Title

The effects of cognitive distraction on behavioural, oculomotor and electrophysiological metrics during a driving hazard perception task

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Abstract

Previous research has demonstrated that the distraction caused by holding a mobile telephone conversation is not limited to the period of the actual conversation (Haigney, 1995, Redelmeier & Tibshirani, 1997**,** Savage, Potter & Tatler, 2013). In a prior study we identified potential eye movement and EEG markers of cognitive distraction during driving hazard perception. However the extent to which these markers are affected by the demands of the hazard perception task are unclear. Therefore in the current study we assessed the effects of secondary cognitive task demand on eye movement and EEG metrics separately for periods prior to, during and after the hazard was visible. We found that when no hazard was present (prior and post hazard windows), distraction resulted in changes to various elements of saccadic eye movements. However, when the target was present, distraction did not affect eye movements.

We have previously found evidence that distraction resulted in an overall decrease in theta band output at occipital sites of the brain. This was interpreted as evidence that distraction results in a reduction in visual processing. The current study confirmed this by examining the effects of distraction on the lambda response component of subjects eye fixation related potentials (*EFRP*s). Furthermore, we demonstrated that although detections of hazards were not affected by distraction, both eye movement and EEG metrics prior to the onset of the hazard were sensitive to changes in cognitive workload. This suggests that changes to specific aspects of the saccadic eye movement system could act as unobtrusive markers of distraction even prior to a breakdown in driving performance.

Keywords: Hazard Perception, Distraction, Eye Movements, Eye Fixation Related Potentials

1. Introduction

Conversing on the telephone has been shown to impair performance on a wide variety of different driving related tasks (DE Haigney, Taylor, & Westerman, 2000; Strayer, Drews, & Johnston, 2003; Törnros & Bolling, 2005). Obviously, physically interacting with a hand held device diverts motor and visual resources away from the task of driving. However, it is the cognitive demands of conversing on the phone that appear to play a central role in the impairments that ensue from telephone use in vehicles. Indeed, previous work has demonstrated that hands free and hand held devices produce similar levels of distraction (Lamble, Kauranen, Laakso, & Summala, 1999; Patten, Kircher, Östlund, & Nilsson, 2004; Strayer & Johnston, 2001). On top of this, it seems that the distraction caused by telephoning may not be limited to the period of the conversation itself (D Haigney & Taylor, 1998; Redelmeier & Tibshirani, 1997), likely arising from cognitive preoccupation with the content of the preceding conversation. Distraction from cognitive preoccupation such as this poses a particular challenge for efforts to improve driver safety and reducing the risk of vehicular accidents: while it is possible to legislate against the use of telephones (hand held or hands free), cognitive preoccupation can come from a variety of sources from contemplating a prior conversation, listening to a quiz on the radio, to constructing a shopping list on the way to the supermarket. Such sources of distraction – similarly to driver fatigue – cannot be legislated against; however, if it is possible to objectively detect when a driver is distracted, then assistive devices can be developed to intervene in such safety critical scenarios. It is therefore unsurprising that research effort has been devoted to identifying objective markers of distraction and fatigue (such as fixation durations, blink rates, blink numbers and head dips – while driving (Philip et al., 2005; Savage, Potter, & Tatler, 2013).

Previous work has demonstrated that variations in cognitive load can affect eye movement measures in a wide variety of different ways during driving tasks. For instance, the introduction of cognitive load resulted in a reduction of the spread of fixations leading to more time being spent fixating on the center of the road (Harbluk, Noy, & Eizenman, 2002; Recarte & Nunes, 2000; Reimer, 2009; Victor, Harbluk, & Engström, 2005). (Harbluk et al., 2002) manipulated the complexity of a mobile telephone conversation, which, along with an increase in the percentage of time spent fixating on the center of the road, resulted in a concurrent decrease in the number of saccades, indicating less extensive scanning of the scene. Fixation durations are often considered to reflect processing time, especially in reading where words that are more difficult to process are fixated upon for longer (Rayner, 1998). Previous work by (Velichkovsky, Rothert, Kopf, Dornhöfer, & Joos, 2002) has shown that the first fixation upon a hazard was typically much longer in duration than those preceding the hazard.

Different characteristics of blinks have been thought to be indicators of both fatigue and mental workload respectively and have both been shown to increase as a function of time on task. Some studies have shown that higher blink rates may be a reliable indicator of mental fatigue and cognitive workload (Fukuda, Stern, Brown, & Russo, 2005; Stern, Boyer, & Schroeder, 1994), whereas other studies have demonstrated that blink durations decreased as a function of primary visual task demand (Ahlstrom & Friedman-Berg, 2006; Benedetto et al., 2011). The different pattern of effects on blink rates and blink durations suggests that cognitive and visual load have qualitatively different effects on blink rates and blink durations: increased blink rates being associated with increases to cognitive load and decreases in blink durations being symptomatic of increases in visual load.

In a hazard perception task, high secondary cognitive task demand resulted in a significant increase in saccade peak velocities (Savage et al., 2013). Saccade peak velocities have also been shown to be affected by mental activation (App & Debus, 1998), alertness (Thomas & Russo, 2007), and mental workload (Di Stasi, Marchitto, Antolí, Baccino, &

Cañas, 2010) as well as drug-induced sedation, sleep deprivation and fatigue (Grace, Stanford, Gentgall, & Rolan, 2010; Schmidt, Abel, DellOsso, & Daroff, 1979; Zils, Sprenger, Heide, Born, & Gais, 2005). Work by Di Stasi and colleagues (2012) specifically has demonstrated that saccade peak velocities decrease as a function of time on task and with increasing mental fatigue. As such we were interested in assessing the effects of cognitive load as well as time on task on the decrease in saccadic peak velocities over time. We predict that increased cognitive workload results in faster mental fatiguing, which will be evidenced by a faster decrease in peak velocities over time. We did not analyse fixation durations, saccade amplitudes, saccade durations; the spread of fixations, blink rates or durations over time as we didn't have a strong theoretical motivation to do so.

From the literature discussed to far it becomes clear that cognitive load has been found to influence a wide variety of oculomotor measures, and these offer attractive, objective measures of the cognitive state of a driver, which, if reliable might provide the underpinnings of in-car monitoring for driver distraction.

Distraction may be revealed not only by changes in oculomotor behaviour, but also by changes in brain activity. Previous driving simulator research has demonstrated that EEG metrics such as theta and alpha frequency power around the time of hazard perception may be good indicators of driver distraction and inattention (Lin, Chen, Chiu, Lin, & Ko, 2011). This is consistent with the finding that changes in cognitive demand results in variations in alpha and theta frequency output (Klimesch, 1999; Klimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). (Savage et al., 2013) found an increase in frontal theta when participants were preoccupied with simultaneously solving puzzles and performing a driving hazard perception task.

While previous research considering how preoccupation influences changes to eye movement behaviour and brain activity throughout the period in which participants conduct a hazard perception task (or other driving-related tasks) provides an overall account of changes that arise from cognitive distraction (e.g., (Klimesch, 1999; Nijboer, Borst, van Rijn, & Taatgen, 2016; Savage et al., 2013; Strayer & Drew, 2004; Strayer & Johnston, 2001), it neglects the fact that the task demands for the driver varies throughout such tasks. Specifically, once a hazardous event appears, the task changes from being vigilant of possible hazards to monitoring the developing hazard. It remains unclear whether the effect of distraction on eye movement behaviour varies as the visual demands of the driver vary. In self-paced settings, previous research has indicated that when the primary driving task becomes difficult, the intrusion of secondary cognitive task demand becomes attenuated (Alm & Nilsson, 1994). Thus drivers modify their driving behaviour to compensate for the demands of the secondary cognitive task.

