8.31	0.00	3.93	6.65	12.49	44.55
Standard Deviation Duration of Glances Non-Forward Driving Related	0.40	0.02	0.54	0.00	0.21	0.31	0.43	6.77
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.41	0.02	0.68	0.00	0.08	0.24	0.38	4.77
Standard Deviation Duration of Glances Center Stack	0.34	0.01	0.44	0.00	0.07	0.30	0.44	3.78
Percent Over 2 Seconds of Glances Forward	28.03	0.32	9.95	0.00	22.61	29.00	34.73	50.00
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.72	0.06	1.96	0.00	0.00	0.00	0.00	15.38

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.80	0.08	2.34	0.00	0.00	0.00	0.00	16.67
Percent Over 2 Seconds of Glances Center Stack	0.54	0.13	3.93	0.00	0.00	0.00	0.00	50.00
Longest Duration of Glances Forward	34.95	0.86	26.63	1.10	15.30	25.95	48.50	147.20
Longest Duration of Glances Non-Forward Driving Related	1.79	0.04	1.36	0.10	1.00	1.40	2.00	13.90
Longest Duration of Glances Non-Forward Non-Driving Related	1.97	0.09	2.84	0.20	0.90	1.20	1.88	29.00
Longest Duration of Glances Center Stack Glance	1.56	0.06	1.80	0.40	0.80	1.20	1.70	15.90
Number of Eyes Open	137.70	5.71	176.22	1.00	41.75	77.50	158.50	1450.00
Number of Blinks	135.52	5.65	174.19	1.00	41.00	76.50	159.25	1436.00
Number No Info	4.03	0.24	7.35	0.00	0.00	1.00	4.00	64.00
Percent Number of Eyes Open	50.41	0.05	1.65	46.67	49.72	50.00	50.54	60.87
Percent Number of Blinks	49.59	0.05	1.65	39.13	49.46	50.00	50.28	53.33
Percent Number of No Info	2.30	0.16	5.04	0.00	0.00	0.79	2.09	50.00
Blink Rate	32.19	0.45	13.94	5.47	23.16	29.62	38.54	91.33
Total Duration of Eyes Open	231.39	8.50	262.31	9.97	76.43	132.50	251.43	1592.03
Total Duration of Blinks	15.19	0.62	19.17	0.17	4.30	8.38	17.90	126.47
Total Duration of No Info	4.47	0.44	13.62	0.00	0.00	0.97	4.11	167.40
Percent Duration of Eyes Open	91.96	0.15	4.55	71.15	90.19	93.10	95.09	98.90
Percent Duration of Blinks	6.04	0.10	3.14	1.10	3.92	5.32	7.53	23.79
Percent Duration of No Info	1.99	0.12	3.70	0.00	0.00	0.59	1.94	21.40
Average Duration of Eyes Open	2.10	0.04	1.30	0.50	1.40	1.83	2.36	10.47
Average Duration of Blinks	0.11	0.00	0.03	0.07	0.09	0.11	0.13	0.23
Average Duration of No Info	0.97	0.03	0.97	0.05	0.55	0.77	1.00	7.18

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Standard Deviation of Duration Eyes Open	1.80	0.04	1.28	0.00	1.02	1.51	2.13	7.94
Standard Deviation of Duration Blinks	0.05	0.00	0.05	0.00	0.03	0.03	0.05	0.59
Standard Deviation of Duration No Info	0.64	0.04	1.33	0.00	0.00	0.31	0.62	9.69
Percent Over 2 Seconds of Eyes Open	39.28	0.21	6.33	12.13	36.73	40.26	43.78	50.00
Percent Over 2 Seconds of Blink	0.05	0.01	0.19	0.00	0.00	0.00	0.00	1.47
Percent Over 2 Seconds of No Info	1.23	0.13	3.97	0.00	0.00	0.07	1.08	50.00
Longest Duration of Eyes Open	9.80	0.20	6.15	1.97	5.43	8.20	12.81	31.73
Longest Duration of Blink	0.44	0.03	0.95	0.10	0.17	0.23	0.40	12.63
Longest Duration of No Info	2.21	0.13	4.03	0.07	0.71	1.20	2.10	40.50
Number of Transitions	74.81	3.58	110.47	0.00	20.00	40.00	80.00	961.00
Duration of Trigger	254.87	9.11	281.02	61.80	86.90	146.90	283.70	1693.70
Transition Rate	0.30	0.01	0.20	0.00	0.17	0.25	0.39	1.20

Table A4. Descriptive statistics for Category 3: Visual-manual interactions.

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	31.13	0.93	20.20	8.00	18.00	27.00	37.00	116.00
Number of Glances Non-Forward Driving Related	6.16	0.26	5.73	0.00	2.00	5.00	8.00	26.00
Number of Glances Non-Forward Non-Driving Related	1.07	0.07	1.43	0.00	0.00	0.00	2.00	6.00
Number of Glances Center Stack	25.90	0.82	17.97	7.00	14.00	23.00	32.00	101.00
Percent Number of Glances Forward	47.95	0.08	1.69	43.33	47.27	48.48	49.15	50.00
Percent Number of Glances Non-Forward Driving Related	10.17	0.35	7.74	0.00	3.41	8.57	15.79	31.75
Percent Number of Glances Non-Forward Non-Driving Related	1.62	0.10	2.18	0.00	0.00	0.00	2.56	8.33
Percent Number of Glances Stack	39.66	0.33	7.17	19.05	34.29	40.68	44.33	51.52
Glance Rate Forward	21.75	0.46	10.10	6.58	13.14	19.16	29.60	42.79
Glance Rate Non-Forward Driving Related	3.90	0.13	2.93	0.00	1.63	3.71	5.70	14.54
Glance Rate Non-Forward Non-Driving Related	0.77	0.05	1.07	0.00	0.00	0.00	1.10	3.80
Glance Rate Center Stack	18.47	0.44	9.66	3.45	10.31	18.01	26.05	40.40
Total Duration of Glances Forward	49.83	1.53	33.33	8.50	25.80	39.70	59.50	169.20
Total Duration of Glances Non-Forward Driving Related	4.76	0.19	4.25	0.00	1.60	3.60	6.40	19.90
Total Duration of Glances Non-Forward Non-Driving Related	0.97	0.06	1.33	0.00	0.00	0.00	1.60	5.90
Total Duration of Glances Center Stack	31.36	0.93	20.37	6.10	16.20	25.90	41.30	108.50

