THE EFFECTS OF INCREASING WORKLOAD ON DRIVERS' EYE MOVEMENT

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ABSTRACT

In recent years, the increasing use of in-vehicle information systems (IVISs) has become a growing safety concern because such IVISs compete with driving tasks over limited visual and cognitive resources, therefore cause higher drivers' workload, which in turn may affect driving performance negatively.

Eye movement measurements were found to be sensitive to the workload increased by in-vehicle secondary tasks. As an indicator for both drivers' vision impacted by external reasons (e.g. environmental changes) and drivers' demands influenced by internal factors (e.g. mental workload increasing), the drivers' eye movement while performing concurrent tasks have been investigated in this paper. The results show that auditory and visual tasks have different effects on drivers' eye movement.

In visual tasks, driver deviation of gaze angle and percent of time looking at in-vehicle display increased, while the percent of time spent on windscreen, on mirrors, frequency of mirrors checking as well as saccade duration and saccade amplitude decreased, which suggest the higher visual workload and reflect the location effect of the display. Especially, the significant decrease in the frequency on mirrors checking is an indication of drivers compromising the information intake in extra visual workload.

While when performing auditory tasks, on the contrary, there were significant increases in blink percentage, blink frequency and a minor increase in blink duration. It is also observed that drivers' horizontal and vertical gaze angles are sensitive measurements for task type and mental workload. According to these finding, a framework for detecting and predicting workload is established.

This work suggested the potential developing a real-time tool of monitoring and predicting drivers' mental workload based on the eye-movement measurements. The future application can be used in in-vehicle alarm systems to enhance the human-related safety.

Keywords: Eye movements; IVIS, driving behaviour; workload; road safety; eye gaze angle; visual searching strategy; saccade .

INTRODUCTION

In recent years, the increasing use of in-vehicle information systems (IVISs) such as cell phones, GPS navigation systems, advanced driver assistance systems, and entertainment systems has become a growing safety concern for drivers, because using these systems involves dual-tasking, i.e. performing a secondary task (e.g. look at the in-vehicle display), during primary task (i.e. driving), which unavoidably increase the drivers' workload. This increased workload is one of the major sources of inattention, which according to the National Highway Traffic Safety Administration , contributes to 25% of all police-reported accidents in the U.S (Wang et al., 1996, Ranney et al., 2000). This is supported by similar comments from the Department for Transport in the U.K (Department for Transport et al., 2009). The impact of drivers' inattention on road safety from other sources could be even higher. It was estimate the in-vehicle sources caused inattention (e.g. talking, interacting with instruments) involved into 55% of accidents (Wierwille and Tijerina, 1996).

To understand the relationship between the increased workload and eye movement, it is essential to understand that the major difference of in-vehicle tasks according to its effect on eye movement is whether it requires extra vision demand or not, although, to some extent, visual task also involves mental elements.

Multiple Resource Theory (Wickens, 1987) divides resources needed to perform a given task can be into different "resource pools", and suggests that different resource types are used for different modalities (e.g. visual or mental) in task performing. In dual-tasking, when two tasks have an overlap in terms of resource requirement, one or both of the tasks' performance will be affected since the resource would soon be occupied; when two tasks require different resources (e.g. one is the visual task and the other is the auditory task), there will be no direct interference to each other and only if the task performance is not affected by the central resource limitation, both of the tasks' performance will keep unaffected.

Driving is a visual intense task. It is crucial for drivers to use vision to perceive the road scene, use manual control to adjust steering, accelerator, and brakes and spatial working memory to judge the relative vehicle position, therefore any extra required vision will create high visual resource competition, therefore more visual conflict will occur, which will be reflected by eye movement measurements. In mental tasks, on the other hand, the visual competition is not as high as when performing the visual tasks. The resource competition is mental-predominately due to the central resource competition, which cannot be observed by drivers' conscious visual behaviour (for example, shifting eye gaze from one object to another). However, as a physiological measurement, some eye movement measurements possess the capability of detecting the mental workload changes, for example, some endogenous eye activity – blink and saccade.

