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DEFENCE R&D DÉFENSE

Investigating Visual Alerting in the Maritime Domain

Report on 3 experiments, with supporting documentation

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Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2010-058
April 2010

Canada

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Contract Report
DRDC Atlantic CR 2010-058
April 2010

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

Aspects of visual alerts were explored to determine what type of visual alerts best captured attention, as measured by reaction time (RT) to the alerts. In part 1, flash rate of alerts was explored to determine the most effective detection. The results suggested that flashing at any of the flash rates was no better than a non-flashing alert. In part 2, the cost of moving an alert from one location to another was investigated. The results showed an alert location-switching cost (slower RTs after switch) that was only present for inexperienced and older participants. In part 3, the relationship between eye-location and cursor location was explored. The goal of this research was to determine if cursor-location was a good proxy for eye-location during a multi-display task that had been used in previous experiments. The results suggested that, for this task, the cursor was in fact an excellent proxy for eye-location with a very high display correspondence between eye and cursor location. Both eye and cursor were found to move from one display to another at the same time. The results have implications for future visual alerting research and the design of automated alerting.

Résumé

Nous avons exploré certains aspects des alertes visuelles pour déterminer celles qui attiraient le mieux l'attention, selon la mesure du temps de réaction (TR) aux alertes. Dans la partie 1, le rythme de clignotement des alertes a été examiné afin de déterminer la détection la plus efficace. Les résultats ont semblé indiquer qu'aucun des rythmes de clignotement n'était meilleur qu'une alerte non clignotante. Dans la partie 2, nous avons étudié le coût du déplacement d'une alerte d'un endroit à un autre. Les résultats ont révélé qu'un coût associé au changement d'emplacement d'une alerte (TR plus longs après le changement) n'était présent que dans le cas des participants inexpérimentés et plus âgés. Dans la partie 3, nous avons examiné la relation entre la direction du regard et la position du curseur. Cette recherche avait pour but de déterminer si la position du curseur était un bon indicateur de la direction du regard au cours d'une tâche sur plusieurs écrans qui avait servi lors d'expériences précédentes. Les résultats ont laissé supposer que, pour cette tâche, le curseur était en fait un excellent indicateur de la direction du regard et que la correspondance entre la direction du regard et la position du curseur était très élevée en ce qui concerne les écrans. Nous avons constaté que les yeux et le curseur allaient d'un écran à l'autre en même temps. Les résultats ont des implications pour les futures recherches sur les alertes visuelles et la conception d'alertes automatisées.

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Executive summary

Investigating Visual Alerting in the Maritime Domain: Report on 3 experiments, with supporting documentation

Joshua P. Salmon; Raymond M. Klein; DRDC Atlantic CR 2010-058; Defence R&D Canada – Atlantic; April 2010.

Background: In command and control centers, like the operations room of a Navy frigate, where workload is high and decisions critical, automated systems that can assist operators are a necessity. One such system would be an automated alerting system, implemented as a means of pointing operators to critical states or events in need of attention. The focus of the research reported here is primarily aimed at alerting operators in a frigate operations room using visual alerting. This research explored a number of questions pertaining to visual alerts, and it extends recent work examining the use of automated visual alerting. The report is divided into three Parts, each addressing different issues associated with alerts.

Results: In Part 1, flash rate was explored to determine whether there exists an optimal flashing rate for visual alerts appearing on personal desktop computer display screens, and whether responses to flashing alerts are faster than static alerts. No difference in reaction time was found as a function of flash on-off rate, nor whether they were flashing or static, although reaction time was generally slower for alert detection during a dual task as compared to a single task. In Part 2, the cost of switching the location of the alert was investigated during a multi-display task. This experiment was based on the expectation that certain kinds of visual information that appear in the periphery can be cognitively packaged with central vision information if the information is task relevant and if the location is consistent. Thus, it was anticipated that a cost in response time to alerts would be noted when the location of the alert was changed. This switching-cost was not found for all participants, but did appear to be present for older participants, and those with less experience with the task. In Part 3, the relationship between eye-location and cursor-location was tested. The goal of this research was to determine the extent that cursor location predicted eye-location during a multi-display task. The results indicated a strong relationship between eye and cursor location suggesting the cursor is a good proxy of eye-location and more generally attention.

Significance: The intended application of this research is toward the Halifax Class frigate operations room where a visual alerting system could support the current auditory alerting system. The results of these three studies can be used to inform the design of automated alerting systems in command and control operations centers. Failure to identify an optimal flashing rate suggests that, for the task used in this work, flashing rate is not important, and indeed, this result supports previous work indicating a static, non-flashing alert is just as effective. Moving the location of the alert produced variable cost in alert detection depending on age and experience in visual tasks. Thus, these factors should be taken into account in the design of visual alerting interfaces.

Future plans: Future work will continue to investigate attributes of visual alerting with the objective of finding the most appropriate alert types for complex multi-display environments.

Sommaire

Investigating Visual Alerting in the Maritime Domain: Report on 3 experiments, with supporting documentation

Joshua P. Salmon; Raymond M. Klein; DRDC Atlantic CR 2010-058; R & D pour la défence Canada – Atlantic; Avril 2010.

Contexte : Dans les centres de commandement et de contrôle, comme la salle des opérations d'une frégate de la Marine, où la charge de travail est lourde et les décisions cruciales, des systèmes automatisés pouvant aider les opérateurs sont une nécessité. Un tel système serait un système d'alerte automatisé mis en place pour signaler aux opérateurs les états ou événements critiques qui requièrent leur attention. La recherche dont il est question ici vise principalement à alerter visuellement les opérateurs dans la salle des opérations d'une frégate. Elle a permis d'explorer un certain nombre de questions liées aux alertes visuelles et s'inscrit dans le prolongement de récents travaux portant sur l'utilisation d'alertes visuelles automatisées. Le rapport est divisé en trois parties, chacune traitant de différentes questions associées aux alertes.

Résultats : Dans la partie 1, le rythme de clignotement a été examiné afin de déterminer s'il existe un rythme optimal pour les alertes visuelles qui apparaissent sur les écrans des ordinateurs personnels de bureau, et si les réactions aux alertes clignotantes sont plus rapides que dans le cas des alertes fixes. Nous n'avons décelé aucune différence dans le temps de réaction en fonction du rythme de clignotement, ni aucune différence dans le fait qu'une alerte soit clignotante ou fixe; toutefois, le temps de réaction était généralement plus long pour la détection des alertes durant une double tâche que durant une tâche unique. Dans la partie 2, nous avons étudié le coût du changement d'emplacement de l'alerte pendant une tâche exécutée sur plusieurs écrans. Cette expérience reposait sur l'attente selon laquelle certains types d'information visuelle qui apparaissent en périphérie peuvent être regroupés de manière cognitive avec l'information de la vision centrale si l'information se rapporte à la tâche et si l'emplacement demeure constant. Ainsi, nous nous attendions à noter un coût au niveau du temps de réaction aux alertes lors du changement d'emplacement de l'alerte. Or, ce coût n'a pas été constaté pour tous les participants, mais il a semblé présent dans le cas des participants plus âgés et de ceux qui possédaient une moins grande expérience de la tâche. Dans la partie 3, nous avons examiné la relation entre la direction du regard et la position du curseur. Cette recherche visait à déterminer dans quelle mesure la position du curseur prédisait la direction du regard durant une tâche exécutée sur plusieurs écrans. Les résultats ont indiqué une solide relation entre la direction du regard et la position du curseur, laissant supposer que le curseur est un bon indicateur de la direction du regard et, plus généralement, de l'attention.

Importance : L'intention consiste à appliquer cette recherche à la salle des opérations de la frégate de la classe HALIFAX, où un système d'alerte visuelle pourrait appuyer le système actuel d'alerte sonore. Les résultats de ces trois études peuvent servir à guider la conception de systèmes d'alerte automatisés dans les centres de commandement et de contrôle. L'incapacité à déterminer un rythme de clignotement optimal donne à penser que, pour la tâche utilisée dans le cadre de ces recherches, le rythme de clignotement n'est pas important. En effet, ce résultat corrobore des études antérieures indiquant qu'une alerte non clignotante, c'est-à-dire fixe, est tout aussi efficace. Le fait de déplacer l'emplacement de l'alerte a engendré un coût variable au niveau de la

détection des alertes, selon l’âge et l’expérience des personnes exécutant des tâches visuelles. Par conséquent, ces facteurs devraient être pris en compte dans la conception d’interfaces d’alerte visuelle.

Projets futurs : Les travaux futurs continueront de porter sur l’étude des caractéristiques des alertes visuelles et viseront à trouver les types d’alerte les plus appropriés aux environnements complexes à écrans multiples.

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Acknowledgements

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1 Introduction

This research was completed under a contract between Defence Research and Development Canada (DRDC) Atlantic and Dalhousie University, Halifax, Nova Scotia. The write-up is divided into three parts based on the slightly different research questions each part was aimed at addressing.

Part 1 investigated flashing alerts and flash rates. Specifically it sought to determine what flash rate (if any) is best for detection, and whether or not flashing alerts are more salient (can be detected more quickly) than static alerts. This research also explored the relationship between % of time alert-on versus % of time alert-off, and explored the level at which participants perceive flashing alerts to be on 50% of the time and off 50% of the time. This research was conducted at Dalhousie in the Psychology Department (Dr. Klein's lab).

Part 2 investigated the cost associated with alert location switching during a multi-display task. Specifically participants completed 30 minutes of a task with visual alerts in one location followed by another 30 minutes with the alert switched to a new location. The goal was to examine theories of spatial attention by determining the cost (in terms of slowed reaction time) associated with having to respond to visual alerts in a new location. In addition, the amount of time to recover (reaction time) after a switch was of interest. This research was conducted at DRDC-Atlantic.

