Jun 23rd, 12:00 AM

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EYE GLANCE ANALYSIS OF THE SURROGATE TESTS FOR DRIVER DISTRACTION

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Summary: The purpose of this study was to examine the eye glance patterns of Detection Response Tasks (DRTs) for assessment of driver distraction during simulated driving. Several types of DRTs across visual, tactile and haptic modalities were used to investigate driver distraction by the ISO Driving Distraction working group. As part of the working group, we conducted a simulated driving study examining driver performance while engaging the primary driving task with visual-manual or auditory-verbal secondary tasks. Results of eye glance analysis showed that the visual DRTs increased visual load in driving more than the tactile DRT. Subsequently, the visual DRTs marginally increased the total glance time for forward view by 6.27 seconds and significantly increased the detection response time by 135.79 ms than the tactile DRT. As for the secondary tasks, the visual-manual secondary task yielded significantly longer total eye-off-the-road time (effect size = 50.75 ms), as well as DRT response times than the auditory-verbal ones time (effect size = 55.85 ms). This study allowed us to examine the relationships between rated situational awareness, DRT performance, and glance patterns, yielding insights into the relationship between objective task performance measures and subjective ratings.

OBJECTIVES

Detection Response Tasks (DRTs) are testing methods that can provide periodic probing into the attentional resources of a person as they engage in a variety of on-going activities. The basic design of a DRT is to present a probe (often called an *event*), whether visual, auditory, or tactile, to a participant who is engaged in one or more ongoing activities, and measure how it takes the participant to respond to the event, typically by pressing a button or a pedal. In a multitasking driving task, increased cognitive demand of secondary tasks can have a significant influence on attentional networks in the brain by increasing event response times (RTs), event miss rates, the duration of single glances off the road and neural activations in brain regions specific for orienting attention and executive function (Young & Angell, 2003, Young, 2012a, 2012b, Bowyer et al., 2009, Hsieh et al., 2009). Currently, several versions of DRTs for assessing driver performance in detection of events while driving have been under investigation by the ISO Detection Response Task working group (ISO TC22/SC13/WG8 DRT Task Force, 2013). Among these DRTs, the Tactile Detection Response Task (TDRT), which uses a vibrating stimulus as a probe, has been recommended as a sensitive surrogate measure for driver distraction with a minimal interference of visual and manual modalities in driving (Engström et al., 2005, Mattes et al., 2008, Engström, 2010, Diels, 2011). Young et al. (2013) further demonstrated that the TDRT has the sensitivity to detect the attentional effects of cognitive load and the specificity to differentiate the effects of cognitive load from those of visual load, verified in simulated and open-road driving. **The purpose of this study** was to examine the eye glance

patterns of DRTs for assessment of driver distraction during simulated driving. As part of the ISO driver distraction working group, we conducted a simulated driving study examining driver performance while engaging the primary driving task with visual-manual or auditory-verbal secondary tasks. In this study, we investigated eye glance patterns, subjective ratings, and DRT reaction times and accuracy, as well as the secondary task performance. All these data were analyzed in this driving study in comparisons among driving-only condition and driving with visual-manual and auditory-vocal secondary tasks.

METHODS

Participants

Sixteen participants, aged 25-45 years old, participated in a simulated driving study (8 males and 8 females) at Wayne State University. All participants were healthy adults who were native speakers of English. They were required to have a valid driver's license and drive more than 6,200 miles per year. This study used the criteria recommended by the ISO Driving Distraction working group (ISO 17488, 2013). Participants were asked to sign a written consent approved by the Human Investigation Committee of Wayne State University, and were financially compensated for their time and effort in participating this study. The open road driving data were collected by Dynamic Research Inc. These data were collected from fifteen subjects (8 males and 7 females) who met similar criteria as the Wayne State simulated driving study.