Effects of visual tasks

For measuring the effect of visual task, traditionally, three measures: the percent road centre, searching area and fixation on the in-vehicle display are used since eyes consciously travel forward and backward between the in-vehicle display and road ahead. In one of the researches carried out in an aviation simulator by Federal Aviation Administration, US, it was found that when detecting a higher visual condensed task, operators' blink duration and pupil diameter increases, but no significant changes were found in blink frequency, saccade frequency and saccade distance (Ahlstrom and Friedman-Berg, 2005). The number of glances is even more strongly affected by visual task complexity than glance duration (Hoffman et al., 2005). Drivers' visual demand increases as the display becoming more complex. For example, Victor et al. found that as the visual task became more difficult; drivers looked less at the road centre area ahead, and looked at the display more often, for longer periods, and for more varied duration (victor et al., 2005, Hoffman et al., 2005, Coeckelbergh et al., 2002). It was also found that the blink rate and blink duration (Van Orden et al., 2000), and saccade duration are decreased (Rognin et al., 2004, Zeghal et al., 2002) while the pupil diameter (Lin et al., 2003, Van Orden et al., 2000), number of saccades (Zeghal et al., 2002), are increased with the increased visual workload (van Orden et al., 2001).

Measurements of number of glance on the in-vehicle display, glance duration, glance frequency, and total task duration have been shown have high correlations with lane-keeping (Wierwille, 1993a, Wierwille, 1993b, Lansdown, 2001), and situation awareness (Angell et al., 2006). The effect of visual task complexity on visual searching are more remarkable for novice drivers than that for experienced ones (Crundall et al., 1999).

Effects of mental tasks

While in mental task, on the contrary, gaze concentration to the road centre area increased as the task getting more complex (victor et al., 2005). Rantanen and Goldberg (Rantanen and Goldberg, 1999) found that participants' visual fields (as measured by a visual perimeter) shrank and changed shape during tone counting tasks. It was found that, for some eye movement measurements, the mental workload may have opposite effects as that in the visual workload (Recarte et al., 2008, Recarte and Nunes, 2003).

Since the distinctly different nature of mental task comparing to visual task, some other eye movement parameters or explanation of parameters were proposed by other researches. Recarte and Nunes found that the mean fixations (including the fixation to locations out and in -vehicle) were longer and saccades were smaller, when participants were performing mental tasks(Recarte and Nunes, 2000, Recarte and Nunes, 2003). Drivers were found to check mirrors more often(Recarte and Nunes, 2000), and their saccade decreased (Harbluk et al., 2007) when performing mental tasks. Many researches have used eye activity measures that correlated with cognitive demands to measure the real-time workload (Ahlstrom and Friedman-Berg (Ahlstrom and Friedman-Berg, 2005, van Orden et al., 2001, Wilson et al., 2000, Wilson and Eggemeier, 1991).

Mental tasks also cause visual detection decreases. Olsson and Burns (Olsson and Burns, 2000) ound that counting backwards interfered with the detection of peripheral lights. Strayer, Drews and Johnston (Strayer et al., 2003) found that when participants were involved in a hands-free phone conversation, they responded slower to the leading vehicle’s brake lights. Horberry and colleagues (Horberry et al., 2006) found that a simulated hands-free mobile phone conversation impaired drivers’ responses to a pedestrian crossing the road.

It was well shown that the various demands had affected the drivers' visual fixation patterns in a very systematic and predictable fashion (Recarte and Nunes, 2000, Nunes and Recarte, 2002, Land and Horwood, 1995, victor et al., 2005).The workload increased by secondary tasks can be observed by looking at drivers’ eye movement. However, it needs to be clear that visual and mental workload have very different effect on eye movement measurements. That is, in order to use eye movement measurements to investigate drivers’ workload, tasks which cause the visual behaviour change need to be categorised and the characters of various eye movement parameters in each type of task have to be studied carefully. Therefore, by looking at drivers’ eye movement, it is premising to develop a real-time tool for instantaneously monitoring the drivers’ workload.

Objective

This paper aims to answer four research questions. (1) how are eye movements influenced by different in-vehicle task types (visual and mental), (2) which measures are most suitable and sensitive to these changes in eye movements? (3)can we use eye movement measurement to monitor drivers’ workload, and (4) if yes, what are the conditions and limitations?

METHOD

Database Description

The field-test data used in this paper were collected as part of an earlier study on the effect of in-vehicle intuitive voice interfaces on driving performance using an instrumented vehicle (Zheng et al., 2008).