Part 3 investigated eye-tracking and cursor location during a multi-display task. Specifically this research sought to investigate the assumption that during this task the participants' eyes are on the same screen/display as their cursor. This experiment also involved changing the standard arrangement of the displays used in this task to ensure that effects of screen location and screen task could be effectively dissociated. This experiment also explored a number of other research questions including whether or not participants move their eyes to a new display before the cursor, and whether the relationship between cursor and eye-location changed over time. This research was conducted at Dalhousie in the Dalplex (Kinesiology Department).

The overall goal of this project was to investigate attributes of visual alerting in order to determine what types of visual alerts are most effective at capturing attention in the context of multi-display tasks. The overall intended application of this research is toward the Halifax Class frigate operations room where a visual alerting system could support the current auditory alerting system. Each part (1-3) is written more-or-less as a self-contained article, with a final General Discussion section that references all aspects of this research.

For a detailed list of steps involved in the analyses, and explanation of the data files, please refer Annexes A and B.

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2 PART 1 – Flash Rate Research

Previous research at Defence Research and Development Canada (DRDC) (Roberts & Foster-Hunt, 2008; Roberts, 2008; Crebolder & Beardsall, 2009a; Crebolder & Beardsall, 2009b) has considered both flashing and static visual alerts with the expectation that a flashing alert would be more salient and better capture attention. However, these studies have failed to show a conclusive preference for flashing alerts over static alerts. One standard flash rate/period (3.5Hz, 300ms) was used in these paradigms and the objective of the current research was to explore whether different flash period would be more or less salient than the standard used in previous research.

This research involved two mini-experiments, the first of which (Experiment #1) was designed to examine the perceived on-off ratio (or duty cycle) of an alert – for example whether or not participants perceived a 400 ms period visual alert shown for 200 ms on and 200 ms off to be on-off 50% of the time (a 50/50 duty cycle). Research conducted by Dr. Klein, and visual persistence literature suggested that in order for a flashing alarm to be considered to have a 50/50 duty cycle, the alarm would really need to be off more time than it was on (Klein, 1983; Sperling, 1960). Thus, Experiment #1 explored the psychophysics of this relationship by allowing participants to adjust the time-on/time-off rates until they perceived alerts to 50/50 duty cycle for each period. The second experiment (Experiment #2) then used these same flash periods in a reaction time (RT) experiment, with both single and dual-task, to determine if alerts at some flash rates were responded to more quickly than others.

2.1 Experiment #1 – Flash Adjusting Experiment

As stated above, the goal of this research was to determine at what point participants perceived flashing alerts of different periods to have a 50/50 duty cycle. For each “trial” participants were asked to adjust the relative amount of time-on, time-off time until the flashing appeared to be on 50% of the time. The ultimate goal was to determine if perceived 50/50 duty cycle for alerts were responded to more quickly than actual 50/50 duty cycle (a question that was explored in Experiment #2).

2.1.1 Method

2.1.1.1 Participants

Seven adult participants participated (3 males). All participants were English speaking with normal or corrected-to-normal vision. All participants were compensated for their time.

2.1.1.2 Stimuli

Red and white alerts (10 cm long and 2 cm tall) were shown flashing with different periods. Five periods were chosen: 100 ms, 200 ms, 300 ms, 400 ms, and 600 ms. Alerts were shown above or below a central fixation at one of two distances of 7.3 or 14.6 visual angles. Alerts were also shown in one of two colors, red (RGB: 255, 0, 0), and white (RGB: 255, 255, 255). The central fixation was a grey circle (RGB: 150, 150, 150) that subtended a visual angle of 0.6 degrees of visual angle (0.5 cm). In summary, there were four variables of interest (1) period (with 5 levels), (2) location (2 levels-top or bottom), (3) distance (close, near), (4) color (white, red). These variables were shown in a mixed design (not blocked).

The experiment was run on an iMac (24" LCD screen) running OSX on 2 GHz Intel Core 2 Duo processor. Graphics were controlled by a NVIDIA GeForce 9400 card with 256 MB of VRAM at a resolution of 1920x1200, and refresh rate of 16.67 ms (60 Hz). Python v2.6 with pygame was used to draw, and present the stimuli.

2.1.1.3 Procedure

Prior to each trial the starting duty cycle of an alert (percentage on to alert off time) was randomly chosen. For example, a 300 ms (period) alert could be chosen to be on for 50ms, and off for 250 ms. Participants were asked to adjust the percentage of alert on by pressing up (more on) or down (less on) on a keyboard. Participants were instructed to adjust the rates until they perceived the alert to be on for 50% of the time and off for 50% of the time (50/50 duty cycle). Once they were satisfied with the percentage on/ percentage off they would advance to the next trial by pressing the CTRL-key. Participants were also asked to wait approximately 3 seconds before pressing the CTRL-key (to ensure confidence in their decision). Participants were asked to maintain fixation during rating. Participants sat an unrestrained distance of approximately 45 cm from the screen.

To become familiar with the task participants were given 8 practice trials with 400, and 600 ms periods. For the full experiment, each alert was shown 4 times, for a total of 160 trials. The entire experiment lasted between 30 minutes to 1 hour (depending on how quickly perceptual judgments were made).

2.1.2 Results

A 5x2x2x2 (period x color x location x distance) mixed-effects analysis revealed a main effect of period, F (4) = 679.73. With increased period, more alert-on was required to perceive a 50/50 duty cycle. No other main effects or interactions were significant. This suggested that the only variable affecting the perception of 50% on, 50% off was the period. No other variables (color, location, or distance from fixation) had an effect.

Notably, for all participants, less time on was required to perceive 50/50 duty cycle (see Figure 1).

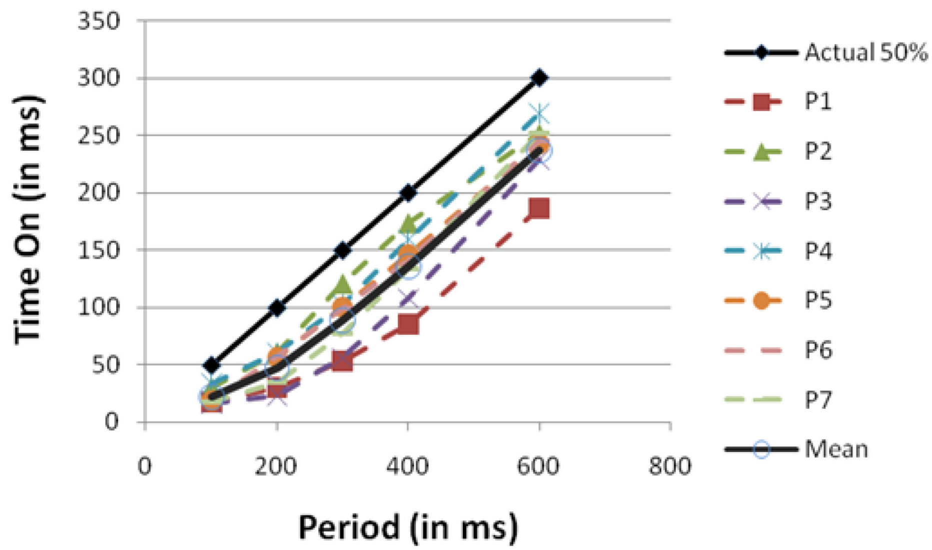

Figure 1: Periods (100, 200, 300, 400, and 600) by the time participants reported the alert needed to be on (to perceive a 50/50 duty cycle). The black solid line shows the ACTUAL 50/50 point for each period. Note, all participants' values were below the actual 50/50 line.

2.1.3 Discussion

These results show quite clearly that in order to perceive a 50/50 duty cycle participants actually need the alert to be on for less time than it is off. Note, this pattern was shown in all participants, although the amount of needed on-off did vary by participant. These results were then used to explore reaction time differences to flashing alerts in Experiment #2.

2.2 Experiment #2 – Flash Reaction Time (RT) Experiment

The goal of Experiment #2 was to use the periods (flash rates) and perceived 50/50 duty cycle from Experiment #1 to explore what types of alerts are responded to fastest. This was explored in both a single-task (respond to alerts only) and dual-task (respond to alerts while concurrently doing a mouse-tracking task) condition. Two more locations were included in this design – left and right (in addition to top and bottom). Whether or not an experimenter was present during testing was also explored as a variable. This variable was included to determine whether or not having an experimenter present increased arousal and motivation of participants (in the form of faster responses to alerts). The general goal of this research was to determine what types of alerts were responded to fastest.

2.2.1 Method

2.2.1.1 Participants

Twelve adult participants participated (3 males). All participants had normal or corrected-to-normal vision. Only one participant reported a visual anomaly (a slow conducting optic tract in one eye), although the results of this participant did not present differently than those of the other participants. Participants were compensated for their time.

2.2.1.2 Stimuli

Red and white alerts were shown at one of 8 locations on the screen. There were 4 near fixation locations (approx. 7.3 visual angles from fixation), and 4 far locations (approx. 14.6 visual angles from fixation). Vertical alerts (those above and below fixation) were drawn 10 cm long and 2 cm tall. Horizontal alerts (those to the right and left of fixation) were drawn 10 cm tall and 2 cm wide (12.5 visual angles and 2.5 visual angles, respectively). Alerts were shown above or below a central fixation at one of two distances of 7.3 or 14.6 visual angles. Alerts were also shown in one of two colors, red (RGB: 255, 0, 0), and white (RGB: 255, 255, 255). Central fixation was a grey (RGB: 150, 150, 150) circle that subtended 0.6 visual angles. Fixation subtended a visual angle of 0.6 degrees.

