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Investigating Visual Alerting in Complex Command and Control Environments

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Abstract

A series of experiments was conducted to investigate visual alerting in complex command and control environments, where operators must use several displays to perform tasks. In the first experiment, the speed of detection of two alerts, one in the form of a short bar and the other a border surrounding the perimeter of the display, were compared under flashing and static states. Findings showed that bar alerts were detected faster than border alerts and that adding a flashing attribute did not provide a benefit. The second study monitored which display participants were attending to when the alert appeared, and the results revealed that alert detection was not always superior when alerts and attention were on the same display. The third experiment investigated display configuration to ensure that the previous findings were not a result of the specific tasks performed on each display. The results are discussed in the context of the limitations of spatial attention.

Introduction

In command and control environments, such as nuclear power plants and military command and control operations centers, system operators are often required to manage, monitor, and interact with several information displays at the same time. Attending to multiple sources of information can be challenging, especially when the work is fast-paced and the consequence of missing critical information is high (Woods, 1995). Environments like these are often supported by some form of automated alerting to provide warnings of system status, critical states, or significant events, to operators.

Alerts are typically visual or auditory, but, regardless of the modality, they must be salient enough to stand out and be noticed by an operator who is fully engaged in other tasks. Visual alerts on a busy display might be difficult to detect, as might audio alerts in a noisy room. As an example, in the Canadian naval frigate operations room the primary means of alerting operators is through an automated audio system. However, the operations room relies on auditory modality for communicating many other kinds of information, either face to face or through multiple channel headsets and, as a result, the auditory system is immensely overloaded. Listening for auditory alerts in environments like this is extremely difficult. Not only are alerts difficult to discern but they can be repetitive and non-informative, with a high level of false alarm rate. Under these conditions it is not unusual for alerts to be turned off (Sorkin, 1988).

The difficulty of detecting alerts amongst multiple competing signals is exacerbated by the inherent nature of human attention. Not only do alerts have to exceed a perceptible signal-to-noise ratio, but they must also be prominent enough to capture and redirect attentional resources fully allocated to another task, or tasks. Individuals working under high workloads, where accuracy and speed of response are critical, are susceptible to attentional tunneling (Wickens, 2005), which refers to attention being completely absorbed and focused to the point where important information outside the area of focal attention is missed or detected slowly (Woods, 1995).

One option is to deliver alerts through a less-used modality, but in most complex command and control environments this state simply does not exist because visual and auditory channels are both used to capacity. The issue therefore becomes one of cost versus benefit, and determining the most appropriate modality and the exact form the alerting stimulus should take becomes a challenge in itself.

This paper reports on a series of experiments investigating visual alerting in complex command and control centers. The work was conducted with the Royal Canadian Navy frigate operations room in mind, but we believe that the findings, to some degree, can be generalized to any complex command and control environment where operators perform critical tasks under stressful conditions.

Visual alerting

Several factors need to be considered when displaying visual alerts on complex, busy displays. In the frigate operations room for example, sensor operators require several monitors for displaying the many different kinds of information and data

feeds, and as sensor platforms develop, it is likely that more and more data will be streamed to their displays, adding further to the volume of information. Primary considerations then are that alert symbology is visible, no matter which monitor the operator is looking at, and that it does not obstruct or interfere with information related to performing a task.

A resolution to the latter issue is to locate alerting symbology in the periphery of the work area. Problematic to this solution, however, is that visual acuity declines with retinal eccentricity, making information in the peripheral vision more difficult to detect (Engel, 1971). Moreover, for a visual alert to be detected, attention must be directed to the location in space where the alert appears, which could be on the display the operator is working on, or on another display. As mentioned earlier, when a task is highly demanding or stressful, it is not unusual for information to be missed if it appears outside the area of focal attention (Wickens, 2005). According to theories of human attention, performing a high-intensity task can cause attentional focus to narrow in on the specific spatial area where the primary information required to perform the task is located. Attention becomes constricted, or tunneled, so much so that information falling outside the area of focal attention is missed, even when (or perhaps because) the consequences are critical (Wickens, 2005). The requirement that any stimulus used for alerting purposes must be salient enough to capture a busy operator's attention, yet discrete enough to avoid interference with task-relevant information becomes more significant and difficult to apply with larger displays, or when there is more than one display.

One possible way to aid in directing attention to an alert in the periphery is to add the attribute of movement to the stimulus (Bartram, Ware, & Calvert, 2003; Bonnet, 1980; Peterson & Dugas, 1972; Ware, Bonner, Knight, & Cater, 1992). In general, the human visual system is well tuned to detect and track movement (Faraday & Sutcliffe, 1997, as cited in Bartram, Ware & Calvert, 2003; Pylyshyn et al., 1994). Based on the physiology of the visual system, where movement-sensitive photoreceptors are abundant in the periphery of the retina, movement is a highly salient cue when it occurs in the peripheral visual field. Bartram and colleagues (Bartram et al., 2003, Experiments 1 and 2) found that stimuli with a moving component were more easily detected than those that changed colour or shape, regardless of how far they were from central vision. One possibility then is to present alerting symbology in a form that has movement associated with it, such as blinking or flashing.

Bartram and colleagues, for example, found movement of icons displayed in the periphery to be more quickly and accurately detected than static icons in the periphery that changed colour or shape. In this study, movement took the form of an icon moving smoothly up and down its height, which could be either 1 or 2 cm, at a frequency of

approximately 3 Hz. The researchers also compared different forms of movement, one of which was flashing, under various levels of task difficulty (Bartram et al., 2003). Task difficulty was varied from low to high engagement by having participants either: (a) study on-line text = low engagement; (b) play an on-line variant of the card game, Solitaire = intermediate engagement; or (c) play a video game, Tetris = high engagement. The task was presented in the center of the display and participants were instructed that this was their primary task. A secondary task consisted of detecting the movement of icons that were placed in the periphery around the outside of the display. Four different kinds of movement were compared: (a) linear—where the alerting icon moved smoothly up and down the length of its height (14 pixels) and then jumped back to its original position; (b) zoom—where the icon grew to 200% its size and then jumped back to its original size; (c) blink—where the icon was flashing on and off; and (d) travel—where the icon moved across the screen. Each of the movement types was presented at two frequencies: (i) slow (1 Hz); and (ii) fast (2 Hz). All the icons were on the screen at all times, and the participant's task was to press a key on the keyboard when movement was detected.

