

Reducing Driver Distraction through Software

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Abstract

Advanced Driver Assistance (ADA) systems currently operate within vehicles, offering drivers assistance to either avoid hazardous situations, or information to make travelling easier. However, these devices have the potential to contribute to driver distraction as they require a certain level of driver attention in order to provide a benefit, taking cognitive, visual, auditory, and manual resources away from the main driving task. As these systems become more prolific in the market, the potential number of devices that can operate within a vehicle at any one time increases. Therefore, this paper presents a new in-vehicle architecture to unobtrusively reduce ADA system related distraction. Our approach consists of sensing and assessing the current driving context. The context is gathered by an in-vehicle system which senses and articulates relevant information about the environment, driver and vehicle. We use Bayesian Networks in our architecture to assess driving distraction and to identify an optimal way to interact with the driver. This paper will address the assessment of driver distraction based on contextual information in relation to the vehicle, the environment, and the driver¹.

1. INTRODUCTION

Driver inattention and distraction are contributing factors in a significant number of traffic crashes (Harbluk, Noy, & Eizenman, 2002; Stutts, Reinfurt, Staplin, & Rodgman, 2001; Transport Canada, 2003; Utter, 2001). According to Queensland Transport (2005) inattention is a contributing factor in 26% of fatal crashes and 29% of hospitalisation crashes, with the number of fatal crashes increasing from 24 in 1994 to 74 in 2003. Driver distraction contributes to these statistics and, as this paper is concerned primarily with distraction, we utilise Noy's (2005) definition to distinguish between driver distraction and driver inattention. Distraction is defined as a "shift of attention away from the driving task for a compelling reason" and inattention is defined as a "shift of attention away from the driving task for a non-compelling reason"(Noy, 2005, p. 4).

Driver distraction has been described as any activity that is not directly related to the primary task of driving, that causes a driver to focus their attention on any event, task or stimuli that reduces their ability to react to the current driving context (see Brooks & Rakotonirainy, 2005). Distraction can occur by way of visual and auditory input, biomechanical actions or cognitive stimuli (Young, Regan, & Hammer, 2003). Visual distraction involves a driver diverting visual attention away from the primary driving task and can be seen as a huge safety problem, as approximately 90% of information available to the driver is accessed by visual means (Wierwille, 1993). Auditory distraction results from a driver focusing on a noise rather than the driving task and manual distraction is the result of a driver not paying attention to the road because they are physically manipulating an object. Visual and biomechanical distraction, can be reduced by speech based interfaces, however cognitive distraction remains a problem (Brooks & Rakotonirainy, 2005). Cognitive distraction can be described as being absorbed by thoughts to such a degree that one is unable to navigate safely (Young et al., 2003). The problem of cognitive distraction becomes even

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more apparent when considering that visual, auditory and manual tasks utilise cognitive resources in order to process this information.

Stutts and Hunter (2003) attribute driver inattention to distractions that come from either inside or outside the vehicle, or are the result of a driver being cognitively removed from the driving task. At present, a number of ADA systems are available, offering drivers assistance to either avoid hazardous situations, or information to make travelling easier. As this form of technology gains in number and popularity, the potential number of devices that will be present in a vehicle at any one moment increases, significantly adding to the probability that drivers will be distracted. Therefore, we suggest that in order to minimise the negative effects they have on road safety, the driving context must be taken into account by these devices.

In order to reduce the distracting effects of these devices, this paper presents a new in-vehicle architecture to unobtrusively reduce ADA system related distraction. This architecture gathers and assesses relevant contextual information about the environment, driver and vehicle, before allowing ADA systems to interact with the driver. We also propose using a Bayesian network for monitoring driver distraction, along with a test strategy to validate this network. A Bayesian network is used as a graphical tool to infer distraction probabilities from observed environment, driver, and vehicle data.