However, if we are to fully understand and isolate the impact of secondary cognitive load on driver behaviour, it is useful to control the visual and cognitive demands of the driving task and deny drivers the possibility of themselves varying the demands of the primary driving tasks. Driving simulators have been used for a number of years as an ecologically valid alternative to on road driving experiments (Davenne et al., 2012; Underwood, Crundall, & Chapman, 2011). The benefit of driving simulators is that the provide a safe, repeatable and controlled environment in which to examine peoples driving behaviour in response to distracting and even dangerous situations. It is important to acknowledge driving in a driving simulator resembles driving in the real world more closely than watching videos of hazards. Nevertheless, for the purpose of our current study assessing the effects of distraction during a video based hazard perception paradigm has several advantages. For instance, one advantage of the video hazard perception task is that it is not a self-paced activity, which means that, unlike real world or simulated driving, participants are unable to reduce the speed of their vehicle in response to a secondary cognitive task.

Reducing driving speed also reduces the speed at which visual information becomes available. This in turn is thought to free up cognitive resources, which allows for the processing of both cognitive and driving tasks. Thus, the video based hazard perception task offers a method for considering whether secondary cognitive load influences visual exploration behaviour. Specifically, it is possible to compare the period prior to the onset of a hazardous event (when the participant is monitoring for hazards) to the period during which the hazardous event is unfolding and must be monitored; and during the ensuing period after the hazardous event has finished. Producing an account of whether and how secondary cognitive load impacts driver's saccadic eye movement behaviour differently depending on the current demands of the hazard perception task will not only provide new insights into the effects of distraction on driving, but also offer the potential for more effective, context-dependent monitoring of driver distraction for in-vehicle devices.

The main aim of the present study was to consider whether previously-identified markers of cognitive preoccupation vary depending on the demands of the hazard perception task. Models of executive control (e.g., (Corbetta, Patel, & Shulman, 2008; Norman & Shallice, 1986) predict that the intrusion of secondary tasks can become attenuated depending on the content of the primary task. Any identified differences in the susceptibility of oculomotor metrics to increases in cognitive task demand may therefore indicate which portion of the hazard perception task was most demanding for participants (before, during or after the hazard onset).

A second key aim of the present work was to consider in more detail the claim made by (Savage et al., 2013) that the overall decrease in occipital theta found during the hazard perception task when cognitively preoccupied was indicative of a reduction in visual processing efficiency. To test this hypothesis, the current study examined differences in Eye Fixation Related Potentials (*EFRP*) between high and low cognitive task demand conditions.

The major advantage of event related potentials (ERPs) is that the time course of cognitive processing can be measured with a high temporal resolution (Kutas & Hillyard, 1983). *EFRP*s were first described by Yagi and colleagues (Yagi, Imanishi, Konishi, Akashi, & Kanaya, 1998; Yagi & Ogata, 1995) and are defined as the measurement of electrical brain activity in response to an eye fixation. The difference between the *EFRP* methodology and the more conventional ERPs is that the average waveforms are time-locked to the onset of a fixation and not to the onset of a stimulus event. As a technique they have been found to be very effective for establishing a timeline of early cognitive processes (Baccino & Manunta, 2005). In the past *EFRP*s have been used to disentangle cognitive/perceptual and attentional factors that affect lexical processing. More recently Hutzler and colleagues (Hutzler et al., 2007) have validated the use of *EFRP*s in real world, ecologically valid settings. One of the most prominent components of *EFRP*s is the lambda response. This is a positive deflection occurring around 80 ms from the onset of a fixation (Kazai & Yagi, 2003)and has been shown to vary depending on the properties of the visual stimuli and attention (Kazai & Yagi, 1999). As such we were particularly interested in determining any differences in *EFRP*s between our high and low cognitive load conditions for the period 50-150 ms after the onset of fixations.

2. Methods

2.1. Design

In this within-subjects experimental design the independent variable was secondary cognitive task demand, which was either high or low. Cognitive load was manipulated by the type of audio clip presented to participants prior to the beginning of the trial. Cognitive load was considered to be high following a wordlist that the participant was required to rehearse during each hazard perception clip and recall at the end of it. The cognitive load task was always presented prior to the start of the hazard perception clip. We included a 1.5 second blank period after the end of the auditory clip and the onset of the video clip for both the high and the low load conditions. This was done in order to assess the effects of cognitive load in isolation from processes involved in language comprehension and production. Participants' performance was compared to control trials following an easy question (e.g., "*What is the capital city of England*"), which participants were required to answer at the end of each trial (low cognitive load). The dependent variables were grouped into three major categories: (1) behavioural, (2) oculomotor, and (3) electrophysiological. Behavioural independent variables consisted of participants' RTs to hazardous events, False Responses (FRs) to non-hazardous events and Missing Responses (MRs) to hazardous events. Dependent variables relating to oculomotor metrics consisted of first saccade latency, fixation durations, saccade amplitudes, saccade durations, average saccade peak velocities, the horizontal spread of fixation positions, blink rates, blink durations and changes in saccadic peak velocities over time. Dependent variables relating to electrophysiological metrics consisted of 1) overall mid-theta (4 - 7 Hz Band) across the full duration of each 30 second hazard perception clip; and 2) the average activity in the 50-150 ms window after the onset of each fixation (eye fixation related potentials – *EFRP*s).

2.2. Participants

17 Participants (7 males) were recruited in and around the University of Dundee by means of the Universities Research Participation System ''*SONA*''. All testing was carried out in the Research Wing of the School of Psychology at the University of Dundee. Participation typically lasted no longer than 2 hours (around 30 minutes for the experimental trials with the rest of the time spent setting up and ensuring good quality data collection for the EEG recordings, gathering informed consent and debriefing participants) and participants were compensated with either course-credit or chocolate. Participants' ages ranged between 18 and

28 (mean age 23). To ensure all participants were familiar with the hazard perception portion of the test, all subjects were required to be in possession of a DVLA approved driver's license and must have been driving for a minimum of 1 year[1]. The University of Dundee's Ethics review board approved this study. The study was conducted in accordance with the tenets of the Declaration of Helsinki.

2.3. Materials

Participants sat at a table with their heads supported by a chinrest 62.5 cm away from a 20" CRT-Monitor on which the visual stimuli were displayed. Subjects were instructed to indicate their responses using SR-Research button boxes. Experiment Builder software by SR-Research was used to program the presentation of the audio and visual stimuli.

Participants' eye movements were recorded using an EyeLink1000 eye-tracker sampling at 1000 Hz and cortical activity was recorded using a 40 channel, BioSemi active electrode system sampling at 2048 Hz, which was connected to a dedicated recording computer utilising BioSemi - Activision software.

For this study we used a total of 32 DVLA approved hazard perception clips, which were provided courtesy of Focus Multimedia Ltd. and Imagitech Ltd. The onset of the hazard in each clip was predefined by Focus Multimedia Ltd. and Imagitech Ltd in the form of screenshots which can be seen in the Appendix. Each video was clipped from 60 to 30 seconds and each clip contained only one clearly identifiable hazard. When truncating the hazard perception clips we made sure that hazards were not within 5 seconds of the start or the end of the clip so that we always had a clearly identifiable prior, during and after window.

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[1] We did not gather data on driving experience beyond this check that participants had held a full license for at least a year. This is because we wanted to ensure familiarity with the hazard perception test, but were not concerned with driving experience more generally.

