Extending the Detection Response Task to Simultaneously Measure Cognitive and Visual Task Demands

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Objective: A set of 4 driving related tasks were used to evaluate the potential for a modified Detection Response Task (DRT) to simultaneously measure visual and cognitive task demands. **Background:** The accurate assessment of cognitive and visual tasks demands in driving has become increasingly important. As of yet, no simple, cost effective approach has been found to measure visual demands in complex, multimodal tasks. **Methods:** Two experiments are presented which evaluate an extension of the standard DRT methodology. The discriminate sensitivity of the experiments is tested using an integrated testing configuration, which systematically increased visual demand across four conditions. **Results:** Results suggest that the standard DRT configurations are highly tuned to selectively evaluate cognitive demand but that a variant of the system may be able to simultaneously evaluate changes in both visual and cognitive task demands. **Conclusions:** These data suggest that the simple, rapid, and reliable assessment of both visual and cognitive task demands is possible, even in highly fluid systems with non-constant visual task requirements.

INTRODUCTION

Attention, in its various forms, has been the focal construct of countless scientific investigations. Within the driving safety literature, attention deficits and diversions have been shown to be a leading factor in the majority of crashes and near crashes (Klauer et al., 2014). Thus, attention measure and management have become the primary focus of many professionals working within the driving domain. In the context of driving, attention is often divided up into cognitive, visual, and manual aspects. While not strictly dissociable, this distinction has been useful for understanding the potential safety implications of dynamic task demands, especially as they relate to potential driving conflicts arising from secondary task interference.

Recently, the National Highway Transportation Safety Administration (NHTSA) has begun to release a series of planned guidelines related to secondary task attention measurement and limits in vehicles. The first of these guidelines addresses driver distractions arising from visual and manual tasks, and describes suitable methods for measurement as well as acceptable performance redlines (NHTSA, 2012). Critically, these guidelines explicitly state that they do not apply to secondary tasks that are not fully visual in nature. Thus, the current guidelines are not designed to measure many modern tasks that use a combination of interaction modes such as voice and vision. For these complex tasks, a new hybrid measurement approach is needed.

One promising candidate to address this issue is the DRT (see ISO 17488, 2014). Using relatively inexpensive and readily available hardware, the DRT provides researchers with a highly sensitive instrument for measuring attention in complex task environments. Unlike many primary task measures, the DRT can deliver simple and powerful results immediately after data collection with very few processing requirements. These features make the DRT a natural choice for benchmarking attention in complex task environments such as driving. However, the DRT has been designed to selectively evaluate cognitive attention and does not currently support the measurement of visual demand.

In order to assess the visual demands of complex tasks, there are a variety of common approaches. In the domain of driving, these have historically included manual eye glance reduction (ISO 15007:1, 2014; ISO 15007:2, 2014), the use of expensive eye tracking systems (e.g., Victor, Harbluk, & Engström, 2005), or the employment of visual occlusion technology (e.g., NHTSA, 2012). Arguably, none of the existing approaches are as simple to implement, as inexpensive, or as flexible as the cognitive demand measures generated by the DRT.

The purpose of this paper is to explore the potential for a modified DRT system to simultaneously measure both the cognitive and visual demands of a set of mixed demand tasks. This exploratory set of experiments is designed to test whether a standard remote DRT configuration is sensitive to changes in forward visual attention and to contrast this sensitivity to a concurrently worn, and fully integrated, head mounted DRT system. In Experiment 2, a modified remote DRT unit was paired with a tactile DRT unit to maximize selective sensitivity to visual and cognitive demands. Together, these studies suggest a novel and promising extension to the standard DRT configuration which allows researchers to simultaneously measure visual and cognitive attention demands in complex task environments such as driving.

EXPERIMENT 1

Method

Participants. Following approval from the university Institutional Review Board, participants were recruited through flyers, by word of mouth, or through an online participant pool database. Participants either received class credit for participation or were compensated $40 upon completion of the 2-hour study. Fourteen female and six male students participated in this research. Participants ranged in age from 18-36 years (*M* = 22.3, *SD* = 3.7). All participants reported normal neurological functioning, normal or corrected-to-normal visual acuity, and had normal color vision (Ishihara, 1993).