Results showed that overall error rate was relatively low, with more icons detected during the text task as compared to the other two tasks, both of which resulted in about equal numbers of icons detected. Of particular interest were the blinking icons, which, other than the fast blinking icon in the Tetris game, proved to be slower and more difficult to detect than any of the other types of motion. The Tetris condition, which was the high engagement condition, also showed that the linear and travel icons were less well detected than in any other condition, and the researchers suggested that the higher error rates overall in this condition may be partly due to interference from similar motion that was occurring in the Tetris task. This observation suggests that the ability to detect visual alerts could be affected by the other tasks an operator is tackling at the time.

The work reported here aims to examine the detectability of visual alerting with and without movement. Two alert types were used in the experiments, and both were presented in the periphery of the display. The first, a flashing border surrounding the perimeter of the display, was a suggested alerting mechanism proposed by subject matter experts while considering the redesign of the navy frigate. The second visual alerting technique was a simple bar, similar to a status bar often used to indicate quantity or intensity of some kind, such as battery charge status on a cell phone. In the studies reported here, this alert took the form of a simple bar with no status level associated with it.

Since this research was inspired by limitations in an existing naval environment, the workstation used in the experiments emulated that environment and was made up

of three displays, each supporting a different kind of information and task. As previously stated, for a visual alert to be detected, attention must be directed to the location in space where the alert appears. In the case where operators use multi-display workstations, the most prominent placement of a visual alert would likely be on the display the operator is working on. However, knowing what display an operator is attending to at any given time is not possible, so presenting alerts on all displays might be the best option. On the other hand, alerts in multiple locations may be overly intrusive and visually distracting, especially if they are flashing (Ware et al., 1992). Thus, the combination of flashing stimuli on multiple displays may reduce effectiveness rather than increase it (Sarter & Woods, 1995; Woods, 1995). To investigate whether there is any significant benefit in presenting alerts on all displays versus one, one variable in the experiments reported here was display location of the alert.

Experiment 1

The objective of Experiment 1 was to evaluate detectability of two different visual alert types—a border (around the perimeter of the display), and a bar (a short bar on the left hand edge of the display). The alerts were presented while performing a task that represented, in low-fidelity, the kind of task performed by a naval operator working in a command and control operations center. The workstation was made up of three displays and information was required from each of the displays in order to perform the task.

Method

Participants

Twenty-four participants (12 males, 12 females), with a mean age of 33 years, consisting of civilians, military, and ex-military personnel, were recruited. All participants reported normal or corrected-to-normal vision, and 21 participants were right-handed. Experimental sessions were approximately 90 minutes in duration.

Apparatus

The task was presented on a workstation consisting of three 20.1-inch liquid crystal display (LCD) computer monitors, running Windows XP Professional (Service Pack 2), with a single keyboard and mouse input device. The displays were configured horizontally, with the middle display directly in front of the participant, and one display on either side (see Figure 1).

Tasks and alerts

Primary task The primary task was to detect, and make a response as quickly as possible to alerts that appeared on the displays. Responses were made by pressing the spacebar on the keyboard.

Figure 1. Border and bar alerts, and left, middle, right displays.

Alert type Alerts took one of two forms: Border (a red, 2 cm continuous band around the display perimeter); and Bar (a red, 2 cm × 10 cm strip placed at the top left-hand edge of the display).

Alert state Alerts could appear in one of two states: Flashing (alerts were flashing at a rate of 3.333 Hz); or Static (alerts were non-flashing [static]).

Alerts could appear on all three displays concurrently or on a single display. The display the alert appeared on (left, middle, right, all) was randomized, with the condition that alerts appeared at all possible display locations an equal number of times.

Secondary task The secondary task was to use all three displays to categorize visual contacts that appeared on the middle display. The task and display set-up was as follows:

- **Tactical display** (middle) depicted a) the participant's ship (ownship), represented as a grey filled circle (60 pixel radius) that remained stationary in the center of the display; and b) other vessels (contacts) represented as yellow triangles that originated in the periphery of the tactical display and advanced toward the ownship in incremental steps at two second intervals. The participant's task was to categorize contacts on the display as hostile or neutral by first moving the mouse cursor over a contact, and using the generated information that appeared on the status display to decide whether the contact was neutral or hostile.

- *Status display* (left) showed attribute information about each contact, which was required in order to classify contacts as hostile or neutral. Three categories of information were available:

Speed: Fast = hostile Slow = neutral

Size: Small = hostile Large = neutral

Weapons on board: Yes = hostile No = neutral

- Based on the above, a score of >2 attributes resulted in the contact being classified as such.
- *Reporting display* (right) - participants entered their categorization response in a text box on the reporting display located to the right of the tactical display. A correct response resulted in the contact of interest disappearing from the tactical display. An incorrect response required repeating the mouse-over contact process and reviewing the information that once again appeared on the status display, and subsequently reporting on the report display.

Participants were told that minimizing the time taken to perform the categorization task was important because contacts coming within a pre-determined radius of the ownship would result in the ownship being destroyed. If this occurred, the task was automatically paused, during which time an audio file of a “kaboom” sound was played, with an accompanying picture of an exploding ship displayed on the tactical display. After three seconds the session automatically restarted, with contacts once again originating in the periphery of the tactical display and moving incrementally toward the ownship.

Procedure

The experiment was a 2 alert Type (border, bar) $\times$ 2 alert State (flashing, static) $\times$ 4 alert Location (left, middle, right, all) within-subjects design. Participants were instructed that detecting alerts was their primary task and that they were to make their response as quickly as possible by pressing the spacebar.

The experiment consisted of 16 blocks, each consisting of one combination of alert Type and State so that there were four conditions. Within each block, 16 alerts were presented randomly, four at each of the display locations.