The same flash-rate periods from Experiment #1 were used (100, 200, 300, 400, and 600). Each period was set so that the percentage of the time on corresponded to average perceived values from Experiment #1. Specifically, the time on period (in refresh rates) were chosen to be: 1, 3, 5, 8, & 14, respectively. This corresponded with alert on times (in ms) of: 16.67, 50, 83.33, 133.33, & 233.33. Two additional periods were used. The first was a 300 ms period with 150 ms alert-on time (corresponding to the REAL 50% mark). The second was a static alert, with no flash. These were labelled as 300r (real 50%) and 600s (static, no flash) in the output files. All other alerts were tagged with a "p" for perceived 50/50 duty cycle. This resulted in 7 alerts with the labels: 100p, 200p, 300p, 400p, 600p, 300r, and 600s.

During a dual task block, participants controlled a hollow black, white-edged, diamond cursor, with a transparent centre that subtended a visual angle of approximately 0.6 visual degrees (Figure 2).

In summary, there were five variables of interest (1) period (with 7 levels), (2) location (with 4 levels – top, bottom, right, left), (3) distance (close, near), and (4) color of alert (white, red), (5) task (single or dual).

Experiment #2, like Experiment #1, was run on an iMac (24" LCD screen) running OSX on 2 GHz Intel Core 2 Duo processor. Graphics were controlled by a NVIDIA GeForce 9400 card with 256 MB of VRAM at a resolution of 1920x1200, and refresh rate of 16.67 ms (60 Hz). Python v2.6 with pygame was used to draw, and present the stimuli.

2.2.1.3 Procedure

Each participant participated in two blocks of trials: single task block and dual task block. During the single task block participants were instructed to respond to alerts (with a space bar press) as quickly as possible while keeping eyes on fixation. Order of alert presentation was randomized. Participants sat an unrestrained distance of approximately 45 cm from the screen. The alert remained on the screen until participants responded. Timing of alert presentation was staggered using a Gaussian noise + 1.5 seconds to help eliminate anticipation responses (that is, there was a minimum ITI of 1.5 s). Anticipation alerts (false positives) were recorded / flagged with a 500 ms grace period. That is, only responses that occurred 500 ms after trial onset and before appearance of an alert were counted as false positives. In false positive trials, alerts were still shown until response, and reaction time of response (to alert) was still recorded.

For the dual task condition participants used the mouse to keep the diamond-shaped cursor in the middle of the fixation circle (Figure 2). Every refresh random noise was added to the location of the cursor so that the cursor did not remain stationary. This task had the effect of providing a continuous distractor of a consistent difficulty level. It also encouraged participants to maintain focus around the fixation mark. In the dual task condition, participants continued to respond to the alerts by pressing space bar with their other hand. Vertical and horizontal cursor distance from the fixation was recorded at each refresh and saved for later analysis. Participants were instructed to continue responding to alerts as quickly as possible while performing the dual-task.

All participants performed the mouse-task with the hand that they normally used to control a mouse (for all but one participant, this was the right-hand). That is, most participants responded to alerts with their non-dominant (left) hand, with the dominant (right) hand being used for the mouse task. For one left-handed participant, their non-dominant (right) hand was used to control the mouse, and they responded to alerts with their dominant (left) hand (this was because they usually use the mouse in their non-dominant hand). Participants used the same hand to respond to alerts in both the single and dual task conditions.

Order of task (single vs. dual) was counter-balanced across participants. Each participant completed a practice block prior to each main block. The main blocks lasted approximately 16-20 minutes, and consisted of 336 trials. The entire experiment lasted approximately 50 minutes.

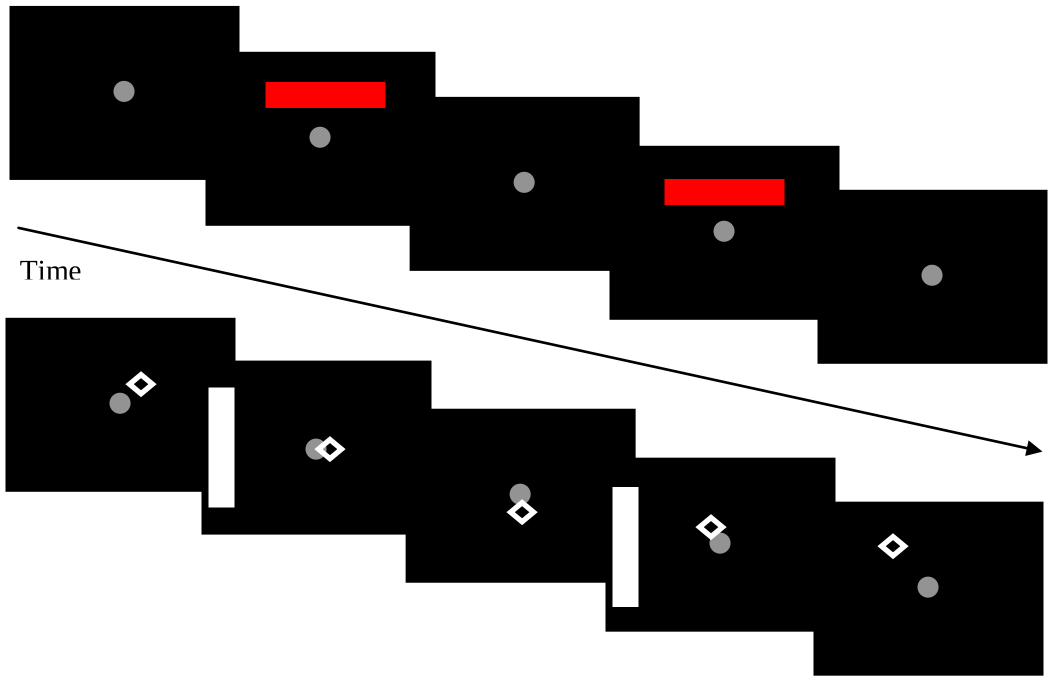

Figure 2: Examples of the display through time. Top Panel show the single task (Experiment#2 single task or Experiment #1) with a single fixation and a flashing red alert near the fixation (top). Bottom Panel shows dual task with the cursor (in the shape of a diamond) being pushed around the screen while the participant attempts to maintain the cursor at fixation (Experiment #2, dual-task). Alert shown in Bottom Panel is a white flashing far alert on the left side of screen.

2.2.2 Results

2.2.2.1 Flash Rate: 100p, 200p, 300p, 400p, 600p

The results from an ANOVA (5 levels of period) suggested no difference between alerts of different flash rates/periods, $F(4,7) = 0.82$, $p = .509$. The means RTs for all flash rates were between 375 ms and 379 ms with a $SD = 73$ ms.

2.2.2.2 Perceived 50/50 (300p) versus Actual 50/50 (300r)

The results from a second ANOVA (2 levels of period) suggested no difference between an alert shown at the perceived 50/50 duty cycle versus those shown at the actual 50/50 duty cycle, $F(1,10) = 0.88$, $p = .347$. With a perceived RT = 379 ms, and an actual-rate RT = 377 ms, SD = 72 ms.

2.2.2.3 Static Alert (600s) versus Flashing Alert (600p)

Finally, there was no difference between static and flashing alerts in this experiment, $F(1,10) = 0.17$, $p = .683$. With a mean RT of 376 ms for flashing alerts and RT=374 ms for static alerts, SD = 70 ms.

2.2.2.4 Exploratory Analyses: Color, Location, Distance, Task & Experimenter

The other variables (Color, Location, Distance, Task, and Experimenter) were tested in a 2 x4x2x2x2 ANOVA. The largest main effect was for Task, $F(1) = 917.11$, $p < .001$, with participants significantly slower at responding to alerts during the dual task condition, $M = 353$ ms compared to $M = 400$ ms. There was also a main effect of location, $F(3) = 6.82$, $p < .001$, with top and bottom bar alert RTs faster than left and right alerts, *M*'s= 372, 373 ms compared *M*'s= 379, 382 ms, respectively.

Only one interaction was significant (at $\alpha = .05$) and that was the interaction between task and distance, $F(1) = 4.51$, $p < .05$. Specifically these results showed a distance effect during the single task (*M*= 356 ms for Far alerts, and *M*=351 ms for Near alerts) but not during the dual task (*M*= 399 ms for Far alerts, and *M*=400 ms for Near alerts). In other words, distance of the alerts had a bigger effect when participants did not have the mouse dual-task to attend to.

2.2.2.5 Mouse Error Analysis

Mouse error lag after onset of each alert was examined for 1000 ms post-alert onset. In other words, the distance of the cursor to the fixation (mouse error) was examining exactly at the time an alert appeared on screen, and 1000 ms afterwards. It was hypothesized that tracking error would increase or decrease after onset of alerts. The results indicated no systematic relationship between performance (error) on the mouse-tracking (secondary task) as a function of when the alerts appeared during the primary task.

2.2.3 Discussion

The results of this experiment were consistent with previous studies conducted at DRDC (Roberts & Foster-Hunt, 2008; Roberts, 2008; Crebolder & Beardsall, 2009a; Crebolder & Beardsall, 2009b), showing no preference for flashing alerts compared to static alerts. In addition, there were no flash-rates/periods that appeared to capture attention better than others, and a perceived 50/50 duty cycle appeared to be no better than alerts flashing at a regular 50/50 duty cycle. These results suggest that a flashing alert is no better or no worse than a static alert during these tasks.

The additional analyses also suggested that alerts shown at the top and bottom of the screen might be better at attracting attention than alerts shown at the side, and distance of the alerts may have an effect (although the effect appears to minimal). Also, colour of the alert does not seem to matter (at least white does not appear to be any better than red or vice versa), and presence of an experimenter does not appear to affect performance on these tasks. By far, the biggest predictor of RTs in this experiment was whether or not participants were performing the dual-task. All participants were slower to respond to alert RTs when they were performing a concurrent mouse-task.

2.2.4 Recommendations

These results suggest flashing alerts are no better or worse than static alerts. Therefore, it does not appear to matter what types of alerts are used. If a flashing alert is used, the flash rate does not appear to matter. Additionally, alerts on the top and bottom of the display appear to be detected a little faster than those on the sides of the screen.