The TRG Instrumented Vehicle and the Eye Tracking System

Data used in this research were collected using the TRG instrumented vehicle designed to collect information in real environments on the road. Sensors can measure vehicle location, speed, and distance to adjacent vehicles, control usage, driver's eye movements, and other driver behaviour actions (McDonald and Brackston, 1997). Four cameras are installed to record video pictures of the front, rear and in-vehicle views, as well as the driver's foot movements. The instrumented vehicle is also equipped with a FaceLABTM eye monitoring system to investigate drivers' eye-movement behaviour, which includes head position, eye glance angle, saccade, blink and the eye fixation on each of 9 pre-defined objects, e.g. left/right/rear view mirrors or in-vehicle display areas. For a more detailed description of the Eye Tracking System, see (Yang et al., 2009).

Experiment Description

An instrumented vehicle was used to collect the data in the field test. The primary task in this experiment was asking drivers following the cars ahead on a selected section of motorway to gain a relatively fixed primary task workload. The test route was a dual carriageway (A34) near Southampton. In each trail, participant was required to drive in varying traffic volume for about 2 hours. The instruction was given to the participant following the leading vehicle at a distance at which they feel comfortable and safe, and not to overtake the leading vehicles.

The secondary tasks were to perform by manipulating 9 typical in-vehicle operations through several different types of Human Machine Interfaces (HMI). The operations of the secondary tasks are given below.

- Turning the radio on;
- Turning the CD player on;
- Changing CD disk;
- Changing CD track;
- Turning the climate control on;
- Changing temperature setting;
- Cellular phone dialling by name;
- Cellular phone dialling by number;
- Entering destination for navigation system.

The visual behaviour while interacting with two of these HMI interfaces, which well presented the performance of typical visual and mental in-vehicle tasks, were selected for the purpose of this study. The interface which presenting the visual tasks is an intuitive-voice interface with the instructions prompted on a central display. When doing this type of tasks (visual tasks), drivers vocally give out the instructions to the in-vehicle system by the reading the prompt instruction. This interface was designed to reduce the mental workload of remembering the task instruction by compromising higher visual workload. While for the mental tasks, the interface is a traditional voice interface, by which drivers have to memorise the instruction beforehand, try to remind themselves during task performing and give out the instructions vocally.

12 subjects (6 male, 6 female) aged from 30 to 60 whose mileage per year is more than 5k attended this study. All subjects held full UK driving licenses. The on-road trials were carried out under guidance of an experimenter. On arrival, participants were given experimental instructions and briefings for driving and in-vehicle operation tasks. After the vehicle calibration, the drivers were giving 20 minutes practice driving to familiarize with the vehicle. During the test trial, the participants were asked to follow a leading vehicle, and perform the 9 test tasks using the different interfaces following the instruction of the experimenter. After completion of all the secondary tasks, the subject was asked to perform the normal car-following task, i.e. following the leading vehicles, to produce a control condition. Each subject ran the three trials in different date.

ANALYSIS METHOD

Apart from task duration, in total, 24 different eye movement measurements was extracted from raw data and analysed for almost every secondary task condition (some in-vehicle display related measurements are not available in metal tasks, for example, fixation duration on in-vehicle display). The explanation of each measurement will be given in the results. The analysis was carried out by comparing the effect of mental and visual tasks on drivers' eye movement measurements to the control condition. Because of equipment fail, only 28 datasets in 36 were analysed in this study. T-test was used to analysis the effect over these 28 datasets.

RESULTS

1. TASK DURATION

The visual interface showed a trend of benefit of the visual prompt in terms of shorter task duration, i.e. the average duration over 9 tasks reduced from 15.9 seconds when performing by traditional voice interface to 15 seconds, but the effect was margin ($t(27) = 1.37$, $p=0.09$).

2. EFFECT OF VISUAL TASKS ON DRIVERS' EYE MOVEMENT

Standard deviation of gaze angle

In order to investigate the impact of in-vehicle tasks on the gaze area, the standard deviation (SD) of gaze angle is investigated, which represents the glance deviation from eye gaze centre in each task. Therefore, a higher deviation of gaze angle suggests the larger visual searching area. An significant of increase of the SD of gaze angle from 12.30 in the control (baseline) to 13.73, (T(27) = -2.56, p = 0.02), was fount during performing the visual tasks, indicating more visual searching.