Within these 30-second clips, hazard onset times varied considerably with a mean of 13.8 s (SD = 5.5 s), ranging from 5.0 s to 22.2 s. The hazardous events lasted for an average of 5.8 s(SD = 2.3 s, range = 2.9 – 10.9 s).

We made use of sixteen 10-item wordlists and sixteen easy to solve questions to manipulate cognitive load (See Appendix 7.1 & 7.2). These wordlists and questions were presented via a set of Logitech loudspeakers at a comfortable but constant volume.

2.4. Procedure

Participants were instructed to fixate on a central fixation point prior to beginning of each trial. Depending on the condition, participants were presented with an easy question (low cognitive load condition – e.g. ‘‘*What is the capital city of Scotland?*’’) or a 10-item wordlist directly before the start of the hazard perception clip. Words within the wordlist were presented at a frequency of 1 every 1.5 seconds resulting in a total audio duration of 15 seconds and each hazard perception clip was of a fixed length of 30 seconds. In both conditions participants were instructed to indicate the onset of hazards in the clip by pressing a button on a response-box. At the end of each trial, depending on the condition, participants were asked to verbally state out loud the answer to the previously presented question (low load) or recall as many words as possible from the previously presented wordlist (high load).

Participants completed one practice trial from each condition prior to the start of testing to familiarize them with the procedure. Participants then completed 15 trials in each condition. The presentation order of conditions was randomly interleaved across trials and the pairing of hazard perception clip and type of audio clip was counterbalanced across participants. EEG and eye movement data were recorded for the full duration of each trial.

2.5. EEG recording

Stimuli were presented using SR-Research Experiment-Builder software with event codes simultaneously sent to the EEG recording system via the TTL parallel output port. Event codes were used to define each clip as well as its appropriate condition in order to guide later analysis. In order to be able to analyse eye fixation related potentials the timings of fixations and saccades were extracted from the raw data and merged with the stimulus events by means of custom-made MatLab routines. Recordings were carried out using a BioSemi CHA-01 active electrode system with a digital sampling rate of 2048 Hz. We used 32 electrodes fitted to an elastic cap. Electrodes were placed according to the 10–20 system at scalp sites of Fp1, Fp2, AF3, AF4, F7, F8, F3, F4, Fz, FC1, FC2, FC5, FC6, T7, T8, C3, C4, Cz, CP1, CP2, CP5, CP6, P3, P4, Pz, P7, P8, PO3, PO4, O1, O2, Oz. Additionally, electrodes were positioned above and below the right eye to monitor the timings of vertical eye movements (VEOGs), at the outer canthi of both eyes for horizontal eye movements for later artifact removal, and on the left and right mastoids and nose to provide alternative reference sites. Electrode sites were prepared with alcohol to reduce scalp impedances. Sigma conductivity gel was applied to each cap electrode fitting point. After pre-processing using PolyRex software (J Kayser, 2003), the data were ultimately analysed using BrainVision Analyser software.

2.6. EEG data processing

In the data pre-processing stage the EEG recordings were down-sampled to the same rate as the Eye Tracker (1000 Hz) using BDF Decimator82. Recordings were then re-referenced to the linked nose reference site using PolyRex version 1.2 (Jürgen Kayser & Tenke, 2003). Stimulus event codes were used to first segment out all valid trials from the continuous EEG data and baseline corrected. The data were then processed for further analyses with a Butterworth Zero Phase Filter with low cut-off frequency of 45 Hz and a high cut-off frequency of 0.53 Hz and a 48dB/oct slope. An Ocular Correction Independent Component Analysis (OC ICA) was then performed on the whole data using a bipolar electrode pair above and below the right eye to identify blink activity and a bipolar electrode pair positioned at the outer canthi of the left and right eyes to identify horizontal eye movement activity. Stimulus event codes were then used to segment the data into high and low load conditions for further analyses. In order to analyse *EFRP*s, EEG and oculomotor measures were recorded separately and then merged by means of a series of custom developed MatLab routines.

2.7. EEG analysis

2.7.1. Overall Frequency differences between conditions

Fast Fourier Transformation was performed on the entire 30 second epoch of each hazard perception trial using a periodic 10% Hamming Window and a resolution of 0.03125 Hz. We then averaged the results for each condition and compared overall power in mid-theta (4 - 7 Hz Band) frequency output. Overall power for this frequency range was calculated for each electrode by measuring the area under the curve of on-going fluctuations in theta band power for both high and low cognitive load conditions

2.7.2. Differences in eye fixation related potentials (EFRPs)

Fixation event codes were used to segment windows 150 ms prior and 600 ms after the onset of each fixation. These segments were averaged and then baseline corrected (BC) on the epoch 150 ms prior to fixation onset to determine differences in overall activity between high and low cognitive load conditions.

2.8. Eye movement recording

Eye movements were recorded using an SR Research EyeLink1000 eye-tracker, sampling at 1000 Hz. Each participant completed three brief eye dominance tests prior to the start of testing so that the experimenter was able to track the subject's dominant eye. A 9-point calibration procedure was used to calibrate the tracker and repeated to validate tracker accuracy. If the validation procedure showed an average error in excess of 0.5° or a maximum error in excess of 1°, the calibration procedure was repeated. Saccades were identified using the standard SR Research algorithm, which detects saccades when eye position deviates by more than 0.1°, with a minimum velocity of 30 deg s^{-1} and a minimum acceleration of 8000 deg s^{-1}, maintained for at least 4 ms. Data were exported to custom-made MatLab routines for subsequent analysis of saccade, fixation and blink events.

2.9. Neurophysiological Measures

Participants' grand averages (GAs) for the theta frequency band was calculated by measuring the area under the curve for each pre-defined frequency range within a specified time window. Similarly, GAs for *EFRP*s were generated by calculating the area under the curve of on-going fluctuation within the specified time windows. We analyzed differences in subjects' EEG measures between high and low cognitive load conditions. However as the length of pre during and post hazard appearance windows were all of different for each clip, we did not attempt to analyze differences in EEG measures across these different time windows. A text file containing participants GAs at each of the 32 electrode sites for high and low cognitive load conditions was exported from BrainVision. In order to explore at which electrode sites significant differences between high and low load could be identified, GAs were analysed in SPSS using paired-samples t-tests.

2.10. Statistical analysis

The hazard perception clips were segmented into three time windows. These time windows were defined as being 1) before the onset of the hazard 2) during the period in which the hazard was on screen; and 3) after the hazard had disappeared from the screen. The analyses were aimed at examining the susceptibility of our dependent variables to increases in cognitive load across these three time windows. Data were analysed using Linear Mixed Models (LMMs) using the *lme4* package (version, 1.1-7; (Bates, Mächler, Bolker, & Walker, 2014) in the *R* statistical programming environment (R Core Team, 2018) LMMs are particularly well suited to datasets such as those collected in this study for several reasons: 1) they are able to deal with uneven distributions of data between conditions in the design; 2) they can combine continuous and categorical factors within the same model; and 3) they can measure variance across subjects and items simultaneously (Kliegl, Dambacher, Dimigen, Jacobs, & Sommer, 2012). In constructing models, time window (before, during and after hazard onset) and cognitive load (high vs. low) were entered as fixed effects in all models. For models of saccade duration and saccade peak velocity, saccade amplitude was also entered into the models as a fixed effect because of the known relationship between saccade amplitude and these measures (Bahill, Clark, & Stark, 1975).