Equipment. A driving simulator, manufactured by L3 communications, was used as the backdrop for data collection. Custom software was written to interface with the simulator's screens and steering wheel. The primary forward display screen measured 42 inches diagonally and was located approximately 36 inches in front of participants. The two peripheral screens were not used for this study.

A simple horizontal tracking task was presented on the forward display. In this task, participants controlled the position of a triangular cursor along the horizontal plane with corresponding left and right steering inputs. A small target ball, 1 cm in diameter, was programmed to move continuously along this horizon. Participants were instructed to track the movement of the ball by maintaining the triangular cursor directly under the ball as it moved across the screen. This task was designed to induce a constant visual load, analogous to maintaining vehicle lane position.

A 9.56 x 7.47 inch Apple iPad Mini tablet was fixed to the simulator dashboard in the high center stack position, just to the right of the steering wheel. During visual task conditions participants were periodically instructed to look at this screen. When active, the screen changed from black to blue. No other information was displayed on the screen.

A Seeing Machines Fovio eye tracker was used to track participants' visual attention to the forward screen. The tracking apparatus was mounted flush to the top of the steering wheel. For the purpose of this study, the forward screen was configured as a single area of interest. All trackable area outside of the forward screen was, by default, assigned as the second area of interest.

A custom DRT (see ISO 17488, 2015), capable of presenting the three standard stimuli (HDRT, RDRT, and TDRT) as well as a remotely presented LED stimulus which featured a color mask, was used. Importantly, this custom DRT device allowed for stimuli to be presented in one of 2 potential methods within the same block of trials. For the first experiment, the DRT device was configured to present either a head-mounted red LED stimulus (HDRT) or a remotely mounted red LED stimulus (RDRT). Each of these stimuli were presented at random, with either one or the other being presented every 3-5 seconds. Once presented, stimuli remained on for 1 second or until participants pressed the response button attached to their left index finger.

Procedure. A within-subjects design was used where participants experienced each of the 4 levels of the primary visual demand manipulation. The levels were labeled based on their Inter Stimulus Interval (ISI). For this study the ISI corresponded to the amount of time that participants were looking forward between prompts to look downward. Levels of Visual Demand were:

1) Baseline – no secondary visual task demands
2) ISI=15 – look forward for ~15 seconds, down for 2
3) ISI=10 – look forward for ~10 seconds, down for 2
4) ISI=5 – look forward for ~5 seconds, down for 2

In each of the ISI conditions, participants were prompted by a tone to look at the center stack display, at which point the display changed from solid black to solid blue. After 2 seconds the display changed again to black, at which point participants were instructed to return their gaze to the tracking task displayed on the forward monitor. The time between prompts to look at the center stack display varied between conditions, included 3 seconds of jitter within each condition, and averaged 15, 10, and 5 seconds for the ISI=15, ISI=10, and ISI=5 conditions respectively. The down interval was fixed at 2 seconds across each of the 3 ISI conditions. Thus, perfect compliance to these instructions, with no delay in transition, would result in 100%, 88.2%, 83.4%, and 72% eyes on forward roadway time for the different conditions.

During each of the four conditions, participants responded to the DRT stimuli and completed the tracking task. Conditions lasted 500 seconds and were counterbalanced across participants. Prior to completing the four experimental conditions, participants were familiarized with each of the tasks independently (e.g., DRT task, Tracking Task, Visual Tasks). Once comfortable with each of the tasks, participants began the experiment.

