Measuring Working Memory Load Effects on Electrophysiological Markers of Attention Orienting during a Simulated Drive.

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Abstract

Intersection accidents result in a significant proportion of road fatalities, and attention allocation likely plays a role. Attention allocation may depend on (limited) working memory (WM) capacity. Driving is often combined with tasks increasing WM load, consequently impairing attention orienting. This study (n = 22) investigated WM load effects on event-related potentials (ERPs) related to attention orienting. A simulated driving environment allowed continuous lane-keeping measurement. Participants were asked to orient attention covertly towards the side indicated by an arrow, and to respond only to moving cars appearing on the attended side by pressing a button. WM load was manipulated using a concurrent memory task. ERPs showed typical attentional modulation (cue: contralateral negativity, LDAP; car: N1, P1, SN, and P3) under low and high load conditions. With increased WM load, lane-keeping performance improved, while dual task performance degraded (memory task: increased error-rate; orienting task: increased false alarms, smaller P3).

Key words: attention orienting, working memory load, event-related potentials, driving simulation

Practitioner Summary

Intersection driver-support systems aim to improve traffic-safety and -flow. However, in-vehicle systems induce working memory (WM) load, increasing the tendency to yield. Traffic flow reduces if drivers stop at inappropriate times, reducing the effectiveness of systems. Consequently, driver-support systems could include WM load measurement during driving in the development phase.

Introduction

Driving is a highly complicated task requiring the integration of various attentional, cognitive, sensory, and psychomotor functions (Ross et al., 2015; Young & Regan, 2007) in road environments of different complexities (Horberry, Anderson, Regan, Triggs, & Brown, 2006). Even though most countries successfully decreased the number of road fatalities, this number still remains too high with the WHO reporting fatality rates of 1.24 million per year (World Health Organization, 2013). Intersection accidents constitute a major problem and encompass a significant proportion of fatalities each year. Often, these accidents result from situations where drivers fail to yield (Bao & Boyle, 2009; Sandin, 2009; Werneke & Vollrath, 2012). Insufficient visuospatial attention allocation has been proposed as an underlying cause for the failure to yield to other road users (Werneke & Vollrath, 2012). Real-life tasks such as yielding situations are complex and involve selective attention orienting to relevant information in a complex sensory environment, together with motor control, memory encoding, and retrieval. Working memory (WM) provides cognitive resources for the coordination of attentional control. However, available WM capacity is limited (Vossen, Ross, Jongen, Ruiter, & Smulders, 2016). Furthermore, the relation between attention and WM may depend on the specific types of both load and attention. Lavie's load theory (Lavie, Hirst, de Fockert, & Viding, 2004) indicates that WM load disrupts top-down, voluntary attention. However, the same does not hold for bottom-up, reflexive attention (e.g., Law, Langton, & Logie, 2010). At the same time, while reflexive attention is affected by perceptual load, voluntary attention is not (e.g., Santangelo, Raffone, Belardinelli, & Spence, 2008).

Driving is often combined with secondary tasks that increase WM load, leaving less spare WM capacity to devote to the driving task (Lavie, 2010; Recarte & Nunes, 2003; Ross, et al. 2014). As yielding situations involve top-down orienting of attention, driving behavior at intersections is expected to be influenced by WM load. Indeed, previous reports indicated that WM load degrades driving performance at intersections as shown by increased crash risks and yielding violations (Fu, Pei, Wu, & Qi, 2013; McEvoy, Stevenson, & Woodward, 2007; Neyens & Boyle, 2007). WM load not only affects responses to changing environments or sudden events, but also continuous driving measures such as steering and speed management (Allen, Marcotte, Rosenthal, & Aponso, 2005; Engström, Johansson, & Östlund, 2005; Ross, et al., 2014). A study from Engström et al. (2005) tested the effect of both perceptual load and WM load and found them to impact differentially on continuous driving. The former led to reduced speed and increased lane keeping variation. Conversely, the latter did not affect speed and resulted in reduced lane keeping variation. Furthermore, WM load led to increased gaze concentration towards the road center, which might have been related to the reduced lane keeping variability.

Measures that can distinguish between various information processing stages are necessary to identify the underlying mechanisms of the influence of WM load (Fort, Collette, Bueno, Deleurence, & Bonnard, 2013). In contrast to reaction time measures (Kessels, Ruiter, & Jansma, 2010), which reflect a convergence of effects in a single outcome measure, electroencephalography (EEG) can provide additional on-line information of ongoing attentional processes. WM load due to a secondary task has been shown to reduce event-related potential (ERP) amplitude, for the primary and/or secondary task (Prinzel, Freeman, Scerbo, Mikulka, & Pope, 2003; Strayer, Drews, & Johnston, 2003; Ullsperger, Freude, & Erdmann, 2000; Wester, Bocker, Volkerts, Verster, & Kenemans, 2008). Fort et al. (2013) used ERP measurement during a driving-like detection task. To investigate underlying mechanisms affected by WM load, they combined behavioral and ERP measures to investigate the impact of warning systems on visual target processing. Participants had to perform a visual detection task, either alone, or combined with a concurrent problem-solving task. An increase in WM load was associated with an amplitude reduction of N1 and N2/P3

components, indicating degraded visual information processing in early perceptual stages. In addition, greater WM load delayed reactions to visual targets.

Spatial cueing tasks in which a cue predicts the likely position of a target stimulus are often used to assess attention orienting. The typical finding is that reaction times are faster and responses are more accurate to stimuli that appear at the cued location (valid trials) than to stimuli that appear at an uncued location (invalid trials) (e.g., Posner, 1978; Jongen, Smulders, & van der Heiden, 2007). Previous EEG research has identified ERP signatures related to attention orienting in cueing tasks. A sequence of lateralized components with a greater positive or negative voltage over the hemisphere contralateral to the direction of the cue has been related to different stages in the control of attention. These include: the early directing attention negativity (EDAN) occurring at posterior sites (200-400 ms after cue onset), the anterior directing attention negativity (ADAN) at frontocentral sites (300-500 ms after cue onset) and the late directing attention positivity (LDAP) at posterior sites (500-700 ms after cue onset) (Jongen, Smulders, & Van Breukelen, 2006; Jongen et al., 2007; Murray, Nobre, & Stokes, 2011). The EDAN may represent processing of physical properties from the cue that are relevant for attention orienting. Meanwhile, the ADAN and LDAP are related to attention orienting, but do not rely on physical cue properties (Jongen et al., 2007; Van Velzen & Eimer, 2003). The former relates to frontal cortex top-down control as well as maintenance of spatial redirection of attention, the latter relates to the anticipatory biasing of brain regions involved in location coding and target processing (McDonald & Green, 2008; Vossen et al., 2016). Subsequently, a sequence of ERP components is evoked in response to the target stimulus over lateral occipital sites consisting of an early P1 component (onset at about 100 ms), followed by an N1 component (onset at about 150 ms). Modulatory effects of attention on processing of the target stimulus are reflected by P1 and N1 amplitude enhancements for attended stimuli in comparison to unattended stimuli (Herrmann & Knight, 2001; Luck, Heinze, Mangun, & Hillyard, 1990; Ruiter, Kessels, Jansma, & Brug, 2006). Finally, ERP components related to non-spatial attention indicate attentional selection and cognitive processing of stimulus features (e.g., movement). Selection negativity (SN) is a broad negativity (150–300 ms after stimulus onset) whose location varies with the nature of the to-be-attended feature. P3 is a late positivity (300 ms after stimulus onset) generated by multiple distributed generators, indicating distribution of cognitive resources and thought to reflect an update of stimulus processing with WM information. Furthermore, P3 reflects post-perceptual processes necessary to carry out the task (Herrmann & Knight, 2001; McGinnis & Keil, 2011; Nobre, Sebestyen, & Miniussi, 2000; Pitts, Padwal, Fennelly, Martínez, & Hillyard, 2014; Ruiter et al., 2006; Shedden & Nordgaard, 2001).