2. RELATED WORK

Previous research investigated the distracting effects of various in-vehicle technologies, such as real-time traffic information (Janssen, Kaptein, & Claessens, 1999), route guidance systems (Young et al., 2003), E-mail / Internet (Lee, Caven, Haake, & Brown, 2001; Young et al., 2003), and in-vehicle radio and CD players (Stutts et al., 2001; Young et al., 2003). Other technologies that are present within a vehicle, such as Collision Warning and Lane Departure Warning systems, have not been measured to discover their distracting potential, although it is accepted that these systems can provide false alarms and nuisance alerts (Eby & Kostyniuk, 2004).

The majority of the research to assess ADA systems utilise two forms of assessment to discover if a driver is distracted while using these systems: reaction time to a braking lead vehicle and lane deviation (Janssen et al., 1999; Lee et al., 2001; Young et al., 2003). These types of assessments are often based on dual-task performance theories. Some examples of these theories include multiple resource theories, malleable attentional resource theory, and strategic task management. For a more detailed discussion of these theories see Lee, Reyes, & McGhee (2004).

Although research utilising reaction time to a braking lead vehicle works well when measuring the distracting effects of a particular device, this type of assessment does not allow for real-time systems to utilise this information in a preventative capacity. In contrast, lane deviations can suggest that a driver is currently distracted. However, interventions based upon this observation are provided at the last moment and may not allow enough time for real-time systems to effectively utilise this information.

Several psychophysiological measures have been useful in providing real-time data for determining if a driver is distracted. These measures include eye movement, gaze direction, glance duration, pupil dilation, blink rate, blood pressure, heart rate, and respiration (Lee et al., 2004). Furthermore, the reliability of these measures to detect distraction is greater when several are used in conjunction, particularly when considering that cognitive processing is required to deal with all forms of distraction. Hankins and Wilson (1998) conducted research with aircraft pilots and discovered that multiple psychophysiological measures “provide a comprehensive picture of the mental demands of flight” and suggest that “it may be possible to develop systems which provide on-line [real-time] monitoring of mental workload that can provide feedback” (Hankins & Wilson, 1998 p. 360). One such system that appears to address this in road safety is the SAVE-IT project (www.volpe.dot.gov/opsad/saveit/).

The SAVE-IT project aims to develop a centralised driver monitoring system that integrates data collected from in-vehicle technologies. This projects ultimate aim is to control

the information flow to a driver through an adaptive interface. However, at the time of writing, SAVE-IT had only provided limited information regarding the specific details of their project. While our research has a similar goal, we aim to control the information flow based on the current driving context.

This provides a significant departure from current research as we include the driving situation in the broader concept of a “driving context”, defining the driving context as “what the driver sees [and hears], the current state of mind and cognitive load on the driver, the current actions of the driver, the environment inside and outside the vehicle, and the current driving situation” (Brooks & Rakotonirainy, 2005, p. 4). In addition, our model entails collecting information based on the driver, environment and vehicle, and our methodology utilises a Bayesian network to assess the probability of driver distraction. A Bayesian network is used as it provides an “efficient representation of, and rigorous reasoning with, uncertain knowledge” (Russell & Norvig, 2003, p. 26). A Bayesian network will enable us to select and then observe individual variables with a high probability of discovering if a driver is distracted, rather than observing multiple variables in order to discover if a driver is distracted.

In conjunction with the Bayesian network, our approach provides an adaptable, context-aware, real-time system. This means that our information control software will take into account all potential technological and non-technological based distractors, as well as the biomechanical, visual, auditory and cognitive demands of the main driving task. Specifically our design will monitor the weather, traffic, passengers, environmental complexity, vehicle dynamics and general driving demands, before allowing more information to be presented to a driver. In the next section we present an overview of our in-vehicle architecture.

3. OVERVIEW OF OUR IN-VEHICLE ARCHITECTURE

In this section we present our in-vehicle architecture designed to unobtrusively reduce ADA system related distraction, as displayed in Figure 1. This design incorporates important contextual data from the environment, vehicle and driver, fusing the information to provide a precise assessment of the current driving context. The most important advantage of this architecture is that it utilises software to process the current driving context via a series of sensors. This allows ADA systems to be provided with a probability of how demanding the current driving context is, and whether or not ADA systems should attempt to interact with the driver.