Subjects and items (hazard perception movie) were entered as random effects in all models. Given the variation in timings of hazard onset and duration reported above together with the nature of hazardous events seen in the screenshots in the Appendix, the inclusion of the by-item random effect term is particularly important to ensure that any variations between clips that arise from the variation in hazards are accounted for in the results that we report. For the random effects structure we attempted to include random slopes and intercepts for all fixed effects and their interactions in order to produce a maximal random effects structure (Barr, Levy, Scheepers, & Tily, 2013). However, maximal structure models often fail to converge. When these models did not converge, we first removed the computation of correlation parameters within the random effects structures. If further simplifications were required for model convergence, we began by simplifying the item term, first, by removing the slopes for the interaction between time window and cognitive load. Following this, the random slope for time window was removed from the item term before removing the slope for cognitive load if necessary (leaving an intercept-only item term in the random effects structure). Throughout simplification of the item term the full structure for the subject term was retained (minus correlation parameters). If models still did not converge once the item term was simplified, the same stepwise simplification procedure was followed for the subject term. In the sections that follow the results are reported for the most complex random effects structure for which the LMM converged.

For all models we report the predictors' coefficient (β), its standard error (SE) and the t- (for linear models) or z- (for binomial models) values. For linear models, *p*-values are not directly supplied by lme4 package, but were generated using the lmerTest library (Kuznetsova, Brockhoff, & Christensen, 2017). For comparisons between time window, we used a categorical predictor with three levels (before, during and after the hazard), coded for simple contrasts to compare each of before and after the hazard to the time when the hazard was visible.

3. Results

3.1. Behavioural Measures

Prior to analyzing our behavioural, oculomotor and electrophysiological data, we wanted to examine whether performance on the easy and difficult cognitive load tasks was different. We did this in order to confirm that our wordlist task was harder than answering a simple question. Only if performance on the high load task was different from the low load task would we be able to confirm that subjects were devoting attention resources to the secondary task. Therefore we first compared subject's performance on the wordlist task (high cognitive load) to their performance on the simple questions task (low cognitive load). We found that subject's performance on the high load task (52.78% correct) was significantly worse than their performance on the low cognitive load task (100% correct), $t(16)= -16.1$; $p< .001$.

To examine overall differences in behavioural responses to the hazard perception clips between conditions irrespective of time windows, the construction of LMMs was carried out as described above without including time window in the fixed effect term. Measured from the appearance of the hazard on screen we found no significant effect of cognitive load on response times (RTs), $\beta = .01$; *SE*= .03; *t*= -.32; *p* = .74, or erroneous responses to non-hazardous events in the movies (false responses; FRs), $\beta = -.19$; *SE*= .11; *t*= -1.82; *p*= .08. Analyses of trials in which the hazardous event was missed (missing responses; MRs) were not carried out, as there were no recorded cases. Average RTs and FRs for both high and low cognitive task demand conditions can be seen in Table 1.

Table 1. Average reaction times (RTs) in milliseconds and false responses (FRs) per clip between both high and low cognitive load conditions along with standard deviations (in parentheses)

Measure	**High Load**	**Low Load**
RTs [*ms*]	2703 (*1913*)	2668 (*1636*)
FRs [*per clip*]	1.32 (*1.51*)	1.40 (*1.65*)

3.2. Oculomotor Measures

Prior to considering differences across the three time windows in the clips, we modeled first saccade latency after the onset of each clip. This measure provides an indication of planning processes and is useful in understanding the effect of cognitive load. An LMM with a single categorical fixed effect of cognitive load showed that first saccade latencies were longer in the high load condition (*M* = 344 ms, *SD* = 215) than in the low load condition (*M* = 289 ms, *SD* = 152), $\beta = .06$, *SE*= .02, *t*= 2.63, *p*= .013.

We then modeled effects of cognitive load across the three time periods (before hazard onset, during hazard appearance and after hazard disappearance) in each hazard perception clip on fixation durations, saccade amplitudes, saccade durations, saccade peak velocities, the horizontal spread of fixation positions, blink rates and blink durations, with separate LMMs for each oculomotor measure. Table 2 summarises these measures across the three time windows and across cognitive load conditions.

Fixation durations were significantly longer during the period in which the hazard was on screen compared to both period before, $\beta = 19.1$, $SE = 3.25$, $t = 5.87$, $p < .001$, and after, $\beta = 26.7$, $SE = 3.25$, $t = 7.98$, $p < .001$, the hazard was present. Moreover, the effect of load differed between the periods before and during the hazard, $\beta = 16.62$, $SE = 6.26$, $t = 2.66$, $p = .008$. A follow-up LMM was run to explore this interaction and showed that cognitive load had an effect while the hazard was present on the screen, $\beta = 17.7$, $SE = 5.52$, $t = 3.20$, $p = .001$, with shorter fixation durations in the high load condition; but there was no effect of cognitive load in the period before the hazard onset ($t < 1$).

For the LMM to predict saccade amplitudes, saccade amplitudes were log-transformed to satisfy model assumptions. Saccade amplitudes were significantly smaller in the period during which the hazard was onscreen as compared to the time windows before, $\beta = .14$, $SE = .01$, $t = 20.74$, $p < .001$, and after, $\beta = .11$, $SE = .01$, $t = 16.67$, $p <.001$, the hazard was visible. Cognitive load did not influence saccade amplitude either as a main effect or through interaction with time window.

Saccade durations (log-transformed in the LMM and with saccade amplitude included as a fixed effect) were overall longer in the high load condition, $\beta = .01$, $SE = .005$, $t = 2.40$, $p = .029$. Saccade durations were shorter in the period when the hazard was visible as compared to periods before the appearance, $\beta = .02$, $SE = .002$, $t = 7.19$, $p < .001$, and after the disappearance, $\beta = .01$, $SE = .002$, $t = 4.91$, $p < .001$. We found no interaction between time windows and cognitive load. Saccade durations increased with saccade amplitudes, $\beta = .06$, $SE < .001$, $t = 176.02$, $p < .001$.

Saccade peak velocities (log-transformed in the LMM and with saccade amplitude included as a fixed effect) were significantly faster in the high compared to the low cognitive task demand condition, $\beta = .02$, $SE = .004$, $t = 3.74$, $p = .002$. Furthermore peak velocities were significantly slower when the hazard was present as compared to periods before, $\beta = .03$, $SE = .003$, $t = 9.69$, $p < .001$, and after, $\beta = .01$, $SE = .003$, $t = 5.21$, $p < .001$, the hazard was on screen. However we found no interaction between time windows and cognitive load. As expected peak velocities increased with increasing saccade amplitude, $\beta = .09$, $SE < .001$, $t = 212.10$, $p < .001$.

Analysis of fixation position variance along the x-axis indicated no significant main effect of cognitive load ($t < 1$) but did suggest a significant reduction of spread when the hazard was present as compared to the period before, $\beta = 7197$, $SE = 397$, $t = 18.13$, $p < .001$, and after, $\beta = 4601$, $SE = 445$, $t = 10.34$, $p < .001$, the hazard was onscreen. We found no interaction between time windows and cognitive load.

Blink rates were higher in the high compared to the low cognitive load condition, $\beta = .10$, $SE = .03$, $t = 3.11$, $p = .007$. Furthermore blink rates were significantly lower during the period where the hazard was visible on the screen than in either the period before the hazard appeared, $\beta = .11$, $SE = .03$, $t = 4.12$, $p < .001$, or after it disappeared, $\beta = .16$, $SE = .03$, $t = 6.17$, $p < .001$. We found no interactions between time windows and cognitive load.

For blink duration, the only significant difference was between the period when the hazard was visible and the period after it disappeared, $\beta = 19.0$, $SE = 9.3$, $t = 2.06$, $p = .040$, with longer blinks after the hazard had disappeared.