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Duration of Glances Forward	54.50	1.00	21.85	16.93	35.56	52.06	76.05	90.20
Percent Duration of Glances Non-Forward Driving Related	5.15	0.19	4.06	0.00	2.09	4.75	7.21	21.00
Percent Duration of Glances Non-Forward Non-Driving Related	1.17	0.08	1.69	0.00	0.00	0.00	1.89	7.29
Percent Duration of Glances Center Stack	38.08	0.96	21.02	4.50	18.33	39.18	54.62	78.29
Average Duration of Glances Forward	2.22	0.09	1.94	0.41	0.70	1.42	3.35	7.65
Average Duration of Glances Non-Forward Driving Related	0.84	0.01	0.30	0.40	0.65	0.78	0.92	2.40
Average Duration of Glances Non-Forward Non-Driving Related	0.93	0.01	0.28	0.40	0.80	0.88	1.03	1.60
Average Duration of Glances Center Stack	1.32	0.04	0.86	0.69	0.94	1.06	1.45	7.24
Standard Deviation Duration of Glances Forward	2.58	0.12	2.56	0.23	0.78	1.41	3.78	12.07
Standard Deviation Duration of Glances Non-Forward Driving Related	0.31	0.01	0.30	0.00	0.15	0.26	0.43	1.81
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.19	0.01	0.28	0.00	0.00	0.11	0.33	1.40
Standard Deviation Duration of Glances Center Stack	0.80	0.05	1.19	0.17	0.36	0.44	0.75	8.90
Percent Over 2 Seconds of Glances Forward	12.74	0.52	11.40	0.00	2.27	8.47	21.95	38.10
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.19	0.03	0.65	0.00	0.00	0.00	0.00	3.33

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.02	0.01	0.16	0.00	0.00	0.00	0.00	1.30
Percent Over 2 Seconds of Glances Center Stack	4.08	0.28	6.13	0.00	0.00	1.61	6.06	30.00
Longest Duration of Glances Forward	10.23	0.43	9.29	1.10	3.80	6.50	13.90	42.70
Longest Duration of Glances Non-Forward Driving Related	1.38	0.04	0.80	0.40	0.90	1.20	1.60	5.70
Longest Duration of Glances Non-Forward Non-Driving Related	1.12	0.02	0.43	0.40	0.90	1.05	1.30	2.80
Longest Duration of Glances Center Stack Glance	3.53	0.19	4.07	1.00	1.80	2.20	3.20	24.80
Number of Eyes Open	51.03	1.91	41.59	9.00	24.00	37.00	66.00	213.00
Number of Blinks	51.45	1.91	41.73	10.00	24.00	37.00	67.00	214.00
Number No Info	0.75	0.07	1.48	0.00	0.00	0.00	1.00	8.00
Percent Number of Eyes Open	49.70	0.06	1.23	47.37	49.23	49.62	50.00	55.10
Percent Number of Blinks	50.30	0.06	1.23	44.90	50.00	50.38	50.77	52.63
Percent Number of No Info	1.38	0.15	3.31	0.00	0.00	0.00	0.91	18.18
Blink Rate	31.67	0.71	15.59	8.91	17.56	31.67	43.54	71.16
Total Duration of Eyes Open	83.44	1.44	31.48	47.00	61.70	72.43	92.73	190.43
Total Duration of Blinks	6.80	0.29	6.33	1.07	2.63	4.33	8.77	32.70
Total Duration of No Info	0.77	0.09	1.95	0.00	0.00	0.00	0.73	12.27
Percent Duration of Eyes Open	92.20	0.20	4.32	79.86	88.80	92.77	95.61	98.44
Percent Duration of Blinks	6.84	0.19	4.19	1.56	2.99	6.47	9.32	17.21
Percent Duration of No Info	0.96	0.12	2.63	0.00	0.00	0.00	0.71	18.21
Average Duration of Eyes Open	2.37	0.07	1.43	0.73	1.27	1.78	3.10	6.70
Average Duration of Blinks	0.12	0.00	0.03	0.08	0.10	0.12	0.14	0.22
Average Duration of No Info	0.93	0.03	0.67	0.07	0.59	0.79	1.04	3.07

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Standard Deviation of Duration Eyes Open	2.09	0.08	1.69	0.38	0.87	1.47	2.93	8.54
Standard Deviation of Duration Blinks	0.05	0.00	0.03	0.02	0.03	0.04	0.05	0.18
Standard Deviation of Duration No Info	0.34	0.04	0.94	0.00	0.00	0.02	0.21	4.47
Percent Over 2 Seconds of Eyes Open	39.84	0.34	7.38	23.60	33.33	41.79	45.61	54.55
Percent Over 2 Seconds of Blink	0.09	0.02	0.37	0.00	0.00	0.00	0.00	2.60
Percent Over 2 Seconds of No Info	0.83	0.10	2.27	0.00	0.00	0.00	0.00	13.64
Longest Duration of Eyes Open	8.90	0.27	5.98	2.30	4.67	6.73	12.07	27.07
Longest Duration of Blink	0.30	0.01	0.18	0.10	0.17	0.27	0.33	0.97
Longest Duration of No Info	1.36	0.09	1.92	0.07	0.62	0.90	1.33	9.77
Number of Transitions	63.77	1.93	42.02	17.00	37.00	55.00	74.00	235.00
Duration of Trigger	94.88	1.62	35.39	63.90	71.20	80.80	105.10	219.60
Transition Rate	0.69	0.02	0.34	0.21	0.39	0.60	0.98	1.38

The following table provides the statistics for just those epochs which included conversations on the cell phone.

Table A5. Descriptive statistics for cognitive epochs with cell phone conversation.

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	35.73	2.79	60.93	0.00	8.00	14.00	40.00	470.00
Number of Glances Non-Forward Driving Related	26.07	2.33	50.83	0.00	5.00	11.00	25.00	399.00
Number of Glances Non-Forward Non-Driving Related	8.54	0.71	15.49	0.00	1.00	3.00	9.00	83.00
Number of Glances Center Stack	3.70	0.26	5.60	0.00	0.00	2.00	5.00	29.00
Percent Number of Glances Forward	46.09	0.37	8.00	0.00	46.45	48.07	48.99	52.94
Percent Number of Glances Non-Forward Driving Related	32.87	0.64	14.06	0.00	25.00	33.33	40.00	100.00
Percent Number of Glances Non-Forward Non-Driving Related	12.50	0.51	11.19	0.00	3.46	9.76	19.68	50.00
Percent Number of Glances Stack	7.74	0.43	9.44	0.00	0.00	4.58	12.70	50.00
Glance Rate Forward	7.10	0.19	4.14	0.00	4.18	6.43	8.59	22.54
Glance Rate Non-Forward Driving Related	6.23	0.46	10.02	0.00	2.64	4.22	6.29	85.71
Glance Rate Non-Forward Non-Driving Related	1.77	0.09	1.95	0.00	0.51	1.17	2.43	11.02
Glance Rate Center Stack	1.17	0.07	1.50	0.00	0.00	0.55	1.95	6.45
Total Duration of Glances Forward	234.48	12.18	265.77	0.00	69.85	138.55	257.08	1275.00
Total Duration of Glances Non-Forward Driving Related	18.28	1.38	30.11	0.00	3.40	8.05	19.65	190.90
Total Duration of Glances Non-Forward Non-Driving Related	9.64	0.91	19.96	0.00	0.83	2.85	10.48	171.30