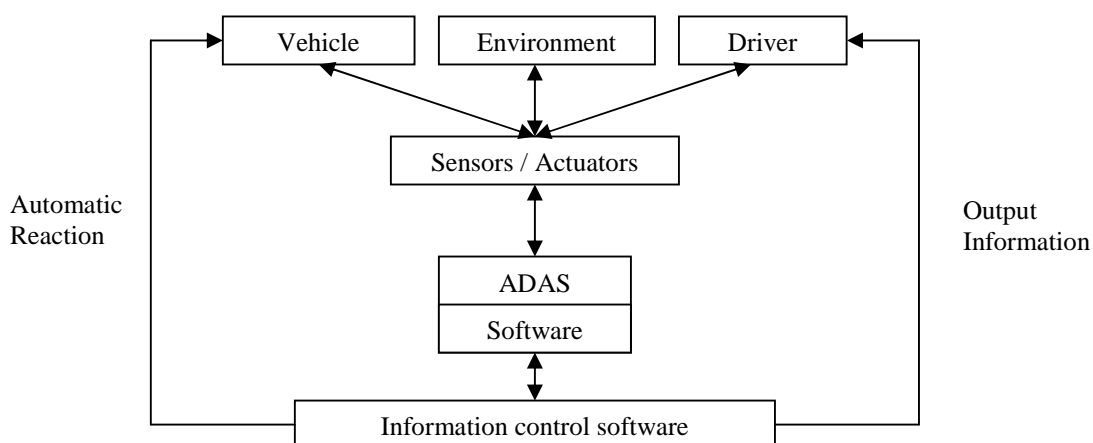


Figure 1 Overview of our in-vehicle architecture.

3.1 Architecture

This section provides a description of the different components and the relationship between components that is displayed in the architecture depicted in Figure 1.

Components

- **Vehicle:** This section of the diagram symbolises the information that is gathered about the vehicle dynamics, such as the braking, acceleration, and steering patterns. The vehicle may also receive instructions from an ADA system, via the software, to react automatically to a particular driving situation.
- **Environment:** This section of the diagram symbolises the information that is gathered about the current environment, both inside and outside the vehicle. Data is gathered about the current weather, traffic, and road conditions, and about the current activities of passengers and other objects within the vehicle.
- **Driver:** This section of the diagram symbolises the information that is gathered about the driver, including eye movement, gaze direction, glance duration, pupil dilation, blink rate, blood pressure, heart rate, and respiration. The driver will also be provided with information from ADA Systems via the software.
- **ADAS:** This section of the diagram symbolises all existing ADA systems that may attempt to interact with a driver, including navigation, real-time traffic information, lane departure warning, collision warning and email or internet facilities. The software portion refers to any programs that are associated with a particular ADA system, including, the software this device needs to function, and an interface for the Information control software to interact with this ADA system.
- **Sensors / Actuators:** This section of the diagram symbolises the devices that are utilised to gather any information about the environment, vehicle and driver. It also symbolises the devices that are used to present information to a driver. These sensors could be physiological, capturing physical data about a driver such as heart or respiratory rate, or vision based, capturing vision based data such as gaze direction or pupil dilation.
- **Information control software:** This section of the diagram symbolises our software that is used to process all the information gathered. This software will be used to filter and prioritise information that is to be presented to the driver, store information that has not been presented to the driver, and present stored information to the driver at a safe time.

Interactions

- **Output information:** This interaction symbolises information that is to be presented to a driver. Information will be presented to the driver if the Information control software has decided that it is either safe to do so or that the information is of vital safety importance.
- **Automatic reaction:** This interaction symbolises the automatic assistance that ADA systems, such as collision avoidance systems, can provide.

3.2 Architecture discussion

Although this architecture could potentially improve the safety of interactions between ADA systems and drivers, there are two potential problems for this system. Firstly, it is virtually impossible to collect enough information about the driver, environment and vehicle

to assess the distraction that may occur within every conceivable driving context. This is mainly due to the fact that driving is a complex task and drivers react differently in different situations.