3 PART 2 – Location Switch Experiment

This study was conducted at DRDC Atlantic as a follow on to previous work (Roberts & Foster-Hunt, 2008; Roberts, 2008; Crebolder & Beardsall, 2009a; Crebolder & Beardsall, 2009b). Existing software programming using EPrime Psychology Software was used as the basis for the experiment with the modifications outlined in Annex A.

3.1 Attentional Limitations in Visual Alerting

3.1.1 Abstract

A study was conducted to investigate the switching cost of changing the location of a visual alert while participants performed a high intensity, multi-display task. Based on the proposition that the spatial window of attention can be extended to include relevant, though non-task-related information, it was hypothesized that response times to the alert would increase immediately following a change in location and then recover. Generally, results showed that this was not the case, but instead response time increased several minutes after the change in location and then recovered. Further investigation revealed that age and expertise (defined as experience with tasks involving multiple displays or video gaming), were strong moderators of the effect of slowed response after switching. Older, less experienced, adults showed an immediate and significant cost that was not shown at all, or was shown later, by the younger, more experienced adults. The results suggest that experience with a specific task, or more general video game experience, can guard against the cost associated with moving an alert to a new, relatively untrained location.

3.1.2 Introduction

In demanding environments, where workload is high and outcome critical, operators may rely on information and data feeds from a number of different sources to aid in making decisions quickly and accurately. Many command and control centers, like the operations room of a Navy frigate, are high workload, and complex environments, where multi-tasking while attending to several information displays is all too familiar. In this kind of intense setting, automated systems that can assist operators are a necessity. One such system would be an automated alerting system, implemented as a means of pointing operators to critical states or events in need of attention.

One of the initial challenges facing the design of such an alerting system is determining the mode of delivery, since typically both visual and auditory modalities are already overburdened in fast-paced environments. The focus of the research reported here is primarily aimed at a frigate operations room and, due to the current nature of that environment, the visual system has been selected as the most appropriate avenue for further investigation.

Placing alerts in the display periphery, to reduce the likelihood that the stimulus form will obstruct or interfere with task-related information, has been identified as a key criterion. However, visual acuity declines with retinal eccentricity making information in the periphery more difficult to detect (Engel, 1971). Furthermore, since an operator's task often necessitates a high level of concentration, focused on a select area of the display, it is not unusual that important information is missed if it appears outside or in the periphery of the area of focal attention. Otherwise known as attentional tunnelling, or attentional spotlight (Wickens, 2005), this problem is compounded as display size increases, or when multiple displays are used.

In general, designing an effective visual alert must ensure adequate salience so a stimulus is effectively noticed by operators who are otherwise engaged, while being subdued in the sense that its presence is not intrusive or visually distracting. In that vein, stimulus form, as an aspect related to attentional salience, has been examined in previous studies (Roberts & Foster-Hunt, 2008; Roberts, 2008; Crebolder & Beardsall, 2009a; Crebolder & Beardsall, 2009b).

One might assume that the larger the surface area a stimulus occupies, the more likely it is to be successful in capturing attention. Somewhat surprisingly then, previous research has consistently shown that a relatively small stimulus, a short bar (10 centimetres (cm) x 2 cm) was detected faster than a larger one, a border, the same width as the bar, that covered the entire surrounding perimeter of the display (Roberts & Foster-Hunt, 2008; Roberts, 2008; Crebolder & Beardsall, 2009a; Crebolder & Beardsall, 2009b).

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 called 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, one might expect a cost in detection rate if the location of the stimulus containing the information changes. This study was designed to examine that proposition, using a short bar as an alerting stimulus presented while individuals performed a high-intensity task.

3.1.3 Method

3.1.3.1 Materials

A multi-display workstation consisting of three 21" LCD displays (Samsung SyncMaster 214T) was used to present the task, which was written using E-prime Psychology software. The workstation and task were designed to emulate a high intensity workload environment, such as the one a naval operations room operator might be exposed to. Participants were required to classify and report targets using the three displays.

Figure 3: Workstation, showing the red alert in the bottom location.

Figure 3 shows the workstation. The centre display was a tactical display that depicted the participant's ownship in the centre, and incoming ships, represented as triangles, moving in incremental steps toward the ownship. The left display was a status display that showed information pertaining to selected ships (selected by mouse-over) that could be used to classify ships as ‘hostile’ or ‘neutral’. The right display was a reporting display where participants reported ‘hostile’ ships by typing one letter string (‘asd’) and ‘neutral’ ship with another letter string (‘qwe’).

Red alerts, 10 cm long and 2 cm wide, were displayed periodically (approx. 5.33 alerts/min, which equalled 16 alerts per block) on all three displays simultaneously. Alerts appeared centered at either the top or bottom of the displays. Duration of the alerts was 4 seconds, or until a spacebar response was made.

3.1.3.2 Participants

Seventeen male and 7 female volunteers participated in this study. Participants ranged in age from 20 to 60 (with a mean age of 42). All volunteers reported normal, or corrected to normal vision; 2 were left-handed, 1 ambidextrous. The study took about 90 minutes to complete and participants were reimbursed following DRDC guidelines (Keefe, 2010).

3.1.3.3 Procedure

Each volunteer participated in three 3-minute practice blocks, and twenty 3-minute experimental blocks. Participants were instructed that their primary task was to respond to the red alerts (with a spacebar press) as quickly as possible. Their secondary task was to identify “vessels” on the tactical display by using the information that appeared on the status display when a vessel was selected. Correctly identified vessels were removed from the display. Motivation for the secondary task was influenced through the penalty of showing an image of an exploding ownship on the screen whenever vessels came within the predetermined radius of the ownship. No reward or penalty was given for responses to the alerts, but the instructions did emphasize these responses were of primary importance.

Two alert locations were possible, top and bottom of the displays. For the first ten blocks all alerts were shown in the same location. For half the participants these alerts were shown on the top of the displays, and for the other half, the bottom of the displays. On the eleventh block alert location was switched (to top or bottom).

3.1.4 Results

3.1.4.1 Experience Measure

Because of the skill required to perform the high intensity, multi-display task used in this study, we believed that participants may have come into the experiment with varying levels of experience. Many of the participants had participated in previous versions of this experiment and/or another experiment that was taking place that involved playing a video game. Therefore, a measure of 'Experience' was calculated for each participant, as follows: i) a point was assigned if the individual had participated in the video game research study; ii) a point was assigned for participating in a previous alerting study, and 2 points if they reported participating in more than one alerting study; iii) a point was assigned for reporting some moderate experience with video games (in general), and 2 points if the participant reported being a heavy player of action video games. These points were then summed to create an 'Experience' score for each participant. The maximum score any participant received was three. In total, four experience groups were created with scores of 0, 1, 2, & 3, with associated N's equal to 6, 7, 5, and 6 respectively.

3.1.4.2 Overall Performance/Training

Over the 20 blocks, each of which was 3 minutes duration, participants showed improvements in both the primary (alerting) task and secondary (ship identification) task. By the final block, participants' average reaction time (RT) to alerts was 788 ms, down from 898 ms in block 1 [$F(1, 23) = 7.23$, $p < .05$]. Likewise, on the secondary task, participants identified an average of 39 ships by the final block compared to 30 ships in the first block [$F(1,23) = 87.591$, $p<.001$].

Not surprisingly, the biggest learning/training effects appeared in the first 10 blocks, with average RT speeding up 100 ms in the first 10 blocks [$F(1,23)=8.20$, $p<.01$], compared to only 25 ms improvement in the second 10 blocks [$F(1,23)=0.592$, $p=.449$].

3.1.4.3 Alert Location Switching

In block 11, where the alert location changed, the cost of this location switch was assessed by looking at the difference in average reaction time between block 10 and subsequent blocks. No significant switching cost was evident in block 11 [$F(1,23)=0.11$, $p=.749$]. There did appear to be a cost in the form of slower RTs a block later in block 12, although this difference did not reach significance [$F(1,23)=2.14$, $p=.157$].

However, since the trend in the data was toward significance it was deemed relevant to take into account the typical distribution of RT data (negative skew) and to conduct a mixed-effects regression analysis using log-transformed RT data and conservative outlier removal. The results from this more powerful analysis showed a difference between block 10 and block 12 that was significant [$t = 2.34$, $p < .05$], with a mean RT cost of 56 ms (M=872 ms in block 12 compared to M=816 ms in block 10). Using this approach, the difference between block 10 and block 11 remained not significant, with M=822 ms in block 11 compared to M=816 ms [$t = -0.09$, $p = .926$].

3.1.4.4 Experience

3.1.4.4.1 Overall Experience Effects

Using the Experience scores for each participant, a correlation between Experience and alert RT in the first experimental block [$r = -.465$, $p < .05$] was revealed, but not the last block [$r = -.266$, $p=.209$]. There was also a correlation between Experience and number of ships identified, with more Experienced participants identifying more ships correctly in both the first and final blocks [$r = .561$, $p < .01$ and $r = .516$, $p < .05$, respectively]. A repeated measures ANOVA on all blocks with Experience (between-subjects) revealed a significant main effect of Block [F (19,380) = 3.52, $p < .001$], but not Experience [F (1, 20) = 1.36, $p = .284$]. Although the interaction between Experience x Block (across all blocks) was significant [F (57,380) = 1.88, $p < .001$]. This suggested experience was moderating the block effect.

3.1.4.4.2 Experience by Alert Location Switching

The results appeared to indicate that participants with no previous task experience (experience level 0) showed the expected RT cost (slower RT) at block 11 & 12, see Figure 4. On the other hand, experienced participants seemed to show the opposite pattern with reduced/faster RT at block 11.

A repeated measures ANOVA, restricting the analysis to blocks 10 through 12, with Experience (between-subjects), revealed a significant interaction between Block x Experience [F (6, 40) = 3.64, $p < .01$]. The main effects of Block (10-12) and Experience were not significant [F (2, 40) = 2.04, $p = .143$, and F (3, 20) = 0.91, $p = .455$, respectively].