Cueing tasks typically involve simplified task situations and abstract shapes, while tasks in real life are more complex and require the allocation of cognitive resources to multiple subtasks to achieve behavioral goals (Vossen et al., 2016). Lee, Lee, and Boyle (2009) adapted a cueing task to a complex virtual driving situation where pedestrian crossing-signs predicted pedestrians' spatial location. WM load was introduced by a verbal-auditory task resembling driver interaction with in-vehicle technology (i.e., requiring participants to listen and respond to auditory messages). It was found that WM load increased the reaction time to detect pedestrians. However, the study did not include online EEG measurements of attentional processes. Vossen et al. (2016) used a computerized orienting task visually resembling an intersection environment to investigate WM load effects on attention orienting. Participants had to covertly (i.e., without moving the eyes) allocate attention to cars appearing on the left or right side of an intersection. They were instructed to press a button as quickly as possible whenever a vehicle appearing at the attended location started to move towards the intersection, while stationary cars and moving cars at the unattended location could be ignored. The behavioral response therefore is comparable to yielding. Compared to a typical

cueing task, where participants are asked to respond to both cued and uncued target stimuli, the instruction to only respond to a subset of the possible targets (i.e., selection) requires more attention. This was supported by the results from Jongen et al. (2007), who found that the ADAN and LDAP were absent in cases of lower attentional selection (i.e., mere detection). Therefore, to investigate effects of WM load on EEG markers of attention orienting, we also gave the instruction to respond only to a subset of the cars (i.e., targets were defined as cars appearing at the attended location that started to move towards the intersection). Furthermore, fewer motor response trials allowed us to investigate more car and target ERPs in a limited time. An auditory-verbal version of the memory task employed by de Fockert, Rees, Frith, and Lavie (2001) was used to introduce WM load, requiring participants to remember and respond to a set of digits in an ascending (i.e., low WM load, 01234) or a randomized order (i.e., high WM load, e.g., 03421). ERP results indicated that drivers used the arrow signs to direct their attention. When WM load was high, performance in the memory task and the concurrent orienting task decreased. Furthermore, ERP components indicated a delay of attention orienting for high versus low WM load. However, although this study attempted to create a driving-like context, continuous measures of driving performance cannot be included in a static lab environment. These results therefore needed to be replicated under ecologically more valid conditions.

The current study (n = 22) aimed to replicate and extend the study by Vossen et al. (2016) by investigating WM load effects on electrophysiological markers of attention orienting. We aimed to replicate WM load effects on brain and behavioral responses during a concurrent driving task in a driving simulator. The latter enabled us to investigate in addition how WM load affects lane-keeping, a continuous measure of driving performance. Therefore, this study translated the orienting task from Vossen et al. (2016) to a simulated driving environment, increasing ecological validity.

Method

Participants

Twenty-two participants with a preliminary or permanent driver's license (i.e., at least 20 hours of driving experience) were included in this study (12 women; age: range = 17-33, mean = 22.91, SD = 4.23; experience in kilometers: range = 210,000-360,365, mean = 56,891, SD = 92,237). For two participants, part of the EEG data was compromised due to technical difficulties; however, the behavioral data were complete and therefore included in the analyses. All participants gave informed consent and received a gift voucher as well as two cinema tickets with a total value of €34 upon completion of the experiment.

Driving Simulator

The experiment was conducted with a fixed-based STISIM M400 (Systems Technology Incorporated) driving simulator including a force feedback steering wheel, brake pedal, accelerator, clutch, and automatic transmission. The virtual environment was displayed on a 180° field screen by a three-part projection system (figure 1). Three projectors offered a resolution of 1024 x 768 pixels, each, and a 60-Hz frame rate. Typical sounds from an engine were added to the simulation. Data were collected at frame rate.

EEG Recording

A BioSemi ActiveTwo System (BioSemi, Amsterdam/NL), with sintered Ag/AgCl electrodes, and an ActiveTwo head cap were used to record reference-free EEG with a sampling rate of 256 Hz. Scalp activity was measured at 64 electrode locations following the international 10-20 system (figure 1). Following the BioSemi protocol electrode offsets were kept below 40

mV (note that BioSemi does not provide impedance measures). The EEG signal was re-referenced offline to the average mastoid signal. Activity related to horizontal and vertical eye movements was recorded from four electrodes (i.e., two at the outer canthi, one above and one below the left eye).

'Insert Figure 1'

Tasks

Memory Task

The memory task was identical to the one in Vossen et al. (2016; see also: de Fockert et al., 2001). Participants were presented with verbally recorded digit sets from one to four, recorded at a rate of 43 bpm. In the low WM load condition the order of the digits was fixed (i.e. 01234). In the high WM load condition, the order of the digits was random (e.g. 03421). Each set lasted about 5-6 s. When an auditory probe consisting of a single digit (e.g., 3) was presented, participants had to respond by saying out loud the number that followed this probe in the set they had previously heard (e.g., 4). To be able to use all four digits, sets always started with zero. Therefore, zero could act as a probe but was never the correct response. The next set of digits was presented after a 2 s interval. There were 72 WM load trials per condition (i.e. low and high WM load). Verbal responses were manually recorded by the experimenter.

Orienting task

The orienting task was designed to match Vossen et al. (2016) as closely as possible while keeping simulator software limitations into account (i.e., feedback during the experimental trial or reduced luminance of the stimuli were not possible). The simulated driving environment consisted of a one-lane road on which participants responded to yielding situations at 512 unsignalized priority intersections, the most used roadway junction in highway transportation systems (Wu, 2001). The timing (see also figure 2) was adapted from a study investigating similar ERP components of attention orienting (Jongen et al., 2006). At each intersection, a cue in the shape of a red arrow in a white square (i.e., resembling an actual road sign, see also figure 1), was presented for 400 ms. After a cue target interval of 1,217 ms, a car appeared on the left-or-right side of the road, centered at a visual angle of about 7° from the center of the screen. After a stationary interval of 260 ms, the car either started to move for 34 ms towards the intersection, or remained stationary for 34 ms. After that, stationary and moving cars disappeared. Participants were instructed to covertly orient attention towards the side indicated by the arrow, and only respond to moving car stimuli appearing at the location previously indicated by the cue. Although the cues indicated the following task-relevant location, they were non-predictive as to whether an actual target car would appear. Cruise control was used to drive at a constant speed (i.e., 70 km/h) to control task timing and minimize EEG artifacts due to movement. A button-press was used to substitute for a brake response without reducing speed, to avoid the additional influence of changing speed. Although the horn button was used, no actual horn was sounded. Accuracy and response time of the brake responses served as the behavioral outcome measures of the orienting task.

'Insert Figure 2'

Dual Task

Figure 2 shows a schematic representation of the dual task consisting of the concurrent execution of the memory and orienting tasks. The memory task served to manipulate WM load in the orienting task. Similar to Vossen et al. (2016), each WM load condition (low vs. high) consisted of 72 memory trials and 256 orienting trials, with 32 orienting trials in each of the eight stimulus conditions: Cue Direction (left vs. right) X Car Location (left vs. right) X Motion (stationary vs. moving). Orienting trial order was randomized within each WM load condition. The instructions were to respond as quickly and accurately as possible to both tasks. After every memory set, participants performed a variable amount of orienting trials (i.e., 2-8), after which they needed to respond to the probe. Orienting trials were presented in sequences of two to eight trials in order to keep the probe unexpected so that constant memory rehearsal was encouraged (within each load condition: 25 sequences of 2 orienting trials, 17 of 3, 12 of 4, 8 of 5, 5 of 6, 3 of 7, and 2 of 8 trials). The order of low and high load dual task trials was also randomized.

Horizontal Electro-Oculogram (HEOG) Calibration Task

The HEOG calibration task was adapted from (Jongen et al., 2007). Participants had to follow a white dot on a grey background that moved from a central location to the left-or-right side of the screen (i.e., equivalent to the car location in the orienting task), as well as 3° up and down (10 trials per condition). The dot returned to the starting position after 1.5 s (Vossen et al., 2016). This task provided a calibration for horizontal eye movements, linking the voltage measurements to lateral movement. Trials with horizontal eye movements could thus be discarded to assure that only trials with covert attention allocation were included.

Continuous Driving Task

Continuous driving control can be measured by providing a controlled stimulus to the driver or the vehicle and measuring the driver response to those manipulations. Examples of controlled stimuli are, wind gusts and roadway curvature (Allen et al., 2005). Therefore, to make the task of lane-keeping more difficult on the virtual straight road, wind gusts were added to measure lane-keeping performance (van Kessel, Geurts, Brouwer, & Fasotti, 2013). Wind in the form of a variable lateral force (i.e., wave pattern computed by the sum of three sine waves). Lateral displacement over time was implemented as a wave pattern consisting of the sum of three sinusoids with 3, 9, and 18 cycles per minute. Participants were instructed to try to remain in the middle of the driving lane, requiring active lane-keeping.

Procedure

Participants were given a cover story that this study investigated cruise control effects on reaction time. The orienting and memory tasks were practiced separately (40 trials and 60 trials, respectively) and combined (76 dual task trials). Verbal feedback was provided by the experimenter during training, and sessions were repeated if the performance level dropped below 80%. No feedback was provided during the experimental trials. The actual experiment consisted of three experimental blocks separated by self-timed breaks and two short regular drives (each 5.5 km in a simulated rural and urban driving environment) to reduce fatigue effects. The experimental task consisted of 72 memory trials and 256 orienting trials.

Preprocessing

EEG data were processed using EEGlab and MATLAB (MathWorks, Natick/US).

Dual Task

EEG data were filtered between 0.1 and 35 Hz. Epochs of 4 s (i.e., an orienting trial) were extracted from 200 ms before cue onset until 1s after car offset. Epochs were demeaned by

subtracting the average amplitude across the whole epoch. Noisy epochs were removed by visual inspection (mean % rejected epochs = 0.40, SD = 0.47). Blink and artifact identification/removal were based on independent component analyses (ICA) (mean number of rejected components = 9.18, SD = 2.13). Remaining noisy epochs (mean % rejected epochs = 1.30, SD = 2.36) were removed after a second visual inspection. The remaining epochs were baseline (200 ms before stimulus onset) corrected before entering the ERP analyses.