The alert condition was held constant throughout each block, and order of blocks was counterbalanced across participants.

Results

Primary task performance

Alert detection Response times to alerts that were present and detected (Hits) were analyzed. Cell means for alert Type, alert State, and alert Location, for each participant, were entered into a repeated-measures Analysis of Variance (ANOVA). Significant effects of alert Type [$F(1, 23) = 20.109, p < .001, MS_e = 41,146.69$], and Location [$F(3, 69) = 30.03, p < .001, MS_e = 16,042.86$] were observed, as well as an interaction between Type and Location [$F(3, 69) = 27.066, p < .001, MS_e = 11,431.66$]. No effect of alert State was present [$F(1, 23) = 5887.22, p > .516, MS_e = 13,566.95$]. Results are shown in Figure 2.

The main effect of alert type with no effect of alert state indicated that, overall, the bar alert ($M = 900$ ms) was responded to significantly faster than the border alert ($M = 994$ ms), whereas whether the alert was flashing or static did not affect response time (flashing: $M = 943$ ms; static: $M = 951$ ms).

The interaction between alert type and alert location showed that detection speed for bar or border alerts depended on the display the alert appeared on. Paired t -tests, conducted on the data collapsed across alert state, showed that bar alerts appearing on all displays were detected faster than when they appeared on any of the single displays, but in the border condition alerts appearing on all displays were only detected faster than right display alerts [$t(23) = -4.199, p < .0001$]. Thus, in the border condition there was no significant difference in detection speed when alerts appeared on the left, middle, or all the displays. These data suggest that presenting bars on all displays is more effective than presenting borders on all displays. Within the bar condition alerts were responded to significantly slower if they appeared on the left display than on any other display. This result initially suggests that the left display is an inferior location for visual alerts for the task used in this study.

Figure 2. Experiment 1 – Mean Response time (in msec) as a function of Alert Type, State, and Location.

Secondary task performance

Target categorization Although performance on the secondary, contact categorization, task was not of primary interest, measures were collected on this task to evaluate whether participants were performing the whole task and not focusing exclusively on detecting alerts. These measures were also collected to gauge performance across time, since performance changing over time might indicate learning effects and inadequate practice time. To normalize variation in count data, arcsine transformations were performed on the data for analysis purposes.

Number of target categorizations attempted The number of attempted contact identifications (responses input into the reporting display) was used as a means of assessing the rate at which participants were performing the categorization task, and thus an indication of the overall ability of participants to perform the task. Total correct and incorrect target classifications for each participant were entered into a one-way repeated measures ANOVA with Block (1–16) as a variable. Results revealed that the time on task (Block) had a significant effect on the number of attempted contact identifications, [$F(4.729, 108.77) = 27.399, p < .01, MS_e = .000$], indicating that performance improved across time, and suggesting that an increase in practice time might have been beneficial.

Target categorization accuracy To examine accuracy on the task and whether or not a speed–accuracy trade-off existed, the percentage of contacts correctly identified was determined. A one-way repeated measures ANOVA was computed on percent correct identifications (task accuracy) with Block (time) as a variable. The ANOVA indicated no effect of Block [$F(7.956, 182.994) = 3.026, p < 0.004, MS_e = .019$], and consequently no speed–accuracy trade-off. Mean percent accuracy was above 90% across the entire task.

Destroyed ownship

The number of times the ownship was destroyed was used as a means of assessing whether participants were sufficiently absorbed in the high-intensity categorization task. Lower frequency of destroyed ownship reflected better performance. Frequency counts for each participant were entered into a one-way ANOVA and an effect of Block (time) was observed [$F(4.785, 110.050) = 3.221, p < .05, MS_e = .424$], with the number of ownship destroyed being greater in earlier blocks than in later ones. However, overall, the frequency of destroyed ownship was relatively low, ranging from a mean of .56 in early blocks to .04 in final blocks. All in all, these results suggest that participants were suitably focused on the secondary task.

Discussion

Experiment 1 was conducted to examine detection to two types of visual alerting, a short bar and a full perimeter border, while performing a high intensity secondary task. The secondary task was designed to emulate the kind of multiple display task operators might perform in a complex command and control domain, where workload is high and where decisions must be made quickly and accurately. Although detecting alerts was the primary task, it was anticipated that performing the secondary task would require participants' focused attention to specific displays and specific areas within those displays. As such, we anticipated that alerts may be missed or detected slowly.

As might be expected, presenting alerts simultaneously on all three displays resulted in optimal alert detection, although it is interesting that this was only a solid finding for the bar alert. Bar alerts that appeared on the left display, the status display, were generally responded to slower than those on any other display. This latter result suggests that the left display is an inferior location for some kinds of visual alerts. However, bar alerts always appeared on the left hand side of a display and subsequently were furthest from central viewing, meaning that, if the participant was working on the middle display, for example, the chances of missing an alert on the left display was comparatively high, as compared to the right display. Alternatively, the poorer performance on the left display might be a product of the task itself. Time on the status display might be less than on others, resulting in less chance of seeing an alert appearing there, or it could be more work-intensive, causing more of an attentional tunneling effect. This question is addressed in Experiments 2 and 3.

In Experiment 1, flashing the alerts provided no advantage over static alerting; a finding that is somewhat surprising given what we know about the visual system's sensitivity to movement and the onset of peripheral stimuli (Folk, Remington, & Johnston, 1992), which is where these alerts appeared. Peripheral vision picks up subtle shifts in energy patterns that help direct attention (Fuller & Carrasco, 2006; Jonides, 1981; Yantis & Jonides, 1990), which is one reason why "flashing" is often used as a means of attracting attention. In Experiment 1 an on–off flashing cycle did not improve detectability, and this finding is generally inconsistent with other research.

Interestingly, in brain-imaging research, selective tuning of neurons for a specific feature in a scene has been demonstrated to increase sensitivity to that feature across the visual field, even when the feature is far away from the attended location (Serences & Boynton, 2007; Treue & Martinez-Trujillo, 2007). Thus, attending to a feature can automatically prime the visual system to detect that feature in other spatial locations. Under this premise one might expect detecting motion in a secondary peripheral task to be

easier if that motion is also contained in primary task stimuli.

