Development of the Enhanced Peripheral Detection Task: A Surrogate Test for Driver Distraction

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ABSTRACT

Up to now, there is no standard methodology that addresses how driver distraction is affected by perceptual demand and working memory demand - aside from visual allocation. In 2009, the Peripheral Detection Task (PDT) became a NHTSA recommended measure for driver distraction [1]. Then the PDT task was renamed as the Detection Response Task (DRT) because the International Standards Organization (ISO) has identified this task as a potential method for assessing selective attention in detection of visual, auditory, tactile and haptic events while driving. The DRT is also under consideration for adoption as an ISO standard surrogate test for driver performance for new telematics designs. The Wayne State University (WSU) driver imaging group [2, 3] improved the PDT and created the Enhanced Peripheral Detection Task I (EPDT-I) [4]. The EPDT-I is composed of a simple visual event detection task and a video of a real-world driving scene. It is simple, easy to learn and run, and convenient for use in the lab, road, or brain imaging environments [5]. With the success of EPDT-I, the WSU driver imaging group further developed the Enhanced Peripheral Detection Task-II (EPDT-II; also called “Wayne State Enhanced DRT” or “Wayne State EDRT”) by adding a number of features to engage participants more with the primary driving task and to assess attentional processes in greater detail. This research also compared performance in the EPDT-II at our lab, EEG, and neuroimaging environments to the open road for validation purposes [6]. In conclusion, the Wayne State EDRT provides a sensitive and up-to-date surrogate test for measuring driver distraction in the lab and on the road.

As for assessment of an individual's driver distraction, there is still no standard methodology that addresses how driver distraction is affected by perceptual demand and working memory demand - aside from the visual allocation. For the first time, the Peripheral Detection Task (PDT) might become a NHTSA recommended measure for driver distraction [1]. In addition, the PDT task was renamed as the Detection Response Task (DRT) in order for the International Standards Organization (ISO) to identify this DRT task as a potential method for assessing selective attention in object event detection across various modalities while driving, such as visual, auditory, tactile and haptic events. Since 2009, the DRT has been under consideration for adoption as an ISO standard surrogate test for driver performance for new telematics designs.

According to the ISO TC22/SC13/WG8, “The DRT method is based on a simple detection-response task where participants respond to relatively frequent artificial stimuli presented with some temporal uncertainty. Detection performance, measured in terms of response time and hit rate, represents the degree to which selective attention is affected by the secondary task under evaluation.” The DRT method may be implemented in several different ways in terms of stimulus presentation modality (visual or tactile) and in terms of whether the DRT is performed while driving (dynamic) or not (static), depending on the purpose of the study.

Many investigations into human performance involve the use of driving simulators. What is often lacking is a validation of these simulators using on-road data. In a series of studies, we investigated the effects of conversation on multitasking performance in a validated driving workload paradigm [2, 3, 6], an Enhanced Peripheral Detection Task (EPDT). Behavioral validation studies for predicting event detection on the road from lab data have recently shown excellent results, with correlations of 0.9 for brake response times to visual events [6]. Validation is especially important given the cognitive complexity of real-world driving tasks and the public policy implications of driver performance research. The WSU driver imaging group is the first to apply neuroimaging measures to a validated driving simulation paradigm.

The WSU driver imaging group created the Enhanced Peripheral Detection Task I (EPDT-I) [4] and EPDT-II [2, 3] that provide additional features to the original PDT. These EPDTs are composed of a simple visual event detection task and a video of a real-world driving scene. They are simple, easy to learn and run, and convenient for use in the lab, road, or brain imaging environments. The WSU driver imaging group does not only add a number of features to engage participants more with the primary driving task, but also provides a window to look into more detailed components of attentional processes in driver performance, as well as neural processing networks in the brain. The detection performance of the EPDT-II in the lab has been validated by open road driving. Results of statistical analysis on driver performance indicated high correlations for detection response times from the lab to the road [6].

**METHODS**

**ENHANCED PERIPHERAL DETECTION TEST-I (EPDT-I)**

The driving distraction study by the WSU driving imaging group [2, 3] used the Enhanced Peripheral Detection Task-I (EPDT-I) [4], comprised of a simple visual event detection task and a video of a real-world driving scene (Fig. 1). The red visual events occurred one at a time in a random order at the central lower position or the left peripheral position. Visual event detection and viewing of the natural driving video occur throughout the task. It was designed to be simple, easy to learn and run, and convenient for use in the lab, road, or brain imaging environments [5].