HEOG Calibration Task

EEG data were filtered between 0.1 and 10 Hz. Epochs of 1 s were time-locked to dot movement and baseline corrected (200 ms before). The median amplitude was first calculated per epoch, and then across trials, for left-and-right eye movements separately. Thirty-five percent of the average of left and right medians served as the criterion for detecting horizontal eye movements. Trials of the main experiment were rejected if the bipolar HEOG derivation exceeded this criterion (mean % rejected epochs = 20.18, SD = 23.07). Two participants were excluded after HEOG correction (i.e., 74% and 75% of the trials were rejected). On average, 90.15 trials were rejected (range 1-350) and 399.6 trials remained from the 512 trials.

Measurements

Statistical analyses were performed with IBM SPSS statistics 20 software with a significance level of alpha = 0.05.

Memory Task

The error rate in the memory task was calculated for the complete sample (n = 22) as the percentage of incorrect verbal responses separately for the low and high WM load condition.

Orienting task

Hits and false alarms rates determined sensitivity *d'* (i.e., the distance between signal and noise) and response bias *c* (i.e., favoring a response regardless of the stimulus). Reaction times to targets, *d'* and *c*, and hit and false alarm rates of the complete sample (n = 22) were entered in three repeated measures analyses of variance (RMANOVA) with factor WM load (low/high).

Event-Related Potentials

ERPs were obtained by averaging time-locked activity in response to cue onset (ADAN, EDAN, LDAP) or car onset (P1, N1, SN, P3). Only trials with a correct response were included. Five participants with too few trials per condition (i.e., cue < 50, car < 20) were excluded from the analyses. Note that these participants were still included in the analysis of the remaining analyses to retain greater statistical power.

Cue ERPs. Epochs related to cue onset were sorted by cue direction and WM load, and averaged (n = 17, mean number of trials = 96.68, SD trials = 19.50 trials). Average ERPs recorded over the right hemisphere (e.g. F8) when attention was oriented to the left were pooled with those of the left hemisphere (e.g. F7) when attention was oriented to the right, to reflect processing in the hemisphere contralateral to the direction of attention. Likewise, ERPs recorded over the hemisphere ipsilateral to the direction of attention were pooled. Thus, we refer to electrode pair F7/8 qualified by the hemisphere with respect to the cued location. To investigate the presence of ADAN we chose the anterior electrode pairs F7/8 and FC5/6. To investigate the presence of EDAN and LDAP, the posterior electrode pairs P7/8 and PO7/8 were selected. Time windows for the analyses were selected based on previous literature (we refer to the introduction for the literature overview) and visual inspection of the cue ERPs. See figure 3 and 4 for grand average cue ERPs to the cued

direction, and hemispheric differences in Cue ERPs, respectively. The visual inspection in the time window of interest (i.e., 300-500 ms) for the ADAN showed that this component was not replicated with the current task conditions (i.e., top two panels figure 4). Three potential components were identified in the lower two panels of figure 4. Mean amplitude in these time windows (50-100 ms, 150-200 ms, and 500-650 ms) in these electrode pairs were entered into a RMANOVA with factors hemisphere (ipsi-/contralateral), WM load (low/high), and electrode (respective sets of anterior vs. posterior electrode pairs).

'Insert Figure 3'

'Insert Figure 4'

Car ERPs. Trials related to car onset were sorted by cue direction, car location, motion condition (stationary or moving), and WM load, and averaged (n = 14, mean number of trials = 28.70, SD = 2.16 trials per condition and participant). Based on the combination of cue direction and car location, trials were pooled depending on whether cars appeared on the attended or unattended side. ERPs at corresponding electrode pairs over the left and right hemisphere were averaged to avoid confounding of target processing with cue-related lateralization (Jongen et al., 2007). Here we refer to the average across sites (e.g. P7, P8) as electrode pair (P7/8). The following electrodes and electrode pairs were investigated: Fz, Cz, Pz, Oz, P7/8, PO7/8 (see figure 5). P1 and N1 were investigated on the averaged P7/8 and PO7/8, SN on Fz and Cz, and P3 on Fz, Cz, Pz, and Oz. Time windows were again selected based on previous literature and visual inspection of the car ERPs (see figure 5). Mean amplitudes in the following time windows (120-150 ms, 170-200 ms, 300-400 ms, and 520-650 ms) were entered into a RMANOVA. For P1 and N1, we conducted a RMANOVA with factors attention (attended vs. unattended, depending on cued location), WM load (low vs. high), and electrode (as specified above). For SN and P3, (after motion onset), motion (stationary vs. moving) was included as additional factor in the RMANOVA.

'Insert Figure 5'

Continuous Driving Task

Lane-keeping was assessed by calculating the standard deviation of the lateral lane position (SDLP). SDLP is a measure of road tracking precision that represents a reliable characteristic of individual driving performance and is sensitive to driver impairment, for instance due to workload or various drugs (De Waard, 1996; Ramaekers, 2003; Ross et al., 2015). SDLP was collected throughout the entire scenario for the total sample (n = 22). The first 500 m (i.e., cruise control initiation) and segments with lane excursions were excluded from the analyses. During the programming of the driving scenario, road segments were marked as occurring under low and high load, respectively. This allowed to compare lane-keeping performance in both WM load conditions. SDLP was entered in a RMANOVA with factor WM load (low/high). To determine whether lane-keeping varied with WM load, we conducted a Pearson correlation analyses (one-tailed) between SDLP and the error rate on the memory task.

Results

Dual Task

Memory Task

Error rates (% error) in the memory task were significantly higher in the high than in the low WM load condition (low: mean = 2.40, SD = 2.65; high: mean = 9.41, SD = 7.07; $F(1,21) = 23.58$, $p < .0005$, $\eta\rho^2 = .529$).

Orienting task

Reaction times (median, in ms) were unaffected by WM load (low: mean = 454.09, SD = 55.99; high: mean = 453.18, SD = 59.05; $F(1,21) = 0.04$, $p = .850$, $\eta\rho^2 = .002$). There was a trend towards lower sensitivity under high load as indicated by a lower d' (low: mean= 3.72, SD= .68; high: mean= 3.50, SD= .71; F= 4.09, p= .056, $\eta\rho^2 = .16$), while WM load did not affect the criterion c (low: mean= .28, SD= .25; high: mean= .21, SD= .35; F= 1.47, p= .24, $\eta\rho^2 = .07$). With increased WM load, participants thus showed a trend towards a decline in detection performance that was not due to a change in response bias. Separate RMANOVAs were conducted to determine whether WM load increased hits and/or false alarms, allowing interpretation in terms of traffic safety implications. Hits were not significantly affected by WM load (low: mean = 92.12%, SD = 7.00; high: mean = 91.05%, SD = 8.79; $F(1,21) = 0.67$, $p = .421$, $\eta\rho^2 = .031$). False alarms however were significantly affected by WM load (low: mean = 0.57%, SD = 0.71; high: mean = 1.16%, SD = 1.39; $F(1,21) = 5.70$, $p =.026$, $\eta\rho^2 = .214$), indicating an increase of false alarms under high WM load.

Event-Related Potentials

Cue ERPs

See figure 4 for a visualization of the time windows and the significant ERP components (i.e., contralateral negativity and LDAP) in response to the cue. The main effect of hemisphere was not significant in the early time window that includes an early positive component indicating sensory processing of the arrow cues (50-100 ms, $F(1,16) = 0.71$, $p = .41$, $\eta\rho^2 = .042$). A significant main effect of hemisphere (ipsi vs. contralateral) confirmed a contralateral negativity (150-200 ms, $F(1,16) = 7.49$, $p = .015$, $\eta\rho^2 = .319$) and a contralateral positivity (LDAP: 500-650 ms, $F(1,16) = 40.25$, $p < .0005$, $\eta\rho^2 = .716$), indicating interpretation of cue direction and directing of attention. There was no significant effect of WM load on these components.

Car ERPs

See figure 5 for a visualization of the time windows and the significant ERP components (i.e., P1, N1, SN, and P3) in response to the car under low and high WM load. Separate RMANOVA's were conducted per component. There were main effects of attention in the windows containing P1 (120-150 ms, $F(1.13) = 9.09$, $p = .010$, $\eta\rho^2 = .412$) and N1 (170-200 ms, $F(1,13) = 5.97$, $p = .030$, $\eta\rho^2 = .315$) at P7/8 and PO7/8, reflecting greater absolute amplitudes of these components for validly vs invalidly cued car stimuli, indicating that processing of the car was enhanced by attention. No WM load effects were found for P1 or N1. A main effect of attention was found for SN (300-400 ms, $F(1,13) = 48.54$, $p < .0005$, $\eta\rho^2 = .789$) at Fz and Cz, indicating non-spatial processing of car features. Again, no WM load effects were found. Finally, with respect to the target (i.e., cued car that is moving), for P3 (520-650 ms) two significant three-way interactions were found (attention by movement by electrode, $F(1,13) = 17.21$, $p < .0005$, $\eta\rho^2 = .570$; attention by WM load by electrode, $F(1,13) = 5.89$, $p = .011$, $\eta\rho^2 = .321$). Therefore, for P3, separate RMANOVA's were conducted per electrode (Fz, Cz, Pz and Oz), with factors attention (attended/unattended), WM load (low/high) and movement (stationary/moving). Significant interactions between attention and movement (table 1) were found for all four electrodes indicating that an increase in P3 amplitude for moving as opposed to stationary cars was greater at attended than at unattended

locations. A significant interaction between attention and WM load (see table 1) was found at Oz, indicating that an increase in P3 amplitude for attended as opposed to unattended cars was smaller under high than under low WM load conditions. The same interaction showed a trend towards significance at Fz.