A follow-up analysis showed that for naïve (experience level 0) participants the cost at block 11 was marginally significant [F (1,5)=6.20, $p = .055$] and significant at block 12 [F (1,5) = 7.82, $p < .05$], whereas for very experienced participants (experience level 3), there was no significant cost of alert location switching at block 11 [F (1, 5) = 1.06, $p = .351$] or block 12 [F (1, 5) = 2.21, $p = .197$].

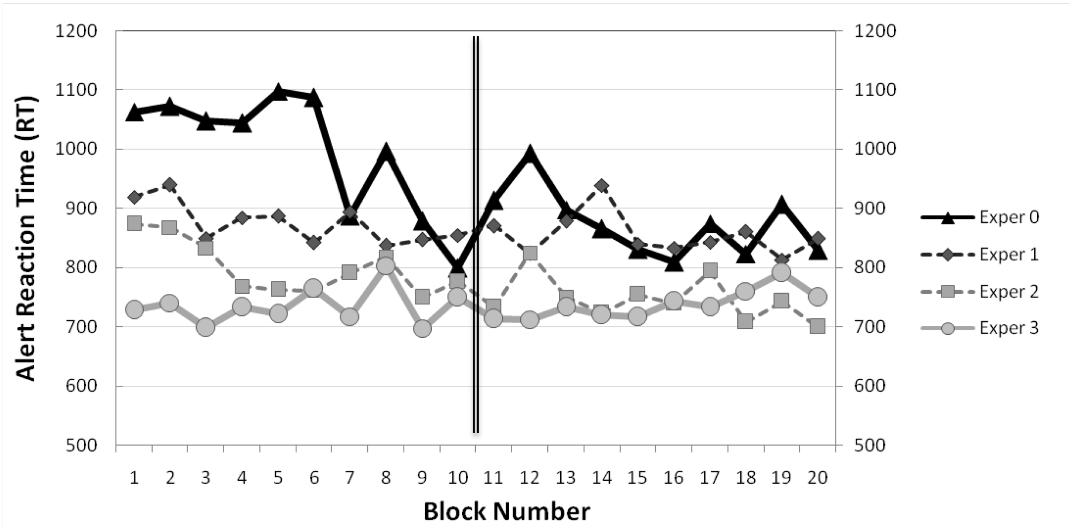

Figure 4: Effects of Experience on average RT to alerts. Experience level of 0 (Exper0) corresponded to participants who had never participated in any of the previous research experiments, and had no experience with video games. Note: Average (group) data shown in following Figure (Figure 5).

3.1.4.5 Age

3.1.4.5.1 Overall Age Effects

Due to the wide range in age of participants, an age analysis was conducted. Age was significantly correlated with RT in that older adults showed slower RT to alerts, with $r = .542$, $p < .01$ and $r = .483$, $p < .05$, for the first and last block respectively, see Figure 5. Age was also strongly correlated to the number of correct ship identifications, with older adults identifying fewer, with $r = -.769$, $p < .001$, and $r = -.769$, $p < .001$, for the first and last block respectively. A repeated measures ANOVA on all blocks with age group (between-subjects) revealed significant main effects of both Age and Block [F (1,22)=11.14, $p < .01$; F (19, 418)=3.04, $p < .001$], with faster RTs for younger participants and later blocks. The interaction between Age x Block (across all blocks) was not significant [F (19, 418) = 0.87, $p < .623$].

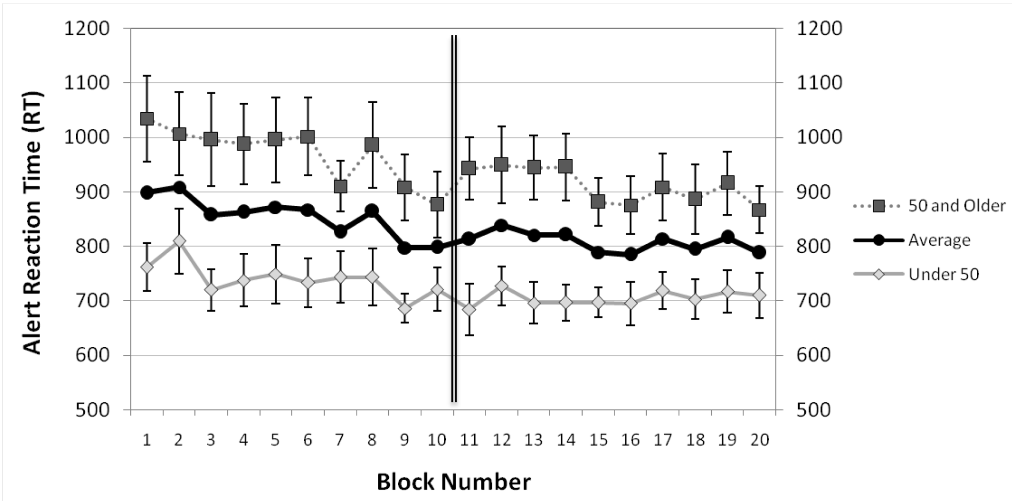

Figure 5: Average Alert RT for each of the 20 blocks by Age. Data for participants 50 years of age and under is depicted with diamonds (N=12, and over 50 years (N=12) is depicted with squares. The group or average data is shown as the heavy line (circles).

3.1.4.5.2 Age by Alert Location Switching

Splitting the participants into two age groups (median split), a repeated measures ANOVA on blocks 10 through 12 with Age (between-subjects) revealed no significant Block x Age interaction [F (2,44) = 2.20, p = .123]. However, this interaction was significant when only considering blocks 11 & 12 [F (1,22) = 4.89, p <.05]. The main effect of age was also significant, with older adults associated with longer RT [F (1,22) = 8.95, p < .01]. No main effect of Block was observed [F (1,22) = 0.41, p = .528]. Follow-up tests revealed that neither age-group showed a significant block effect, however, the interaction and RT means clearly support a trend towards a location-switching cost for older participants, but not for younger participants.

3.1.4.6 Experience versus Age

A moderately strong negative correlation existed between Age and Experience [r = -.641, p < .01], possibly due to the fact that many of the younger participants had experience with video games, and the older participants did not. Exploratory regression analyses were conducted to see which variable (Age or Experience) was a better predictor of the differential cost switching effects observed between block 10 & block 11.

First, a standard regression was conducted to predict switch cost (block 11 RT – block 10 RT) with both Age and Experience as predictors. The model was significant with Age and Experience together explaining 26% of the variance [R^2 = .259] [F(2,23) = 3.66, p<.05]. Based on this analysis, both Age and Experience appeared to be contributing approximately equal amounts to the model.

Subsequently, a stepwise regression was conducted on the same dependent variable (switch cost), the results showing that Experience was the better predictor of the RT switch cost, explaining 21% of the variance [R^2 = .21] [F (1, 23) = 5.93, p<.05]. Under this analysis it appeared that Age would have not contributed significantly to the model [t = 1.146, p = .265]. Overall, these analyses suggested that Age or Experience were strong predictors of the switch cost (or lack of) between blocks 10 and 11. Although the predictive power of these two variables were somewhat redundant to each other, Experience was a better predictor than Age.

3.1.5 Discussion

The purpose of this study was to investigate effects of changing the location of a visual alert, as assessed by reaction time to the alerts. It was hypothesized that alert response time would slow down immediately after the location switch, and that one explanation for this cost might be that the attentional system can be trained to capture and process relevant information even when it appears outside the area of focal attention. Consequently, a deficit in performance would be noted when that information appears in a new, untrained, location, as in this experiment where the location of the alert changed. Thus, even when an operator's attention is fully concentrated on an unrelated task and area of the display, an alert would be captured as a feature within the attentional window and a drop in performance would follow when the alert moved to a new location.

The overall results from this experiment showed that this was not the case, since no significant decrement in performance was observed immediately after the alert changed location. Interestingly, however, is the drop in response time observed several minutes (1 block) after the switch. Thus, it would appear that participants were perhaps more vigilant in detecting newly located alerts right after the location change, compared to later.

This finding prompted the investigators to look more closely at factors known to affect response time. The effects of age, for example, are well-documented, with older adults typically displaying slower response times than younger (Haier, 2005; Porciatti, et al., 1999; Rypma et al., 2001). Experience in video gaming is also seen as a means of improving performance in realms beyond the gaming world. Research has shown that video gaming experts develop greater attentional capacity that increases with game playing experience (Green & Bavelier, 2003).

Perhaps the most interesting finding in this research then, was that experience and age were strong moderators of the effect of slowed switching. In particular, highly experienced and young individuals did not show the expected location-switching cost. On the other hand, inexperienced and older participants were more likely to show the alert-switching cost that was hypothesized.

The results suggest that experience with a specific task, or more general video game experience, can guard against the cost associated with moving an alert to a new, relatively untrained location.

Thus, it is recommended that any visual alerting system implemented in the future be presented always at the same location on the screen. Or, if an alert needs to be moved, or shown at different locations, it is important to train operators at all possible locations the alert may appear (to avoid a reaction time cost at the new location).

4 PART 3 – Eye-Tracking Experiment

This study was conducted at Dalhousie University, Halifax, Nova Scotia using in-house eye-tracking equipment.

4.1 Eye-tracking during a 3-display Alerting Task

4.1.1 Introduction

Several research studies have been conducted at DRDC-Atlantic using a 3-display alerting task designed to simulate the kind of task a naval radar operator might perform (Roberts & Foster-Hunt, 2008; Roberts, 2008; Crebolder & Beardsall, 2009a; Crebolder & Beardsall, 2009b; Crebolder, Salmon, Klein, 2010). The goal of these studies has been to determine what form visual alerts should take to be most effective at capturing attention. During this 3-display task alerts have been shown on one or all of the displays and the most recent study investigated whether or not reaction times to alerts varied as a function of which screen participants were attending. In that study the cursor (mouse) location was used as a proxy/indicator/predictor of where participants were attending when the alert appeared. However, whether or not cursor location was actually a good indicator of where a participant's eyes were looking was not known. Thus, the relationship between eye-location and cursor-location was explored in the current research.