Percentage of time on each area (windscreen, mirror, in-vehicle display and others)

Distributions of fixation location were observed by comparing the control condition and during visual task. The experiment results showed that the percentage of time looking at windscreen has been reduced from 80% in control condition to 71% when engaging in visual tasks, T (27) = 3.45, p = 0.001, (p<5%), and the percentage of time checking on the mirrors is reduced from 5.6% to 4.2%, T(27) = 3.18, p = 0.003, (p<5%). Meanwhile, the percentage of time looking at the in-vehicle display is 7% during the visual tasks. The distributions of gaze percentage on different objects in control condition and during visual tasks performing are illustrated in Figure 1.

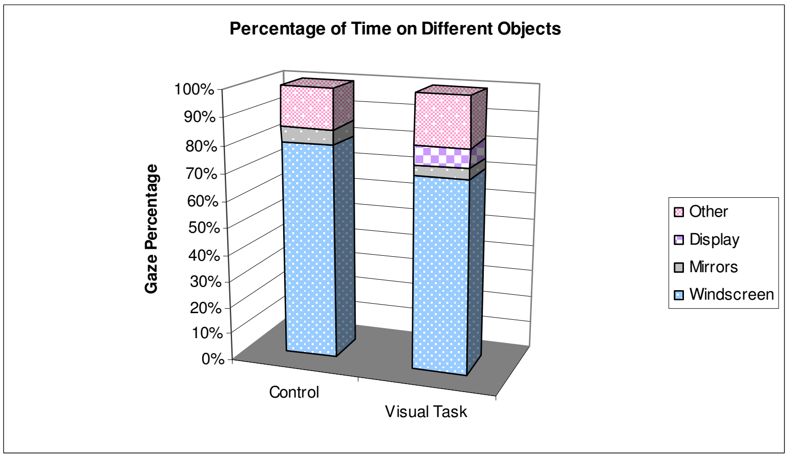
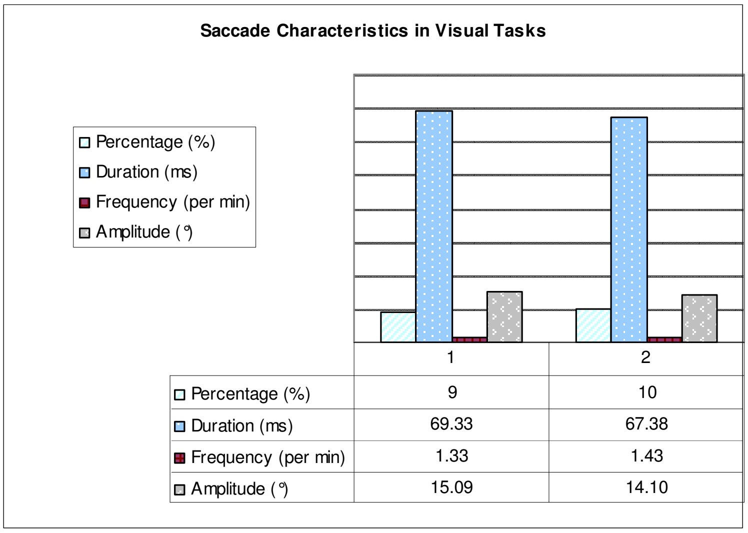


Figure 1 – Gaze Percentage on Different Objects

Saccade (percentage, duration, frequency, amplitude)

Saccade is another important parameter of the eye-movement behaviours. The change of saccade duration, frequency, velocity, and amplitude in the control and visual tasks is demonstrated in Figure 2. There was no significant change in terms of saccade percentage, (t (27) = -0.57, p = 0.58) and saccade frequency (T(27) = -0.78, p = 0.44). The saccade duration is decreased from 69.3ms to 67.3ms, (T(27) =2.4, p = 0.02), but the change was minor, only 2%, which suggested that the saccade duration may not be a convincing measurement. The saccade Amplitude was found to decrease by 11%, from 15.08 to 14.1, T(27) = 3.34, p = 0.02.



	1	2
Percentage (%)	9	10
Duration (ms)	69.33	67.38
Frequency (per min)	1.33	1.43
Amplitude (°)	15.09	14.10

Figure 2 – Saccade Characteristics in Visual Tasks

Blink

The visual tasks had no significant effect on the blink, which is a complicated measure especially when both visual and mental workload involves.