Metrics. Four performance measures were evaluated. These were: Eyes on Road Time, defined as the sum of eye glances to the forward roadway divided by the total number of eye glances, excluding all cases where eye data was not available for the left or right eyes; Tracking Performance, defined as the standard deviation of the difference between the participant controlled steering cursor and the experimentally controlled target cursor. Reaction Time, defined as the sum of all valid reaction times to the DRT task divided by the number of valid reaction times; Hit Rate, defined as the number of valid responses divided by the total number of stimuli presented during each condition; and

DRT data were cleaned following procedures specified in ISO 17488 (2015). Consistent with the standard, all responses briefer than 100 ms or greater than 2500 ms were rejected for calculations of Reaction Time. Responses that occurred later than 2500 ms seconds from the stimulus onset were coded as misses.

Results

Due to equipment malfunctions, data from 3 participants were only partially available for the analysis of Eyes on Road Time, Tracking Performance, or Hit Rate. All other participants contained a complete data set.

Eyes on Road Time. A One-Way Repeated Measures ANOVA of eye data indicated a significant effect of experimental condition on the percentage of time that participants spent with their eyes fixated on the forward roadway, $F(3, 42) = 41.8$, $p < .001$, partial $\eta^2 = 0.75$. Pairwise comparisons indicated the each of the 4 conditions differed from the others (p's < .01) with the exception that the ISI = 15 condition did not differ from ISI = 10 condition, $p = 1$. See the left panel of Figure 1.

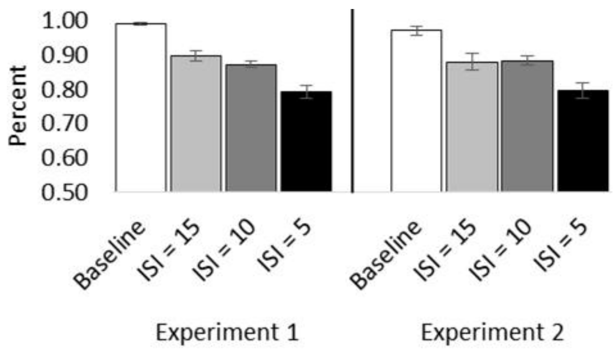

Figure 1. Percent Eyes Forward across the 2 experiments. Error bars represent the standard error of the mean.

Tracking Performance. A One-Way Repeated Measures ANOVA indicated a significant effect of experimental condition on the Standard Deviation of Tracking Error across the four experimental conditions, $F(3, 51) = 19.9$, $p < .001$, partial $\eta^2 = 0.54$. Pairwise comparisons indicated that the baseline condition differed from the three visual task conditions (p's < .05), that the ISI = 15 condition differed from the ISI = 5 condition ($p < .05$) but not the ISI = 10 condition ($p = 1$), and that the ISI = 10 condition did not differ from the ISI = 5 condition ($p > .05$). See the left panel of Figure 2.

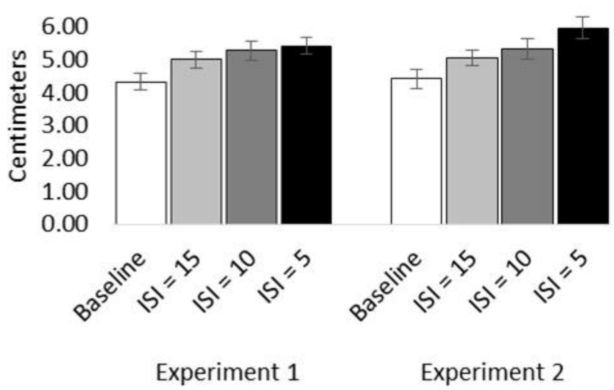

Figure 2. Standard Deviation of Tracking Error. Error bars represent the standard error of the mean.

Reaction Time. A 2 (Alert Stimuli) x 4 (Visual Demand) Repeated Measures ANOVA revealed both a main effect of Stimulus, $F(1, 19) = 18.27$, $p < .001$, partial $\eta^2 = 0.49$, and a main effect of Condition, $F(3, 57) = 17.36$, $p < .001$, partial $\eta^2 = 0.87$; however, the interaction between Stimulus and Condition was not significant, $F(3, 57) = 0.636$, $p > .05$, partial $\eta^2 = 0.032$. Pairwise comparisons indicated that the Baseline condition significantly differed from the 3 visual conditions (p's < .001) but that the three visual conditions did not differ from each other (all p's > .5). See the left panel of Figure 3.