The current research study employed the use of faceLAB eye-tracking software (www.seeingmachines.com). This front-mounted camera system did not require participants to wear any apparatus on their head (like the EyeLink system, http://www.sr-research.com/EL_II.html), and generally, allowed for greater freedom of movement. In addition, a number of modifications were made to the experimental task as compared to previous studies (see *Part 2 – Location Switch Experiment* for a general description of the task and 3-display workstation).

First, each participant completed 6 blocks in which the arrangement of the tasks was different every time; that is, sometimes the radar-like display would be on the left display and sometimes on the right.

Second, the type of task performed on the second (Status) display was modified to better differentiate it from the third (Reporting) display. Specifically participants now had feature check-boxes on this display instead of categorical/classification boxes ('hostile'/'neutral') as in previous research. With previous designs participants would classify on the Status display report that classification on the Status display and then report again on the Reporting display. With this new way, participants would only have to report classification ('hostile' or 'neutral') on the Reporting Display.

Third, the ship features were designed so that there was always at least one hostile attribute (ensuring necessary clicking on the Status Display) since hostile attributes were what participants were selecting on the Status Display.

Fourth, the penalty for missing ships was reduced (from a graphic of the ownship blowing up) to a simple counter in the corner of the display indicating the number of missed ships. This last change was implemented primarily to reduce eye-tracking noise by maintaining continuity of the task through the block. That is, with the old penalty system, the screen would freeze for an entire task for 2 s while it showed the ship blowing up picture – this might cause participants to look away. In the current design, at a minimum, it would have required throwing out eye-tracking data from this period.

Another change in the current design was that, instead of each display being presented on a separate LCD screen, all 3 displays were presented on the same Smartboard side-by-side (see Figures 6). This reduced the visual angles required of the participant but allowed for better eye-tracking because the participants did not have to move their eyes and head as much to see all displays. The participant also sat further from the displays than they had in previous research (2.3 m instead of 0.5 m).

These changes were relatively minor and it was assumed that they produced minimal effects on the comparative value of this research.

A number of objectives were set out at the beginning of this research: (1) To determine the percentage of time participants were looking at the same screen the cursor was on, as a function of display task; (2) To determine whether the relationship between eye and cursor was moderated by practice; (3) To determine if task-related display-switching occurred in the eye or cursor first (and by how much).

4.1.2 Method

4.1.2.1 Participants

Twelve (5 females, 7 males) participants participated in this study. All participants were recruited through Dalhousie University, Halifax, Nova Scotia. The participants had an average age of 25 years (range: 18-31 years). All participants were right-handed with normal or corrected to normal vision. On average, these participants reporting playing 4.17 hours of video games a week (range: 0-30, SD: 8.53 hrs/wk).

4.1.2.2 Materials

4.1.2.2.1 General Equipment

Two networked laptops were used to control the experiment. Laptop #1 (L1) was a Dell Latitude E6500, 2.40 GHz, Intel Core Duo with 2.00 GB of RAM running Windows Vista (SP1) and was used to record the eye-tracking data using faceLAB software, version 5.0 (www.seeingmachines.com). It was connected through FireWire cables to the faceLAB cameras. Laptop #2 (L2) was a Toshiba, 2.17 GHz, Dual CPU with 2.00 GB of RAM running Windows Vista (SP1) and was used to present the stimuli to a Smartboard (www.smarttech.com) using a VGA connection. FaceLAB cameras were screwed to a surveying stand, and faceLAB 16 mm camera lenses were used. The faceLAB equipment and software were setup in ‘laboratory’ and ‘precision’ mode (i.e. using a single Infra-Red lens). The desk at which the participant was sitting was equipped with a mouse and keyboard which were connected to the presentation laptop (L2) using USB extension cables (1.8 m long). Both laptops were connected to the Smartboard using 3 VGA cables connected through a TruLink 2-port VGA Switcher/Extender that allowed quick presentation switching between the two laptops. A standard USB cable and IP-protocols were used to network the two laptops.

4.1.2.2.2 Set-up

FaceLAB cameras were attached to a surveying stand positioned approximately 1.34 m from the Smartboard and standing 102 cm tall. The cameras were angled pointing up approximately 10.5 degrees. Each participant sat at a desk 71 cm tall and 60.5 cm deep. The desk itself was placed on a wooden stand 10 cm tall (desk was raised because the eye-tracking system required participants to be above the cameras, and surveying stand was already as low as it could go). Participants sat in an adjustable grey desk chair with no arms. The chair could be adjusted up and down for a height range of 32-45 cm. The wheels were removed from the chair, and the chair was placed in a wooden stand 5.5 cm tall, so that participants' movements would be minimized. The chair could still rotate up to 90 degrees in either direction. The chair itself put participants approximately 90 cm from the faceLAB cameras. The experimenter sat approximately 75 cm behind the participant in front of a second desk that held both laptops as well as a desktop computer that was used for data analysis, but was not used during data collection. For a better sense of the set-up refer to Figures 6A and 6B (and the additional photos in Annex C).

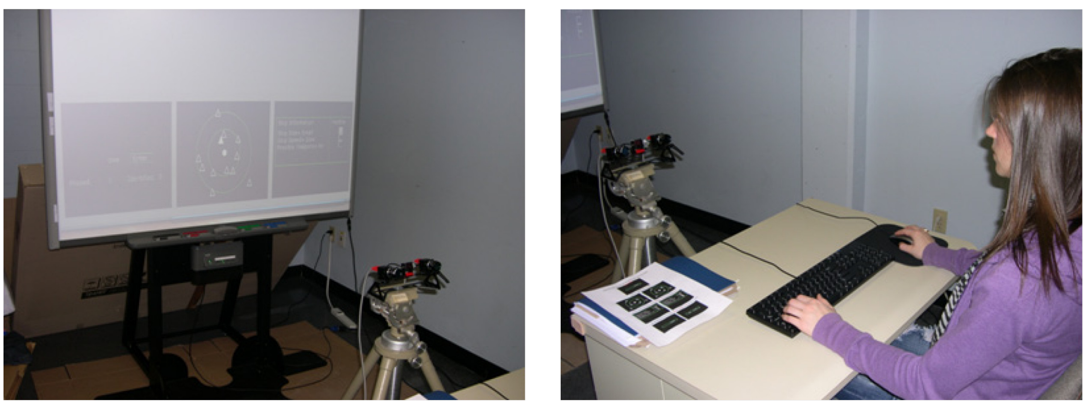

Figure 6: A. The Smartboard with the 3 display task up (faceLAB cameras shown in foreground). B. The desk, keyboard and mouse used by the participant during the experiment. (For a better sense of the overall set-up refer to Annex C).

4.1.2.2.3 Task: Ship Identification and Alerting

The task involved shifting attention between three displays as a part of a ship classification task that required participants to determine whether a ship was hostile or neutral. The three displays were labelled as follows: (1) Tactical display, which showed incoming ships depicted as white triangles on the screen. (2) Status display, contained information about the ship selected on the Tactical display, as well as checkboxes for hostile attributes. (3) Reporting display contained a textbox for reporting (hostile or neutral), as well as a submission ("Enter") box, and scores for number of ships identified. A copy of handout provided to aid instructions is shown in Annex D.

The participant's task was to identify ships by (1) selecting a ship on the tactical display by clicking the mouse on the ship, (2) checking off all hostile ship attributes on the list of neutral and hostile attributes that appeared on the status display and (3) typing a letter string on the reporting display to classify the ship as hostile ('asd'), or neutral ('qwe') and, subsequently clicking the submit button. Ships with two or more hostile attributes were correctly classified as hostile, and ships with one hostile attribute were correctly classified as neutral (every ship had at least one hostile attribute to ensure mouse movement to the status display was required every time). Ship attributes were chosen randomly by the computer but resulted in equal numbers of hostile and neutral ships. Ship attributes included Size (small or large), Speed (fast or slow) and Possible Weapons (yes or no). Examples of the handout used to aid instructions to the participants shown in Annex D.

Correctly identified ships would disappear from the Tactical display, whereas incorrectly identified ships remained on the display. All ships gradually moved toward the centre circle that represented the participants' ownship. If a ship reached the centre before it was identified, the ship would disappear and the score for number of missed ships would increase. Participants were instructed to attempt to minimize the number of ships they missed and maximize the number of ships they correctly identified.

The Tactical display screen was updated every 2 seconds (meaning the ships moved in incremental steps toward the centre every 2 seconds). Ships moved relatively slowly, and it took between 1.5 – 2 minutes for a single ship to get from the edge to the middle of the display. Thus, ships moved an average of 8.57 cm/min or 2.2 degrees/min. There were as many as 12 (maximum) ships visible on the tactical display at any one time. Ships were re-populated almost immediately.

Alerts took the form of a static red bar, placed at the top-center of the display screen. Alerts were displayed periodically (approx. 5.11 alerts/min, which equalled about 26 alerts, range: 24-28, per block) on all three displays simultaneously. Alerts remained on the screen until participants pressed the spacebar in response. Responding to alerts was emphasized as primary importance.

4.1.2.2.4 Visual Angles

Each participant sat about 2.24 m from the Smartboard screen. The entire width of the Smartboard, 156.5 cm long and 117 cm tall, subtended a visual angle of approximately 34.9 degrees. The 3 displays were each 49 cm long with a break of 2 cm between each screen, spanning a total of 151 cm, or 34.0 degrees of visual angle. The displays were also 37 cm tall, but data was only presented on approximately 18-32 cm of that, depending on the display type (4.6-8.1 degrees). For example, the largest ring of the tactical display had a diameter of 29 cm, with the smaller ring at 16.7 cm.