Perhaps most interesting is the result in our study that the bar was detected faster than the border alert, despite the fact that the border occupied considerably more real estate on the screen. This finding is consistent with unpublished pilot work in our lab, where time to detect a flashing border was longer than time to detect a non-flashing bar. Considering the results from a physiological perspective, research in the field of neuroscience, rooted in propagation speeds and the ratio of different kinds of cells in the visual cortex, has reported faster processing of target stimuli with greater eccentricity, and slower processing of larger stimuli, that stimulate a larger cortical area, as compared to smaller ones (Carrasco, McElree, Denisova, & Girordano, 2003).

Clearly, something about the bar makes it more effective at capturing attention in the context of the task used in these studies. The findings from Experiment 1 support the assumption that the form the alert takes (e.g., border vs bar) has an impact on the mechanism underlying attention, and that certain properties of alerting stimuli appear to be more beneficial in capturing attention than others. Understanding more fully how these attributes interact with the role of attention is important if these visual alerting systems are to be transferred into the real world.

The results from Experiment 1 suggest that participants may have experienced attentional tunneling, manifest in a delay in detecting alerts that appeared outside the focal area of attention (Wickens, 2005). Attentional tunneling refers to the phenomenon of being fully absorbed in a task to the point where attentional resources are used to capacity and cannot be redirected, reassigned, or shared. Attentional tunneling can facilitate performance, but factors such as fatigue, stress, and task engagement, can negatively influence the ability to assign attentional resources, making it impossible to handle multiple tasks successfully. Under these conditions information, that may or may not be relevant, tends to be missed (Wickens, 1996). In Experiment 1 the secondary task of protecting the ownship by categorizing and eliminating approaching vessels was highly engaging and may have required full attention, which resulted in a deficiency in available resources and in missing the onset of a red alert in the periphery.

There are a number of different models of attention that have been developed to account for how attention moves across space from one location to another. According to the spotlight theory (LaBerge, 1983), shifts in attention are continuous, much like a spotlight sweeping across a surface area. The continuous theory of attention proposes that the area the spotlight illuminates is limited and constant, and as the spotlight moves, attention moves to other objects within the next illuminated area.

An alternative hypothesis builds on the spotlight theory by proposing that attention shifts in a discrete fashion, and that it is possible to decrease the amount of attention at one

point within the spotlight while increasing at another, much like a zoom lens. Under this model, attention is graded, and the size of the spotlight can change according to task demands (Eriksen & St James, 1986).

These theories might account for missed or slow responses to alerts, but they do not address the issue of why a certain kind of alert is slower to detect than another. In the study reported here, border alerts were consistently detected slower than bar alerts, even though both types appeared at the same eccentricity. It is reasonable then to take a deeper look at what kinds of attributes facilitate moving attention from one object to another.

Attention can be redirected either overtly, by directly looking at the source of interest, or covertly by being aware but without accompanying eye movement. Overt visual attention is controlled and voluntary, and involves directing the eyes to the source of interest. Thus, the object of interest lies directly in the central fovea. Turning to attend to someone talking would be considered a goal-driven orientation. Overt attention is primarily a top-down, goal-driven process, and is deliberate and relatively slow, due to the extent of cognitive translation and/or interpretation required (Posner, 1980).

Covert orientation on the other hand, where the object or location of interest lies in peripheral vision, is an automatic, direct, and quick process (Helmholtz, 1925, Eriksen & Hoffman, 1973), and is stimulus driven. For example, although the speed of detecting an object typically declines as eccentricity increases (Engel, 1971)—that is, as the object is located further out into the periphery and away from central vision—a salient change to the object, such as a change in brightness, or the onset of movement, will cause attention to deploy to the stimulus automatically, and without conscious effort. This stimulus-driven response to peripheral cues is strong enough that responses can be faster to peripheral stimuli than to central ones, even when individuals are instructed to ignore stimuli in the periphery (Jonides, 1980). Since participants in the experiments conducted here are fully absorbed in tasks not related to the alert, as are operators in the real world, the visual alert must hold attributes that initiate covert attention in order to draw attention to the alerting stimulus.

One way to elicit attention to a new spatial location is via exogenous cues, which involve reflexive orienting to a salient stimulus that appears outside the central fovea (Müller & Rabbitt, 1989). Exogenous cues can draw attention to something independent of the task, and irrelevant to the task. A flashing light in peripheral vision would be considered an exogenous cue, as might the onset of the alerting stimuli appearing in the periphery in Experiment 1. Another way attention can reorient is through endogenous cueing but, in contrast to exogenous cues, endogenous cues are goal-directed. They can allocate attention on the basis of task instructions and knowledge about the current environment, for example (Hillstrom and Yantis, 1994).

Experiment 2

Gaining a better understanding of the relationship between the location of information needed to perform a task and spatial attention might help in our understanding of some of the findings from Experiment 1. One fundamental question is whether or not alerts are detected more effectively when they appear on the same display to which the operator is attending. One would assume that they are, since the ability to detect peripheral information generally tends to drop off as eccentricity increases. Consequently, if an alert appears on a display that the participant is not focused on it is less likely to be captured in the field of spatial attention. Of particular interest in this work is whether certain forms of alerts are captured more efficiently than others. For example, is the bar alert detected more rapidly than the border alert because it falls within a defined attentional radius or spotlight, perhaps because of its more compact, concise form, as compared to the border? In that case, bar alerts should be detected faster when participants are attending to the same display the alert appears on. Alternatively, there may be no difference in detectability of alerts as a function of the location of spatial attention, regardless of the form they take.

Knowing where the participant is attending while performing the task would be advantageous for this research, and, ideally, this kind of data could be collected by monitoring eye movement using eye-tracking equipment. An alternative, though less sophisticated method, is to record the location of the mouse cursor as an estimate of where the operator is attending¹.