Variations of DRTs

Three DRTs were used to examine the effect of secondary tasks on driving, including the Head-mounted DRT (HDRT), Remote DRT (RDRT) and Tactile DRT (TDRT). HDRT and RDRT utilize visual stimuli. The head-mounted DRT is composed of a red light affixed on the left side of a head-mounted device, whereas the Remote DRT refers to the detection of one visual light mounted in a fixed location on the left side of the visual field, away from the driver's body. Both the Head-mounted visual stimulus DRT and Tactile stimulus DRT were manufactured by TNO (Netherlands). For the TDRT, a small tactor was affixed to participants' left shoulders, at the base of their necks. The tactor began vibrating every 3-5 seconds, and participants were asked to respond to it by pressing a button affixed to their index finger by pressing it against a steering wheel they were using. The major focus of this study was to use DRT performance and eye glance patterns for evaluating the effects of two types of secondary tasks (auditory-vocal and visual-manual) on driving.

Secondary Tasks

Two secondary tasks were tested during the primary driving and DRT tasks. One secondary task (i.e., *N-Back task*) is an auditory-verbal-cognitive task. The other secondary (i.e., *Surrogate Reference task*) is a visual-manual task. Each secondary task had two levels of difficulty (i.e., easy and hard). More detailed information can be found in ISO DRT working group document. *N-Back task* (Mehler, Reimer, & Dusek, 2011) is a verbal digit memory recall task. A series of digits were presented auditorily. Subjects were asked to repeat the number verbally. In the 0-back (easier) task, subjects were asked to repeat the last number heard. In the 1-back (harder,

relative to the 0-back) task, they were asked to repeat the number that was heard before the last number. Surrogate Reference Task (SuRT, ISO, 2010) is a visual search and response task. Subjects were asked to look for a larger circle among the distractor circles. In the easy SuRT, the target circle was bigger and easier to discriminate than the hard SuRT.

Driver Metrics

The driver metrics measurements included DRT reaction times, DRT accuracy (the proportion of events that were responded to by the participant), and driver performances for secondary tasks. Secondary task performance metrics, such as reaction times and error rates for n-back and SuRT, and task time and button presses for individual SuRT trials were collected. Eye glance data were recorded and collected through the Dikablis eye-tracking system (Ergoneers GmbH, Germany) during secondary tasks and during baseline performance periods. Eye glance data analyses include total-eyes-off-the-road time (TEORT), total glance time (TGT), mean glance duration (MGD) and mean long glance duration (MLGD) for comparison among different tasks and among different DRTs. TEORT was computed as the total amount of time a participant glanced away from the primary task driving screen during a task; MGD was computed as the mean time a participant glanced away from the primary task driving screen before glancing back to the screen; Subjective workload ratings were also collected and analyzed, including frustration level, mental demand, situational awareness and time sharing. Ratings were made on a 1-100 point scale, participants were given a description of the scale before making their rating. For example, for situational awareness, they were told to consider the following: "How aware were you of surrounding traffic when you were performing the secondary task?"

Testing Procedures

The simulated driving study utilized the "semi-static" driving simulator in the WSU Driving Safety Lab. The stationary driving simulation can be conducted in a laboratory setting with a computer monitor and a steering wheel. A recorded video of a driving scene, recorded from the perspective of a driver, is used for drivers to watch. A visual icon is projected onto the driving scene which participants can move left and right, and they are asked to keep the marker in the center of the lane that the recording vehicle is currently occupying. The driver rotated the steering wheel in order to control the movement of the visual icon. Participants were instructed to take this task as their primary task (Hsieh, Young & Seaman, 2012). This driving simulation was done on a fixed base, and the term "semi-static" is applied because there is a component of driving simulation present (lane-tracking), as opposed to DRT studies in which there is no driving simulation component present.DRT and secondary task stimuli and methods were used as specified in ISO Draft Standard WD17488 (2013). For the DRT tests, when participants detected a visual stimulus on the left side of the driving scene, a visual stimulus on the left side of a head-mounted device, or a tactile stimulation at the base of their left shoulder, they pressed a button affixed to their left index finger against the steering wheel (which they held in order to perform the simulated lane-tracking task). Each visual or tactile stimulus lasted for 1 sec unless the subject responded faster than 1 sec. The inter-stimulus interval was from 3 to 5 secs. Drivers were instructed to respond to target stimulation as quickly and as accurately as possible. Only RTs between 100 ms and 2500 ms were considered as valid responses. All the other RTs were considered as misses. The secondary tasks such as visual-manual (i.e., SuRT task), auditory-verbal or cognitive tasks (i.e., N-Back task) were introduced while participants engaged in the