The target ships were 2.5 x 2.5 cm (approx. 0.6 degrees). The text on the screen stood 2 cm (approx. 0.5 degrees).The mouse cursor was 2 cm tall and 1 cm wide (approx. 0.5 by 0.3 degrees). The checkboxes were 2.5 x 2.5 cm (approx. 0.6 degrees). The red alerts were 12 cm long and 2.5 cm tall, (approx. 3.1 degrees by 0.6 degrees).

4.1.2.3 Procedure

4.1.2.3.1 Set-up prior to each participant

Prior to participants arriving in the lab, (1) both laptops and the Smartboard were turned on, (2) the network and physical connections were tested, (3) faceLAB was started and the experimenter ran a calibration on himself, testing for eye-tracking accuracy. If accuracy was low, the cameras were re-focused, re-levelled, measured and calibrated using a special calibration board designed for the system. Step 3 was then repeated until a good calibration could be achieved on the experimenter; (4) the Smartboard and presentation software were tested, ensuring that everything was being sent properly to the Smartboard, (5) paperwork was readied, and participants were assigned a condition.

There were six possible screen arrangements (1. STR, 2. SRT, 3. TRS, 4. TSR, 5. RST, 6. RTS [where S refers to Status, T to Tactical, and R to Reporting, displays]), and participants were assigned to one of 6 random condition order designed in Latin square. The orders were: a) 126354, b) 231465, c) 342516, d) 453621, e) 564132, and f) 615243. Each participant was assigned to one of these orders/condition.

4.1.2.3.2 Procedure for Participants

After informed consent, each participant was introduced to the eye-tracking equipment and given a demonstration of a good eye-calibration (on the experimenter). Participants were then asked to sit at the desk facing forward. The first step involved adjusting the participants chair up and down until their head was centered in the cameras. FaceLAB software was used to calibrate the participants' eyes. The calibration process involved (1) automatic and manual calibration of the participants' "head model" and (2) calibration on the board as measured by the distance between where participants were looking and where the cameras detected participants' gaze with a 9-point calibration. This second step involved the Show SID (Screen Intersection Display) between the eyes and display locations pre-measured and set up in the world model prior to the experiment. These two calibration steps (head model, and calibration to the screen) were repeated until a satisfactory calibration was achieved (defined by less than 1 degree of visual error on both the left and right eye). As a part of the calibration step, participants also filled out a short demographic survey. In total, the calibration process lasted approximately 30 minutes.

The 3-display task was then explained (see Appendix B), and each participant was provided with a practice session. The practice session lasted a duration of 4 minutes, and screen arrangement was identical to the arrangement the participant would see in the first block. No eye-tracking data was recorded during practice, but the experimenter watched the eye-tracking in real-time to ensure that tracking accuracy would be satisfactory once the task commenced.

Once practice was finished, participants began the first of their 6 regular blocks. In each block, the arrangement of the 3-displays was different. Each participant saw all possible arrangements across the six blocks. Each block began with an extra L2 calibration that involved showing the cursor as a diamond that moved around the perimeter of the displays stopping at the edges, corners & centre. During this calibration, participants were asked to follow the diamond with their eyes. This set-up allowed for later spatial and temporal matching between where/when participants were looking, and where/when the eye-tracking cameras thought the participant was looking. The L2 calibration step lasted approximately 1 minute, with each block of the task for a total 5 minutes. Thus, each block lasted a total of 6 minutes duration and each participant ran in 6 blocks. The duration of the experimental blocks, including breaks took approximately 40 minutes.

After all 6 blocks were completely participants were debriefed, allowed to ask any questions they had, allowed to view some of their eye-tracking data, and compensated for their time. The entire experiment lasted approximately 1.5 hours.

4.1.3 Additional Methodological Results / Details

4.1.3.1 Clock Synchronization, Network & Temporal Resolution

Due to drift in computer clock times, especially laptop clock times, equivalent clock times on each laptop was not assumed. Instead, a network was set-up between the two computers so that the time on both computers could be stored through the duration of the experiment along with the output. Specifically a server was setup on L1 using Python that listened in the background for signals from L2. L2, as a part of its program, had client software that sent a signal to L1 on iteration of its loop. What was recorded on L2 was (1) the time the signal was sent, (2) the time reported from L1, and (3) the time the signal was received back from L1. With this information it was then possible to calculate any drift between the two clock times and line up the eye-tracking output from L1 with the behavioural data from L2.

L1 had a temporal resolution of a single refresh at 60 Hz or 16.66 milliseconds (ms). L2 had a temporal resolution that was more variable, but usually better, with an average of 5-6 ms. This meant L2 generated 3 times as much data as L1. The network speed (round-trip) was approximately 2 ms, this meant any time L2 received from L1 occurred approximately 1 ms earlier. This information was used to precisely synchronize the clocks (post data-collection) between the two output files. Because both computers were keeping their own time it was impossible to line up time points from L1 and L2 exactly, but with the help of an R-script synchronization with an average offset (error) of approximately 2 ms was achieved. This meant eye-tracking and cursor location data could be interpreted with an average error ± 2.19 ms. The worst match was 102 ms, although errors this large were rare, with a median = 1.00 ms (range: 0-102 ms, SD=3.77 ms), and errors larger than 10 ms on only 4% of the trials.

4.1.3.2 Eye Calibration (faceLAB show SID)

The goal during the show SID faceLAB calibration step was to achieve the lowest possible calibration error. In practice, the goal was to achieve an error lower than 1 degree of visual angle for each participant (recall the entire screen spanned approximately 34.9 degrees of visual angle left to right). Across all 12 participants an average calibration error of 0.79 and 0.78 visual degrees was achieved for the left and right eye respectively (*SD*s = 0.26 and 0.33 respectively). The worst calibration on any one participant was visual errors of 1.2 and 1.3 degrees respectively. The best calibration on any one participant was 0.5 degrees of error on both eyes.

4.1.3.3 L2 eye-tracking Calibration to 3 displays (Green Screens)

An additional calibration step was included at the beginning of each block. The goal of this step was to determine upon which of the three displays eye-tracking quality was good both spatially and temporally. On the left-most display across all 12 participants for the calibration step, the eye-tracking cameras registered the eyes 62.2 % of the time they were expected to be there (of a theoretical 100%). This calibration was best on the middle display (81.8%) and at about 72.5 % on the right display. Sources of error for this calculation were likely due to location changes of the participant's head position. Specifically, if a person was perfectly calibrated to the screen/displays during the show SID phase, then, if they moved their head closer to the cameras (leaned in during the task) the projected eye-positions would expand causing the software to project eye-positions OFF the displays. Fortunately, due to the fact that the tasks were displayed on different screens for different blocks, this error was spread around equally, with 70.8 %, 72.7%, and 71.6% accuracy on the (R)eporting, (S)tatus, and (T)actical display respectively across the entire experiment. Also, the degree of this error was quite variable by participant, with the best participant at 93.3% and the worst participant at 41.0 % (*M*=71%, with seven participants above 70%).

4.1.3.4 Eye-tracking Display X-axis Correction

An X-correction was applied to the data as follows. The average X-position on each display was calculated. These average positions were then used to convert any OFF-display locations to ON-display. Specifically, for all trials in which the eye X-position was greater than or equal to (>=) to the average X-position of the right display, the eye-position was changed to "Right Display". The same fix was applied to the left display (all positions less than or equal to the average X for left were modified). The effect of this correction is that a number of trials where the eye-position was labelled as "Smartboard" or "Nothing" were then considered either "Left_Display" or "Right_Display", which hopefully corrected for the effect of participants leaning toward the screen. This correction was only applied to the Left and Right Display (no X-correction was applied to the Centre Display).

This data correction improved L2 calibration noticeably with cameras registering eyes on the left display 86.5% of the time (up from 62.2%), on the centre display 81.8% of the time (same as before), and on the right display 82.1% of the time (up from 72.5%). Translated to task, these were accuracies of 82.5%, 83.9% and 84.4% respectively for displays to be used by R, S, and T. This was a noticeable improvement which more appropriately equated eye-tracking on all 3-displays. On a participant by participant basis, the worst participant was brought up to 71.9% (up from 41.0%). The best participant was still at 93.3%, but the average over the group was 83% (up from 71%, with all but one participant over 70%).

These percents should be thought of as a measure of the degree to which the eye-tracker was correctly measuring the eyes at the position we were asking participants to look. Thus, about 80% of the time the eye-tracker measured the eyes where we were asking participants to look (during the L2 green screens calibration). Conversely, 20% of the time the eye-tracker was measuring participants' eyes at a location other than where we were asking them to look. There are multiple potential sources of error here, (1) eye-blinks, when the tracker can't find the eyes, (2) problems at the boundaries, meaning the corners, especially the upper right corners of the left & centre display may not have been registered as ON that display, (3) participants not following task instructions, including looking somewhere else or off the screen, and (4) noise in the eye-tracker.

4.1.4 Primary (Eye-Tracking) Results

4.1.4.1 Correlation between Eye and Cursor During Task

The average percentage of the time eyes and cursor were on the same display once the task started was 84.4%. This meant that participants' cursor and eyes were measured on the same display 84.4% while performing the task, even though this was more than the % of time measured in the calibration (82.7% during L2 calibration). This difference between task and calibration % may have been due to the fact that calibration points were at the corners of the displays or boundaries, while most task-related information was in the centre of the displays. Still, this result suggests a strong relationship between mouse/cursor location and eye fixation location.

4.1.4.1.1 By Task Screen

This cursor-eye relationship was strongest for the Status and Tactical Displays (86.5% and 85.4% respectively), and noticeably weaker for the Reporting display (72.2%). A repeated measures ANOVA with Block and task-display (Status, Tactical, Reporting) as predictors verified this difference with a significant main effect of task-display, $F(2,110)=38.44$, $p < .001$, but not of block, $F(5,110)=1.65$, $p = .163$. Also, the interaction between these two variables did not reach significance, $F(10,110)=1.66$, $p = .100$, see Figure 7.