Table 2. Average Fixation Durations (Fix. Durs) in milliseconds, Saccade Amplitudes (Sacc. Amps) in degrees, Saccade Durations (Sacc. Durs) in milliseconds, Saccade Peak Velocities (Sacc. PVs) in degrees per second, horizontal spread of fixations (X/-position variance; in pixels), Blink Rate (Blink Rate) per second and Blink Durations (Blink Durs) in milliseconds between high and low cognitive load conditions for the time windows before during and after the hazard was on screen

along with standard deviations (in parentheses). Please note that DVs are reported to an accuracy that reflects the measurement of the variable.

	Before		**During**		**After**	
	High	Low	High	Low	High	Low
Fix. Durs[2,3,4]	332 (*187*)	332 (*174*)	342 (*195*)	357 (*193*)	321 (*183*)	333 (*176*)
Sacc. Amp [2,3]	2.9 (*2.2*)	2.9 (*2.2*)	2.3 (*1.9*)	2.2 (*1.8*)	2.7 (*2.1*)	2.7 (*2.2*)
Sacc. Durs [1,2,3]	29 (*13*)	29 (*12*)	26 (12)	26 (*11*)	29 (*13*)	28 (*13*)
Sacc. PV [1,2,3]	207 (*116*)	204 (*113*)	177 (*109*)	172 (*111*)	204 (*118*)	192 (*113*)
X-Spread [2,3]	11729 (*8143*)	12472 (*8493*)	5232 (*5987*)	5115 (*5588*)	9611 (*667*)	9853 (*7151*)
Blink Rate [1,2,3]	0.54 (*0.39*)	0.41 (*0.36*)	0.39 (*0.52*)	0.28 (0.*45*)	0.56 (*0.41*)	0.49 (*0.41*)
Blink Durs [3]	192 (*208*)	163 (*199*)	199 (*226*)	179 (*201*)	200 (*210*)	205 (*202*)

1 Denotes a significant main effect of cognitive load
2 Denotes a significant difference between periods before and during
3 Denotes a significant difference between periods during and after
4 Denotes a significant interaction between cognitive load and time window

3.2.1. Saccade peak velocities over time

Saccade peak velocities were analysed as a function of time on task between both high and low cognitive load conditions. To this effect an LMM model was tested with cognitive load, trial number and saccade number as fixed effects as well as two random factors for hazard perception clip and participant. Peak velocities decreased as a function of saccade number, $\beta = .007$, $SE = .001$, $t = 4.79$, $p < .001$, and trial number, $\beta = .003$, $SE = .001$, $t = 2.21$, $p < .027$, with these two predictors interacting significantly, $\beta = .004$, $SE = .001$, $t = 2.50$, $p < .012$. As expected given our previous analyses, we found that peak velocities were faster when cognitive load was high (195°/sec) as compared to low (189°/sec) , $\beta = .012$, $SE = .003$, $t =$

4.16, *p* < .001. However, we found no interaction between either trial number or saccade number and cognitive load.

3.3. Electrophysiological Measures

3.3.1. Overall Frequency differences between conditions

Participants' grand average (GA) of mid-theta (4 – 7 Hz) frequency output was calculated for each electrode individually for both high and low cognitive load conditions for each 30s hazard perception clip. We found significantly more theta activity at T8 (t(15) = -2.69; p = .017) and CP6 (t(15) = -2.54; p = .023) and a marginally significant increase at Pz (t(15) = -2.1; p = .053) in the high compared to the low cognitive task demand condition.

3.3.2. Differences in eye fixation related potentials (EFRPs)

After fixation event codes were used to segment epochs 150 ms prior to and 600 ms following fixations, grand averages were calculated for the interval 50 ms – 150 ms after each fixation onset. We found that distraction resulted in a reduced amplitude of the lambda response at electrode O1 (*t*(16) = 2.14; *p* = .049) and marginally at Oz (*t*(16) = 2.11; *p* = .051). Differences in *EFRP*s between high and low load conditions at O1 can be seen in Figure 1.

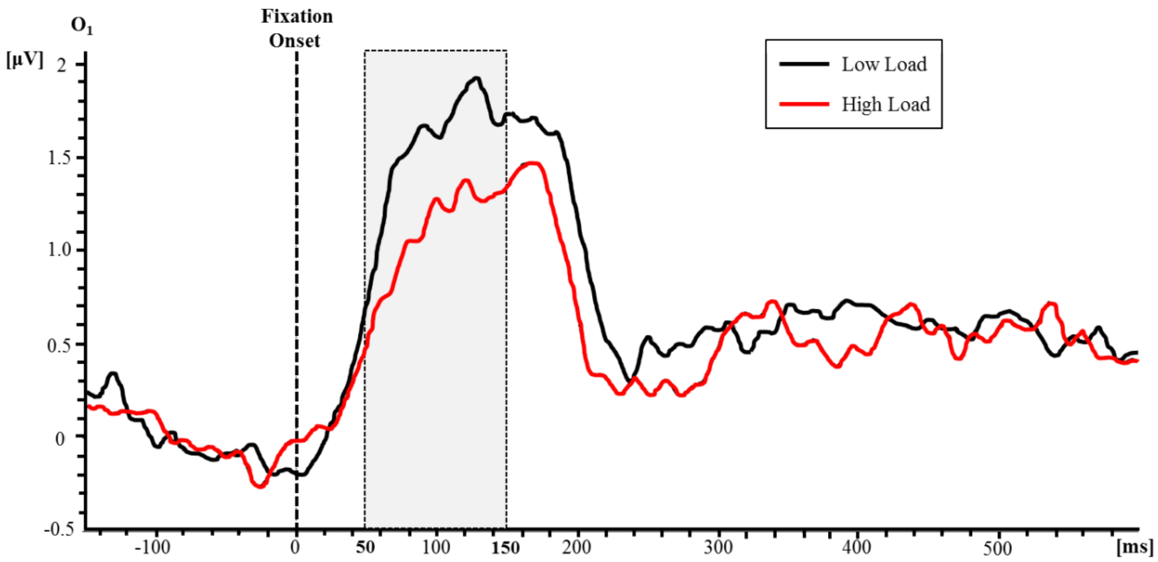

Figure 1. Grand average *EFRP*s for both low and high cognitive load conditions at the electrode site O$_1$. Differences between conditions were calculated in the highlighted area 50-150 ms after each fixation onset. Fixation onset is highlighted at 0 ms.

4. Discussion

We considered whether the effects of cognitive load might vary depending on the content of the hazard perception video, specifically we were interested in comparing the period during which the hazard was visible to periods before it appeared and after it disappeared from view.

4.1. Behavioural consequences of distraction

Contrary to previous findings (e.g., Savage et al., 2013) reaction times and false responses were not significantly increased when the cognitive load from the secondary task used in the current paradigm was high. We reason that shortening the hazard perception clips reduced the variability of visual task across clips but also led to a reduction in primary task uncertainty. Hazard perception clips used in the DVLA's hazard perception assessment may contain a number of potential hazards that ultimately do not turn out to be hazardous. However, reducing the original clip length in such a way as to only include one clearly identifiable hazard (and no potential hazards) may well have resulted in the primary task being easy enough for participants to be able to simultaneously process both primary and secondary tasks without detriment. This was also supported by the fact that not a single participant missed a single hazard (no missing responses in either condition). Another reason why we may not have replicated findings from our previous study (Savage et al., 2013) is that in the past we compared a high level of cognitive load to no cognitive load whereas in the current experimental paradigm we are comparing low versus high cognitive load. This difference in secondary task may have resulted in a smaller effect on behavioral measures.

