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Limits of spatial attention in three-dimensional space and dual-task driving performance

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abstract

The present study examined the limits of spatial attention while performing two driving relevant tasks that varied in depth. The first task was to maintain a fixed headway distance behind a lead vehicle that varied speed. The second task was to detect a light-change target in an array of lights located above the

either be consistent with the response of the central feature (e.g., a central “S” with adjacent “C” characters) or inconsistent with the

speed 18 m behind the constant speed lead vehicle to establish a perception of the desired headway distance to be maintained folto encode both color and location. This is a particularly difficult task as it requires subjects to encode the color at each location in the array in order to detect a change. In the second experiment we examined the spatial extent of attention when the task required drivers to detect the onset of a color. Drivers were presented with the same driving scenario examined in Experiment 1. However, for the light detection task drivers were required to detect the onset of a yellow light (i.e., a light in the array changed from red to yellow or from green to yellow). This is an easier light detection as the detection event is identified by a single source of information (the

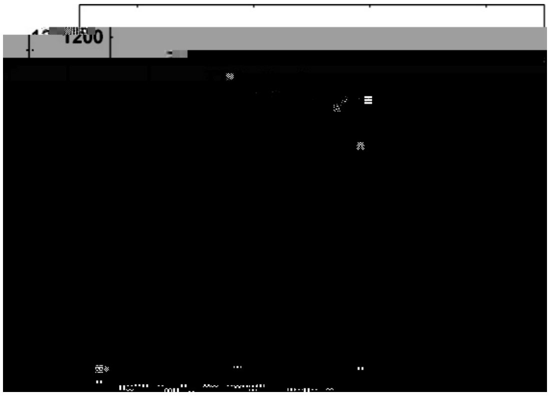
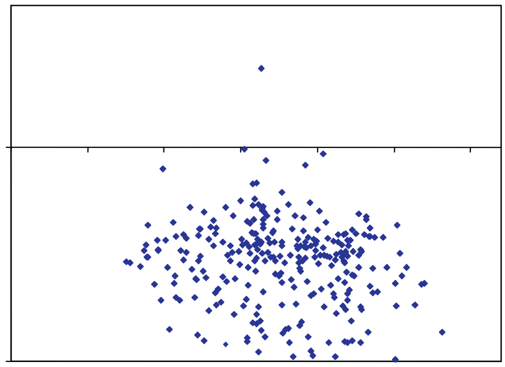


Fig. 3. Reaction time as a function of light-change target position and distance. Error bars are ±1 standard error. The results are from Experiment 2.

ANOVA. There were no significant main effects or interactions, $p > .05$. Overall subjects were quite accurate in performing the light detection task with average accuracy of 98% (SD = 2.3%). For comparison purposes we have included the results for accuracy in Fig. 3.

The mean RT for each subject in each condition was analyzed in a 2 (workload) by 3 (position) by 4 (location) ANOVA. The main effect of workload was significant, $F(1,19) = 11.1$, MSE = 12381, $\omega^2 = 0.006$, $p < .05$. According to this result, greater RT occurred for the high (mean RT of 768 ms, SD = 174) as compared to low (mean RT of 726 ms, SD = 171) workload condition. The main effect of position was significant, $F(2,38) = 35.7$, MSE = 13216, $\omega^2 = 0.04$, $p < .05$. The mean RT for the 3, 6 and 9 position were 699 (SD = 148), 742 (SD = 178), and 799 ms (SD = 185). Post hoc comparisons (Tukey HSD test) indicated significant differences ($p < .05$) between all pairwise comparisons. The effects of position as a function of workload are presented in Fig. 4 for comparison purposes. As is



efficiently. These results are consisent with the theory that spatial attention in 3D scenes is optimal at a particular location in the 3D scene and declines with changes in the 3D location relative to the optimal position. In addition, the effect of the horizontal position of the light-change target increased as a function of distance for both experiments (see Figs. 2 and 3). These results, considered together, suggest that spatial attention during driving is an asymmetric 3D region in space (Andersen, 1990).

The results also indicate that the spatial extent of attention changed as a function of workload of a central task. We manipulated workload of the car following task by increasing the speed variation of the lead vehicle. The results indicated an overall increase in RT as a function of workload for the position of the target as well as the depth of the target. Thus, the present study did not find evidence of differential effects of workload on the spatial extent of attention in the horizontal and depth dimensions.

In Experiment 3 we examined whether the effects of distance on RT was due to the spatial distribution of eye fixations while performing the driving tasks. An analysis of eye fixations indicated that the distribution of fixations was much smaller immediately prior to light changes that subsequently occurred at a far distance as compared to a near distance. The light detection performance was similar to that observed in Experiment 2—RT decreased as a function of distance. Thus, the distance effect observed in Experiments 2 and 3 could not be due to the spatial distribution of eye fixations prior to the light change.

Previous research on 3D attention examined spatial attention when display durations were brief (to control for eye movements) and a flanker task was used. The present study found the same pattern of results when eye movements were not controlled and a dual task paradigm was used in which subjects had to continously monitor a centrally located task. Driving an automobile, as well as other closed loop control tasks such as flying an aircraft, requires the operator to constantly monitor a centrally located task as part of closed loop control (e.g., maintaining a constant glide slope while landing, Galanis et al., 1998). We would expect that the 3D spatial limits of attention obtained in the present study, which involved driving, would also occur in other operator control systems that involve monitoring a centrally located task while attending to information in a 3D scene.

The results of this research suggest an important if not unique aspect of visual processing. It has generally been assumed that when a driver is looking at a target information in the immediate vicinity of the target is processed and the driver can respond to the information present. Targets located in more peripheral regions in the retinal projection receive less processing and as a result the driver is less likely to respond or will respond with a delay. The results of the present study suggest that a driver can be looking or fixating a stimulus and an adjacent stimulus, located at a greater distance, may not be processed or may require additional time to process. This finding has important implications for the design of head up displays (HUDs) which are intended to optimize performance by presenting displays in an overlapped region of the visual field with the outside scene (Martin-Emerson and Wickens, 1997; Sojourner and Antin, 1990). Consider a HUD of a speedometer in a vehicle. By using collimation the optical focus of the driver is at an infinite distance allowing the driver to read the speedometer and monitor the roadway without a change in optical focus. This type of design assumes that minimizing eye movements between an indash speedometer and the outside view of the roadway will result in improved driving performance and increased safety.

The results of the present study suggest a potential serious limitation with HUD (head-up display) technology. Although the driving scene and the HUD symbology are in close 2D spatial proximity the driver might have considerable difficulty in processing both information sources if the information in the driving scene and the HUD symbology are preceived as being separated in depth. This might occur despite the use of collimation if there are scratches or dirt on the windscreen. An important issue for future 5(while)-(5(T*[(w in tasks such driving flying ng aircraty.

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