primary driving task and the DRTs. Participants were told that their first priority was to drive safely by maintaining the position of the visual icon in the center of the lane. As for the secondary tasks and DRTs, they were told to pay attention to both, as much as they were able to. They were trained first for each task before actual data collection for baseline driving, the primary and secondary tasks. The task order was given in a pseudo-random order which is counter-balanced across subjects. Each task lasted 2 minutes. Subjective workload and simulation awareness ratings were given using a simplified NASA TL/X scale (Young & Angell, 2003).

RESULTS
Driver Behavioral Performance

These surrogate tests were significantly correlation with the results from the on road study ((r = 0.79, p = 0.0006) with sensitivity to the attentional effects of an increased cognitive load, specifically the cognitive n-Back task only, shown in Figs. 1 and 2. DRT response times increased and accuracy decreased from easy to hard for both visual-manual task (SuRT) and auditory verbal task (N-Back).
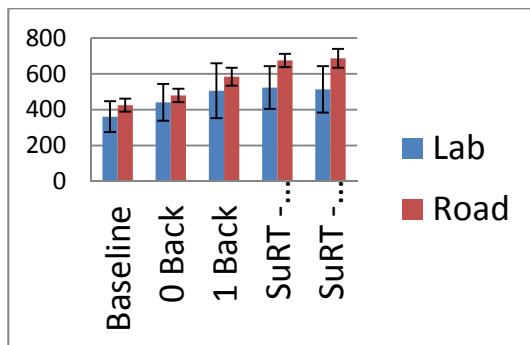

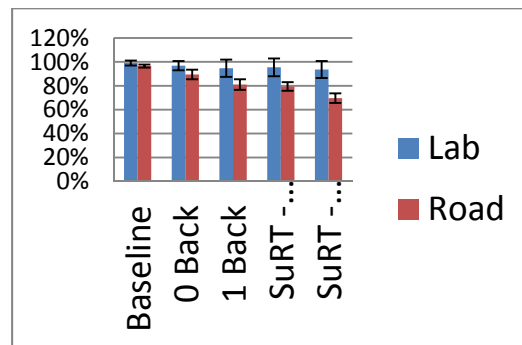**Figure 1. Response times to DRTs during secondary task performance in lab and on road**

Figure 2. Accuracy to DRTs during during secondary task performance in lab and on road

Eye Glance Patterns

Results of eye glance analysis, using within-subject t-tests, showed that the visual DRTs increased visual load during testing more than the tactile DRT. The visual DRTs marginally increased the total glance time for forward view by 6.27 seconds ($t(15) = 2.06$, $p = .055$) and the detection response time significantly by 135.79 ms over the tactile DRT ($t(15) = 4.42$, $p < .001$). As for the secondary tasks, the visual-manual secondary tasks yielded a significantly longer total eye-off-the-road time (Visual-Manual vs. Auditory-verbal secondary tasks = 65.22 ms vs. 14.46 ms; effect size = 50.75 ms, $t(15) = 15.524$, $p < .0001$), as well as significantly longer DRT response times (Visual-Manual vs. Auditory-verbal secondary tasks = 518.35 ms vs. 462.50 ms; effect size = 55.85 ms, $t(15) = 3.61$, $p < .01$) than the auditory-verbal tasks. Among all the DRTs, the TDRT response times were sensitive to attentional effects of an increased cognitive load from 0-back to 1-back, but not visual load (Figure 3). The TDRT RTs in the laboratory were highly correlated with those on the road (r = 0.91, p = 0.033). On the other hand, the Total Eyes Off-Road Time (TEORT) from the forward view was sensitive to an increased visual load, but not cognitive load. These two metrics clearly measure two separate dimensions which are