Figure 1. Participants were instructed to focus on the “primary driving” task (watching the driving video while responding to the lights), while engaging in a secondary task, such as simulated cellular conversations. The visual event detections and viewing of the natural driving video occurred throughout the experiment.

The EPDT-I was designed to be conducted with secondary tasks to assess interference, and the secondary task used in this study was a simulated hands-free cellular phone conversation. In this research, we utilized the EPDT-I with a secondary conversation task while recording neural responses, using functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG).

In this study, the EPDT-I employed a personal computer, monitor, and a driving simulator foot pedal. During the behavioral study, the subject was instructed to focus their attention on activities occurring in a video of a driving scene recorded from a moving vehicle and to respond to target visual events, while engaging in a secondary task (e.g., simulated cellular conversations). The primary driving task required subjects to view the driving scene and depress a
pedal with one's foot in response to small red circles randomly presented below or to the left of the driving scene at frequent and varying time intervals. These targets appeared every four to six seconds, for a duration of 3.5 seconds, unless a participant responded, at which point they disappeared. The same visual event duration and interval were used in previous study [4]. Latencies to respond to the circles, as well as failures to respond to the circles within 3.5 seconds, were recorded by the software presenting the video and circle targets. Participants were instructed to treat this task as a simulation of driving a vehicle.

As for the secondary task, subjects were told to press a mouse button in response to the sound of a ringing phone and then to answer simple pre-recorded questions delivered over a speaker, such as, “Could you tell me your birth date?” This condition included answering the cellular call by pressing a button, carrying on a hands-free conversation, viewing the driving video, and pressing a pedal in response to the appearance of red circles.

Accuracy and reaction time data are collected and analyzed. The EPDT-I was successfully administrated while recording neural responses with both functional MRI and magnetoencephalography (MEG) with secondary conversation tasks [2, 3].

ENHANCED PERIPHERAL DETECTION TEST-II (EPDT-II)

With the success of EPDT-I, the WSU driver imaging group continued to develop the Enhanced Peripheral Detection Task-II (EPDT-II) by adding a number of features to EPDT-I to better engage participants with the primary driving task and to assess attentional processes at a greater level of detail [6, 20, 21, 22, 23, 24]. Like EPDT-I, it is designed to be simple to learn, simple to run, and convenient for use in neuroimaging environments. The EPDT-II is still at its core based on event detection, but instead of only presenting red circle targets, the task also presents green circle non-targets, to which they are instructed not to respond. The visual targets lasted for 2.5 seconds until the participant responded with a stimulus interval of every 3-5 seconds. The green targets provide a means to measure subjects' abilities to inhibit a response, which other research has indicated reduced attention to the primary task. The EPDT-II paradigm allows sufficient target and non-target events that provide additional events in response to the red lights, which help improve statistical power in investigation of subcomponents of cognitive attention and distraction. Besides watching a driving video as in EPDT-I, in EPDT-II participants are asked to keep tracking the lane that the vehicle is traveling by moving an on-screen arrow as close as possible to the center of the lane, providing additional driving metrics. We have also successfully replicated the design during in-vehicle road-testing and established cross-site validity for its principle measures. It is a flexible tool, permitting simple modification to include all varieties of demand.

The EPDT-II provides a platform to explore the nature of the event detection performance associated with the secondary task as well as the ability to inhibit responses to non-targets, a necessary and key component to investigating driver distraction. Contrasting accuracy and response time performance of non-targets to targets permits researchers to explore the nature of the demand associated with the secondary task as well as the ability to inhibit responses to stimuli, which can also be important for driving safety. Therefore, EDPT-II could be a powerful tool for making inferences about cognitive processes in the attention networks.