Fixation Frequency on Mirrors

The fixation frequency on mirrors when performing visual tasks decreased about 25%, from 8 time per minute, averagely to 6 times per minute, $T(27) = 3.26$, $p = 0.003$, ($p<0.05$). It was proposed from previous research that the mirror using is a indicator of collecting crucial driving-related information (Pastor et al., 2006), therefore, the decrease in mirrors checking may suggest an effect of omitting some driving information while encounter to higher visual workload.

3. EFFECT OF MENTAL TASKS ON DRIVERS' EYE MOVEMENT

As discussed above, since there was no visual demand required in mental task, the effect of it was unsurprisingly different with that of visual task. The results showed that most of the eye movement measurements listed above were not influenced by the metal task performing compare with control condition (i.e. "normal" car following). However, paired T-test showed that three "blink" parameters changed significantly during mental tasks (Detail see Table 1).

Table 1 - Blink measurements during mental tasks

	Baseline	Auditory Task	T-value	df	p-value
Blink Percentage (%)	0.10	0.13	-3.67	27	<0.01
Blink Duration (ms)	182.19	187.66	-3.09	27	<0.01
Blink Frequency (times per min)	0.52	0.65	-3.27	27	<0.01

The Blink Percentage shows the percent in terms of time when blink happened when performing mental tasks. Blink Duration is the average over duration of each blink in mental task conducting. Blink Frequency presents the measurements of averagely how many times blinks occur per minute. As it shows in table 1, drivers' blink percentage increased about 30%, and blink frequency in per minute increased 25% while engaging in mental tasks. The increase of blink duration is significant but minor, only 3%, which suggested that this measurement is more stable across mental task and normal driving.

Comparing to other widely used eye movement measurements, for example percentage of road ahead and fixation time on in-vehicle display, blink is a less well know measure of non-spontaneous eye activity (Neumann and Lipp, 2002). It responds differently to specific environmental stimuli. When visual workload is high, blink frequency and duration decrease since visual input is disrupted when eye-lids close. On the other hand, blink frequency increases when the task requires the eyes frequently moving from one object to another, because blinks tend to punctuate the end of an episode of information intake (Fogarty and Stern, 1989).

While performing mental task, no extra vision was required. The effect on eye blink suggested increase of mental workload (Recarte et al., 2008).

DISCUSSION AND RECOMMENDATION

In order to investigate the impact of the increased visual workload on drivers' visual behaviour, many different eye movement measurements were analysed during visual and mental tasks. Comparing to some surrogate in-vehicle tasks (Jamson and Merat, 2005) or tasks which involves decision making and computation (Blanco et al., 2006), the tasks selected in this study are relatively easier and therefore even higher workload was induced, the extra workload is still in the acceptance of drivers. Because of the visual aid provided by the visual tasks, there was a significant benefit when performing tasks by visual interface in terms of task duration.

When performing visual tasks, the increases of deviation of gaze angle indicated more visual searching behaviour. A different distribution of fixation location was found, i.e. during visual tasks, drivers spent less percent of time looking at windscreen and mirrors, and more time was contributed to looking at in-vehicle display. Frequency on mirrors decreased significantly, which is an indication of drivers compromising the information intake in extra visual workload. The findings reflect the increased visual workload.

It was also found that the saccade duration became shorter and saccade amplitude reduced while visual tasks. This may caused by the location of in-vehicle display, which is quite close to driver, therefore when more searching was made that location, therefore, saccade was observe as shorter and the amplitude decrease.

No significant effect on eye blink was found in visual tasks, one of the explanations is that blink is a complicate measurement, especially when both visual and mental workload