independent and orthogonal to each other. These findings are consistent with the dimensional model of driver distraction by Young et al. (2003). The total glance time (TGT) showed similar sensitivity to physical load in a visual-manual SuRT task as the TEORT.
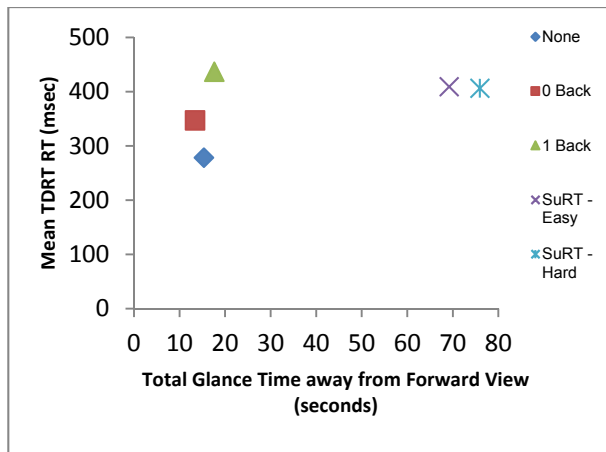

Figure 3. Response times to TDRT vs. total eye glance away times from forward view during secondary task performance in lab
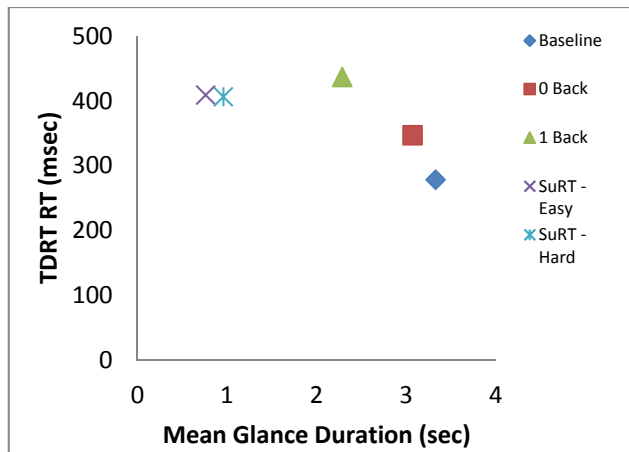
Figure 4. Response times to TDRT vs. mean glance duration during secondary task performance in lab..

While the TEORT measured the visual and physical demand, the Mean Glance Duration (MGD) was sensitive to cognitive load, just like TDRT response times. Figure 4 showed an inverse correlation ($r = -0.721$, R-squared = .5195) between mean glance duration and TDRT RTs. The mean long glance duration (MLGD) was also more sensitive to cognitive load than visual-manual load. This study also allowed us to examine the eye glance patterns for missed events, providing an opportunity to assess the cognitive effect in cases of "looked-but-did-not-see". Figure 5A showed that a visual event was in the left side of the driving scene. This participant's eye glance was to the forward view during a visual peripheral event, but the event was missed. This missed event is contrasted below to a hit case and to a miss case with the eyes off the road scene, on the screen where the participant is performing the Visual-Manual secondary task (i.e., 5B, 5C). Overall, we found evidence that some visual DRTs were missed despite participants having been looking in a region where the DRT should have been noticeable, providing evidence for a "looked-but-did-not-see" phenomenon, where participants were looking in the correct region but the stimulus failed to be attended to.