Continuous Driving

Compared to the low WM load condition, SDLP decreased significantly in the high WM load condition indicating higher lane-keeping performance with increased WM load (low: mean = 0.040, SD = 0.01; high: mean = 0.037, SD = 0.01; $F = 9.09$, $p = .01$, $\eta\rho^2 = .30$). The correlation analyses indicated a trend towards significance ($r = -.348$, $p = .056$) between SDLP in the high WM load and the error rate to the memory task in the high WM load condition (table 2).

Discussion

Extending on Vossen et al. (2016), this study (n = 22) was the first to investigate the effect of WM load on ERPs related to attention orienting in a simulated driving environment, while including a continuous measure of driving performance (i.e., lane-keeping). The results showed that typical ERP markers of attention orienting that are usually observed in laboratory tasks were also present in a simulated driving environment. These results support the potential for identifying future research and the development of hypotheses with respect to attention orienting. In accordance with Vossen et al. (2016), we found markers in response to the cue (contralateral negativity and LDAP), attentional modulation of the car (P1, N1 and SN), and target-evaluation in response to movement (P3). Similar to Vossen et al. (2016), the effect of movement onset was larger at attended than at unattended locations, indicating an effective filtering mechanism. The early negativity appeared too early (i.e., 150-200 ms) to be considered an EDAN (Jongen et al., 2007; Murray et al., 2011). Therefore, similar to Jongen et al. (Jongen et al., 2006; Jongen et al., 2007), we interpret it as an early posterior component related to sensory aspects of the cue but not to attention orienting. Contrary to Vossen et al. (2016), an ADAN in response to the cue, reflecting the programming and initiation of attention shifts (Eimer, 2014), was not observed. The ADAN has been considered a modality-unspecific attentional control mechanism that is mainly related to attention orienting. Recent studies however questioned this assumption, or ascribed more functionality to the occurrence of an ADAN (Talsma, Sikkens, & Theeuwes, 2011). The absence of an ADAN in the current study is consistent with the notion that ADAN reflects another process than attention orienting (Green, Conder, & Mc Donald, 2008; Praamstra, Boutsen, & Humphreys, 2005; van der Lubbe, Neggers, Verleger, & Kenemans, 2006). Research by van der Lubbe et al. (2006) indicated that the presence of ADAN reflects saccadic inhibition as participants need to inhibit eye movements towards target appearance. Or, as van der Lubbe et al. (2006) state: “Ah, the right side is relevant” (EDAN); “… I shouldn't look at the right…” (ADAN); “but focus my attention over there” (LDAP).” Although speculative, it is possible that the instruction to stay in the middle of the lane increased the ease to concentrate on the middle of the road, thereby automatically inhibiting the tendency to look at potentially relevant target locations.

The error rate on the memory task, and the false alarm rate on the orienting task, increased under high WM load. This resembles previous research indicating that WM load degrades attention (Lee et al., 2009; Vossen et al., 2016). With respect to the orienting task, participants tended to respond more liberally. According to the Load theory from Lavie (Lavie et al., 2004; Lavie, 2010), active maintenance of goal-directed behavior (e.g., deciding to yield) in the presence of interference (i.e., distraction) depends on spare WM capacity. As indicated by the increased error rate on the memory task, the high WM load condition was

more cognitively challenging, leaving fewer resources to devote to the decision to yield. Performance has two important aspects: speed and accuracy. Although they are qualitatively different, it is usually assumed that there exists a tradeoff between the two, in the sense that a participant can generally choose to be faster, but at the cost of more errors. Dependent upon effects on the chosen strategy, subtle effects of experimental variables may either concern speed or accuracy, or both. In this case, no effects on speed were found. Therefore, participants did not compensate the decrement in performance that was caused by the high WM load (i.e., increased false alarms) by slowing the reaction time.

Translated to real driving, in case of high WM load and ensuing doubt, drivers have an increased tendency to yield, thereby increasing their safety margins (as found previously under conditions of increased WM load; Engström et al., 2005; Son, Lee, & Kim, 2011) and reducing chances for crossing-path crashes. Therefore, the increased tendency to yield might be a compensatory strategy to deal with reduced resources to devote to the task. In this way, traffic safety would not be directly compromised by the increased WM load as unnecessary yielding may be less likely to result in an accident than failing to yield, thereby minimizing risk. Nevertheless, traffic flow will be reduced when drivers stop at inappropriate times. Indeed, distraction introduced by WM load negatively influenced traffic flow in a study from Stavrinos et al. (2013) (i.e., talking on the phone and most pronounced for distraction induced by writing text messages). Importantly, as reduced traffic flow might lead to congestion, traffic safety could be indirectly affected in case the increased proximity of following vehicles leads to ‘secondary crashes’ (e.g., multiple-vehicle crashes) (Stavrinos et al., 2013), which is supported by an increased likelihood of rear-end- crashes in teen drivers under conditions of increased WM load (Neyens & Boyle, 2007).

The results showed no effects of WM load on ERP responses to the cue, which is in contrast to Vossen et al. (2016) who found WM load effects on markers of orienting that indicated decreased processing of the cue. However, these effects concerned modulations of ADAN and EDAN, components that did not appear to begin with in the current study. Similar to Vossen et al. (2016), WM load did not affect markers of nonspatial orienting in response to the car stimuli. Finally, in contrast to Vossen et al. (2016), WM load decreased attentional resources available for processing a salient target-relevant event, as indicated by a reduced P3 in the high WM load condition for Fz and Oz. As no WM load effects were found in response to the cue indicating the to-be-attended side (i.e., resembling a road sign indicating right-of-way) or in response to the appearance of the car (i.e., simulating an approaching car), WM load only affected later stages of decision-making (i.e., do I have to react or not). This phase probably required more baseline attentional resources as the decision is more relevant here (i.e., compared to lab task) because of the immersion in a driving context. Considering task description, as well as latency and scalp topography of the observed P3, the current results could reflect a decrease in P3b. The P3b is a late central-parietal component (~400-700ms) indicating categorization, the update of working memory, or monitoring of decision-making (Bruder, Kayser, & Tenke, 2009; Verleger, Jaskowski, & Wascher, 2005). Furthermore, P3b is elicited when being presented with stimuli of unequal probability and attention needs to be paid to the infrequent ones (Fjell & Walhovd, 2003). This is in agreement with research where WM load decreased P3b in response to a sign indicating the direction of a required lane change (550 ms post-stimulus) (Lei, Welke, & Roetting, 2009).

In line with previous research (Cuenen et al., 2015; Engström et al., 2005; He, McCarley, & Kramer, 2014), the SDLP measurement indicated improved lane-keeping performance with increasing WM load. There are two prevailing theories to explain this effect (Lemercier et al., 2014). First, increased lane-keeping is accompanied by reduced visual scanning, indicating attention decrement (Reimer, 2009), which could also support the argument made above for the missing ADAN. Second, it signals the prioritization of driving

over the memory task, indicating improved performance of the driving task compared to the memory task (Becic et al., 2010; Engström et al., 2005). Recent research favors the latter. First, higher WM load induced by performing a backward counting task, was found to relate to increased lane-keeping performance independent of eye movements during a simulated drive (Cooper, Medeiros-Ward, & Strayer, 2013). Second, He et al. (2014) let participants perform a simulated lane-keeping task under conditions of lateral wind and WM load (low: listen and repeat back randomly ordered digits; high: listen, reorder, and repeat randomly ordered digits). They found a similar increase in lane-keeping performance with increasing WM load. An increased coupling of steering-to-lateral-winds under high WM load suggested that the increased lane-keeping indicated true improvement in lateral control. Therefore, participants in our study may have compensated for increasing WM load by prioritizing lane-keeping. The correlation analyses provides preliminary support for this assumption as the reduced lane-keeping variability under high WM load showed a trend towards an association with higher error rate in the high WM load. This may suggest that the WM load manipulation depleted additional cognitive resources, in line with Lavie's theory (Lavie et al., 2004; Lavie, 2010). As in He et al. (2014), it is still not clear why drivers would selectively protect lateral control as participants were not instructed to prioritize lane-keeping. Driving – at least in more experienced drivers – can be considered a highly overlearned behavior. Therefore, it is quite plausible that the prioritization of lane-keeping is a reflexive adaptation. It is possible that drivers did not voluntarily and consciously prioritized lane-keeping but rather performed automatically. Cooper et al. (2013) suggested that under conditions of high WM load, lane-keeping becomes an encapsulated inner-loop process requiring minimal attention, a process they describe as being similar to the swing of professional golf players which has been found to degrade when attention is paid to it (Cooper et al., 2013). However, as we were not able to find a highly significant relation between lane-keeping variability and error rate under conditions of high WM load, further research is necessary to support our hypothesis.