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Total Duration of Glances Center Stack	4.06	0.37	8.18	0.00	0.00	1.40	4.20	67.40
Percent Duration of Glances Forward	85.51	0.76	16.58	0.00	85.05	90.03	92.54	98.32
Percent Duration of Glances Non-Forward Driving Related	7.95	0.60	13.13	0.00	3.29	5.28	7.36	100.00
Percent Duration of Glances Non-Forward Non-Driving Related	3.53	0.23	4.95	0.00	0.62	2.07	4.91	37.51
Percent Duration of Glances Center Stack	2.65	0.41	9.02	0.00	0.00	0.72	2.85	94.64
Average Duration of Glances Forward	9.99	0.29	6.36	2.01	5.66	8.09	13.30	29.90
Average Duration of Glances Non-Forward Driving Related	0.80	0.03	0.61	0.10	0.60	0.69	0.85	6.37
Average Duration of Glances Non-Forward Non-Driving Related	1.21	0.04	0.96	0.20	0.70	0.96	1.38	7.90
Average Duration of Glances Center Stack	1.07	0.06	1.22	0.40	0.70	0.87	1.02	10.60
Standard Deviation Duration of Glances Forward	11.90	0.37	8.11	1.89	5.81	10.16	15.15	41.37
Standard Deviation Duration of Glances Non-Forward Driving Related	0.44	0.03	0.70	0.00	0.19	0.31	0.43	6.77
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.54	0.04	0.86	0.00	0.00	0.28	0.57	4.77
Standard Deviation Duration of Glances Center Stack	0.41	0.02	0.51	0.00	0.12	0.33	0.52	3.78
Percent Over 2 Seconds of Glances Forward	30.61	0.42	9.25	0.00	26.69	31.06	36.36	50.00

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.81	0.11	2.35	0.00	0.00	0.00	0.00	15.38
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	1.31	0.14	2.95	0.00	0.00	0.00	1.08	16.67
Percent Over 2 Seconds of Glances Center Stack	0.91	0.24	5.13	0.00	0.00	0.00	0.00	50.00
Longest Duration of Glances Forward	41.85	1.13	24.56	8.70	21.15	37.80	56.05	116.80
Longest Duration of Glances Non-Forward Driving Related	1.80	0.08	1.65	0.10	0.98	1.30	1.93	13.90
Longest Duration of Glances Non-Forward Non-Driving Related	2.53	0.16	3.59	0.20	1.00	1.50	2.80	29.00
Longest Duration of Glances Center Stack Glance	1.80	0.10	2.21	0.40	0.90	1.30	1.80	15.90
Number of Eyes Open	152.22	9.06	197.67	7.00	44.00	87.00	183.50	1450.00
Number of Blinks	149.81	8.96	195.38	8.00	42.00	87.00	178.50	1436.00
Number No Info	3.95	0.30	6.56	0.00	0.00	1.00	4.50	36.00
Percent Number of Eyes Open	50.49	0.09	1.92	46.67	49.73	50.00	50.56	60.87
Percent Number of Blinks	49.51	0.09	1.92	39.13	49.44	50.00	50.27	53.33
Percent Number of No Info	2.01	0.19	4.08	0.00	0.00	0.69	1.93	23.91
Blink Rate	31.36	0.63	13.79	6.38	23.42	29.02	36.96	91.33
Total Duration of Eyes Open	258.05	12.90	281.50	34.73	82.97	142.67	255.82	1351.37
Total Duration of Blinks	16.74	0.96	21.03	0.93	4.62	9.47	19.22	126.47
Total Duration of No Info	5.27	0.77	16.84	0.00	0.00	0.97	4.88	167.40
Percent Duration of Eyes Open	92.06	0.20	4.44	75.59	90.51	93.11	95.08	98.90
Percent Duration of Blinks	6.00	0.14	3.14	1.10	3.95	5.50	7.53	23.79
Percent Duration of No Info	1.93	0.18	3.90	0.00	0.00	0.46	1.42	21.40
Average Duration of Eyes Open	2.10	0.05	1.19	0.50	1.49	1.86	2.33	10.47

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Average Duration of Blinks	0.12	0.00	0.03	0.07	0.10	0.11	0.13	0.23
Average Duration of No Info	1.12	0.06	1.23	0.05	0.54	0.76	1.10	7.18
Standard Deviation of Duration Eyes Open	1.88	0.06	1.22	0.31	1.20	1.59	2.08	7.94
Standard Deviation of Duration Blinks	0.06	0.00	0.07	0.02	0.03	0.03	0.05	0.59
Standard Deviation of Duration No Info	0.92	0.08	1.72	0.00	0.03	0.37	0.96	9.69
Percent Over 2 Seconds of Eyes Open	39.25	0.29	6.28	12.13	37.01	40.16	43.33	49.06
Percent Over 2 Seconds of Blink	0.09	0.01	0.24	0.00	0.00	0.00	0.00	1.47
Percent Over 2 Seconds of No Info	0.91	0.09	1.93	0.00	0.00	0.00	0.96	11.25
Longest Duration of Eyes Open	10.31	0.27	5.96	2.17	5.82	9.03	13.47	31.73
Longest Duration of Blink	0.55	0.06	1.24	0.13	0.20	0.27	0.48	12.63
Longest Duration of No Info	2.91	0.24	5.26	0.07	0.61	1.35	2.84	40.50
Number of Transitions	73.33	5.73	125.00	0.00	16.00	28.00	82.25	961.00
Duration of Trigger	283.07	13.81	301.24	61.80	97.28	166.10	305.68	1458.00
Transition Rate	0.22	0.01	0.14	0.00	0.12	0.20	0.27	0.77

The following table provides the statistics for just those epochs which involved **non**-cell-phone conversations—in other words, conversations with passenger or self.

Table A6. Descriptive statistics for cognitive epochs with conversation (passenger/self) (no-cell-phone).

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	37.21	1.90	41.54	1.00	14.00	25.00	37.00	223.00
Number of Glances Non-Forward Driving Related	27.54	1.35	29.56	2.00	11.00	18.00	29.00	169.00
Number of Glances Non-Forward Non-Driving Related	7.14	0.58	12.59	0.00	2.00	3.00	8.00	89.00
Number of Glances Center Stack	4.51	0.48	10.51	0.00	0.00	1.00	3.00	70.00
Percent Number of Glances Forward	47.39	0.14	3.02	25.00	46.94	48.08	48.72	51.61
Percent Number of Glances Non-Forward Driving Related	37.82	0.47	10.34	7.41	31.82	39.44	45.16	53.33
Percent Number of Glances Non-Forward Non-Driving Related	8.10	0.29	6.39	0.00	3.70	7.04	12.12	35.48
Percent Number of Glances Stack	4.84	0.38	8.39	0.00	0.00	1.08	5.45	38.89
Glance Rate Forward	13.33	0.29	6.41	1.81	9.41	12.24	16.52	32.26
Glance Rate Non-Forward Driving Related	10.32	0.27	5.96	1.36	7.20	9.41	12.83	46.15
Glance Rate Non-Forward Non-Driving Related	2.14	0.09	2.00	0.00	0.67	2.05	2.83	11.00
Glance Rate Center Stack	2.01	0.21	4.63	0.00	0.00	0.20	1.89	27.65
Total Duration of Glances Forward	166.76	10.00	218.11	1.10	53.50	89.90	197.20	1532.50
Total Duration of Glances Non-Forward Driving Related	20.76	0.98	21.35	0.70	7.60	14.10	24.90	110.50