Experiment 2 was designed to investigate how attention plays a role in alert detection with the premise that bar alerts are processed more rapidly than border alerts when the focus of operator attention is on the display on which the alert appears. The location of the mouse cursor was used as an estimate of where the operator was looking and an assumption of the location of spatial attention.

The poorer performance on the left display, the status display, in Experiment 1 might be explained by the location of the alert on the displays, being further out in the periphery on the left display. This possibility was addressed in Experiment 2 by moving the location of the bar alert from the left side to the top and bottom centre of the displays. This change served to moderate the location of the alert and to better equate the peripheral distance to which the participant must attend.

Method

Participants

Twenty-four volunteers (11 males, 13 females) participated in this study. Age ranged from 18 to 59 years, with a

mean age of 31 years. All participants but one were right-handed, and all reported normal or corrected-to-normal vision. All participants were novice with respect to the task to be performed in the experiment. The study took about one hour to complete.

Procedure

The procedure was the same as Experiment 1, with the exception that Experiment 2 consisted of 24 blocks, in contrast to 16 blocks in the first experiment.

Apparatus

The apparatus was identical to that used in Experiment 1, but the software used in Experiment 2 was capable of recording the location of the cursor with respect to the display it was on at any given time.

Tasks and alerts

The task and stimuli were the same as in Experiment 1 but, as shown in Figure 3, the location of the bar alert was moved to the center top and center bottom edge of the display, as opposed to the left-hand side in Experiment 1. On half the bar trials the red bar appeared on the top, and on half on the bottom of the display. The experiment was a within-subjects 2 alert Type $\times$ 2 alert State $\times$ 4 alert Location $\times$ 3 cursor Location) design.

Results

Primary task performance

Alert detection Response time cell means for Alert Type, State, and Location, for each participant, were entered into a repeated measures ANOVA. The analysis showed effects of alert Type [$F(2, 46) = 29.631, p < .0001, MS_e = 18051.105$], with bar alerts being detected faster than border; and alert Location [$F(3, 69) = 25.889, p < .0001, MS_e = 15,651.776$], with significant differences between every alert location in the bar condition but only between the right and all, and left and all displays in the border condition. There was no effect of State [$F(1, 23) = .368, p > .365, MS_e = 9499.206$], indicating that the flashing component provided no benefit. An interaction between

Figure 3. Displays used in Experiment 2, with the bar alert located at top-center.

¹ Salmon & Klein (2010) have shown that cursor location provides an acceptable assumption of where the eyes are looking, and see also Experiment 3 reported here.

alert Type and alert Location was also present [$F(6, 138) = 3.915, p < .0011, MS_e = 10,687.671$], showing that performance across displays differed depending on the type of alert being shown.

An analysis of alert top bar ($M = 906.26$ ms) and bottom bar ($M = 920.43$ ms) indicated no difference in detection rate for the two bar positions [$t(23) = -1.213, p > .236$]. As a matter of interest, a paired comparison t-test was also conducted on the data of the top and bottom locations combined and the side bar data from Experiment 1. Results showed no significant difference in detection rate [$t(23) = -1.213, p > .236$] for bar placement, suggesting that having the bar further out in the periphery on the left display as compared to other displays in Experiment 1 was an unwarranted concern.

Figure 4 shows the response time results for alert Type, State, and Location with top and bottom bar data collapsed. Bar alerts appearing on all displays were detected fastest ($M = 829$ ms), and on the right display slowest ($M = 985$ ms).

Cursor location To examine the association between locus of spatial attention and alert location, the display the cursor was on was used as an indicator of where the participant was looking. Thus, the cursor location was an assumption of the location of spatial attention.

Cell means for Alert Type and Location, and Cursor location, for each participant were entered into a repeated measures ANOVA. Effects of Alert Type [$F(2, 46) = 12.909, p < .0001, MS_e = 46,629.276$], Alert Location [$F(3, 69) = 16.414, p < .0001, MS_e = 37,379.834$], and Cursor Location [$F(2, 46) = 3.892, p < .028, MS_e = 113,207.069$] were found. Post-hoc comparisons again revealed no difference in detection rate between top and bottom bar alerts [$t(23) = -.738, p > .467$], and the effect of type was limited to a difference between bar and border. Results are shown in Figure 5.

An interaction between Alert Location and Cursor Location was observed [$F(6, 138) = 3.582, p < .0021, MS_e = 30,498.645$] indicating that performance differed depending on where the participant was attending when the alert appeared. Post-hoc comparisons showed that for the

Figure 4. Experiment 2 – mean response time (ms) to alerts, as a function of alert Type, State and Location, with Bottom and Top bar data collapsed.

Figure 5. Experiment 2 – Mean response time (in msec) to alerts, as a function of Alert Type and Location and Cursor Location, with Bottom and Top bar collapsed.

border alert, when alerts appeared on the left display, detection was significantly slower if the participant was attending to that display, as compared to when they were attending to the middle display and the alert appeared on the left display [$t(23) = 3.493, p < .0021$]. This result suggests an effect of attentional tunneling since the alert took longer to detect even though it appeared on the display to which the participant was attending. In contrast, attending to the right or middle displays resulted in no significant difference in response time, regardless of whether an alert appeared at either of those locations. In both these cases detection was significantly faster than when attention was on the left display [cursor left vs middle: $t(23) = 2.243, p < .036$] [cursor left vs right $t(23) = 2.139, p < .044$].

For the bar alert, response to an alert was considerably slower when it appeared on the right display and attention was on the left as compared to when attention was on the right display [$t(23) = 2.424, p < .025$]. There was no significant difference between attending to the middle or right displays when alerts appeared on the right display. However, the participant could be attending to the middle display and detect an alert on the left display faster than when they were attending to the left display, where the alert appeared [$t(23) = 2.150, p < .043$].

Discussion

In Experiment 2 the location of the cursor was used as a means of assessing the location of spatial attention. Coupled with the location of the alert, results sometimes showed that alerts were detected fastest when they appeared on the display on which the participant was attending. This result is not unexpected since one would assume that working on the same display on which the alert appears is conducive to detecting the alert. However, there were some interesting departures from this trend.