Limitations

First, questions can be raised concerning the ecological validity of these results as the driving context was rather simplistic, while driving through intersections in real-life can be extremely complicated. The simplified nature of the driving task allowed us to investigate ERPs related to attention orienting, which would otherwise be compromised by movement. The choice of a simplistic scenario can be further justified by a driving simulator study (Werneke & Vollrath, 2012) that found the highest level of crashes at the least complicated intersections and attributed this result to inadequate attention allocation. However, future studies should evaluate the effect of intersection complexity as it is likely that drivers will show stronger attentional effects as in the current study and possibly then also stronger modulation by load. Second, to minimize experimental duration (the current procedure took three to four hours) and reduce fatigue effects, we decided against a control condition without any load of WM. As the low WM load condition was already quite demanding due to the combination with the orienting task and active lane-keeping, a contrast with a truly non-demanding baseline condition (no memory task) might have revealed additional effects of WM load. Nevertheless, this situation more closely resembles true driving which is executed in a dynamic and complex environment requiring vehicle control in changing circumstances. Third, as a crash would discontinue cruise control, vehicles owning right-of-way did not complete their maneuver to drive onto the road. A study from China indicated that drivers decide to yield 1.3-1.5 s before reaching the merging point at unsignalized intersections (i.e., no priority control) (Liu, Lu, Wang, Wang, & Zhang, 2013), leaving a time-window between the decision and the event. From the current results, it is not possible to determine how drivers might have reacted during this limited time-gap from brake-onset to the merging point.

Transferred to the current study, it is possible that drivers might brake initially but then continue driving when they realize their mistake (i.e., false alarm). If the other driver, not owning right-of-way, notices the brake reaction and assumes that the other driver will stop, the risk of a crossing-path crash increases when decides to cross as well.

Recommendations

Intersection driver-support systems have been used to improve traffic safety, and recently also traffic flow (e.g., Chen, Cao, & Logan, 2011; Dotzauer, de Waard, Caljouw, Pöhler, & Brouwer, 2015). Still, in-vehicle systems induce WM load, even without using visual stimuli (Becic, Manser, Creaser, & Donath, 2012; Becic, Manser, Drucker, & Donath, 2013; Solovey, Zec, Perez, Reimer, & Mehler, 2014). As this could increase the tendency to yield, thereby affecting traffic flow, the effectiveness of such systems might be reduced. Therefore, WM load measurements should be included when developing intersection driver-support systems. One option to assess the WM load of drivers is to include EEG measurement to intersection driver-support systems (Lei et al., 2009). Previous research already investigated the use of ERPs to measure WM load with the use of a secondary task (Coleman, Turrill, Hopman, Cooper, & Strayer, 2015; Lei et al., 2009). For instance, Coleman et al. (2015) found an increased P3 latency, in conjunction with a reduced amplitude, in a signal detection task when drivers interact with in-vehicle voice-command systems resembling varying levels of WM load. The use of ERPs in response to the driving task to measure WM load is further supported by previous research indicating a reduction of P3 amplitude in response to brake lights of a leading vehicle in a car-following-task, while drivers were talking on the phone (Strayer & Drews, 2007). A major concern however is the practical applicability of EEG during active driving. For instance, in the study by Coleman et al. (2015), there was a degradation of signal quality due to increased environmental noise (e.g., computers), making the transfer to on-road driving, where even more noise will be present, challenging.

Conclusions

The current results provide support for the theory from Lavie that performance depends on available WM resources (Lavie, 2010; Ross, et al., 2014). Although lane-keeping increased under high WM load, task performance decreased as indicated by an increased error rate in the memory task, increased tendency to inappropriately yield in the orienting task, and a smaller P3 in response to movement. Furthermore, this study confirmed that typical markers of attention orienting can be found in more ecologically valid settings. However, discrepancies between the current study and Vossen et al. (2016) need further investigation. Although further applications in even more realistic driving environments are called for, the current results support the usefulness of WM load measurement during driving in the development of driver-support systems.

References

Allen, R. W., Marcotte, T. D., Rosenthal, T. J., & Aponso, B. L. (2005). Driver assessment with measures of continuous control behavior. *PROCEEDINGS of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design* (pp. 165-172), San Diego: University of Iowa.

Bao, S., & Boyle, L. N. (2009). Age-related differences in visual scanning at median-divided highway intersections in rural areas. *Accident Analysis and Prevention, 41*, 146–152.

Becic, E., Dell, G. S., Bock, K., Garnsey, S. M., Kubose, T., & Kramer, A. F. (2010). Driving impairs talking. *Psychonomic Bulletin & Review, 17*(1), 15-21. doi:10.3758/PBR.17.1.15

Becic, E., Manser, M. P., Creaser, J. I., & Donath, M. (2012). Intersection crossing assist system: Transition from a road-side to an in-vehicle system. *Transportation Research Part F, 15*, 544-555. Retrieved from http://dx.doi.org/10.1016/j.trf.2012.05.010

Becic, E., Manser, M., Drucker, C., & Donath, M. (2013). Aging and the impact of distraction on an intersection crossing assist system. *Accident Analysis and Prevention, 50*, 968-974. Retrieved from http://dx.doi.org/10.1016/j.aap.2012.07.025

Bruder, G. E., Kayser, J., & Tenke, C. E. (2009). Event-Related Brain Potentials in Depression: Clinical, Cognitive and Neurophysiologic Implications. In S. J. Kappenman, & (Eds.), *The Oxford Handbook of Event-Related Potential Components* (pp. 563-592). New York: Oxford University Press.

Chen, H., Cao, L., & Logan, D. B. (2011). Investigation Into the Effect of an Intersection Crash Warning System on Driving Performance in a Simulator. *Traffic Injury Prevention, 12*, 529-537.

Coleman, J. R., Turrill, J., Hopman, R. J., Cooper, J. M., & Strayer, D. L. (2015). Assessing cognitive distraction using event related potentials. *PROCEEDINGS of the Eighth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* Salt Lake City.

Cooper, J. M., Medeiros-Ward, N., & Strayer, D. L. (2013). The Impact of Eye Movements and Cognitive Workload on Lateral Position Variability in Driving. *Human factors, 55*(5), 1001–1014. doi:10.1177/0018720813480177

Cuenen, A., Jongen, E. M., Brijs, T., Brijs, K., Lutin, M., Van Vlierden, K., & Wets, G. (2015). Does attention capacity moderate the effect of driver distraction in older drivers? *Accident Analysis and Prevention, 77*, 12-20.

de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The Role of Working Memory in Visual Selective Attention. *Science, 291*, 1803-1806.

De Waard, D. (1996). *The measurement of drivers' mental workload. (Unpublished Doctoral Dissertation).* University of Groningen, Haren, The Netherlands: University of Groningen Traffic Research Centre.

Dotzauer, M., de Waard, D., Caljouw, S. R., Pöhler, G., & Brouwer, W. H. (2015). Behavioral adaptation of young and older drivers to an intersection crossing advisory system. *Accident Analysis and Prevention, 74*, 24-32. Opgehaald van http://dx.doi.org/10.1016/j.aap.2014.09.030

Eimer, M. (2014). The time course of spatial attention: Insights from event-related brain potentials. In A. Nobre, S. Kastner, & Eds., *The Oxford Handbook of Attention* (p. 289).

Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F, 8*(2), 97–120.

Fjell, A. M., & Walhovd, K. B. (2003). On the Topography of P3a and P3b Across the Adult Lifespan—A Factor-Analytic Study Using Orthogonal Procrustes Rotation. *Brain Topography, 15*(3), 153-164.

Fort, A., Collette, B., Bueno, M., Deleurence, P., & Bonnard, A. (2013). Impact of totally and partially predictive alert in distracted and undistracted subjects: An event related potential study. *Accident Analysis and Prevention*, 578-586. Opgehaald van http://dx.doi.org/10.1016/j.aap.2012.06.005

doi:10.1016/j.brainres.2010.09.094

Fu, C., Pei, Y., Wu, Y., & Qi, W. (2013). The Influence of Contributory Factors on Driving Violations at Intersections: An Exploratory Analysis. *Advances in Mechanical Engineering*, 8. Opgehaald van http://dx.doi.org/10.1155/2013/905075

Green, J. J., Conder, J. A., & Mc Donald, J. J. (2008). Lateralized frontal activity elicited by attention-directing visual and auditory cues. *Psychophysiology, 45*, 579–587. doi:10.1111/j.1469-8986.2008.00657.x

He, J., McCarley, J. S., & Kramer, A. F. (2014). Lane Keeping Under Cognitive Load: Performance Changes and Mechanisms. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 56*(2), 414-426. doi:10.1177/0018720813485978

Herrmann, C. S., & Knight, R. T. (2001). Mechanisms of human attention: event-related potentials and oscillations. *Neuroscience & Biobehavioral Reviews, 25*(6), 465-476.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185–191.