involves. There is no significant change in duration on windscreen and mirrors, suggesting these measurements may not be suitable for not severe visual workload.
The in-vehicle tasks that do not require extra visual demands, i.e. mental tasks, have a different impact on drivers' eye movement compared to those that required extra vision. In this study, the impact of mental tasks on drivers' eye movement was found mostly on eye blink measurements. A higher blink percentage, a slightly longer blink duration, and higher blink frequency were found when performing mental tasks. According to physiclogical explanation, these findings suggest the higher mental workload when no extra vision is required.
To answer the questions in research objectives, the results showed that visual tasks caused increased deviation of gaze angle, less percentage of time looking at windscreen and mirrors, and more time on in-vehicle display. When performing visual tasks, drivers looked at mirrors less frequently comparing to control condition; while when performing mental tasks, drivers' blink more often and for a slightly longer. These findings were tested to be suitable and sensitive to the impact of in-vehicle tasks on drivers' eye movement. All these findings suggested the potential of using eye movement to help monitoring drivers' workload as a real-time tool. However, it needs to be bear in mind that driving is a complex task with many elements which could impact on drivers' visual behaviour. Meanwhile, the eye movement itself is very sensitive and task-specific. Therefore there are two preconditions of effectively using eye movement in the future research:

- The eye movement measurements have to be considered and analysed in the frame of task characteristics, and each eye movement parameter has to be well understood in each task condition;
- The future eye movement research is expected to reveal more of the cognitive processes that are hidden behind the eye movement pattern in driving.

REFERENCES

Ahlstrom, U. and F. Friedman-Berg (2005). Subjective workload ratings and eye movement activity measures. Federal Aviation Administration, William J. Hughes Technical Center.

Angell, L., J. Auflick, P. A. Austria, L. Tijerina, W. Biever, T. Diptiman, J. Hogsett and S. Kiger (2006). Driver workload metrics project - Task 2, Final Report. NHTSA.

Blanco, M., W. J. Biever, J. P. Gallagher and T. A. Dingus (2006). The impact of secondary task cognitive processing demand on driving performance. Accident Analysis and Prevention, 38, 895-906.

Coeckelbergh, T. R. M., F. W. Cornelissen, W. H. Brouwer and A. C. Koojjman (2002). The effect of visual field defects on eye movements and practical fitness to drive. Vision Research, 42, 669-677.

Crundall, D., G. Underwood and P. Chapman (1999). Driving experience and the functional field of view. Perception 28, 1075-1087.

Department for Transport, Scottish Government & Welsh Assembly Government (2009). Reported road casualties Great Britain: 2008 Annual Report. London: The Stationery Office.

Fogarty, C. and J. A. Stern (1989). Eye movements and blinks: Their relationship to higher cognitive processes. International Journal of Psychophysiology, 8, 35-42.

Harbluk, J. L., Y. I. Noy, P. L. Trbovich and M. Eizenman (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. Accident Analysis & Prevention, 39, 372-379.

Hoffman, J. D., J. D. Lee, D. V. McGehee, M. Macias, A. W. Gellatly (2005). Visual sampling of in-vehicle text messages - Effects of number of lines, page presentation and message control. 84th Annual Meeting of the Transportation-Research-Board. Washington, DC, Transportation Research Board National Research Council.

Horberry, T., J. Anderson, M. A. Regan, T. J. Triggs and J. Brown (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. Accident Analysis and Prevention, 38, 185-191.

Jamson, A. H. and N. Merat (2006). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. Transportation Research Part F - Traffic Psychology and Behaviour, 8, 79-96.

Land, M. and J. Horwood (1995). Which parts of the road guide steering? Nature, 377, 339-340.

Lansdown, T. C. (2001). Causes, measures and effects of driver visual workload. In: Stress, Workload, and Fatigue (P. A. Hancock and P. A. Desmond ed.). pp. 351-372.Lawrence Erlbaum Associates.

Lin,Y., W. J. Zhang and L. G. Watson (2003). Using eye movement parameters for evaluating human-machine interface frameworks under normal control operation and fault detection situations. International Journal of Human-Computer Studies, 59, 837-873.

McDonald, M. and M. Brackston (1997). The role of the instrumented vehicle in the collection of data on driver behaviour. IEE Colloquium on Monitoring of Driver and Vehicle Performance, 122, 7/1-7/3.

Neumann, D. L. and O. V. Lipp (2002). Spontaneous and reflexive eye activity measures of mental workload. School of Psychology, The University of Queensland, Australia.

Nunes, L. and M. A. Recarte (2002). Cognitive demands of hands-free- phone conversation while driving. Transportation Research Part F: Traffic Psychology and Behaviour, 5, 133-144.

Olsson, S. and P. C. Burns (2000). Measuring driver visual distraction with a peripheral detection task. NHTSA Driver Distraction Internet Forum, Washington, DC.