Secondly, this system must collect a very large amount of data in order to discover the current state of the driving context. This problem is compounded by the fact that relevant information must be selected, fused and then analysed before it can be used to decide the actions of an ADA system. Considering that numerous devices could attempt to interact with a driver at the same moment, and some for safety reasons, this provides a significant challenge.

To address these problems, we have designed a Bayesian network that will assess the probability that a driver is distracted. This will reduce the amount of data that the information control software must process in order to determine that the driver does not need to be provided with more information at this time as they are distracted.

In the next section we present design for a Bayesian network that could be used to assess the current level of driver distraction. This network could be used to discover both the probability that a driver is currently distracted based on any number of potential distractors, or the probability that distraction is actually occurring based on any number of distraction measures.

4. COMBINING DISTRACTION WITH BAYESIAN NETWORK

This section provides a diagram of our proposed Bayesian network for driver distraction (Figure 2). In essence a Bayesian network deals with probabilistic knowledge and consists of random variables, referred to as nodes, connected by arcs which represent a probabilistic dependency between parent and child nodes. These networks are designed to provide a tool for dealing with uncertainty and complexity (Russell & Norvig, 2003). In order to effectively monitor driver distraction, a system that integrates contextual data - environment, vehicle, and driver - into one representation is needed. Therefore we have chosen a Bayesian network model as it provides the best option when dealing with this type of issue.

Central to our model, as presented in Figure 2, is the target hypothesis variable that we intend to infer, distraction. The nodes located above the hypothesis variable are the contextual factors that can lead to distraction, with nodes located at the very top providing specific instances of distractors. The various technology and non-technology based interactions lead to visual and auditory input, and biomechanical actions. These in turn contribute to distraction and inattention, and are also essential in performing the main driving task. The nodes located below the hypothesis variable are the information variables which provide the cues or are symptoms of distraction. These nodes also provide a way of determining that a driver is currently distracted. The information variables that are depicted in this diagram could also be linked to inattention and the main driving task, but have been left out of this diagram to reduce confusion.

It is important to note that visual and auditory input, and biomechanical actions do have an influence on cognitive processing, as cognitive processing is required when a driver needs to interpret visual or auditory information, and when conducting some biomechanical action. A summary of all nodes is provided in the Appendix.