However, despite there being no significant effect of load on reaction times and false responses, analyses of eye movements and electrophysiology indicated that previously identified signatures of distraction were affected by the increase in cognitive task demand. A major consideration for potential markers of distraction is their ability to identify increases in crash risk before the actual crash occurs (Liang, Lee, & Reyes, 2007). Therefore, the observation that oculomotor and electrophysiological metrics are susceptible to variations in cognitive task demand although no increases in reaction times, false responses and missing responses were found raises interesting possibilities in this domain, with the possibility that these measures might reveal impacts of cognitive load prior to them becoming sufficient to significantly impair hazard detection.

4.2. The effect of distraction on oculomotor metrics

For all of the eye movement measures tested here, there were differences between the period when the hazard was visible and either the period before it appeared, or the period after it appeared, or, in some cases, both. This consistent pattern clearly indicates that viewing behaviour changed when the hazard was visible on the screen compared to when it was not.

We found overall effects of cognitive load for saccade duration, saccade amplitude, and blink rate. Thus, throughout the entire 30-s clip high cognitive load resulted in longer duration saccades, faster saccadic peak velocity, and more frequent blinks, despite this cognitive load not impacting behavioural responses. Therefore these measures may be indicative of increased cognitive load prior to any changes in behaviour that would ordinarily lead to an increase in crash risk. Higher saccade peak velocities and more frequent blinks under high cognitive load supports our previous work on the effects of cognitive load on hazard perception (Savage et al., 2013) together with several other previous studies (e.g., (Ahlstrom & Friedman-Berg, 2006; Di Stasi, Renner, et al., 2010).

Beyond any overall effects of cognitive load, we found effects of cognitive load specific to certain periods of the hazard perception clips for fixation duration. Specifically, fixation duration generally increased when the hazard was visible compared to before it appeared, but more so in the low load condition, such that there was an effect of cognitive load while the hazard was visible that was not found prior to its appearance. In general longer fixation durations have been thought to reflect primary task difficulty, in reading for instance, more difficult words are fixated upon longer (Rayner, 1998). Longer fixation durations during the period where the hazard was visible may reflect more effortful processing involved in monitoring the potential hazard in order to be able to react to the hazard onset in an appropriate and timely manner. Interestingly the effect of cognitive load was the opposite to what we had expected, with shorter fixation durations when cognitive load was high as compared to low.

It is somewhat surprising that we did not find any effects of cognitive load on the horizontal spread of fixations in the present study. One of the most consistent findings in simulated and real-world driving research is that the introduction of a secondary cognitive task results in the reduction of spread or a narrowing of fixations towards the center of the road (Reimer, 2009; Victor et al., 2005), and we have previously reported this under high cognitive load in the hazard perception task (Savage et al., 2013). It is possible that our failure to find an effect here might arise from shortening the videos to 30 seconds and this reducing the difficulty of the task.

In addition to saccade peak velocities being faster in the high than the low cognitive load condition, we also found that peak velocities decreased as a function of saccade number and trial number. Previous research has interpreted the decrease in peak velocities as a function of time on task as a measure of mental fatigue (Di Stasi et al., 2012; Galley, 1993). These findings demonstrate that saccade peak velocities are sensitive to changes in secondary cognitive task demand as well as time on task, but in a way that does not interact, and as such could provide a basis of monitoring changes in drivers' mental processes in real time. As saccade peak velocity models in our analyses included saccade amplitude as a fixed effect, the overall change in peak velocities as well as the change in peak velocities over time cannot be accounted for on the basis of changes in saccade amplitude.

First saccade latency is a measure typically recorded in pro and antisaccade tasks as well as visual search tasks and is thought to reflect the speed at which new incoming visual information is being processed and appropriate saccade programs are written. In the current experimental paradigm we included a gap of 1500 ms between the offset of the secondary wordlist and the onset of the primary hazard perception task. During this period, the visual scene was blank, thus alerting participants to and preparing them for the imminent onset of the primary task. Therefore we argue that first saccade latencies in this current experimental paradigm may reflect preparatory mechanisms occurring before the start of the primary hazard perception task. First saccade latencies were significantly longer in the high compared to the low cognitive load condition. This suggests that increased secondary task demand may be interfering with the preparatory mechanisms prior to the start of the primary task.

4.3. Electrophysiological consequences of distraction

Analyses of EEG data from this current experiment revealed that increased cognitive load was associated with 1) significantly higher tonic theta frequency power at temporal and central parietal sites; and 2) significantly smaller grand average *EFRP*s at occipital and temporal sites. Whilst for eye movement metrics we analyzed the effect of the three different time windows (pre hazard visibility; during hazard visibility and post hazard visibility), we did not make the same comparisons for our EEG measures. This was because the duration of pre, during and post epochs were different for each hazard perception clip. Furthermore the visual content of pre during and post epochs were very different. EEG metrics are extremely sensitive to variations in visual stimuli (Müller, Gruber, & Keil, 2000). Therefore having different sized windows with different visual content would greatly affect the frequency content of our subjects EEG data.

Overall frequency differences calculated on the entire 30-second period of the hazard perception trials indicated that mid-theta was significantly higher at left temporal, left central parietal as well as central parietal sites in the high cognitive load condition. This is in line with previous research, which has indicated that increased theta band energy is evident during spatial working memory tasks (Gevins, Smith, McEvoy, & Yu, 1997; Klimesch, 1999; Tesche & Karhu, 2000). Increases in theta band power output have also been linked with organizing multi-item working memory in non-spatial tasks (Raghavachari et al., 2001). Therefore, results from this current experiment are in support of these previous studies, which have found increases in theta band energy at a large variety of different cortical sites. It should be noted that although the differences in frequency outputs in this current study were significant, these differences were in fact very small. Therefore, it is difficult to make any strong claims as to the causes of these frequency differences under these specific circumstances. Previous authors have argued that increased activity in the theta band most likely reflected greater cortical engagement in response to processing two tasks (Jensen & Tesche, 2002). Furthermore, greater frontal theta band output was thought to demonstrate the activation of neural networks associated with the allocation of attention relative to the target stimulus. Therefore differences in this frequency metric are thought to be indicative of processes related to a specific component of mental calculation. The differences in theta band output found in the current paradigm seem to support the hypothesis that increased mental workload results in an increase (synchronization) of theta frequency band across a variety of cortical sites.

In a previous piece of work we found reduced theta activity at occipital sites in high compared to low secondary cognitive load conditions whilst viewing hazard perception videos (Savage et al., 2013). We argued that the reduction in occipital theta may reflect a reduction in processing of the visual primary task and that the reduction in theta was most likely associated with a reduction in the depth of visual processing. In order to verify this and to gain a more nuanced insight into the depth of visual processing occurring during fixations in the current study, we analysed differences in *EFRP*s between high and low cognitive load conditions.