Jongen, E. M., Smulders, F. T., & Van Breukelen, G. J. (2006). Varieties of attention in neutral trials: Linking RT to ERPs and EEG frequencies. *Psychophysiology, 43*, 113–125.

Jongen, E. M., Smulders, F. T., & van der Heiden, J. S. (2007). Lateralized ERP components related to spatial orienting: Discriminating the direction of attention from processing sensory aspects of the cue. *Psychophysiology, 44*, 968–986.

Kessels, L. T., Ruiter, R. A., & Jansma, B. M. (2010). Increased Attention but More Efficient Disengagement: Neuroscientific Evidence for Defensive Processing of Threatening Health Information. *Health Psychology, 29*(4), 346-354.

Law, A. S., Langton, S. R., & Logie, R. H. (2010). Assessing the impact of verbal and visuospatial working memory load on eye-gaze cueing. *Visual Cognition*, 18(10), 1420-1438.

Lavie, N. (2010). Attention, Distraction, and Cognitive Control Under Load. *Current Directions in Psychological Science, 19*(3), 143-148.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load Theory of Selective Attention and Cognitive Control. *Journal of Experimental Psychology: General, 133*(3), 339–354.

Lee, Y.-C., Lee, J. D., & Boyle, L. N. (2009). The Interaction of Cognitive Load and Attention-Directing Cues in Driving. *Human Factors, 51*(3), 271-280. doi:10.1177/0018720809337814

Lei, S., Welke, S., & Roetting, M. (2009). Driver's Mental Workload Assessment Using EEG Data in a Dual Task Paradigm. *PROCEEDINGS of the 21st (ESV) international technical conference on the enhanced safety of vehicles.* Berlin.

Lemercier, C., Pêcher, C., Berthié, G., Valéry, B., Vidal, V., Paubel, P.-V., Cour, M., Fort, A., Galéra, C., Lagarde, E., Maury, B. (2014). Inattention behind the wheel: How factual internal thoughts impact attentional control while driving. *Safety Science, 62*, 279–285.

Liu, M., Lu, G., Wang, Y., Wang, Y., & Zhang, Z. (2013). Preempt or yield? An analysis of driver's dynamic decision making at unsignalized intersections by classification tree. *Safety Science, 65*, 36-44. Retrieved from http://dx.doi.org/10.1016/j.ssci.2013.12.009

Luck, S. J., Heinze, H. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index focused attention within bilateral stimulus arrays. II. Functional dissociation of P1 and N1 components. *Electroencephalography and clinical neurophysiology, 75*(6), 528-542.

McDonald, J. J., & Green, J. J. (2008). Isolating event-related potential components associated with voluntary control of visuo-spatial attention. *Brain Research, 1227*, 96-109. doi:10.1016/j.brainres.2008.06.034

McEvoy, S. P., Stevenson, M. R., & Woodward, M. (2007). The prevalence of, and factors associated with, serious crashes involving a distracting activity. *Accident Analysis and Prevention, 39*, 475-482. doi:10.1016/j.aap.2006.09.005

McGinnis, M. E., & Keil, A. (2011). Selective Processing of Multiple Features in the Human Brain: Effects of Feature Type and Salience. *PLoS ONE, 6*(2). doi:10.1371/journal.pone.0016824

Murray, A. M., Nobre, A. C., & Stokes, M. G. (2011). Markers of preparatory attention predict visual short-term memory performance. *Neuropsychologia, 149*, 1458-1465. doi:10.1016/j.neuropsychologia.2011.02.016

Neyens, D. M., & Boyle, N. L. (2007). The effect of distractions on the crash types of teenage drivers. *Accident Analysis and Prevention, 39*, 206–212. doi:10.1016/j.aap.2006.07.004

Nobre, A. C., Sebestyen, G. N., & Miniussi, C. (2000). The dynamics of shifting visuospatial attention revealed by event-related potentials. *Neuropsychologia, 38*, 964±974.

Pitts, M. A., Padwal, J., Fennelly, D., Martínez, A., & Hillyard, S. A. (2014). Gamma band activity and the P3 reflect post-perceptual processes, not visual awareness. *NeuroImage, 101*, 337-350. Opgehaald van http://dx.doi.org/10.1016/j.neuroimage.2014.07.024

Posner, M. I. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. L. Pick, & E. Saltzman (Red.), *Modes of Perceiving and Processing Information* (Vol. 137, pp. 137-157). New York: Taylor & Francis group.

Praamstra, P., Boutsen, L., & Humphreys, G. W. (2005). Journal of Neurophysiology. *94*, 764-774. doi:doi:10.1152/jn.01052.2004

Prinzel, L. J., Freeman, F. G., Scerbo, M. W., Mikulka, P. J., & Pope, A. T. (2003). Effects of a psychophysiological system for adaptive automation on performance, workload, and the event-related potential P300 component. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 45*(4), 601-614.

Ramaekers, J. G. (2003). Antidepressants and driver impairment: empirical evidence from a standard on-the-road test. *The Journal of Clinical Psychiatry, 64*(1), 20-29.

Recarte, M. A., & Nunes, L. M. (2003). Mental Workload While Driving: Effects on Visual Search, Discrimination, and Decision Making. *Journal of Experimental Psychology: Applied, 9*(2), 119–137.

Reimer, B. (2009). Impact of Cognitive Task Complexity on Drivers' Visual Tunneling. *Transportation Research Record: Journal of the Transportation Research Board, 2138*, 13-19. doi:10.3141/2138-03

Ross, V., Jongen, E. M., Brijs, T., Brijs, K., Ruiter, R. A., & Wets, G. (2015). The relation between cognitive control and risky driving in young novice drivers. *Applied Neuropsychology: Adult, 22*(1), 61-72. doi:10.1080/23279095.2013.838958.

Ross, V., Jongen, E. M., Wang, W., Brijs, T., Brijs, K., Ruiter, R. A., & Wets, G. (2014). Investigating the influence of working memory capacity when driving behavior is combined with cognitive load: An LCT study of young novice drivers. *Accident Analysis and Prevention, 62*, 377– 387.

Ruiter, R. A., Kessels, L. T., Jansma, B. M., & Brug, J. (2006). Increased Attention for Computer-Tailored Health Communications: An Event-Related Potential Study. *Health Psychology, 25*(3), 300-306.

Sandin, J. (2009). An analysis of common patterns in aggregated causation charts from intersection crashes. *Accident Analysis and Prevention, 41*, 624–632.

Shedden, J. M., & Nordgaard, C. L. (2001). ERP time course of perceptual and post-perceptual mechanisms of spatial selection. *Cognitive Brain Research, 11*, 59-75.

Solovey, E. T., Zec, M., Perez, E. A., Reimer, B., & Mehler, B. (2014). Classifying Driver Workload Using Physiological and Driving Performance Data: Two Field Studies. *ACM CHI Conference on Human Factors in Computing Systems.* Toronto, Canada.

Son, J., Lee, Y., & Kim, M. H. (2011). Impact of traffic environment and cognitive workload on older drivers' behavior in simulated driving. *International Journal of Precision Engineering and Manufacturing, 12*(1), 135-141.

Santangelo, V., Finoia, P., Raffone, A., Belardinelli, M.O., & Spence, C. (2008). Perceptual load affects exogenous spatial orienting while working memory load does not. *Experimental Brain Research*, 184, 371-382.

Stavrinos, D., Jones, J. L., Garner, A. A., Griffin, R., Franklin, C. A., Ball, D., Welburn, S. C., Ball, K. K., Sisiopiku, V. P., Fine, P. R. (2013). Impact of Distracted Driving on Safety and Traffic Flow. *Accident Analysis and Prevention, 61*, 63-70. doi:10.1016/j.aap.2013.02.003

Strayer, D. L., & Drews, F. A. (2007). Cell-Phone–Induced Driver Distraction. *Current Directions in Psychological Science, 16*(3), 128-131.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell Phone-Induced Failures of Visual Attention During Simulated Driving. *Journal of Experimental Psychology: Applied, 9*(1), 23–32.

Talsma, D., Sikkens, J. J., & Theeuwes, J. (2011). Stay Tuned: What Is Special About Not Shifting Attention? *PLoS ONE, 6*(3), e16829. doi:10.1371/journal.pone.0016829

Ullsperger, P., Freude, G., & Erdmann, U. (2000). Auditory probe sensitivity to mental workload changes - an event-related potential study. *International Journal of Psychophysiology , 40*, 201-209.

van der Lubbe, R. H., Neggers, S. F., Verleger, R., & Kenemans, L. J. (2006). Spatiotemporal overlap between brain activation related to saccade preparation and attentional orienting. *Brain Research, 1072*, 133-152. doi:10.1016/j.brainres.2005.11.087

van Kessel, M. E., Geurts, A. C., Brouwer, W. H., & Fasotti, L. (2013). Visual scanning training for neglect after stroke with and without a computerized lane tracking dual task. *Frontiers in Human Neuroscience, 7*(358).