Subjective Ratings

Fig. 5A:Look-but-not- see case

Fig. 5B: Successful hit case

Fig. 5C:Miss case with the eyes off the road scene

Among all the subjective ratings, situational awareness showed the most significant correlation with DRT reaction times (Fig. 6, $r = -0.68$, R-squared = .4637). An inverse correlation was found

between DRT RTs and situational awareness. The higher the subjects rated situational awareness, the shorter their DRT reaction times. Figure 7 showed a positive correlation between DRT accuracy and situation awareness ($r = -0.719$, R-squared $= .5164$). The higher subjects rated situational awareness for a given task, the higher their DRT accuracy.
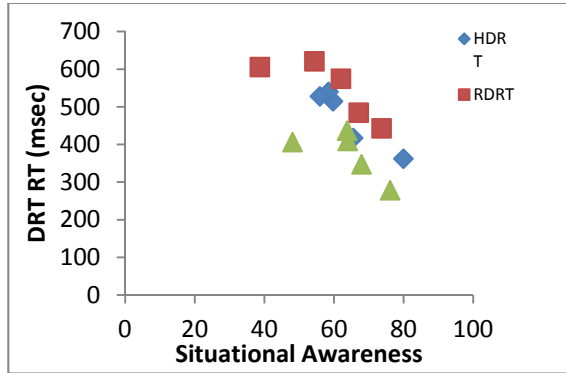

Figure 8. Response times to DRTs vs. situation awareness during secondary task performance in lab.
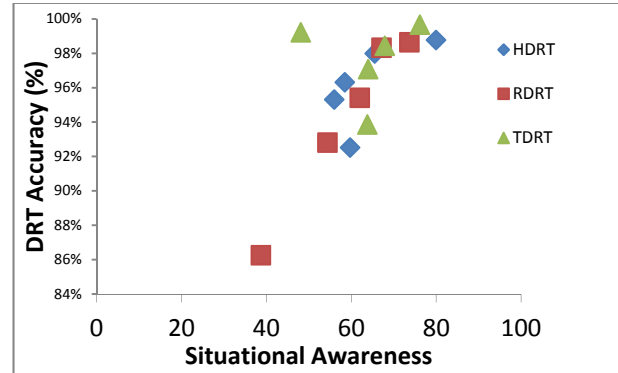
Figure 9. Accuracy to DRTs vs. situation awareness during secondary task performance in lab.

DISCUSSION

Results of this study recommended the DRTs as surrogate tests for evaluating the changes in visual and cognitive load from driver distraction. Among all the surrogate tests, the TDRT has been shown to be very sensitive to cognitive distraction under a series of dynamic and orthogonal dimension analyses. Particularly the physical demand appeared to be distributed in the one dimension; while the cognitive demand in the other dimension. Eye glance patterns also showed sensitivity to task demands competing for limited visual, manual and cognitive resources, which yielded significant correlations with DRT response times and subjective ratings. The eye glance pattern and event detection findings are consistent with Young et al. (2003, 2012) papers on dimensions of driver performance. The driver metrics which are sensitive to changes in cognitive load include: DRT reaction times, DRT accuracy, mean glance duration (MGD), mean long glance duration (MLGD), and subjective ratings of situation awareness. The driver metrics that are sensitive to changes in physical demand include: total eye off the road time (TEORT), total glance time (TGT), and the secondary task times. Comparisons among different tasks and among different DRTs show the possible effects of each secondary task and the dimension that the driver metrics is measuring. Based on the findings of this research, we recommend using a combination of TDRT and other driver metrics in the evaluation of driver distraction.

CONCLUSION

This study demonstrated the DRT surrogate tests for measuring the attentional effects of visual-manual and auditory-verbal secondary tasks on driver behavior and perception. The DRTs can be used to evaluate the visual and cognitive load of multitasking. Moreover, results of this study indicated that TDRT is a more sensitive surrogate test for evaluation of cognitive distraction, particularly in combination with other driver metrics measurements, such as eye glance analyses, subjective ratings, and secondary task times.

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