Overall, as in Experiment 1, border alerts were detected more slowly than bar. However, for bars and borders, alerts that appeared on the left display were detected slower even

when participants' attention was on that display, although this was not the case for the right display, where detection was best when alerts and attention were on the same display. The left display was the status display where information about a contact was listed and used to determine the contact category (neutral or hostile). This task may have required more attention than other tasks using the other displays, resulting in attention being more focused on the task at hand and alerts taking longer to be noticed.

Another interesting finding was related to the right and middle displays, where detecting alerts that appeared on either of those displays was not affected by the location of spatial attention as long as the participant was attending to either one of those displays. Thus, putting an alert on the right display while the participant was using the middle display, and vice versa, appeared to cause little or no interference in their ability to detect alerts that appeared on either of those displays. There was a non-significant trend toward a similar pattern between the left and middle displays. On the whole, this finding suggests that putting alerts on a display next to the one to which the participant is attending results in equally good alert detection.

The results from Experiment 2 can be summarized as follows:

- Border alerts were detected slower than bar, as in Experiment 1.
- No advantage or disadvantage was observed by adding a flashing component, as in Experiment 1.
- Overall, alerts on the left display produced slow responses even when attention was on that display.
- Alerts appearing on the middle or right displays were detected equally fast as long attention was on either one of those displays.

With respect to the first point, where bar alerts are consistently detected faster than border alerts: peripheral vision is sensitive to temporal changes in contrast that help direct attention, and the visual system's orienting mechanism is designed to point attention toward eye-catching stimuli (Coren, Ward & Enns, 1994). Cues that inform us about where something will likely happen are termed information cues, and one possibility worth considering is that the bar is a more effective information cue than a border surrounding the edge of a display. Due to its more edged and compact form, the physical appearance of a bar may make it more effective at directing and capturing covert attention. Posner (1980), by demonstrating the effect of expectation on response time, showed that attention could be covertly oriented without eye movement. In fact, the area of attentional coverage can be expanded to include specific locations if pre-knowledge is provided about the location of an upcoming stimulus (Engel, 1971). Thus, the spotlight of attentional focus may be whole-task specific, expandable to include associated information, even if that

information is related to a second, unrelated task. If this were so, the bar may be more suited to being included in the attentional field, perhaps because of its form and consistent location. This possibility was investigated in our lab by changing the location of the bar during the experiment (Crebolder, Salmon, & Klein, 2010). We expected to see a drop in performance at the point at which the location changed, but in fact found that the decline was delayed by several minutes. This result suggests that participants were alert to the change at the time it occurred but that their attention dropped off soon afterwards.

With respect to the second point, finding no difference in detection rate based on flashing or non-flashing stimuli is another result that we have consistently found (Crebolder & Beardsall, 2009; Crebolder, Salmon, & Klein, 2010; Roberts & Foster-Hunt, 2008; Salmon & Klein, 2010). We have not been able to conclude why this might be and comparing several different flash on-off rates (100, 200, 300, 400, 600) showed no difference in alert detection compared to having alerts static (Salmon & Klein, 2010).

Points 3 and 4 relate to differences in performance as a result of the displays and where the alert appears in relation to where the participant is attending. First, these findings suggest that it is more difficult to detect alerts when they appear on the left display, and secondly, that the right and middle displays showed no difference as long as attention is on one of those displays. Both of these findings bring into question whether the results are a consequence of the specific tasks within the secondary task being conducted on those displays, or whether they are related to a more generalizable perceptual bias or advantage to one side of centre over another.

Experiment 3

Experiment 3 was designed to examine the results from Experiments 1 and 2 in the context of the overall secondary task used in these experiments and the configuration of the displays for that task. The display arrangement in experiments conducted using this task has always been left = status display; middle = tactical display; right = reporting display. The secondary task requires participants to mouse over a contact on the tactical display, examine the information presented on the status display, and report their categorization decision on the reporting display. The overall goal of the task is to protect an ownship from being penetrated by contacts. The task was designed to ensure, as much as possible, that participants were engaged and that they attended to each of the three displays and we are confident that this is the case based on secondary task data that shows high accuracy and improved speed of response across time on the categorization task.

However, based on the finding that alerts appearing on the left display tended to be responded to slower than any other display, and that the right and middle displays were interchangeable as far as alert detection is concerned, it is questionable whether each display is given an equal amount of attention. If not, some of the conclusions drawn from the results might be erroneous. To investigate this proposition further, the configuration of the displays within the workstation was changed in Experiment 3 so that every possible combination of arrangements was used by each participant. Determining whether the findings from Experiments 1 and 2 are limited to the tasks performed (status, tactical, reporting), or whether they are limited to the specific locations of the displays within the overall workstation (left, middle, right), will help to establish whether results are drawn from effects of perceptual bias or effects that are specific to the tasks and display layout arrangement.

Experiment 3 used only bar alerts and was a $2 \times 4 \times 6$ within-subject design, that consisted of alert Type (2—bottom bar, top bar), alert Location (4—left, middle, right, all), and display Configuration (6—STR, SRT, RTS, RST, TRS, TSR, where S = Status; R = Reporting; T = Tactical).

This study was provided an opportunity to trial the use of a recently acquired eye-tracking system, and the eye-tracking data was used to further validate cursor location as a means of determining on which display participants are attending.

Method

Participants

Twenty-four volunteers (18 males, 6 females) participated in the study. Age ranged from 19 to 51 years, with a mean of 25.7 years. Twenty-two participants were right-handed, and all reported normal or corrected-to-normal vision. The study took about 90 minutes to complete.

Apparatus

Apparatus was identical to that used in Experiment 1, with the addition of a ViewPoint® EyeTracker PC-60 SceneCamera System by Arrington Research used to monitor where participants were looking while completing the task.

Also in this experiment the display configuration was rotated throughout the six possible arrangements, so that each participant saw each arrangement four times. The order in which the arrangements occurred was counter-balanced across participants.

Tasks and alerts

The task was identical to Experiment 1, and stimuli for alerts were the same with the exception that there was no border alert included in this study. On half the trials a top

bar alert was presented and on the remainder a bottom bar alert. The experiment consisted of 24 blocks for each participant, with 4 blocks of each alert type (top, bottom bar) and 16 alerts in each block (four at each display location).