In the past the electrophysiological correlates of cognitive processing have been restricted to experimental paradigms in which the exploration of the visual information was highly controlled. Such low level tasks included visual pattern reversal (e.g., (Kazai & Yagi, 2003) and word recognition (e.g., (Baccino & Manunta, 2005) paradigms. However, more recently it has been argued that monitoring electrophysiological activity during fixations provides insight into the self-paced acquisition of perceptual information within the visual scene. The most commonly analysed component of *EFRP*s is the lambda response, a positive deflection of cortical activity around 80 ms following the onset of a fixation. This component has been shown to vary both with attention and the properties of the visual stimuli. The lambda response has been shown to reflect the afferent input of visual information from fixation to the visual cortex (Billings, 1989; Thickbroom, Knezevic, Carroll, & Mastaglia, 1991; Yagi, 1979). Previous work has demonstrated that the size of the lambda response is significantly smaller under conditions of increased cognitive workload (Ries, Slayback, & Touryan, 2018; Ries, Touryan, Ahrens, & Connolly, 2016; Takeda, Yoshitsugu, Itoh, & Kanamori, 2012). In a driving simulator study Takeda and colleagues (Takeda et al., 2012) found that a secondary spatial working memory task resulted in a decrease in the magnitude of the lambda response whereas a verbal working memory task did not. The authors argued that drivers were able to divide their attention resources between the driving and a verbal working memory task but that the decline in visual processing accuracy was inescapable when attempting to share resources between the driving and a spatial working memory task. In the current study we increased our participants working verbal working memory load by presenting a list of words prior to the onset of the hazard perception clip. In contrast to (Takeda et al., 2012), we found that the lambda response following the onset of fixations was significantly less positive in the high as compared to the low cognitive load condition. This indicates that verbal working memory load was in fact sufficient to result in a decline in visual processing. The fact that Takeda et al. (2012) found no effect of verbal working memory may be that their secondary task did not occupy working memory resources to the same extent as our own verbal working memory manipulation.

Reduced amplitudes of the lambda component of *EFRP*s at occipital sites are associated with a reduction of the depth of visual processing (Ries et al., 2018; Ries et al., 2016; Takeda et al., 2012). As such, findings from the current study seem to support our previous interpretations that increased cognitive load results in a decrease in the processing of visual information. In line with previous research, results from this current study suggest that *EFRP*s are a useful tool in the assessment of cognitive processes (Baccino & Manunta, 2005). An important consideration is that the amplitude of the lambda response has been shown to be positively correlated with the size of saccades (Dandekar, Privitera, Carney, & Klein, 2011; Dimigen, Sommer, Hohlfeld, Jacobs, & Kliegl, 2011; Yagi, 1979). However the latency of the response is not affected by saccade amplitude when time-locked to the onset of fixations. This suggests that the lambda response reflects fixation-related visual processing as supposed to merely being an artifact of saccade sizes. In the current study we found that saccade amplitudes were affected by the presence of the hazard but not by cognitive load. The fact that we have demonstrated a reduction in the magnitude of the lambda response as a consequence of increased cognitive load supports the claim that it does in fact reflect fixation related visual processing. Therefore the reduction in the size of the lambda response may indicate a reduction in the processing of visual information. One aim of the current study was to examine the susceptibility of behavioural, oculomotor and electrophysiological measures to increases in secondary cognitive task demand. Although behavioural metrics were not affected by cognitive load, previously identified markers of distraction were still susceptible to changes in secondary cognitive task demand.

Reducing the length of the primary hazard perception clips may have resulted in the primary task being less demanding than the original full one minute clips as evidenced by the lack of missing responses. Interestingly this current study suggested that increases in secondary cognitive task demand were associated with changes in oculomotor and electrophysiological measures despite no adverse effects on behaviour being found. Therefore it could be argued that the discussed changes in eye movements and EEG metrics may be more sensitive indicators of the compensatory control mechanisms designed to compute the secondary tasks whilst simultaneously maintaining primary task performance.

Analyses of eye movements across different periods within the hazard perception clip demonstrated that the appearance of the hazard led to longer fixation durations as well as a reduced horizontal spread of fixation positions. This difference may be characterised in terms of searching for and monitoring a potential hazard; specifically reduced spread and longer fixations when monitoring the ongoing hazard, while it was visible in the hazard perception clip. Models of executive function (e.g., (Corbetta et al., 2008; Norman & Shallice, 1986) postulate a flexible mediation of cognitive resources depending on current task demands, it could be reasoned that monitoring a potential hazard which is present is perceived as more demanding in comparison to scanning the visual scene when no potential hazards were present.

One major consideration for meaningful markers of cognitive distraction within driving situations is the ability to detect an increase in crash risk before the crash actually occurs. As oculomotor and neurophysiological metrics were significantly affected by the introduction of a secondary cognitive task although no changes in behaviour were observed, results from this current study imply that specifically measures of saccadic peak velocities, blink rates, phasic and tonic theta as well as *EFRP*S may be indicative of variations in cognitive task demand. Most importantly these metrics were sensitive to increases in cognitive load in the absence of any changes in behaviour.

While using a video based hazard perception task has many advantages, future research would benefit greatly from assessing the effects and interactions of visual and cognitive task demand on hazard perception performance in a driving simulator or in a closed course driving experiment. Driving is a complex and demanding task which, is almost 80% visual in nature (Hills, 1980). However driving in the real world requires the physical control of the vehicle, which in itself can be very demanding. Hazard perception videos do not require the driver to physically control a vehicle. Therefore by assessing the interaction of visual and cognitive load while incorporating the physical demands of controlling the vehicle, will give researchers a much more nuanced insight into the allocation of attention resources when driving in the real world.

5. Conclusions

The aims of the current study were to 1) compare the susceptibility of previously identified oculomotor markers of distraction across three different periods within each clip (before, during and after the hazard was on screen); and 2) consider whether cognitive distraction had an effect on eye fixation related potentials (*EFRP*s) within a video based search task. As the hazard perception task does not allow subjects to directly influence primary task difficulty (i.e. by slowing down driving speed), it was predicted that compensatory behaviour would be reflected in more subtle changes in viewing behaviour and electrophysiology. We found evidence that saccade peak velocities, blinks and the spread of fixations along the x-axis were affected by cognitive load, even before the onset of the hazard in the viewed hazard perception clips.

As with our previous study (Savage et al., 2013) average theta frequency output for the full 30-second hazard perception clip was significantly greater at central, parietal and temporal sites when secondary cognitive task demand was high. Following on from this, the current study has provided evidence that increased cognitive load. Following on from this, we found that the lambda component of *EFRP*s was significantly smaller at occipital sites under when cognitive load was high as compared to when it was low. Reduced amplitudes of this component of *EFRP*s at occipital sites supports our previous interpretations (Savage et al., 2013) that the incoming visual information was not being processed to the same extent as when full cognitive resources are available. Most importantly, these metrics were sensitive to increases in cognitive load in the absence of any changes in primary hazard perception task performance. This suggests that these markers may in future be used to detect distraction prior to an increase in crash risk.

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7. Appendix

7.1. Wordlist 10 words @ 1.5 sec interval = 15 seconds per WL

WL 1: soot, joker, captain, fly, story, stove, rock, corn, bread, sofa

WL 2: star, peel, uncle, hospital, grow, desk, ranger, bird, shoe, fish

WL 3: stove, mountain, glasses, towel, cloud, lamb, boat, gun, pencil, church

WL 4: drum ,curtain, bell, coffee, school, parent, moon, garden, hat, farmer

WL 5: nose,turkey, colour, house, river, doll, mirror, nail, sailor, heart,

WL 6: dessert, face, letter, bed, machine, milk, helmet, music, horse, road

WL 7: forest, water, ladder, girl, foot, shield, pie, insect, ball, car

WL 8: dish, jester, hill, coat, tool, violin, tree, scarf, ham, suitcase,

WL 9: cousin, earth, knife, stair, dog, banana, radio hunter, bucket, field

WL 10: orange, armchair, toad, cork, bus, chin, beach, soap, hotel, donkey,

WL 11: spider, bathroom, casserole, soldier, lock, book, flower, train, rug, meadow

WL 12: harp, salt, finger, apple, chimney, button, log, key, rattle, gold

WL 13: toffee, sand, pony, plate, heart, jail, envelope, silk, dart screw

WL 14: wood, stool bread, street, head, barn, window, hand, hole, balloon,

WL 15: mouse, crayon, fountain, hot, stranger, stocking, teacher, nest, children, rose

7.2. Easy Control Questions

Q1: What is the capital city of Scotland?