Hit Rate. The remaining data were analyzed using a 2 (Alert Stimuli) x 4 (Visual Demand) Repeated Measures ANOVA. Results indicated that the Hit Rates across the two Stimuli did

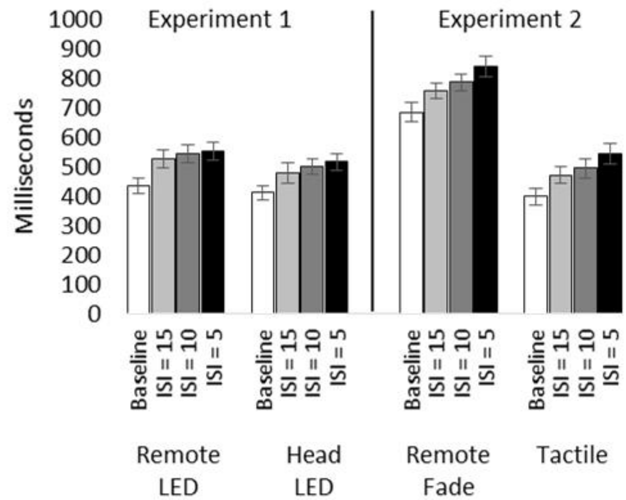

Figure 3. DRT Reaction Time across the 2 experiments. Error bars represent the standard error of the mean.

not differ, $F(1, 16) = 3.34$, $p > .05$, partial $\eta^2 = 0.17$, nor did Hit Rates across the four Condition, $F(3, 48) = 2.27$, $p > .05$, partial $\eta^2 = 0.124$. See the left panel of Figure 4.

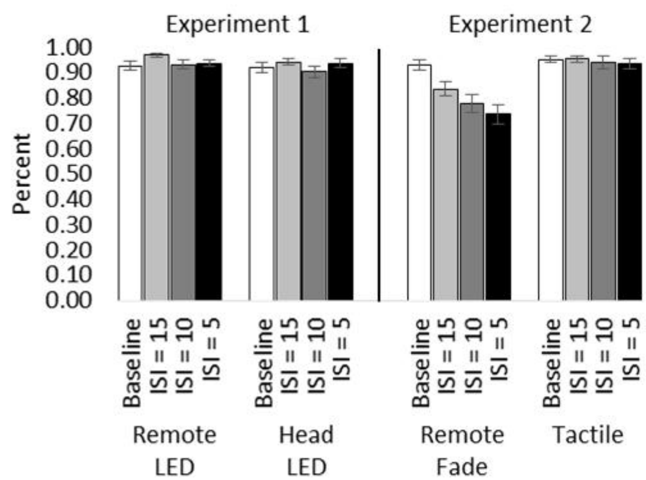

Figure 4. DRT Hit Rate across the 2 experiments. Error bars represent the standard error of the mean.

Discussion – Experiment 1

Results from this experiment indicated that the visual conditions were successful in getting participants to remove their eyes from the forward roadway across the conditions. Not surprisingly, this diversion led to a consistent degradation in tracking performance. Based on prior research, it is also not surprising that the more visually demanding the task, the greater the increase in reaction time (Young, Hseih, & Seaman, 2013). However, like others before, we attribute this increase in reaction time to increases in the cognitive demand of the task and not necessarily the visual demand of the task.

Notably, there was no change in Hit Rate as the visual demand of the tasks increased. We expected to find a decrease in the Hit Rate to the Remote LED as drivers increasingly looked away from the forward roadway. The fact that hit rates were not sensitive to visual demand suggests that the LED stimulus may have been too visually salient to pick up on the structural interference arising from downward glances. Indeed, further internal piloting suggested that the Remote LED onset could be detected even when an individual is nearly looking backward. On the one hand, this ease of detection suggests that the highly salient LED onset can cut through visual demand and provide a clean measure of cognitive load. This finding is important for the measurement of cognitive demand in mixed visual-cognitive tasks. On the other hand, the finding suggests that the standard RDRT configuration may not always be appropriate for measuring the effects of visual demand.