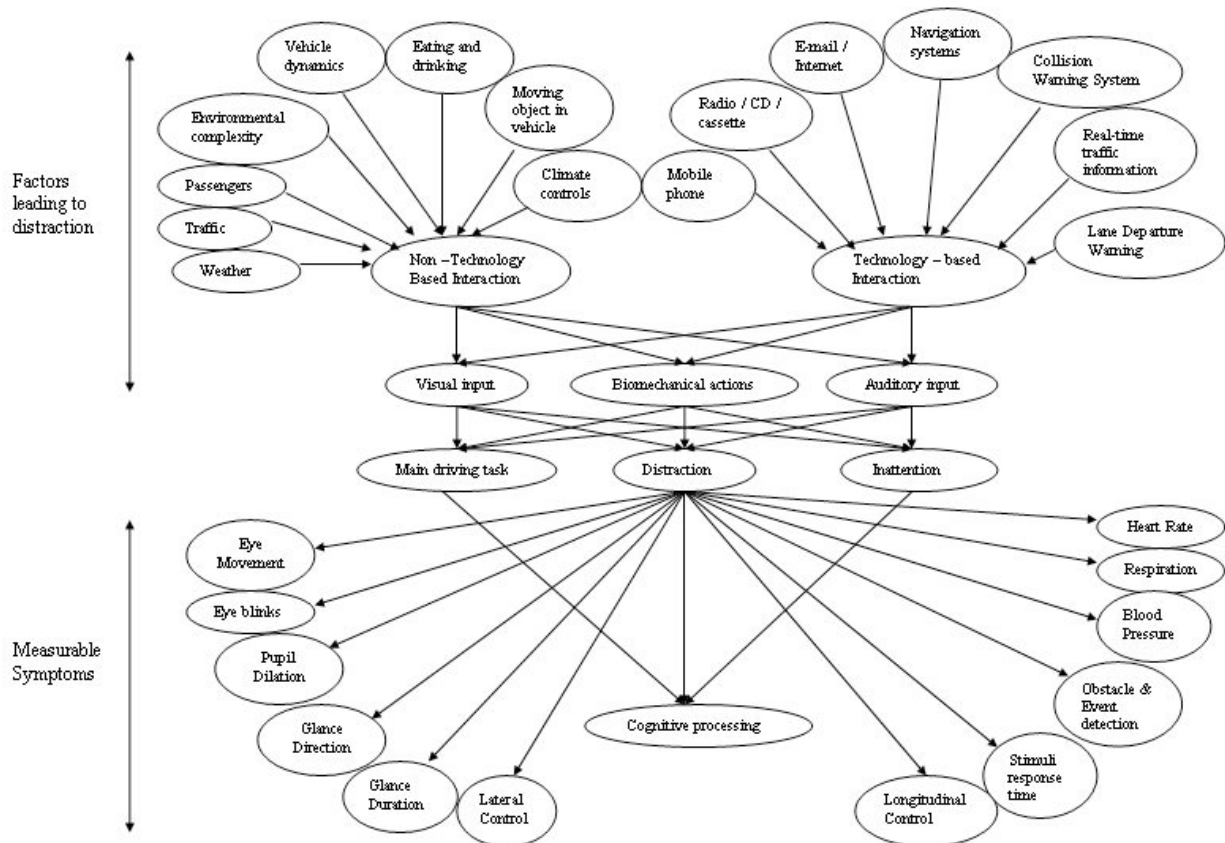


Figure 2: Proposed Bayesian network for monitoring driver distraction

The Bayesian network model enables us to discover the probability that a driver is distracted, based on the values of one or more nodes. For example, we can estimate the probability that a driver is distracted when only using a navigation system, or when using a navigation system whilst they are engaged in a mobile phone conversation. We can also discover the conditional probability that one or more measures will successfully determine if a driver is distracted. For example, we can discover the conditional probability that a driver is currently distracted by measuring just the eye movement, or the eye movement in conjunction with heart rate. However, if the probability of detecting distraction from one method is high enough, there is no need to assess the data from another method

As our Bayesian network has not yet been tested, the next section documents how we intend to validate the network.

4.1 Building a Bayesian network for monitoring driver distraction

Considering that the driver distracted state is a concept that has not been identified or measured, the only way to capture this state is to actually observe it taking place. Therefore, to ensure that valid probabilities are provided for each node, we will be collecting observational data. As Bayesian networks contain a “learning” phase in which the Bayesian Conditional Probability Tables (CPT; (see Russell & Norvig, 2003) are filled, the objective of this experiment is to gather enough data to provide a CPT for each node in the Bayesian network for monitoring driver distraction (Figure 2).

Experiment

Driver distraction will be assessed by measuring the response time of a representative sample of drivers, within a driving simulator, to the periodic braking of a lead vehicle. An independent assessment of each potential distracter, as identified in Figure 2, will be completed, including: eating and drinking; moving object in vehicle; adjusting climate controls; and all technology based interactions. Also, an independent assessment of each contextual element, as identified in Figure 2, will be completed, including: weather, traffic,

passengers, environmental complexity and vehicle dynamics. A case-control study design will be used, with the control group being observed under the following conditions: minimal distracter interaction, calm weather, no traffic or passengers, and relatively little environmental complexity. All participants will be asked to complete pre-defined routes that constitute representative courses, with the course being altered and run on different days in order to gather data about all contextual elements under different conditions.

We will use reaction time to measure the distracting probability of those devices and non-technology based interactions identified in the Bayesian network for monitoring driver distraction. However, if a probability can be provided from the literature, then this information will be used.

The test vehicle will be equipped with devices to measure all identified variables in the Bayesian network for monitoring driver distraction, from eye movement to heart rate. These devices for measuring distraction will also be tested independently, so as to discover their reliability at assessing distraction.

4.2 An example of the use of Bayesian networks

This section provides an understanding of the Bayesian network concept. In order to demonstrate how our proposed Bayesian network will be applied, a simplified model is presented in Figure 3.