Procedure

The procedure was the same as in Experiment 1, except that calibration of the eye-tracker was required prior to data collection beginning, and a head-mounted camera was worn throughout the experiment.

Results

Primary task performance

Alert detection Cell means for alert Type, Location, and display Configuration, for each participant, were entered into a repeated measures ANOVA. No effects for alert accuracy were noted and, consistent with other experiments, no difference in response time to top and bottom bar alerts was observed [$F(1, 23) = .563, p > .462, MS_e = 9782.255$]. There was an effect of alert Location showing that performance differed depending on the display on which the alert appeared [$F(3, 69) = 57.603, p < .0001, MS_e = 9626.773$]. No significant effect of display configuration was evident [$F(5, 115) = .846, p > .521, MS_e = 20,497.762$], and no interaction of display configuration and alert location [$F(5, 345) = 1.485, p > .107, MS_e = 6559.952$], indicating that performance on detecting alerts did not differ regardless of where the status, tactical, and reporting displays were located within the configuration of the workstation. Results are shown in Figure 6 below, with top and bottom bar collapsed.

Cursor and eye-tracking

An examination of the eye-tracking and cursor location data verified that cursor location is a relatively good assessment of what display participants are attending. Of the 24 participants, 17 produced eye-tracking data that could be used, and the analysis revealed a strong correlation between horizontal eye and cursor position

Figure 6. Mean response time (ms) to alerts as a function of alert location and display configuration (S = Status; R = Reporting; T = Tactical).

($r = .700$, $p < .011$) and a weak correlation between vertical eye and cursor position ($r = .209$, $p < .001$).²

Discussion

Experiment 3 was designed to investigate whether rearranging the location of the status, tactical, and reporting displays within the workstation would have an effect on alert detection, because Experiment 1 results showed a bias against detecting bar alerts on the left display, and Experiment 2 informed us that a similar bias was prevalent when attention was on that display. This was true whether alerts were bars or borders. These results may have been due to the tasks associated with the status, tactical, and reporting displays which always appeared in the same configuration. If some tasks, like the task on the left display for example, placed more demand on attentional resources than others, the potential for detecting or missing alerts might not be the same for all alert locations (displays). However results from Experiment 3, where the configuration of the displays was rearranged, provide no evidence to support that hypothesis. Thus, the findings imply that the biases noted in previous results are perceptual in nature and that alerts appearing to left of a center display are more susceptible to being missed and responded to slowly.

General Discussion

The findings from this series of experiments provide information on visual alerting techniques that are important for complex command and control environments. The first experiment compared two different forms of alerting and found that flashing those alerts provided no benefit, even though considerable research exists in the literature showing that the attribute of movement in peripheral vision draws attention to the source location (Ware et al., 1992). Supporting the findings however is the literature that points to a resistance to attentional capture when participants are highly focused (Yantis & Jonides, 1990), which was the intended state in these experiments to ensure that the multi-display task was fully engaging, as might be found in any command and control operations center. Although participants were instructed to make detecting alerts their first priority, is it likely that the amount of attentional focus required to perform the secondary, categorization task overruled that directive.

The studies also found that bar alerts were detected faster than a whole perimeter border, a finding previously observed (Crebolder & Beardsall, 2009; Crebolder, Salmon, & Klein, 2010; Roberts & Foster-Hunt, 2008;

Salmon & Klein, 2010) and one that is somewhat surprising given the larger area that the border monopolizes in comparison to the bar. Related to that finding, the second study sought to determine whether a difference in alert detectability changed depending on where spatial attention was located. Interesting results were revealed, showing that, for bars and borders, alert detection was not always better when attention was on the display the alert appeared on. An important inference from these results is that the evidence reduces support for the hypothesis that information on a display can be included in the spotlight of attention even if it is not related to the task at hand, which in this case was the categorization task. We hypothesised that the bar alert would be more likely to be assimilated into the attentional field because of its relatively compact and small edged form, as compared to the border that is continuous and more seamlessly blends with the edge of the display. Future work in our lab will investigate the difference between bar and border alerts in finer detail with respect to the location of spatial attention and alert location.

Finally, to investigate the possibility that findings were a consequence of the specific tasks performed in the categorization task, the displays were rearranged in the third experiment. Results showed that difficulties with detecting alerts on the left display were not due to display configuration but suggest rather that a perceptual bias is evident.

In summary, within the context of the tasks used these experiments:

- Flashing had no effect on detection speed.
- A simple bar was detected faster than a border alert.
- A perceptual bias existed, seen as slowed responses to alerts appearing on the left display, regardless of the task associated with that display.
- For best detection, alerts should appear on all displays rather than any single display.

Detecting alerts in high workload environments is subject to a dependency on context and task. For example, adding status information or a level of hierarchy to the alert could conceivably impact performance and change the results significantly. Consequently any generalization of these results to other complex command and control environments needs to be done carefully. In general the findings do point to the need to verify that the kind of alert used and the way it is presented is fitting with the environment and the tasks operators are performing.

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²The eye-tracker system was used in this study as a means of gaining familiarity with using the system and collecting data. Consequently, beyond the eye-tracking-cursor correlation, the data are not reported (but see Greenberg & Crebolder (2011) for more details on the eye-tracking system and its use in this study).