From these results it was determined that two changes could be made to maximize the potential discriminate sensitivity of the DRT to both visual and cognitive demands. First, prior research has suggested that the tactile DRT may be more sensitive to cognitive demand than the head mounted DRT or the remote DRT (Harbluk et al., 2013). One reason for this may be the potential for visual interference between the primary tasks and the LED stimuli. In this way, reaction times to the LED stimulus would be partially affected by the visual demands of the environment and not just the cognitive load of the task. While this was not seen in the current study, it would be consistent with accounts of attention such as Multiple Resource Theory (Wickens, 2002). For these reasons, we determined that the tactile DRT would be used instead of the head mounted DRT. Second, for the remote DRT to be sensitive to visual demand we determined that the stimulus onset needed to be muted. Ideally, the onset would be 100% detectable when looking forward but not detectable when looking away from the forward roadway. In this way, the stimulus would provide a reliable surrogate for the percentage of visual attention to, and away from, the forward roadway.

EXPERIMENT 2

Method

Participants. Seventeen females and ten males participated in this research. Participants ranged in age from 18-36 years (M = 22.3, SD = 3.7). All other recruitment procedures and participation requirements were identical to those detailed in Experiment 1.

Equipment. All equipment was identical to that detailed in Experiment 1 with the exception that a tactile DRT (TDRT) was used in place of the head mounted DRT (HDRT) and a custom remote DRT with a color mask was used instead of the standard remote DRT (RDRT).

The custom remote, fading DRT with color mask was configured to display a red color mask when not active. When active, the LED would rapidly fade from red to orange and back over the course of 1 second. If, during this transition, participants responded with a button press, the LED would immediately change to the full red color. All other timing for this variation of the DRT was consistent with Experiment 1.

Identical to Experiment 1, both the tactile DRT and the remote fade DRT stimuli were presented within the same experimental block with one of the stimuli being presented at random every 3-5 seconds.

Procedure. The experimental procedure for Experiment 2 was identical to that outlined in Experiment 1.

Results

Eyes on Road Time. Similar to Experiment 1, a One-Way Repeated Measures ANOVA of the eye data indicated a significant effect of experimental condition on the percentage of time that participants spent with their eyes fixated on the forward roadway, $F(3, 66) = 33.2$, $p < .001$, partial $\eta^2 = 0.60$. Pairwise comparisons again indicated that all visual conditions differed from each other with the exception that the ISI = 15 and the ISI = 10 conditions did not significantly differ ($p > .05$). See the right panel of Figure 1.

Tracking Performance. A One-Way Repeated Measures ANOVA indicated a significant effect of experimental condition on the Standard Deviation of Tracking Error across the four experimental conditions, $F(3, 69) = 36.8$, $p < .001$, partial $\eta^2 = 0.62$. Pairwise comparisons again indicated that all Conditions differed from each other with the exception that the ISI = 15 and the ISI = 10 conditions did not significantly differ ($p > .05$). See the right panel of Figure 2.

Reaction Time. A 2 (Alert Stimuli) x 4 (Visual Demand) Repeated Measures ANOVA revealed both a main effect of Stimulus, $F(1, 23) = 32.9$, $p < .001$, and a main effect of Condition, $F(3, 69) = 43.5$, $p < .001$; however, the interaction between Stimulus and Condition was not significant, $F(3, 69) = 0.243$, $p < .05$, partial $\eta^2 = 0.01$. Pairwise comparisons indicated that while the ISI = 15 and the ISI = 10 conditions did not differ ($p > .05$), all other conditions were significantly different (p's $< .05$). See the right panel of Figure 3.