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Total Duration of Glances Non-Forward Non-Driving Related	5.93	0.48	10.40	0.00	1.40	2.60	6.40	74.60
Total Duration of Glances Center Stack	3.32	0.33	7.16	0.00	0.00	0.70	2.40	43.40
Percent Duration of Glances Forward	80.65	0.48	10.43	42.31	76.06	82.16	87.98	97.25
Percent Duration of Glances Non-Forward Driving Related	12.68	0.29	6.31	1.96	8.80	11.34	16.52	38.95
Percent Duration of Glances Non-Forward Non-Driving Related	2.95	0.15	3.24	0.00	0.89	2.40	3.95	20.54
Percent Duration of Glances Center Stack	2.47	0.25	5.45	0.00	0.00	0.25	2.04	32.87
Average Duration of Glances Forward	5.38	0.25	5.40	0.95	2.82	4.07	5.59	32.19
Average Duration of Glances Non-Forward Driving Related	0.76	0.01	0.17	0.35	0.65	0.75	0.83	1.35
Average Duration of Glances Non-Forward Non-Driving Related	0.79	0.01	0.18	0.40	0.70	0.78	0.89	1.32
Average Duration of Glances Center Stack	0.78	0.01	0.22	0.40	0.64	0.71	0.88	1.34
Standard Deviation Duration of Glances Forward	6.37	0.34	7.51	0.00	3.01	4.24	6.66	44.55
Standard Deviation Duration of Glances Non-Forward Driving Related	0.35	0.01	0.17	0.07	0.23	0.31	0.43	0.96
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.23	0.01	0.18	0.00	0.14	0.21	0.28	1.18
Standard Deviation Duration of Glances Center Stack	0.24	0.01	0.28	0.00	0.06	0.21	0.36	1.69

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Forward	24.46	0.45	9.83	0.00	18.31	25.00	31.82	43.75
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.60	0.06	1.25	0.00	0.00	0.00	0.36	6.45
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.09	0.02	0.45	0.00	0.00	0.00	0.00	3.23
Percent Over 2 Seconds of Glances Center Stack	0.02	0.01	0.16	0.00	0.00	0.00	0.00	1.32
Longest Duration of Glances Forward	25.61	1.22	26.60	1.10	11.30	18.10	26.20	147.20
Longest Duration of Glances Non-Forward Driving Related	1.77	0.04	0.80	0.40	1.20	1.60	2.10	4.70
Longest Duration of Glances Non-Forward Non-Driving Related	1.20	0.03	0.66	0.40	0.90	1.10	1.30	4.80
Longest Duration of Glances Center Stack Glance	1.17	0.03	0.57	0.40	0.70	1.00	1.65	3.20
Number of Eyes Open	118.05	6.46	140.92	1.00	38.00	72.00	154.00	807.00
Number of Blinks	116.18	6.39	139.35	1.00	37.00	70.00	148.00	799.00
Number No Info	4.13	0.38	8.34	0.00	0.00	1.00	4.00	64.00
Percent Number of Eyes Open	50.31	0.06	1.21	48.28	49.67	50.00	50.48	56.21
Percent Number of Blinks	49.69	0.06	1.21	43.79	49.52	50.00	50.33	51.72
Percent Number of No Info	2.69	0.28	6.10	0.00	0.00	0.93	2.59	50.00
Blink Rate	33.31	0.65	14.14	5.47	22.15	31.01	41.86	66.13
Total Duration of Eyes Open	195.33	10.57	230.60	9.97	72.63	105.83	231.60	1592.03
Total Duration of Blinks	13.08	0.74	16.19	0.17	3.97	7.43	16.93	85.37
Total Duration of No Info	3.39	0.33	7.27	0.00	0.00	1.00	3.43	54.53
Percent Duration of Eyes Open	91.83	0.22	4.71	71.15	89.50	93.09	95.26	98.65
Percent Duration of Blinks	6.09	0.14	3.16	1.35	3.89	5.28	7.23	17.86
Percent Duration of No Info	2.08	0.16	3.44	0.00	0.00	0.87	2.27	17.58

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Average Duration of Eyes Open	2.09	0.07	1.45	0.63	1.25	1.74	2.47	9.97
Average Duration of Blinks	0.11	0.00	0.02	0.08	0.09	0.10	0.12	0.22
Average Duration of No Info	0.79	0.02	0.40	0.09	0.56	0.79	0.94	2.33
Standard Deviation of Duration Eyes Open	1.70	0.06	1.36	0.00	0.80	1.28	2.19	7.44
Standard Deviation of Duration Blinks	0.04	0.00	0.02	0.00	0.02	0.03	0.05	0.09
Standard Deviation of Duration No Info	0.30	0.01	0.32	0.00	0.00	0.25	0.52	1.51
Percent Over 2 Seconds of Eyes Open	39.32	0.29	6.42	18.62	35.91	41.38	44.23	50.00
Percent Over 2 Seconds of Blink	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.34
Percent Over 2 Seconds of No Info	1.67	0.26	5.65	0.00	0.00	0.42	1.24	50.00
Longest Duration of Eyes Open	9.11	0.29	6.37	1.97	4.57	7.33	11.80	31.43
Longest Duration of Blink	0.29	0.01	0.18	0.10	0.17	0.23	0.33	0.93
Longest Duration of No Info	1.35	0.05	0.99	0.10	0.80	1.03	1.62	5.20
Number of Transitions	76.87	3.99	87.03	3.00	29.00	52.00	80.00	482.00
Duration of Trigger	215.73	11.31	246.68	62.20	79.90	126.30	257.70	1693.70
Transition Rate	0.41	0.01	0.23	0.04	0.27	0.35	0.52	1.20

The following table provides the statistics for the epochs which involved visual-manual interactions.

Table A7. Descriptive statistics for epochs with visual-manual interactions.

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	31.13	0.93	20.20	8.00	18.00	27.00	37.00	116.00
Number of Glances Non-Forward Driving Related	6.16	0.26	5.73	0.00	2.00	5.00	8.00	26.00
Number of Glances Non-Forward Non-Driving Related	1.07	0.07	1.43	0.00	0.00	0.00	2.00	6.00
Number of Glances Center Stack	25.90	0.82	17.97	7.00	14.00	23.00	32.00	101.00
Percent Number of Glances Forward	47.95	0.08	1.69	43.33	47.27	48.48	49.15	50.00
Percent Number of Glances Non-Forward Driving Related	10.17	0.35	7.74	0.00	3.41	8.57	15.79	31.75
Percent Number of Glances Non-Forward Non-Driving Related	1.62	0.10	2.18	0.00	0.00	0.00	2.56	8.33
Percent Number of Glances Stack	39.66	0.33	7.17	19.05	34.29	40.68	44.33	51.52
Glance Rate Forward	21.75	0.46	10.10	6.58	13.14	19.16	29.60	42.79
Glance Rate Non-Forward Driving Related	3.90	0.13	2.93	0.00	1.63	3.71	5.70	14.54
Glance Rate Non-Forward Non-Driving Related	0.77	0.05	1.07	0.00	0.00	0.00	1.10	3.80
Glance Rate Center Stack	18.47	0.44	9.66	3.45	10.31	18.01	26.05	40.40
Total Duration of Glances Forward	49.83	1.53	33.33	8.50	25.80	39.70	59.50	169.20
Total Duration of Glances Non-Forward Driving Related	4.76	0.19	4.25	0.00	1.60	3.60	6.40	19.90
Total Duration of Glances Non-Forward Non-Driving Related	0.97	0.06	1.33	0.00	0.00	0.00	1.60	5.90