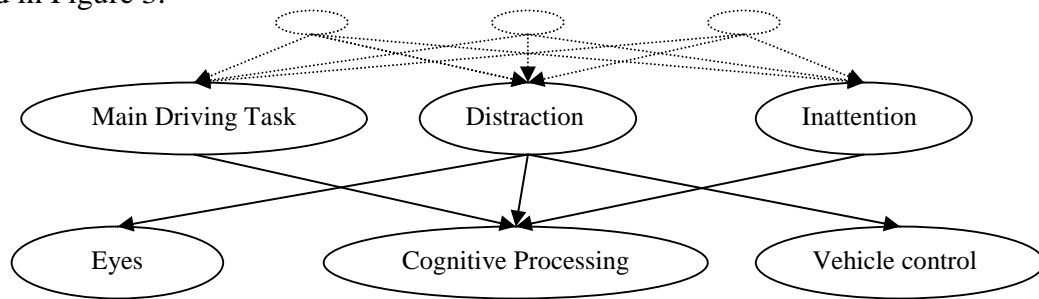


Figure 3 Simplified Bayesian network

In this simplified diagram, the node *Vehicle control* represents the lateral and longitudinal control nodes of Figure 2. The node *Eyes* represents the *vision related* observation nodes of Figure 2 (like *Eye movement* and *Glance duration*).

The basic task of the Bayesian network is to compute the posterior probability distribution for a set of query variables, given some observed events. Here the query variables could be *Cognitive processing* and *Inattention*. The observed events could be *Eyes* and *Vehicle control*. The CPT of the nodes *Eyes* and *Vehicle control* can be obtained from experiments with a driving simulator.

The CPT of the node *Cognitive processing* should reflect the additivity of *Main Driving Task* and *Distraction* levels. A smart ADA system would use this Bayesian network by computing the posterior probability of the *Cognitive processing* (unobservable variable) given the values of the observable variables like *Eyes* and *Vehicle control*. Exact inference in Bayesian networks is only practical for very small networks or networks having simple topology (Russell & Norvig, 2003). For more complex networks, as depicted in Figure 2, stochastic approximation techniques like Markov Chain Monte Carlo (MCMC) give reasonable estimates of the true posterior probabilities and can cope with much larger networks than can exact algorithms.

5. CONCLUSIONS AND FUTURE WORK

Driver distraction is a significant road safety issue. As Advanced Driving Assistant systems gain in number and popularity, the potential number of devices that will be present in a vehicle at any one moment increases, significantly adding to the probability that drivers will be distracted. This paper provides a new in-vehicle architecture that is designed to enable

ADA system related distraction to be unobtrusively reduced. The architecture gathers and assesses relevant contextual information about the environment, driver and vehicle, before allowing ADA systems to interact with the driver.

In order to reduce time needed to process and analyse the amount of data that could potentially be collected by this system, this paper also presented a Bayesian network for assessing distraction. This network is designed to assess the probability that a driver is distracted, rather than relying on a large amounts of raw data.

At present this network has not been tested, and future work will include experiments to discover the probabilities associated with the relevant nodes of our Bayesian network. Once we have these probabilities, we will be able to proceed with the creation of software for information control within a vehicle