Van Velzen, J., & Eimer, M. (2003). Early posterior ERP components do not reflect the control of attentional shifts toward expected peripheral events. *Psychophysiology, 40*, 827-831.

Verleger, R., Jaskowski, P., & Wascher, E. (2005). Evidence for an Integrative Role of P3b in Linking Reaction to Perception. *Journal of Psychophysiology, 20*(2).

Vossen, A. Y., Ross, V., Jongen, E. M., Ruiter, R. A., & Smulders, F. T. (2016). The Effect of Working Memory Load on Electrophysiological Markers of Visuospatial Orienting in a Spatial Cueing Task Simulating a Traffic Situation. *Psychophysiology, (53)*2, 237-51, doi: 10.1111/psyp.12572.

Werneke, J., & Vollrath, M. (2012). What does the driver look at? The influence of intersection characteristics on attention allocation and driving behavior. *Accident Analysis and Prevention, 45*, 610– 619.

Wester, A. E., Bocker, K. B., Volkerts, E. R., Verster, J. C., & Kenemans, J. L. (2008). Event-related potentials and secondary task performance during simulated driving. *Accident Analysis and Prevention, 40*, 1-7.

World Health Organization, W. (2013). *Global status report on road safety 2013: supporting a decade of action.* Retrived August 2014, from http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/

Wu, N. (2001). A universal procedure for capacity determination at unsignalized (priority-controlled) intersections. *Transportation Research Part B: Methodological, 35*(6), 593–623. doi:10.1016/S0191-2615(00)00012-6

Young, K., & Regan, M. (2007). Driver distraction: A review of the literature. In I. J. Faulks, M. Regan, M. Stevenson, J. Brown, A. Porter, & J. D. Irwin, *Distracted driving* (pp. 379-405). Sydney: NSW: Australasian College of Road Safety.

Att*Mov						Att*Load					
Electrode	**Condition**	**M**	**SE**	**F**	**p**	**Electrode**	**Condition**	**M**	**SE**	**F**	**p**
Fz	AS	.478	1.38	10.10	.01*	**Fz**	AL	1.74	1.32	4.50	.05*
	AM	4.32	1.31				AH	3.05	1.24		
	US	1.07	.64				UL	1.39	.71		
	UM	1.52	.79				UH	1.21	.78		
Cz	AS	2.55	1.43	22.13	.00*	**Cz**	AL	6.04	1.50	.02	.90
	AM	9.81	1.81				AH	6.29	1.51		
	US	2.87	.88				UL	3.16	1.36		
	UM	3.60	1.03				UH	3.30	1.26		
Pz	AS	3.40	1.28	77.79	.00*	**Pz**	AL	9.05	1.62	.20	.67
	AM	14.28	2.13				AH	8.63	1.70		
	US	2.48	.78				UL	3.08	.74		
	UM	3.71	.81				UH	3.11	.90		
Oz	AS	1.60	.85	63.76	.00*	**Oz**	AL	5.42	.97	6.16	.03*
	AM	8.24	1.26				AH	4.41	1.00		
	US	1.17	.39				UL	1.55	.48		
	UM	2.45	.43				UH	2.06	.40		

TABLE 1: P3 means and standard errors describing Attention by Movement (Att*Mov) and Attention by Load (Att*Load) contrasts; AS= Attended Stationary, AM= Attended Moving, US= Unattended Stationary, UM= Unattended Moving, AL= Attended Low load, AH= Attended High load, UL= Unattended Low load, UH= Unattended High load; $^{*}p \leq .05$.

	SDLP_low	SDLP_high	Error rate_low	Error rate_high
SDLP_low	1	.926**	.182	-.329
SDLP_high	.926**	1	.032	-.348
Error rate_low	.209	.032	1	.298
Error rate_high	-.329	-.348*	.298	1

TABLE 2: Pearson correlations; *p≤.05 (one-tailed); **p≤.01 (one-tailed); SDLP: lane-keeping in the low and high load. Error rate: error rate is the responses to the memory task in the low and high load.

Figure captions

FIGURE 1: Experimental environment.

FIGURE 2: Schematic Representation of the Dual Task (Adapted from Vossen et al., 2016).

FIGURE 3: Grand average cue ERPs to the cued direction, under low (left column) and high WM load (right column), recorded ipsilateral (solid line) or contralateral (dotted line) electrodes.

FIGURE 4: Hemispheric differences in Cue ERPs (contra- minus ipsilateral electrodes). Grey shaded areas indicate the time windows of interest. The name of the components are added in black font, except for the windows where no ADAN was found (i.e., only window for F7/8 and FC5/6) and where the early positivity was not confirmed by statistical analyses (i.e., first window for P7/8 and PO7/8).

FIGURE 5: Car ERPs, averaged across ipsi- and contralateral electrodes, under low (left column) and high WM load (right column). Grey shaded areas indicate the time windows of interest, the name of the components are added in black font.