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Total Duration of Glances Center Stack	31.36	0.93	20.37	6.10	16.20	25.90	41.30	108.50
Percent Duration of Glances Forward	54.50	1.00	21.85	16.93	35.56	52.06	76.05	90.20
Percent Duration of Glances Non-Forward Driving Related	5.15	0.19	4.06	0.00	2.09	4.75	7.21	21.00
Percent Duration of Glances Non-Forward Non-Driving Related	1.17	0.08	1.69	0.00	0.00	0.00	1.89	7.29
Percent Duration of Glances Center Stack	38.08	0.96	21.02	4.50	18.33	39.18	54.62	78.29
Average Duration of Glances Forward	2.22	0.09	1.94	0.41	0.70	1.42	3.35	7.65
Average Duration of Glances Non-Forward Driving Related	0.84	0.01	0.30	0.40	0.65	0.78	0.92	2.40
Average Duration of Glances Non-Forward Non-Driving Related	0.93	0.01	0.28	0.40	0.80	0.88	1.03	1.60
Average Duration of Glances Center Stack	1.32	0.04	0.86	0.69	0.94	1.06	1.45	7.24
Standard Deviation Duration of Glances Forward	2.58	0.12	2.56	0.23	0.78	1.41	3.78	12.07
Standard Deviation Duration of Glances Non-Forward Driving Related	0.31	0.01	0.30	0.00	0.15	0.26	0.43	1.81
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.19	0.01	0.28	0.00	0.00	0.11	0.33	1.40
Standard Deviation Duration of Glances Center Stack	0.80	0.05	1.19	0.17	0.36	0.44	0.75	8.90
Percent Over 2 Seconds of Glances Forward	12.74	0.52	11.40	0.00	2.27	8.47	21.95	38.10

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.19	0.03	0.65	0.00	0.00	0.00	0.00	3.33
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.02	0.01	0.16	0.00	0.00	0.00	0.00	1.30
Percent Over 2 Seconds of Glances Center Stack	4.08	0.28	6.13	0.00	0.00	1.61	6.06	30.00
Longest Duration of Glances Forward	10.23	0.43	9.29	1.10	3.80	6.50	13.90	42.70
Longest Duration of Glances Non-Forward Driving Related	1.38	0.04	0.80	0.40	0.90	1.20	1.60	5.70
Longest Duration of Glances Non-Forward Non-Driving Related	1.12	0.02	0.43	0.40	0.90	1.05	1.30	2.80
Longest Duration of Glances Center Stack Glance	3.53	0.19	4.07	1.00	1.80	2.20	3.20	24.80
Number of Eyes Open	51.03	1.91	41.59	9.00	24.00	37.00	66.00	213.00
Number of Blinks	51.45	1.91	41.73	10.00	24.00	37.00	67.00	214.00
Number No Info	0.75	0.07	1.48	0.00	0.00	0.00	1.00	8.00
Percent Number of Eyes Open	49.70	0.06	1.23	47.37	49.23	49.62	50.00	55.10
Percent Number of Blinks	50.30	0.06	1.23	44.90	50.00	50.38	50.77	52.63
Percent Number of No Info	1.38	0.15	3.31	0.00	0.00	0.00	0.91	18.18
Blink Rate	31.67	0.71	15.59	8.91	17.56	31.67	43.54	71.16
Total Duration of Eyes Open	83.44	1.44	31.48	47.00	61.70	72.43	92.73	190.43
Total Duration of Blinks	6.80	0.29	6.33	1.07	2.63	4.33	8.77	32.70
Total Duration of No Info	0.77	0.09	1.95	0.00	0.00	0.00	0.73	12.27
Percent Duration of Eyes Open	92.20	0.20	4.32	79.86	88.80	92.77	95.61	98.44
Percent Duration of Blinks	6.84	0.19	4.19	1.56	2.99	6.47	9.32	17.21
Percent Duration of No Info	0.96	0.12	2.63	0.00	0.00	0.00	0.71	18.21
Average Duration of Eyes Open	2.37	0.07	1.43	0.73	1.27	1.78	3.10	6.70

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Average Duration of Blinks	0.12	0.00	0.03	0.08	0.10	0.12	0.14	0.22
Average Duration of No Info	0.93	0.03	0.67	0.07	0.59	0.79	1.04	3.07
Standard Deviation of Duration Eyes Open	2.09	0.08	1.69	0.38	0.87	1.47	2.93	8.54
Standard Deviation of Duration Blinks	0.05	0.00	0.03	0.02	0.03	0.04	0.05	0.18
Standard Deviation of Duration No Info	0.34	0.04	0.94	0.00	0.00	0.02	0.21	4.47
Percent Over 2 Seconds of Eyes Open	39.84	0.34	7.38	23.60	33.33	41.79	45.61	54.55
Percent Over 2 Seconds of Blink	0.09	0.02	0.37	0.00	0.00	0.00	0.00	2.60
Percent Over 2 Seconds of No Info	0.83	0.10	2.27	0.00	0.00	0.00	0.00	13.64
Longest Duration of Eyes Open	8.90	0.27	5.98	2.30	4.67	6.73	12.07	27.07
Longest Duration of Blink	0.30	0.01	0.18	0.10	0.17	0.27	0.33	0.97
Longest Duration of No Info	1.36	0.09	1.92	0.07	0.62	0.90	1.33	9.77
Number of Transitions	63.77	1.93	42.02	17.00	37.00	55.00	74.00	235.00
Duration of Trigger	94.88	1.62	35.39	63.90	71.20	80.80	105.10	219.60
Transition Rate	0.69	0.02	0.34	0.21	0.39	0.60	0.98	1.38

Each of the following three tables separately provide the statistics for each type of baseline just-driving epoch.

Table A8. Descriptive statistics for baseline just-driving epochs matched to the cell phone conversation epochs.