Hit Rate. A 2 (Alert Stimuli) x 4 (Visual Demand) Repeated Measures ANOVA revealed that the Hit Rates across the two Stimuli were significantly different, $F(1, 23) = 29.3$, $p < .001$, hit rates across the four Conditions also differed, $F(3, 69) = 9.54$, $p < .001$, and that the interaction between Stimulus and Condition was also significant, $F(3, 69) = 16.7$, $p < .001$, partial $\eta^2 = 0.42$. Pairwise comparisons indicated that Hit Rate differed between the Baseline and all other conditions (p's $< .05$) but that none of the other conditions differed from each other (p's $> .05$). See the right panel of Figure 4

A follow-up One-Way Repeated Measures ANOVA on Condition for just the Remote Fade Stimulus indicated a similar pattern but found that the ISI = 15 condition now differed from both the ISI = 10 and ISI = 5 conditions (p's $< .05$).

Discussion – Experiment 2

Similar to Experiment 1, results indicated that the experimental manipulations successfully drove participants to look away from the forward roadway and that these glances led to a decrease in tracking performance. Similarly, reaction time measures from both the tactile DRT and remote DRT stimuli were again sensitive to the visual demand manipulations.

Those similarities aside, Hit Rate yielded a very different pattern than what was observed in Experiment 1. Here, the remote fade DRT stimulus displayed clear sensitivity to increases in visual demand in a manner that would be expected due to failed detections. Conversely, the mean hit rate for the tactile DRT was again near the response ceiling and did not differ between the various conditions.

GENERAL DISCUSSION

The purpose of this research was explore variants of the DRT for selectively evaluating visual and cognitive task demand. In order to simultaneously assess both visual and cognitive demands, a dual-DRT setup was used which presented stimuli in one of two methods. In the first experiment, a head mounted and remote mounted LED setup were used. Each stimulus was activated at random, one at a time, one stimulus every 3-5 seconds. Results from this setup suggested sensitivity to cognitive but not visual demand. In the second experiment, a tactile and fading remote stimulus were used. The tactile stimulus complied with the TDRT specifications of ISO 17488 (2015) while the fading remote stimulus deviated from the standard in order to increase its potential sensitivity to visual task demands. Results indicated that this dual-DRT setup was sensitive to both cognitive and visual demands and that these distinct demands could be measured simultaneously.

These findings are important because they begin to nuance the potential utilities of the various DRT types. Based on these results, we suggest that the tactile DRT (TDRT) may be the most appropriate stimulus for cutting through potential visual conflicts arising from the primary task while selectively targeting cognitive task demands. While the standard head mounted DRT (HDRT) and the remotely mounted DRT (RDRT) which feature a flashing red LED stimulus may also cut through primary visual task conflicts, it may sometimes be the case that the visual demands from the primary tasks interfere with the visually presented stimuli in an undesirable manner. In such cases, the reaction time reported from the standard HDRT and RDRT may be partially contaminated by the visual demands of the primary tasks.

These data suggest that the standard DRT configurations may not be sensitive to visual task demands due to their general visual salience. A more appropriate measure of visual attention using the DRT should be sufficiently salient that it is rarely missed when looking forward but often missed when looking away from the forward roadway. While we freely acknowledge that this outcome could be attained through a variety of approaches, the color mask used in this research appears to have been effective. Alternative approaches could involve dimming the LED stimulus or otherwise changing its onset / offset characteristics. Fortunately, there is a rich literature on perceptual salience from which to motivate potential approaches.

Importantly, data presented in these studies was collected in an indoor environment which presents very different challenges than an outdoor environment. Indeed, it may be possible to use the standard remote DRT setup outdoors even though it proved insensitive to visual attention in these indoor experiments. Additionally, future research should more rigorously model the relationship between eyes off road time and hit rate. These data suggest that the two can be highly associated; however, such a relationship should be clearly established using an appropriate design and statistical modeling technique.

Data presented in this set of experiments suggest that some variant of the dual-DRT approach may be suitable to quickly and reliably measure simultaneous changes in both visual and cognitive task demands. Future research should build off of these findings and explore the most appropriate method for delivering the remote LED stimulus so that it is maximally sensitive to visual attention in all lighting conditions.

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