Q2: What is the capital city of England?

Q3: What city are you in?

Q4: What is five multiplied by ten?

Q5: What is one hundred minus twenty five?

Q6: What do people blow out on their birthdays?

Q7: How many sides does a square have?

Q8: What is the capital city of France?

Q9: What is half of one hundred?

Q10: How many sides does a triangle have?

Q11: What is four multiplied by five

Q12 What is three times ten?

Q13: What is the capital city of Germany?

Q14: At what temperature does water begin to boil?

Q15: At what temperature does water begin to freeze?

7.3. Practice Materials

7.3.1. Practice wordlist

Bar, coach, cabin, pond, park, helicopter, ocean, cherry, laundry, swallow

7.3.2. Practice Question:

In the UK what number do you dial in an emergency?

7.4 Screenshots of the hazard onset for hazard perception videos


Car Merging into lane


Car stopped on lane


Pedestrian crossing


Car cutting into lane


Car approaching in lane


Cyclist on Roadside


Pedestrian on Roadside


Bus stopped in lane


Bus stopped in lane


Car cutting into lane


Pedestrian on Roadside


Car approaching in lane


Horses on Roadside


Cyclist in lane


Pedestrian crossing

Pedestrian Crossing

Car stopped on lane

Car pulling out

Tractor in lane

Pedestrian on Roadside

Pedestrian Crossing

Car approaching in lane

Car cutting into Lane

Car pulling out

Motorcycle pulling out

Car parked in lane

Van stopping in lane

Pedestrian on Roadside

Car stopped on lane

Pedestrian crossing

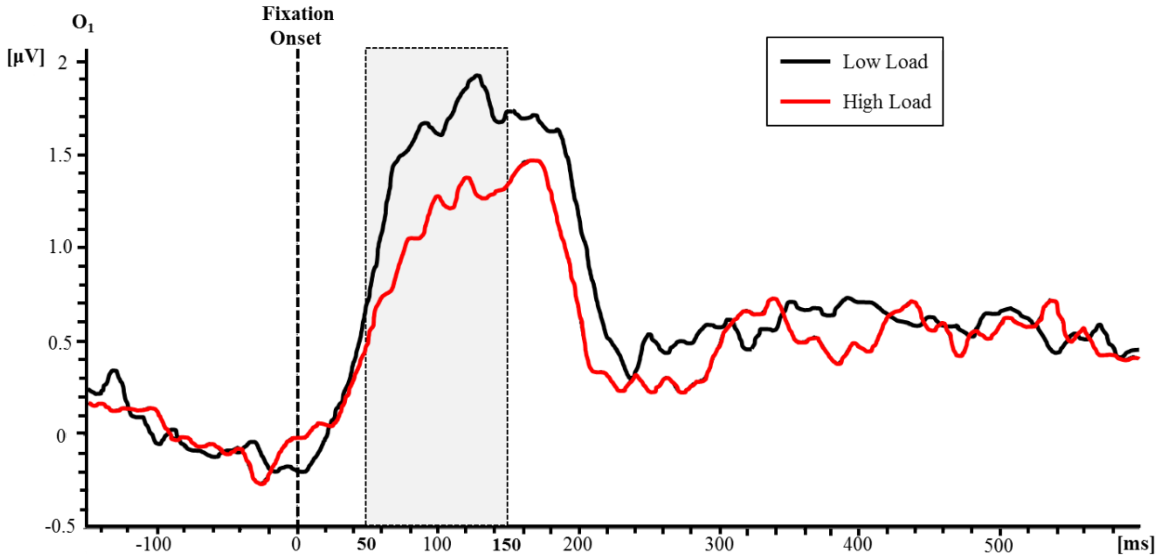

Figure 1. Grand average EFRPs for both low and high cognitive load conditions at the electrode site O_1. Differences between conditions were calculated in the highlighted area 50-150 ms after each fixation onset. Fixation onset is highlighted at 0 ms.

7.4 Screenshots of the hazard onset for hazard perception videos

Car Merging into lane

Car stopped on lane

Pedestrian crossing

Car cutting into lane

Car approaching in lane

Cyclist on Roadside

Pedestrian on Roadside

Bus stopped in lane

Bus stopped in lane

Car cutting into lane

Pedestrian on Roadside

Car approaching in lane

Horses on Roadside

Cyclist in lane

Pedestrian crossing

Pedestrian Crossing

Car stopped on lane

Car pulling out

Tractor in lane

Pedestrian on Roadside

Pedestrian Crossing

Car approaching in lane

Car cutting into Lane

Car pulling out

Motorcycle pulling out

Car parked in lane

Van stopping in lane

Pedestrian on Roadside

Car stopped on lane

Pedestrian crossing

Table 1. Average reaction times (RTs) in milliseconds and false responses (FRs) per clip between both high and low cognitive load conditions along with standard deviations (in parentheses)

Measure	**High Load**	**Low Load**
RTs [*ms*]	2703 (*1913*)	2668 (*1636*)
FRs [*per clip*]	1.32 (*1.51*)	1.40 (*1.65*)

Table 2. Average Fixation Durations (Fix. Durs) in milliseconds, Saccade Amplitudes (Sacc. Amps) in degrees, Saccade Durations (Sacc. Durs) in milliseconds, Saccade Peak Velocities (Sacc. PVs) in degrees per second, horizontal spread of fixations (X/-position variance; in pixels), Blink Rate (Blink Rate) per second and Blink Durations (Blink Durs) in milliseconds between high and low cognitive load conditions for the time windows before during and after the hazard was on screen along with standard deviations (in parentheses). Please note that DVs are reported to an accuracy that reflects the measurement of the variable.

	Before		**During**		**After**	
	High	Low	High	Low	High	Low
Fix. Durs^{2,3,4}	332 (*187*)	332 (*174*)	342 (*195*)	357 (*193*)	321 (*183*)	333 (*176*)
Sacc. Amp ^{2,3}	2.9 (*2.2*)	2.9 (*2.2*)	2.3 (*1.9*)	2.2 (*1.8*)	2.7 (*2.1*)	2.7 (*2.2*)
Sacc. Durs ^{1,2,3}	29 (*13*)	29 (*12*)	26 (12)	26 (*11*)	29 (*13*)	28 (*13*)
Sacc. PV ^{1,2,3}	207 (*116*)	204 (*113*)	177 (*109*)	172 (*111)*	204 (*118*)	192 (*113*)
X-Spread ^{2,3}	11729 (*8143*)	12472 (*8493*)	5232 (*5987*)	5115 (*5588*)	9611 (*667*)	9853 (*7151*)
Blink Rate ^{1,2,3}	0.54 (*0.39*)	0.41 (*0.36*)	0.39 (*0.52*)	0.28 (0.*45*)	0.56 (*0.41*)	0.49 (*0.41*)
Blink Durs ^{3}	192 (*208)*	163 (*199*)	199 (*226*)	179 (*201*)	200 (*210*)	205 (*202*)

1 Denotes a significant main effect of cognitive load
2 Denotes a significant difference between periods before and during
3 Denotes a significant difference between periods during and after
4 Denotes a significant interaction between cognitive load and time window

Author Contribution statement

Steven W Savage: Conceptualization, Methodology, Software, Investigation, Data collection, Analysis, Visualization, Writing – Original Draft, Writing – Review and Editing,

Douglas D Potter: Supervision, Conceptualization, Methodology

Ben W Tatler: Supervision, Conceptualization, Methodology, Software, Analysis, Writing - Review & Editing