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	26.55	0.64	14.05	14.00	16.00	24.00	32.50	58.00
Number of Glances Non-Forward Driving Related	22.18	0.66	14.45	12.00	14.00	17.00	22.50	60.00
Number of Glances Non-Forward Non-Driving Related	5.27	0.22	4.80	0.00	2.50	5.00	6.00	17.00
Number of Glances Center Stack	1.55	0.08	1.69	0.00	1.00	1.00	1.50	6.00
Percent Number of Glances Forward	47.60	0.08	1.77	44.44	46.54	47.06	48.85	50.00
Percent Number of Glances Non-Forward Driving Related	39.77	0.40	8.67	23.53	34.31	41.38	46.61	51.72
Percent Number of Glances Non-Forward Non-Driving Related	9.50	0.35	7.60	0.00	4.44	6.90	14.30	25.00
Percent Number of Glances Stack	3.13	0.17	3.69	0.00	0.98	1.61	3.32	11.76
Glance Rate Forward	10.55	0.19	4.16	4.31	7.63	10.10	13.76	17.71
Glance Rate Non-Forward Driving Related	8.36	0.12	2.67	4.62	6.28	7.86	10.06	13.28
Glance Rate Non-Forward Non-Driving Related	2.41	0.10	2.29	0.00	0.70	1.82	3.70	7.53
Glance Rate Center Stack	0.94	0.06	1.39	0.00	0.19	0.44	0.74	4.43
Total Duration of Glances Forward	142.89	4.71	102.86	36.50	67.25	119.40	192.80	393.30
Total Duration of Glances Non-Forward Driving Related	20.99	0.64	14.06	10.60	12.90	17.30	21.15	60.20
Total Duration of Glances Non-Forward Non-Driving Related	6.65	0.32	7.08	0.00	2.20	3.70	8.20	23.50

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Total Duration of Glances Center Stack	1.46	0.07	1.58	0.00	0.70	1.00	1.70	5.70
Percent Duration of Glances Forward	79.19	0.51	11.20	56.77	72.74	82.98	86.97	93.48
Percent Duration of Glances Non-Forward Driving Related	13.45	0.24	5.14	6.52	9.89	12.00	16.43	23.00
Percent Duration of Glances Non-Forward Non-Driving Related	5.90	0.35	7.56	0.00	0.99	2.47	6.93	23.02
Percent Duration of Glances Center Stack	1.46	0.10	2.13	0.00	0.24	0.66	1.37	7.01
Average Duration of Glances Forward	5.55	0.15	3.19	2.24	3.19	4.73	6.75	13.01
Average Duration of Glances Non-Forward Driving Related	0.96	0.01	0.15	0.59	0.89	1.01	1.04	1.17
Average Duration of Glances Non-Forward Non-Driving Related	1.21	0.03	0.66	0.60	0.87	1.08	1.23	2.96
Average Duration of Glances Center Stack	0.98	0.01	0.30	0.60	0.80	0.90	1.00	1.60
Standard Deviation Duration of Glances Forward	7.51	0.20	4.44	2.33	4.05	6.36	11.17	14.49
Standard Deviation Duration of Glances Non-Forward Driving Related	0.56	0.01	0.24	0.27	0.37	0.56	0.70	0.95
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.44	0.03	0.65	0.00	0.15	0.26	0.39	2.26
Standard Deviation Duration of Glances Center Stack	0.07	0.01	0.16	0.00	0.00	0.00	0.00	0.45
Percent Over 2 Seconds of Glances Forward	23.32	0.31	6.79	13.73	19.12	22.58	28.41	34.48

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Driving Related	1.79	0.09	1.94	0.00	0.00	1.96	2.86	5.65
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.51	0.08	1.68	0.00	0.00	0.00	0.00	5.56
Percent Over 2 Seconds of Glances Center Stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longest Duration of Glances Forward	29.37	0.82	17.85	9.00	18.15	27.40	39.05	70.20
Longest Duration of Glances Non-Forward Driving Related	2.44	0.05	1.12	1.20	1.70	2.30	2.65	5.10
Longest Duration of Glances Non-Forward Non-Driving Related	1.87	0.08	1.74	0.70	1.15	1.40	1.68	6.70
Longest Duration of Glances Center Stack Glance	1.08	0.02	0.35	0.60	0.90	1.00	1.30	1.60
Number of Eyes Open	68.00	3.57	77.87	9.00	24.25	41.50	75.25	273.00
Number of Blinks	67.80	3.56	77.59	9.00	21.25	42.50	76.25	271.00
Number No Info	1.30	0.08	1.77	0.00	0.00	0.50	2.50	5.00
Percent Number of Eyes Open	50.33	0.08	1.68	48.72	49.50	49.72	50.14	54.35
Percent Number of Blinks	49.67	0.08	1.68	45.65	49.86	50.28	50.50	51.28
Percent Number of No Info	2.46	0.18	3.84	0.00	0.00	0.28	4.44	10.87
Blink Rate	18.78	0.41	9.02	2.93	15.01	18.91	23.69	34.66
Total Duration of Eyes Open	179.38	4.96	108.12	54.07	97.30	174.10	219.90	429.00
Total Duration of Blinks	9.28	0.53	11.59	1.13	2.77	4.12	9.12	38.83
Total Duration of No Info	1.32	0.12	2.54	0.00	0.00	0.18	1.18	8.10
Percent Duration of Eyes Open	94.30	0.20	4.29	84.09	93.12	95.01	97.20	99.01
Percent Duration of Blinks	4.06	0.11	2.40	0.61	2.53	3.62	5.39	8.28
Percent Duration of No Info	1.64	0.18	3.95	0.00	0.00	0.11	0.36	12.60
Average Duration of Eyes Open	4.86	0.26	5.62	1.57	2.19	3.03	3.60	20.28
Average Duration of Blinks	0.13	0.00	0.03	0.07	0.12	0.13	0.14	0.18

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Average Duration of No Info	0.81	0.02	0.50	0.37	0.44	0.70	0.90	1.62
Standard Deviation of Duration Eyes Open	4.81	0.29	6.39	1.59	1.98	2.54	3.32	22.58
Standard Deviation of Duration Blinks	0.06	0.00	0.05	0.02	0.03	0.04	0.07	0.19
Standard Deviation of Duration No Info	0.33	0.02	0.50	0.00	0.00	0.22	0.24	1.21
Percent Over 2 Seconds of Eyes Open	44.75	0.22	4.84	37.68	40.66	45.31	48.17	52.17
Percent Over 2 Seconds of Blink	0.13	0.01	0.23	0.00	0.00	0.00	0.14	0.63
Percent Over 2 Seconds of No Info	1.86	0.15	3.18	0.00	0.00	0.00	3.26	8.70
Longest Duration of Eyes Open	21.22	0.84	18.34	8.30	10.00	15.48	24.07	69.77
Longest Duration of Blink	0.47	0.02	0.51	0.13	0.18	0.20	0.68	1.70
Longest Duration of No Info	1.29	0.06	1.32	0.37	0.67	0.70	1.10	3.60
Number of Transitions	54.55	1.34	29.15	28.00	34.00	50.00	64.00	123.00
Duration of Trigger	187.64	5.23	114.21	69.40	100.70	175.30	228.15	470.70
Transition Rate	0.33	0.01	0.14	0.13	0.25	0.34	0.42	0.59

Table A9. Descriptive statistics for baseline just-driving epochs (called full baselines) matched to "other cognitive epochs" (conversations with passenger/self).