References

- Bartram, L., Ware, C., & Calvert, T. (2003). Moticons: detection, distraction and task. *International Journal of Human-Computer Studies*, 58, 515–545, doi: [10.1016/S1071-5819\(03\)00021-1](https://doi.org/10.1016/S1071-5819(03)00021-1).
- Bonnet, C. (1980). Thresholds of motion perception. In A. H. Wertheim, W. A. Wagenaar, & H. W. Leibowitz (Eds), *Tutorials on motion perception*. New York: Plenum.
- Carrasco, M., McElree, B., Denisova, K., & Giordano, A. M. (2003). Speed of visual processing increases with eccentricity. *Nature Neuroscience*, 6, 669–670, doi: [10.1038/nn1079](https://doi.org/10.1038/nn1079).
- Coren, S., Ware, L. M., & Enns, J. T. (Eds.). (1994). *Sensation and Perception*. Orlando, Florida: Harcourt Brace & Company.
- Crebolder, J. M., Salmon, J., & Klein, R. 2010. The cost of location switching during visual alerting: effects of experience and age. *Proceedings of the 54th Human Factors and Ergonomics Society Annual Meeting*, San Antonio, CA: Human Factors and Ergonomics Society.
- Crebolder, J. M., & Beardsall, J. (2009). Alerting in complex command and control environments. *Proceedings of the 53rd Human Factors and Ergonomics Society Annual Meeting*, San Antonio, CA: Human Factors and Ergonomics Society.
- Engel, F. L. (1971). Visual conspicuity, directed attention and retinal locus. *Vision Research*, 11, 563–575, doi: [10.1016/0042-6989\(71\)90077-0](https://doi.org/10.1016/0042-6989(71)90077-0).
- Eriksen, C. W. & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics*, 25, 319–327.
- Eriksen, C. W. & St James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics*, 40, 225–240, doi: [10.3758/BF03211502](https://doi.org/10.3758/BF03211502).
- Faraday, P. & Sutcliffe, A. (1997). Designing effective multimedia presentations. *Proceedings of SIGCHI '97 Conference on Human Factors Computing Systems*. New York, NY: Association of Computing Machinery. pp.272–279.
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary convert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 1030–1044, doi: [10.1037/0096-1523.18.4.1030](https://doi.org/10.1037/0096-1523.18.4.1030).
- Fuller, S. & Carrasco, M. (2006). Exogenous attention and color perception: performance and appearance of saturation and hue. *Vision Research*, 46, 4032–4047, doi: [10.1016/j.visres.2006.07.014](https://doi.org/10.1016/j.visres.2006.07.014).
- Greenberg, S. & Crebolder, J. M., (2011). *Visual alerting and display configuration for sensor operators*. Defence Research and Development Canada, DRDC Atlantic TM 2011–065.
- Helmholtz, H. von (1925). *Treatise on physiological optics. Physiological Optics, Vol. III*. Washington DC: Optical Society of America.
- Hillstrom, A. P. & Yantis, S. (1994). Visual motion and attentional capture. *Perception & Psychophysics*, 55, 399–411, doi: [10.3758/BF03205298](https://doi.org/10.3758/BF03205298).
- Jonides, J. (1980). Towards a model of the mind's eye movement. *Canadian Journal of Psychology*, 34, 103–112.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds), *Attention and Performance XI*. Hillsdale, NJ: Lawrence Erlbaum, pp.187–283.
- LaBerge, D. (1983). Spatial extent of attention to letters and words. *Journal of experimental psychology: Human perception and performance*, 9(3), 371–379, doi: [10.1037/0096-1523.9.3.371](https://doi.org/10.1037/0096-1523.9.3.371).
- Müller, H. J. & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interpretation. *Journal of experimental psychology: Human perception and performance*, 15(2), 315–330, doi: [10.1037/0096-1523.15.2.315](https://doi.org/10.1037/0096-1523.15.2.315).
- Peterson, H. E. & Dugas, D. J. (1972). The relative importance on contrast and motion in visual detection. *Human Factors*, 14, 207–216.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32, 3–25.
- Pylshyn, Z., Burkell, J., Fisher, B., Sears, C., Schmidt, W., and Trick, L. (1994). Multiple parallel access in visual attention. *Canadian Journal of Experimental Psychology*, 48(2), 260–283, doi: [10.1037/1196-1961.48.2.260](https://doi.org/10.1037/1196-1961.48.2.260).
- Roberts, S. & Foster-Hunt, T. (2008). *Evaluation of visual alerts in the maritime domain: behavioural research study*. Defence Research and Development Canada (DRDC) Atlantic Contract Report, CR 2010–057.
- Salmon, J. P. & Klein, R. M. (2010). *Investigating visual alerting in the maritime domain: Report on 3 experiments, with supporting documentation*. Defence Research and Development Canada (DRDC) Atlantic Contract Report, CR 2010–058.
- Sarter, N. B. & Woods, D. (1995). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. *Human factors*, 37, 5–19, doi: [10.1518/001872095779049516](https://doi.org/10.1518/001872095779049516).
- Serences, J. T. & Boynton, G. M. (2007). Feature-based attentional modulations in the absence of direct visual stimulation. *Neuron*, 55, 301–312, doi: [10.1016/j.neuron.2007.06.015](https://doi.org/10.1016/j.neuron.2007.06.015).
- Sorkin, R. D. (1988). Why are people turning off alarms? *Journal of the Acoustical Society of America*, 84, 1107–1108, doi: [10.1121/1.397232](https://doi.org/10.1121/1.397232).
- Treue, S. & Martinez-Trujillo, J. C. (2007). Attending to features inside and outside the spotlight of attention. *Neuron*, 55, 174–176, doi: [10.1016/j.neuron.2007.07.005](https://doi.org/10.1016/j.neuron.2007.07.005).
- Ware, C., Bonner, J., Knight, W., & Cater, R. (1992). Moving icons as a human interrupt. *International Journal of Human-Computer Interaction*, 4, 341–348, doi: [10.1080/10447319209526047](https://doi.org/10.1080/10447319209526047).
- Wickens, C. D. (1996). Designing for stress. In E. Salas & J. E. Driskell (Eds). *Stress and Human Performance*. Mahwah, NJ: Lawrence Erlbaum.
- Wickens, C. D. (2005). Attentional tunnelling and task management (Tech. Rep. AHFD-05-23/NASA). Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.
- Woods, D. (1995). The alarm problem and directed attention in dynamic fault management. *Ergonomics*, 38, 2371–2393, doi: [10.1080/00140139508925274](https://doi.org/10.1080/00140139508925274).
- Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention: voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 121–134, doi: [10.1037/0096-1523.16.1.121](https://doi.org/10.1037/0096-1523.16.1.121).