Figures

Figure 1

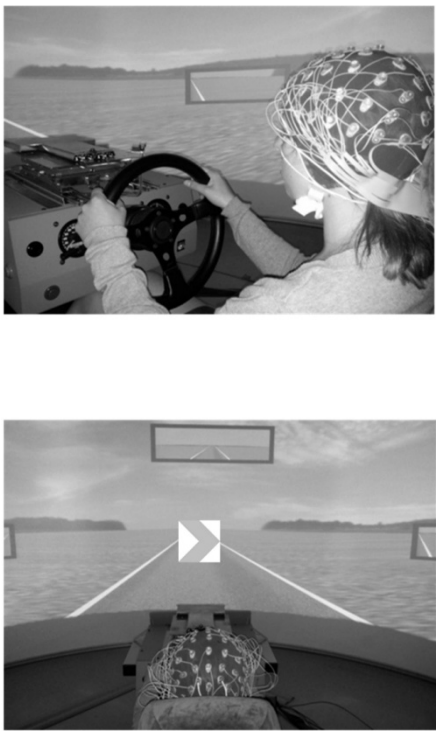


Figure 2

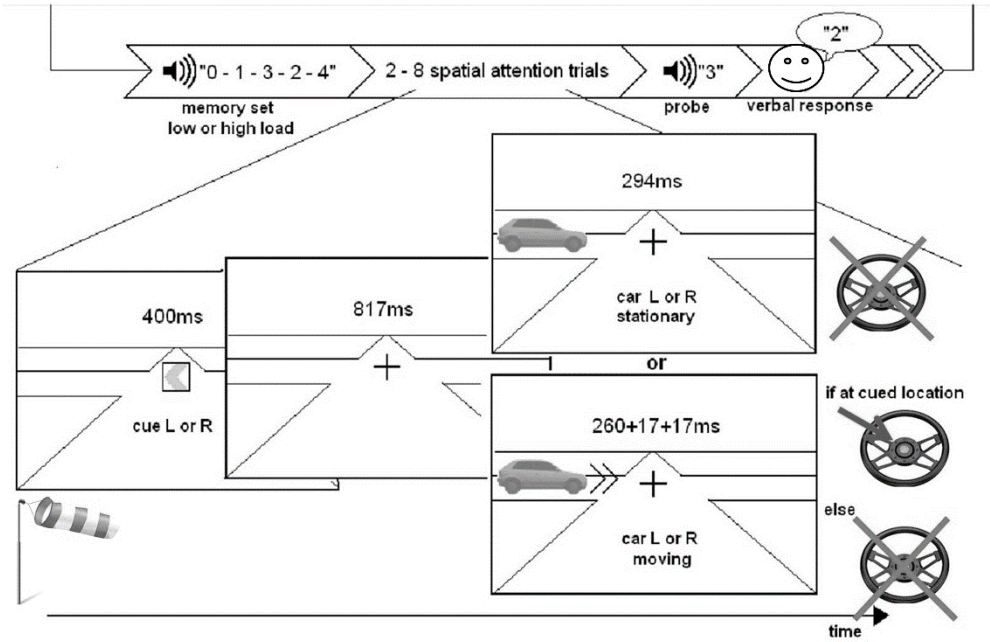


Figure 3

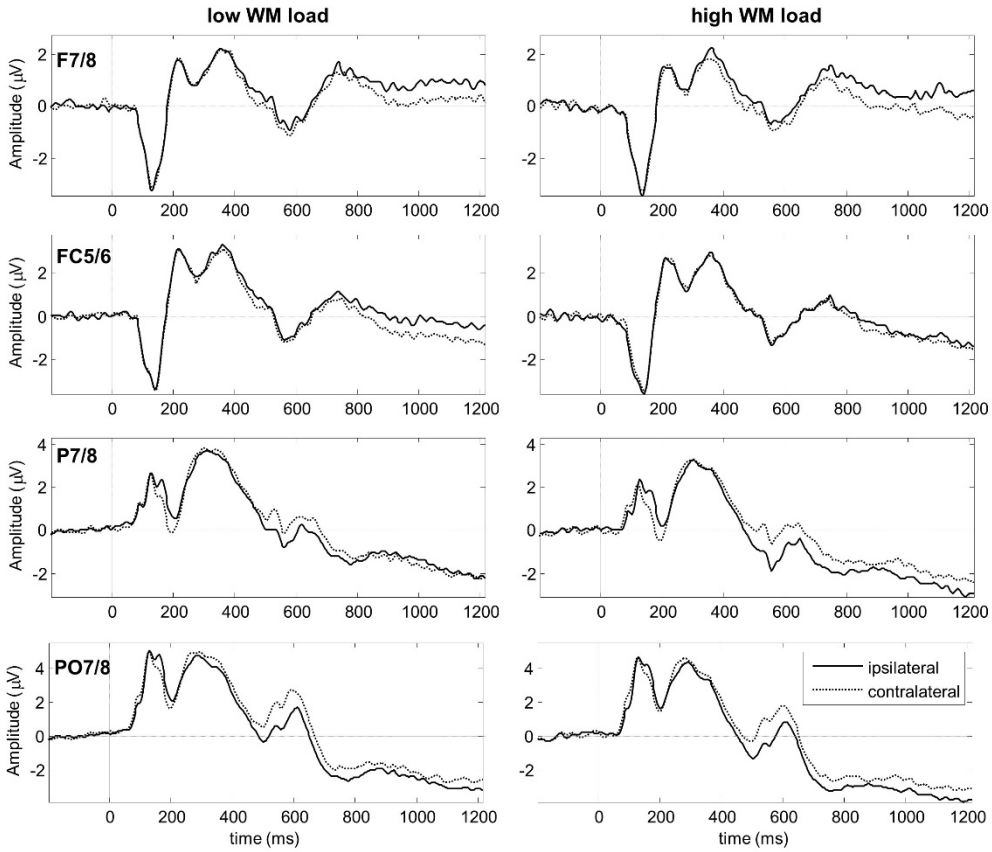

low WM load
high WM load
F7/8
FC5/6
P7/8
PO7/8
Amplitude (μV)
time (ms)
ipsilateral
contralateral

Figure 4

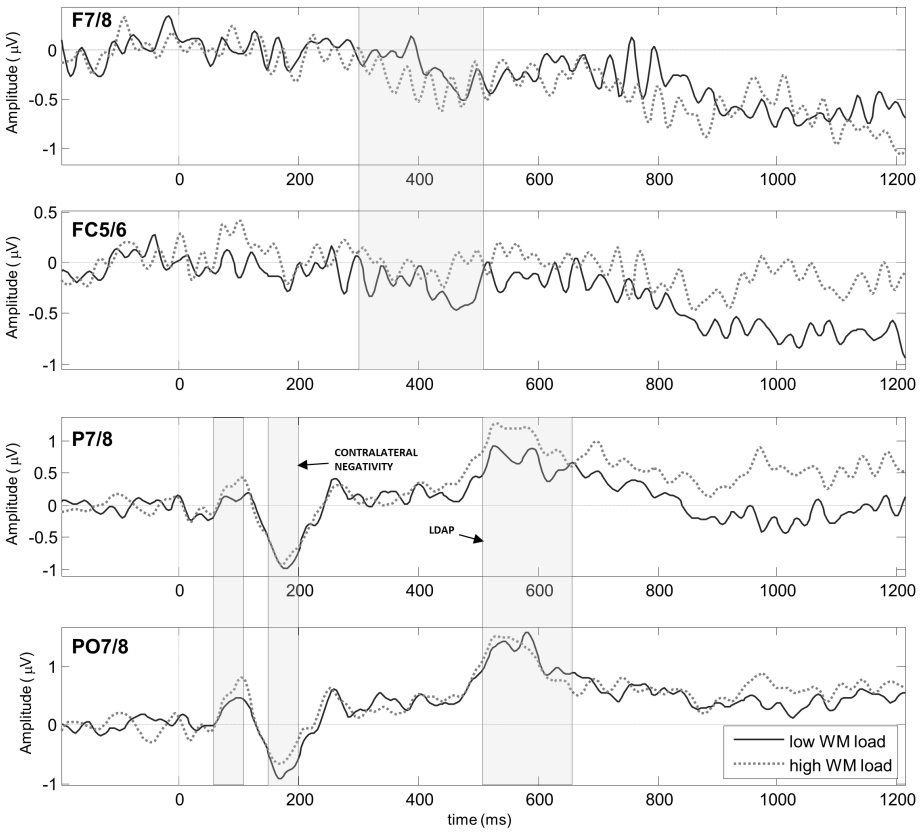
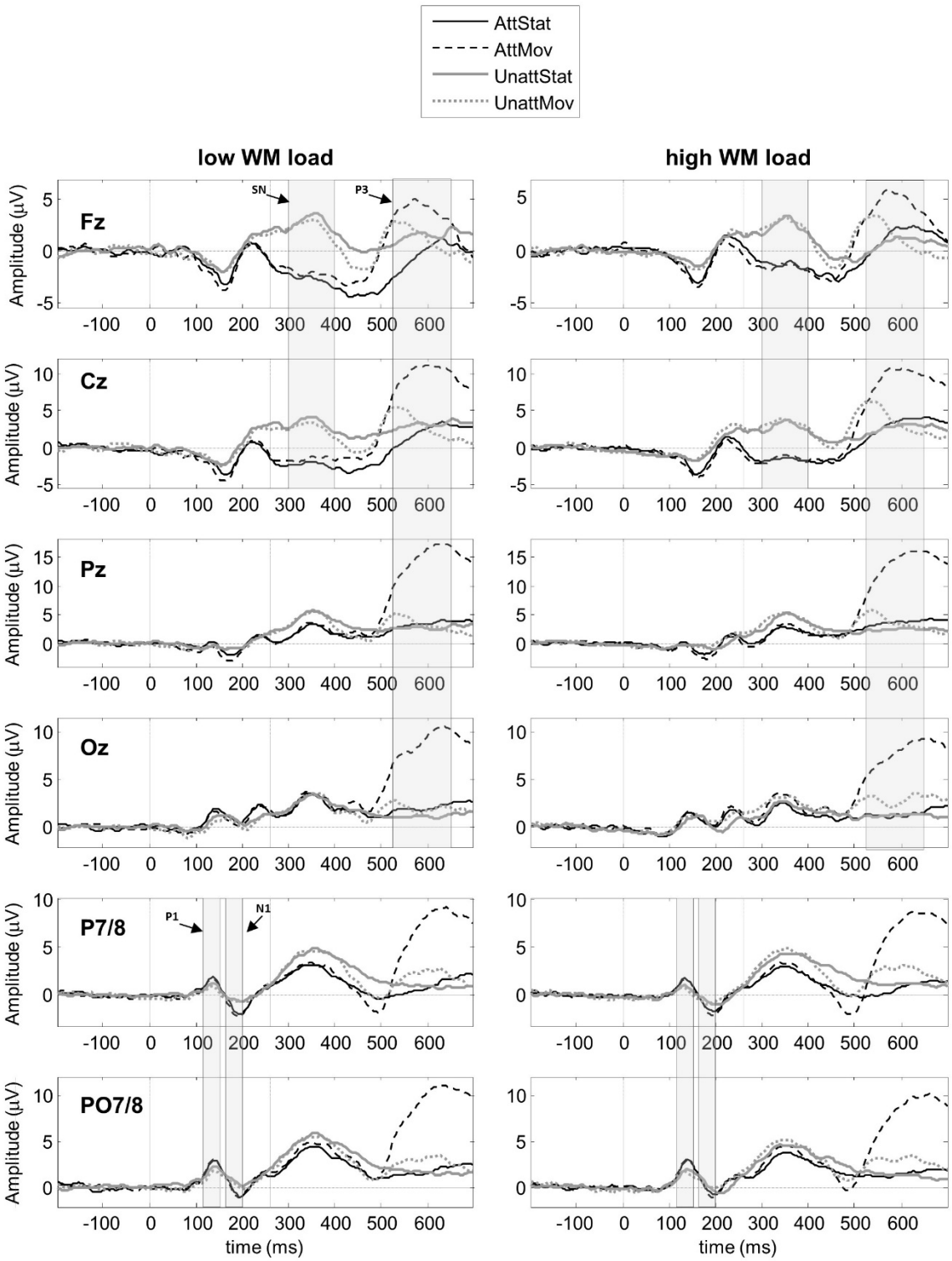

F7/8
FC5/6
P7/8
PO7/8
Amplitude (µV)
CONTRALATERAL NEGATIVITY
LDAP
low WM load
high WM load
time (ms)

Figure 5


AttStat
AttMov
UnattStat
UnattMov
low WM load
high WM load
Fz
Cz
Pz
Oz
P7/8
PO7/8
SN
P3
P1
N1
Amplitude (µV)
time (ms)