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Appendix: Summary of Nodes

Node	State	Description	Ref
Auditory Input	Yes, No	Stimuli accepted via auditory means	(Young et al., 2003)
Biomechanical action	Yes, No	Manual manipulation of an object	(Stutts et al., 2005; Young et al., 2003)
Blood Pressure	Low, Medium, High	Drivers blood pressure	(Lee et al., 2004)
Climate Controls	Yes, No	Controls to adjust the in-vehicle climate	(Stutts et al., 2005; Stutts et al., 2001)
Cognitive processing	Low, Medium, High	Current utilisation of Cognitive resources	(Lansdown, Brook-Carter, & Kersloot, 2004; Lee et al., 2004; Transport Canada, 2003; Young et al., 2003)
Collision Warning System	Active, Not Active	System to warn the driver that the vehicle is too close to another object	(Cheng, Hashimoto, & Suetomi, 2002; Dagan, Mano, Stein, & Shashua, 2004; Srinivasa, Chen, & Daniell, 2003)
Distraction	Low, Medium, High	Is distraction present	(Stutts et al., 2005; Stutts et al., 2001; Young et al., 2003)
Eating & Drinking	Yes, No	Driver eating or drinking	(Stutts et al., 2001; Young et al., 2003)
Email/ Internet	In use, Not in use	Internet and email facilities are available in vehicles	(Young et al., 2003)
Environmental Complexity	Low, Medium, High	Objects and information sources outside the vehicle.	(Fletcher, Loy, Barnes, & Zelinsky, 2005)
Eye blinks	Few, Average, A lot	Eye blink rate	(Lee et al., 2004)
Eye Movement	Left, Right, Central, Up, Down	Fixations and scan patterns	(Lee et al., 2004; Transport Canada, 2003)
Glance Direction	Left, Left-Centre, Centre, Right-Centre, Right	Direction driver is looking	(Lee et al., 2004; Sodhi M, Reimer B, & Llamazares I., 2002; Transport Canada, 2003; Young et al., 2003)
Glance Duration	Quick, Intermediate, Slow	Time spent looking in one direction	(Lee et al., 2004; Sodhi M et al., 2002)
Heart Rate	Slow, Medium, Fast	Rate at which the heart beats	(Lee et al., 2004)
Inattention	Low, Medium High	Is the driver inattentive	(Queensland Transport, 2005; Stutts & Hunter, 2003)
Lane Departure Warning System	Active, Not Active	System to warn driver that the vehicle is leaving its lane	(Li, Zheng, & Cheng, 2004; Suzuki & Jansson, 2003)
Lateral Control	Bad, Average, Good	Drivers ability to maintain lateral control of a vehicle	(Young et al., 2003)
Longitudinal Control	Bad, Average Good	Drivers ability to maintain longitudinal control of a vehicle	(Lee et al., 2004)
Main driving Task	Low, Medium, High	Requirements of driving task	(Fuller & Santos, 2002)
Mobile Phones	In use, Not in use	Wireless communication devices	(Stutts, Reinfurt, Staplin, & Rodgman, 2001; Young et al., 2003)
Moving object in vehicle	Yes, No	Any unsecured object	(Stutts et al., 2001)
Navigation Systems	In use, Not in use	System to help a driver find a destination	(Young et al., 2003)
Non-Technology Based Interaction	Yes, No	Driver engaging with a non- technology based element	(Stutts et al., 2005; Young et al., 2003)
Obstacle & Event Detection	Bad, Average, Good	Ability to detect obstacles and driving events	(Lee et al., 2004)
Passengers	None, Quiet, Bearable, Noisy	Other persons present in the vehicle	(Stutts et al., 2001; Young et al., 2003)

Pupil Dilation	Small, Medium, Large	Diameter of the pupil	(Lee et al., 2004)
Radio / CD / Cassette	Low, Medium, Loud, Off	In-vehicle entertainment system	(Stutts et al., 2001; Young et al., 2003)
Real-time traffic information	In use Not in use	System to provide up to date traffic information	(Janssen, Kaptein, & Claessens, 1999)
Respiration	Slow, Medium, Fast	Rate at which breaths are taken	(Lee et al., 2004)
Stimuli Response Time	Bad, Average, Good	Drivers response time to driving related stimuli	(Lee et al., 2004)
Technology - Based Interaction	Yes, No	Driver engaging with a technology based element	(Young et al., 2003)
Traffic	None, Light, Medium, Heavy	Density of traffic	(Galski, Ehle, & Bradley, 1998; Stutts et al., 2001)
Vehicle Dynamics	Lateral Longitudinal	Vehicle position and movement	(Gruyer, Rakotonirainy, & Vrignon, 2005)
Visual Input	Yes, No	Stimuli accepted visually	(Young et al., 2003)
Weather	Sunny, Rainy, Windy, Foggy, Calm	Current weather conditions	(Stutts et al., 2005)