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	9.94	0.41	8.95	0.00	3.25	7.00	13.50	31.00
Number of Glances Non-Forward Driving Related	10.67	0.41	8.90	1.00	4.25	7.50	13.00	31.00
Number of Glances Non-Forward Non-Driving Related	0.06	0.01	0.24	0.00	0.00	0.00	0.00	1.00
Number of Glances Center Stack	0.22	0.03	0.55	0.00	0.00	0.00	0.00	2.00
Percent Number of Glances Forward	43.52	0.52	11.28	0.00	43.25	46.80	47.84	50.00
Percent Number of Glances Non-Forward Driving Related	54.55	0.56	12.28	40.00	50.00	52.70	55.30	100.00
Percent Number of Glances Non-Forward Non-Driving Related	0.11	0.02	0.48	0.00	0.00	0.00	0.00	2.04
Percent Number of Glances Stack	1.82	0.23	4.99	0.00	0.00	0.00	0.00	20.00
Glance Rate Forward	5.66	0.15	3.23	0.00	4.10	5.09	7.77	10.87
Glance Rate Non-Forward Driving Related	11.82	1.02	22.21	2.00	4.45	6.85	9.36	100.00
Glance Rate Non-Forward Non-Driving Related	0.03	0.01	0.11	0.00	0.00	0.00	0.00	0.47
Glance Rate Center Stack	0.17	0.02	0.40	0.00	0.00	0.00	0.00	1.35
Total Duration of Glances Forward	91.18	2.74	59.85	0.00	39.30	99.85	133.30	210.20
Total Duration of Glances Non-Forward Driving Related	8.29	0.30	6.60	0.60	3.53	6.35	9.98	23.60
Total Duration of Glances Non-Forward Non-Driving Related	0.04	0.01	0.19	0.00	0.00	0.00	0.00	0.80
Total Duration of Glances Center Stack	0.16	0.02	0.39	0.00	0.00	0.00	0.00	1.20

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Duration of Glances Forward	85.79	1.00	21.87	0.00	88.26	91.40	93.72	98.13
Percent Duration of Glances Non-Forward Driving Related	13.96	1.00	21.92	1.87	5.79	8.60	11.74	100.00
Percent Duration of Glances Non-Forward Non-Driving Related	0.04	0.01	0.15	0.00	0.00	0.00	0.00	0.63
Percent Duration of Glances Center Stack	0.21	0.02	0.53	0.00	0.00	0.00	0.00	1.85
Average Duration of Glances Forward	13.13	0.46	10.06	4.51	6.78	9.90	13.20	36.75
Average Duration of Glances Non-Forward Driving Related	0.80	0.01	0.15	0.56	0.73	0.77	0.86	1.15
Average Duration of Glances Non-Forward Non-Driving Related	0.80	-	-	0.80	0.80	0.80	0.80	0.80
Average Duration of Glances Center Stack	0.77	0.01	0.29	0.60	0.60	0.60	0.85	1.10
Standard Deviation Duration of Glances Forward	9.18	0.26	5.78	3.61	5.25	7.95	8.78	26.61
Standard Deviation Duration of Glances Non-Forward Driving Related	0.26	0.01	0.17	0.00	0.17	0.24	0.32	0.71
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.00	-	-	0.00	0.00	0.00	0.00	0.00
Standard Deviation Duration of Glances Center Stack	0.09	0.01	0.16	0.00	0.00	0.00	0.14	0.28
Percent Over 2 Seconds of Glances Forward	33.96	0.50	10.97	0.00	28.78	33.91	42.14	47.22
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Percent Over 2 Seconds of Glances Center Stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longest Duration of Glances Forward	32.12	0.98	21.41	12.70	17.10	27.30	38.40	101.60
Longest Duration of Glances Non-Forward Driving Related	1.21	0.02	0.36	0.60	1.13	1.20	1.38	1.90
Longest Duration of Glances Non-Forward Non-Driving Related	0.80	-	-	0.80	0.80	0.80	0.80	0.80
Longest Duration of Glances Center Stack Glance	0.83	0.01	0.25	0.60	0.70	0.80	0.95	1.10
Number of Eyes Open	57.50	2.37	51.65	5.00	26.75	48.50	57.75	209.00
Number of Blinks	58.11	2.36	51.58	6.00	27.25	49.00	58.75	210.00
Number No Info	0.50	0.04	0.86	0.00	0.00	0.00	1.00	3.00
Percent Number of Eyes Open	49.27	0.06	1.25	45.45	49.40	49.55	49.97	50.79
Percent Number of Blinks	50.73	0.06	1.25	49.21	50.03	50.45	50.60	54.55
Percent Number of No Info	0.63	0.06	1.26	0.00	0.00	0.00	0.90	4.76
Blink Rate	29.57	0.68	14.88	7.56	17.07	31.26	38.37	54.35
Total Duration of Eyes Open	112.67	3.17	69.22	9.67	55.53	101.00	141.08	276.27
Total Duration of Blinks	8.44	0.40	8.66	0.50	3.65	6.25	9.15	36.10
Total Duration of No Info	0.15	0.02	0.34	0.00	0.00	0.00	0.06	1.27
Percent Duration of Eyes Open	93.10	0.18	3.96	84.75	90.90	94.19	96.04	97.87
Percent Duration of Blinks	6.77	0.18	4.04	2.13	3.63	5.51	8.95	15.25
Percent Duration of No Info	0.13	0.01	0.31	0.00	0.00	0.00	0.06	1.12
Average Duration of Eyes Open	2.84	0.10	2.15	0.95	1.46	1.91	3.41	8.37
Average Duration of Blinks	0.14	0.00	0.03	0.08	0.12	0.14	0.16	0.17
Average Duration of No Info	0.33	0.02	0.47	0.03	0.09	0.18	0.23	1.27

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Standard Deviation of Duration Eyes Open	2.09	0.09	1.96	0.26	0.84	1.36	3.29	7.80
Standard Deviation of Duration Blinks	0.04	0.00	0.01	0.02	0.03	0.04	0.05	0.08
Standard Deviation of Duration No Info	0.03	0.00	0.05	0.00	0.00	0.00	0.06	0.09
Percent Over 2 Seconds of Eyes Open	42.49	0.26	5.69	28.40	40.72	43.97	46.72	49.51
Percent Over 2 Seconds of Blink	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Percent Over 2 Seconds of No Info	0.15	0.03	0.65	0.00	0.00	0.00	0.00	2.78
Longest Duration of Eyes Open	9.01	0.33	7.27	1.93	3.93	6.18	11.88	25.27
Longest Duration of Blink	0.26	0.00	0.08	0.13	0.20	0.25	0.33	0.43
Longest Duration of No Info	0.36	0.02	0.46	0.03	0.09	0.22	0.32	1.27
Number of Transitions	19.89	0.82	17.90	0.00	6.50	13.50	27.00	61.00
Duration of Trigger	128.86	3.16	68.95	60.30	67.70	113.50	156.58	286.60
Transition Rate	0.15	0.00	0.10	0.00	0.07	0.13	0.20	0.36

Table A10. Descriptive statistics for baseline just-driving epochs matched to visual-manual interactions.