In our research, while performing the event detection task during driving, participants were also asked to respond to simulated hands-free incoming calls, which could involve pre-recorded messages with two speech tones (i.e., neutral vs. angry speech tones). For example, a 9-minute task, consisting of event detection, video watching and lane tracking, was divided into experimental conditions of single tasking (the EPDT-II alone) and multi-tasking (the EPDT-II plus hands-free cell phone conversations). This method allows for behavioral contrasts between single- and multi-tasking conditions. While our work has focused on evaluation of the impact of cellular conversations, additional secondary tasks (such as audio, visual, manual, tactile, haptic, emotional or cognitive tasks) can be readily incorporated into this EPDT-II design with minimal adjustment. Our research also compared participants’ performance in the EPDT-II at numerous sites, including our WSU lab, neuroimaging environments, and on the road (see below), for validation purposes. By comparing response times, errors, and lane tracking, task performance can ensure the validity of this task across testing sites and across multiple demand task conditions [6].

Figure 2. Enhanced Peripheral Detection Test-II (also called Wayne State EDRT) design
ON-ROAD TESTING

We also successfully conducted an on-road version of the EPDT-II in Ann Arbor, Michigan with the University of Michigan Transportation Research Institute (UMTRI) with 16 healthy adult participants. Rather than monitoring a video screen, drivers in the on-road task monitored the roadway, as in normal driving. The in-vehicle target detection task used two pairs of red and green high-output light emitting diodes (LEDs), one pair positioned in the straight-ahead direction on the top of the dashboard and the other pair on the inside of the door nearest the driver-side rear view mirror. Participants pressed a button to answer calls, and the same button to end calls. While performing this task, subjects drove a test vehicle on real roads. Figure 3 shows the on-road vehicle set-up, with LED light events. As in the lab, subjects engaged in hands-free cell phone calls while completing the primary task of driving and responding to the red LEDs (or not responding to the green LEDs).

NEUROIMAGING STUDIES

Electroencephalography (EEG)

Electroencephalography (EEG) data were recorded from 20 subjects in the lab at WSU using a 64-channel Waveguard cap. Data were bandpass filtered at 1-30 Hz, corrected for artifacts using Independent Components Analysis, averaged with artifacts removed, and corrected for baseline differences. EEG signals from 22 central electrodes were organized by position - front, middle, and back - into a three level factor for statistical analysis purposes. Within-subject ANOVAs were computed on minimum (N200) and maximum (P300) amplitude using position and condition as factors. Effects were assessed within 200 msec blocks (N200 = 150 - 250 msec post stimulus onset; P300 = 250 - 350 msec). Interaction terms indicate changes in effects across the scalp.

N200 and P300 are components of event-related potentials (ERPs) time-locked to the onset of a visual stimulus event. Changes in N200 and P300 magnitude have been found to reflect changes in various aspects of cognitive processing, such as target anticipation. By observing differences in these components over different scalp sites, we were able to identify the timing and approximate locations associated with various cognitive processes for the primary and secondary tasks.

Functional Magnetic Resonance Imaging (fMRI)

We collected functional Magnetic Resonance Imaging (fMRI) data from 10 participants using a 3T GE MRI at Henry Ford Hospital using the same EPDT-II paradigm. Due to the restraints of the scanner, the visual angle from the center light to the left light was reduced from 20 degrees to 12 degrees. Participants steered using a handheld controller with two buttons, and again responded to red targets using a foot pedal.

RESULTS

Behavioral findings: EPDT II

Forty subjects participated in the lab study and 16 subjects participated in on road study. Two-way within-subject ANOVAs were conducted on reaction times obtained in the lab and on the road. Results show a main effect of conversation (baseline vs. neutral vs. angry) in the lab (F(2,126) = 12.03, p < .001), as well as in the car (F(2,75) = 16.50, p < .001). Results show a main effect of light position (left vs. center) only in the lab (F(1,126) = 4.66, p < .05), with the center light being associated with significantly faster responses. There was no significant interaction between speech and light position. These results suggest that the effect of conversation on event detection is consistent across lab and road testing platforms, whereas the effect of light position is the only thing that differentiates the lab study from on-road study. Results of behavioral data analysis on these subjects showed that there is a significant longer visual reaction times during a concurrent speech task (purple bars) than with no speech (blue bars) in lab and car (See Fig. 4), with no statistical interaction between the sites. However, this effect was moderated by presenting speech questions in an angry voice (yellow bars).