Pastor,G. P., Tejero, M. Choiz and J. Roca (2006). Rear-view mirror use, driver alertness and road type: An empirical study using EEG measures. Transportation Research Part F: Traffic Psychology and Behaviour, 9, 286-297.

Recarte, M. A. and L. M. Nunes (2000). Effects of verbal and spatial- imagery tasks on eye fixations while driving. Journal of Experimental Psychology: Applied, 6, 13-18.

Recarte, M. A. and L. M. Nunes (2003). Mental workload while driving: Effects on visual search, discrimination, and decision making. Journal of Experimental Psychology: Applied, 9, 119-137.

Recarte, M. A., E. Perez, A. Cconhillo and L. M. Nunes (2008). Mental workload and visual impairment: Differences between pupil, blink, and subjective rating. The Spanish Journal of Psychology, 11, 374-385.

Ranney, T. A., E. Mazzae, R. Garrott and M. J. Goodman (2000). NHTSA driver distraction research: Past, present and future. NHTSA.

Rantanen, E. M. and J. H. Goldberg (1999). The effect of mental workload on the visual field size and shape. Ergonomics, 42, 816-834.

Rogmin, L., I. Grimaud, E. Hoffman and K. Zeghal (2004). Assessing the impact of a new instruction on air traffic controller monitoring tasks. The International Conference on Human-Computer Interaction in Aeronautics, AAAI Press, Toulouse, France.

Strayer, D. L. F. A. Drews and W. A. Johnston (2003). Cell phone induced failures of visual attention during simulated driving. Journal of Experimental Psychology: Applied, 9, 23-52.

van Orden,K. F., T.-P. Jung and S. Makeig (2000). Combined eye activity measures accurately estimate changes in sustained visual task performance. Biological Psychology, 52, 221-240.

van Orden,K. F., W. Limbert, S. Makeig and T.-P. Jung. Eye activity correlates of workload during a visiospatial memory task. Human Factors, 43, 111-121.

Victor, T. W., J. L. Harbluk and J. A. Eenstrom (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. Transportation Research Part F-Traffic Psychology and Behaviour, 8, 167-190.

Wang, J. S., R. R. Knipling and M. J. Goodman (1996). The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. The 40th Annual Proceedings of the Association for the Advancement of Automotive Medicine, Vancouver, British Columbia.

Wickens, C. D. (1987). Attention. In Human Factors Psychology (P. A. Hancock ed.), pp. 29-80. Elsevier, Amsterdam.

Wierwille, W. W. (1993a). Demands on driver resources associated with introducing advanced technology into the vehicle. Transportation Research Part C, 1, 133-142.

Wierwille, W. W. (1993b). Visual and manual demands of in-car controls and displays. In Automotive Ergonomics (B. Peacock and W. Karowowski, ed.), Taylor & Francis, London.

Wierwille, W. W. and L. Tijerina (1996). An analysis of driving accident narratives as a means of determining problems caused by in-vehicle visual allocation and visual workload. In Vision in Vehicles (V, A. G. Gale, ed.), North-Holland, Amsterdam.

Wilson, G. F. and F. T. Eggemeier (1991). Psychophysiological assessment of workload in multi-task environments. In Multiple-Task Performance (D. L. Damos, ed.), Taylor & Francis, London.

Wilson, G. F., J. D. Lambert and C. A. Russell (2000). Performance enhancement with real-time physiologically controlled adaptive aiding. The Human Factors and Ergonomics Society 44th Annual Meeting, Santa Monica, CA.

Yang,Y., M. McDonald, P. Zheng and M. Shehab (2009). The effect of heavy goods vehicles on drivers' visual behaviours. The 16th World Congress for ITS Systems, Stockholm, Sweden.

Zeghal,K., I. Grimaud, E. Hoffman and L. Rognin (2002). Delegation of spacing tasks from controllers to flight crew: Impact of controller monitoring tasks. The IEEE/AIAA Digital Avionics Systems Conference, IEEE Press, Irvine, CA.

Zheng, P., M. McDonald and C. Pickering (2008). Effects of intuitive voice interfaces on driving and in-vehicle task performance. The 11th International IEEE Conference on Intelligent Transportation Systems, Beijing, China.