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Number of Glances Forward	11.43	0.33	7.11	1.00	7.00	10.00	17.00	21.00
Number of Glances Non-Forward Driving Related	8.29	0.35	7.63	1.00	3.00	6.00	11.00	23.00
Number of Glances Non-Forward Non-Driving Related	1.43	0.08	1.72	0.00	0.50	1.00	1.50	5.00
Number of Glances Center Stack	2.57	0.11	2.37	0.00	1.00	2.00	3.50	7.00
Percent Number of Glances Forward	45.40	0.25	5.53	33.33	45.80	46.67	48.10	50.00
Percent Number of Glances Non-Forward Driving Related	30.69	0.49	10.78	13.33	28.57	28.57	32.88	50.00
Percent Number of Glances Non-Forward Non-Driving Related	6.93	0.54	11.83	0.00	1.09	2.86	5.08	33.33
Percent Number of Glances Stack	14.48	0.56	12.24	0.00	3.79	19.05	20.71	33.33
Glance Rate Forward	8.31	0.19	4.21	1.31	7.05	7.19	10.59	14.37
Glance Rate Non-Forward Driving Related	5.90	0.23	4.95	1.31	3.02	4.23	7.01	15.74
Glance Rate Non-Forward Non-Driving Related	1.21	0.08	1.76	0.00	0.21	0.68	1.17	5.03
Glance Rate Center Stack	1.85	0.06	1.34	0.00	1.00	1.44	2.99	3.57
Total Duration of Glances Forward	67.74	1.30	28.32	44.30	53.00	56.60	69.45	128.40
Total Duration of Glances Non-Forward Driving Related	6.19	0.21	4.63	0.70	2.55	7.10	8.15	14.10
Total Duration of Glances Non-Forward Non-Driving Related	1.23	0.07	1.61	0.00	0.20	0.90	1.35	4.60
Total Duration of Glances Center Stack	2.00	0.09	1.88	0.00	0.60	2.00	2.65	5.50

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Duration of Glances Forward	87.39	0.26	5.70	80.14	83.27	87.25	90.55	96.72
Percent Duration of Glances Non-Forward Driving Related	7.51	0.23	5.06	1.53	4.28	5.36	10.51	16.08
Percent Duration of Glances Non-Forward Non-Driving Related	1.79	0.13	2.73	0.00	0.14	1.03	1.75	7.72
Percent Duration of Glances Center Stack	2.41	0.08	1.76	0.00	1.10	2.41	3.94	4.36
Average Duration of Glances Forward	11.43	0.67	14.60	3.44	4.79	7.43	7.63	44.30
Average Duration of Glances Non-Forward Driving Related	0.83	0.01	0.21	0.61	0.71	0.75	0.91	1.18
Average Duration of Glances Non-Forward Non-Driving Related	0.80	0.01	0.23	0.40	0.90	0.90	0.90	0.92
Average Duration of Glances Center Stack	0.75	0.01	0.20	0.40	0.70	0.79	0.85	1.00
Standard Deviation Duration of Glances Forward	6.04	0.17	3.80	0.00	4.27	4.95	8.75	11.28
Standard Deviation Duration of Glances Non-Forward Driving Related	0.30	0.01	0.15	0.00	0.28	0.33	0.36	0.46
Standard Deviation Duration of Glances Non-Forward Non-Driving Related	0.18	0.01	0.25	0.00	0.00	0.00	0.42	0.49
Standard Deviation Duration of Glances Center Stack	0.13	0.01	0.17	0.00	0.00	0.06	0.28	0.35
Percent Over 2 Seconds of Glances Forward	28.08	0.36	7.87	20.00	23.03	25.71	30.95	42.86
Percent Over 2 Seconds of Glances Non-Forward Driving Related	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Percent Over 2 Seconds of Glances Non-Forward Non-Driving Related	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Percent Over 2 Seconds of Glances Center Stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longest Duration of Glances Forward	24.90	0.53	11.57	11.20	18.00	21.10	30.85	44.30
Longest Duration of Glances Non-Forward Driving Related	1.30	0.02	0.35	0.70	1.15	1.30	1.55	1.70
Longest Duration of Glances Non-Forward Non-Driving Related	0.94	0.02	0.35	0.40	0.90	0.90	1.20	1.30
Longest Duration of Glances Center Stack Glance	0.97	0.02	0.34	0.40	0.85	1.00	1.15	1.40
Number of Eyes Open	50.43	0.83	18.13	31.00	42.00	44.00	55.00	84.00
Number of Blinks	50.43	0.85	18.47	30.00	42.00	43.00	56.00	84.00
Number No Info	1.71	0.10	2.29	0.00	0.00	1.00	3.00	5.00
Percent Number of Eyes Open	50.07	0.04	0.90	49.41	49.42	49.62	50.41	51.76
Percent Number of Blinks	49.93	0.04	0.90	48.24	49.59	50.38	50.58	50.59
Percent Number of No Info	2.20	0.16	3.38	0.00	0.00	0.60	3.32	8.20
Blink Rate	34.23	0.46	10.11	24.75	27.85	30.63	36.98	54.53
Total Duration of Eyes Open	82.57	1.51	32.94	51.17	64.32	77.63	84.42	151.70
Total Duration of Blinks	7.37	0.16	3.43	3.10	4.87	6.03	10.55	11.60
Total Duration of No Info	1.32	0.09	1.91	0.00	0.00	0.20	2.27	4.50
Percent Duration of Eyes Open	90.11	0.12	2.72	86.44	88.21	90.20	92.15	93.41
Percent Duration of Blinks	8.04	0.13	2.74	5.28	6.04	6.92	9.71	12.55
Percent Duration of No Info	1.85	0.14	2.98	0.00	0.00	0.12	2.60	7.66
Average Duration of Eyes Open	1.68	0.02	0.43	0.95	1.53	1.65	1.89	2.30
Average Duration of Blinks	0.14	0.00	0.04	0.10	0.12	0.14	0.15	0.24
Average Duration of No Info	0.69	0.02	0.34	0.20	0.59	0.81	0.91	0.93

Eye-Glance Variable	Mean	Standard Error	Standard Deviation	Minimum	Quartile 1	Median	Quartile 3	Maximum
Standard Deviation of Duration Eyes Open	1.37	0.03	0.68	0.72	0.90	1.12	1.65	2.64
Standard Deviation of Duration Blinks	0.06	0.00	0.04	0.02	0.04	0.05	0.07	0.12
Standard Deviation of Duration No Info	0.17	0.01	0.21	0.00	0.00	0.14	0.31	0.42
Percent Over 2 Seconds of Eyes Open	37.98	0.23	5.05	27.98	36.97	40.00	40.81	42.35
Percent Over 2 Seconds of Blink	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Percent Over 2 Seconds of No Info	1.19	0.11	2.41	0.00	0.00	0.00	0.89	6.56
Longest Duration of Eyes Open	6.65	0.15	3.27	3.37	4.37	4.93	8.90	11.70
Longest Duration of Blink	0.32	0.01	0.14	0.13	0.23	0.30	0.40	0.53
Longest Duration of No Info	0.95	0.02	0.54	0.20	0.75	1.08	1.28	1.43
Number of Transitions	23.43	0.70	15.30	2.00	13.50	20.00	35.00	45.00
Duration of Trigger	93.96	1.67	36.33	61.40	71.35	87.50	98.25	169.60
Transition Rate	0.26	0.01	0.15	0.02	0.19	0.23	0.34	0.48

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