We conducted an independent analysis for within subject comparison of the detection response times for 10 subjects who participated both in the lab and on road. Results of ANOVAs showed a significant Conversation reaction time effect in both behavioral lab and MRI center (F(9,2) = 5.24, p < .01) with less than 4% Error rates in both the Lab and MRI (MRI<Lab). This findings confirmed that concurrent conversation could cause slightly longer response times than the driving only baseline across multiple testing sites (i.e., in the lab, on road, and in the MRI center).
Electroencephalography (EEG) findings

Across-scalp peak evoked amplitude differences were significant. The N200 (top) varied across the cortical positions (front, mid and back) and task conditions (p < .001). The P300 (bottom) also varied across positions and conditions (p < .05) in Figure 6a. While neutral speech peaks were larger than no speech peaks across scalp, the ERP pattern changed with angry speech, showing larger mid-peaks (orange) at N200 and larger posterior peaks (brown) at P300 in Figure 6b.

Results of EEG analysis indicated that there is difference between angry and neutral in the ERP waveform, most notably the P300, where we have a larger peak and a larger area under the curve for the neutral ERP signals in blue color than the angry ERP signals in black color. Consistent with response time finding, the EEG results showed that current conversations while driving cause more P300 signals than the baseline driving. In addition, the locus of the emotion affect (i.e., angry speech tone) seems to modulate the attentional networks - by increasing N200 signals in the mid brain region and increasing P300 signals in the posterior brain region. Angry speech tone could possibly make brain signals more alert and sensitive in detection of visual stimuli.

For the EEG data we collected in the lab, we primarily looked at evoked potentials at 200 (N200) and 300 (P300) milliseconds after stimulus onset. These give us a sense of how attention was allocated to these stimuli as subjects responded.

In Figure 6b, on the left are negative potentials around 200 milliseconds post-stimulus onset. As we expect, baseline (no conversations at all) and no conversation (periods of...
silence between calls) were similar, but we see larger amplitude peaks when we add a conversation task. However, when that conversation contained angry speech, the pattern is radically altered - frontal peaks increased in magnitude compared to neutral speech in N200, while rear peaks increased in magnitude in P300 compared to neutral speech (Figure 6b).

We see a similar trend in the positive peaks around 300 milliseconds. Neutral speech incurred an overall increase in amplitude to peaks at front, middle, and rear positions (contrary to a study by Strayer), while adding angry questions actually decreases activation in two regions, while increasing further in rear electrodes.

Overall, it is clear that the attention brain networks have been modulated by secondary tasks such as cellular conversations while driving. There is a categorically different pattern observed during conversations simply by changing the valence of the questions asked from neutral to angry.

**Functional Magnetic Resonance Imaging (fMRI)**

The fMRI analysis indicated increased activations ($t > 3.2; p < 0.002$) associated with both speech tasks, compared to no speech, in the bilateral temporal lobes, the left inferior frontal gyrus, and the left middle frontal gyrus; and decreased activations in the right inferior parietal lobe and the right cuneus (Fig. 7).

Figure 8 shows direct comparisons between angry and neutral speech tasks with increased activations ($t > 2.8; p < 0.006$) in the right prefrontal gyrus, the right middle frontal gyrus (BA10), the right insular, the right superior temporal gyrus, the right paracentral lobule (BA5), the right claustrum, and the right inferior parietal lobe (BA40). Decreased activations were found in the left frontal operculum, the left lingual gyrus (BA18), and the left parahippocampal gyrus (BA28).
Correlation analysis between lab and road

The correlation analysis was done to determine the lab-to-road predictive validity of the EPDT for event detection. The major event detection metric was the foot RT to a red light event. (There were few misses under any condition.) The behavioral data were split post-hoc into 18 task segments for correlation analysis. Results of correlation analysis between the lab and road RT task segment pairs shows a strong correlation ($r = 0.90$, $t = 9.03$, $df = 16$, $p < 0.000001$), see Figure 9 [6].

**DISCUSSION**

In a series of EPDT studies, we found that hands-free cellular phone conversations give rise to slightly longer behavioral reaction times for visual event detection during simulated driving in the lab and on-road driving, which is consistent with previous studies. The brain imaging results based on EEG and MRI brain activations also confirmed that cellular conversations increases brain activation in language and attention areas. The underlying mechanisms for engaging hands-free cell phone conversations while driving can increase the response time to a visual event have been identified in a series of neuroimaging studies at WSU and Henry Ford Hospital. The brain region which is closely correlated with the changes in response times for visual events in these dual-task conditions have been tentatively established from our studies using fMRI [2, 3], and EEG recordings [22, 24]. The brain region which mediates the reaction times to a visual event while multitasking of driving and hands-free cell phone conversations is the right superior parietal lobe, a site known for multi-modal sensory-motor integration and preparation of motor responses. Findings of this driving imaging study are also supported by three attention networks - alerting, orienting, executive attention, based on Posner's attention model [25]. Among three attention networks, the alerting and orientation networks activate similar brain regions, i.e., the parietal cortex and the superior parietal lobe respectively [26], as those in this study.

As a sensitive test, the Wayne State EDRT elicits the behavioral and brain pattern changes caused by potential driver distractions. The novel findings of this study are: 1) a subtle change of speech tone could possibly improve behavioral reaction time performance and 2) activating the right fronto-parietal networks and dampening the left frontal activity under the influence of cellular conversations while driving. The EPDT-II (also called Wayne State Enhanced DRT - Wayne State EDRT) provides a window to look into how driver distraction occurs behaviorally and neurologically. A subtle emotional factor, such as changing speech tone from neutral to angry, might permit a processing advantage. The neural mechanism may be linked to an early central negativity and later posterior positivity, or an enhanced “readiness to respond” in central and posterior cortical regions linked to attention.

The findings based on a series of studies that we conducted in the lab, road, and brain imaging centers suggested that the Wayne State EDRT demonstrated the reliability and sensitivity in measuring selective attention while driving. This task has been validated by an open road driving study conducted at UMTRI. Results of statistical analysis on driver performance indicated a high lab-to-road predictive validity at 0.9 correlations of the Wayne State EDRT for event detection from the lab to the road [6].
In conclusion, the Wayne State EDRT is a sensitive and up-to-date surrogate test for measuring selective attention while driving. This task provides a simple, easy to learn and run, and convenient platform to assess driver distraction for use in the lab, road, or brain imaging environments. This task also allows us to investigate more detailed cognitive components of driver distraction, as well as neurological processes of attention networks in the brain.

LIMITATIONS

1. Wayne State EDRT does not address cognitive and behavioral deficits beyond specific attention, cognitive functions as described in this study.

2. The data evaluated in Wayne State EDRT were for visual, manual, auditory and verbal tasks in a low-to-moderate workload demand. More studies need to be done to test across different modalities and different levels of cognitive demands.

3. Most of the DRT and EDRT studies were conducted with adults between 25 and 65 years old. It is important to test the populations across life span from younger to older drivers, so that we will understand better behavioral patterns and neural mechanisms underlying cognitive attention for drivers younger than 25 years old and older than 65 years old.

SUMMARY/CONCLUSIONS

1. The Wayne State EDRT serves as a sensitive and up-to-date surrogate test for measuring selective attention while driving.

2. The Wayne State EDRT provides a simple, easy to learn and run, and convenient platform to assess driver distraction for use in the lab, road, or brain imaging environments.

3. The Wayne State EDRT has a high lab-to-road predictive validity at 0.9 correlations of the EPDT for event detection from the lab to the road.

4. An emotional stimulus such as angry speech tone provides an advantage for visual event processing times.

5. The neural mechanism may be linked to an early central negativity and later posterior positivity, (an enhanced “readiness to respond”) in central and posterior cortical regions linked to attention.

6. The Wayne State EDRT allows us to investigate more detailed components of driver distraction, as well as neurological processes of attention networks in the brain.

7. These fMRI and EEG findings of the Wayne State EDRT studies could have substantial implications on the design of in-car speech interfaces to enhance driver safety.

REFERENCES


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DEFINITIONS/ABBREVIATIONS

CAMP
Crash Avoidance Metrics Partnership

DRT
Detection Response Task

PDT
Peripheral Detection Task

RT
Response Time to Event

Wayne State EDRT
Wayne State Enhanced Detection Response Task