Follow-up comparisons revealed that although there was not a difference between the (T)actical and (S)tatus displays overall, there was a significant difference in the final block (block 6), with a higher cursor-eye relationship for the (S)tatus display, 92.7% compared to 86.0%, $F(1,11)=16.50$, $p = .002$. Also, the difference between the (T)actical display and (R)eporting display (both of which required only a single click) was diminished by the final block, with 86.0% and 78.8% in the final block, $F(1,11)=6.16$, $p = .030$.

Finally, additional follow-up comparisons (block1 vs block6) revealed a trend for the relationship between eye-cursor to go up over time. This was most true for the (S)tatus and (R)eporting displays, 83.6% to 92.7% and 72.5% to 78.9%,but did not appear to be true of the (T)actical display, 88.9% to 86.0%. The associated significance values for these were, $F(1,11)=7.48$, $p = .019$ (S), $F(1,11)=7.25$, $p = .021$ (R), and $F(1,11)=1.79$, $p = .208$ (T), respectively.

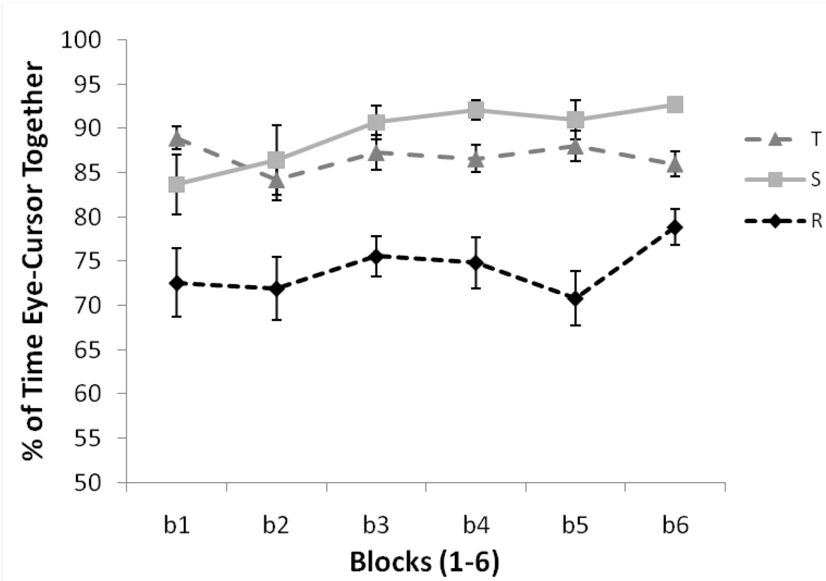

Figure 7: Relationship between eye & cursor for each of the 3 task-related displays over the six blocks (for all 12 participants averaged together). Error bars represent the standard error (across the 12 participants).

4.1.4.2 Task-Switching, Eye versus Cursor

There was an *a prior* hypothesis that the eyes would switch from display to display faster than the cursor. In other words, there was an expectation that cursor display-switching would lag behind eye display-switching. This was tested by first looking at each of the 3 displays separately, creating vectors of data for when the participant's eyes were on (=1) versus off (=0) a display and then correlating the cursor on/off vectors with the eye on/off vectors. Next, the cursor data was shifted both forward and backward through time and re-correlated with the eye-data. The purpose of this was to determine at what time-shift these data were most highly correlated. The highest correlation would be an indicator of how much (on average) the cursor lagged ahead or behind the eyes.

The results suggested NO lag for any of the displays, with the highest correlations on all displays for the non-time-adjusted values, time = 0, see Figure 8. This was true for switching to any of the 3-display types with an average correlation r = .760, and lower after a single screen refresh of 16.67 ms (r = .759 before and r = .758 afterward). These results demonstrated quite clearly that the eyes were not ahead of the cursor, and the cursor was not ahead of eyes. Eyes and cursor switched display at the same time as each other, which did not support our *a prior* hypothesis that the eyes would be a little ahead of the cursor.

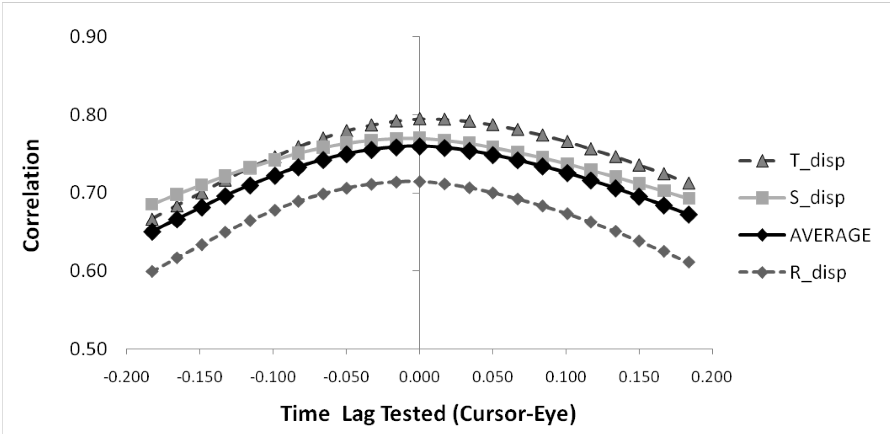

Figure 8: Correlation between lagged cursor-time and eye-time. High correlations indicate the strongest relationship. Time lag shown in seconds (0.100 sec = 100 ms). Correlation represents Pearson-r.

4.1.5 Behavioral (Non eye-related) Results

4.1.5.1 Overall Performance – Primary Task (Response to Alerts)

Overall alert reaction time (RT) did not significantly improve (get faster) with practice, with a mean alert RT of 998 ms in block 1 and 912 ms in block 6, F (1,11)=3.30, p = .097. However, with Experience added as predictor (between subjects) the interaction between Experience and block was significant with, F (1,10) = 5.20, p < .05, with inexperienced participants showing faster RTs in block 6 (1273 ms in block 1 compared to 1080 ms in block 6) and experienced participants showing no difference RTs by block 6 (801 ms in block 1 compared to 792 ms in block 6).

4.1.5.1.1 Alert RT by Task (Cursor Location)

Additionally, alert RT as a function of which display the cursor was on (when participants RESPONDED to the alert) was tested with a repeated measures ANOVA. There was a significant main effect of cursor location, F (2, 20) = 10.50, p < .01, with the fastest RTs when the cursor was on the Tactical Display (824 ms) and slowest RTs when the cursor was on the Reporting Display (1018 ms) with RTs on the Status Display in between (913 ms). Unlike the block effect, this effect did not interact with Experience, F (2, 20) = 1.42, p = .266, that is, experienced and inexperienced participants both showed faster RTs to alerts when their cursor was on the Tactical display and slower RTs to alerts on the Reporting display.

4.1.5.2 Overall Performance – Secondary Task (# of Ships)

The secondary task, total number of ships identified per (5 minute) block was analyzed. For comparison to previous research (i.e. Crébolder, Salmon, & Klein, 2010), a measure of experience was included. Participants were classified as experienced if they had participated in another experiment using this task, or reported playing more than 1 hour/week of video games. Seven participants met classification for 'experienced', while five were considered to have no experience.

Experienced participants appeared to be performing better at the secondary task, identifying an average of 67 ships compared to 57 for non-experienced participants, see Figure 5. However, a repeated measures ANOVA with Experience (between-subjects) and Block (within-subjects) revealed no significant Experience effect, F (1, 10) = 2.66, p = .134, although the Block effect was significant, F (5, 50) = 31.44, p < .001, with more ship identifications in later blocks. The interaction between Block by Experience was not significant, F (5, 50) = 1.13, p = .355, again see Figure 9.

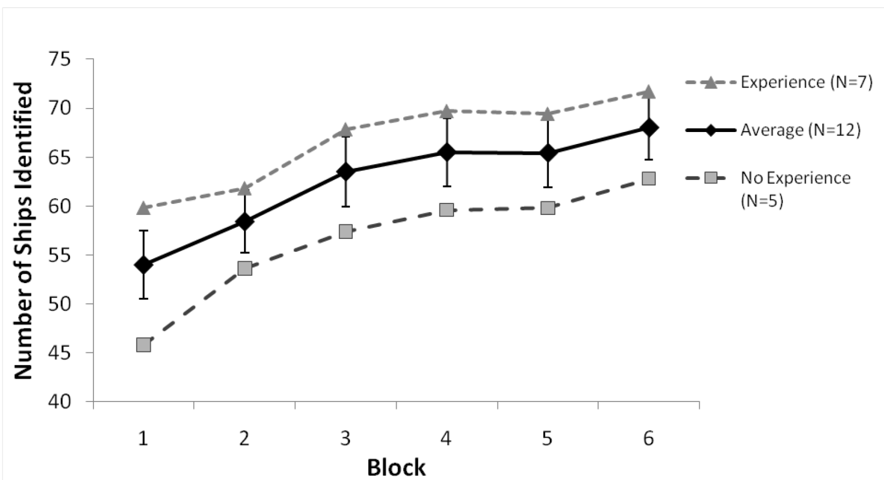

Figure 9: Total Number of ships identified by Block. The average for the group (N=12) is shown in black. Experienced participants (N=7) shown as triangles, and non-experienced participants (N=5) shown as squares. Error bars around the average data represent the standard error for the group.

4.1.5.3 Exploratory: Alert RT as a function of Proximity

An additional variable (Closest Ship) was added to data collection that had not been present in previous paradigms. This variable recorded the distance of the ship closest to the ownship at the centre of the Tactical display (the ship closest to being missed). The *a prior* hypothesis about this variable was that although the primary task was to respond to alerts, and identifying ships was the secondary task, nonetheless the two would impact each other. Specifically, we predicted alert RT would be slower when ships were close to the center of the Tactical display (a failure state for the secondary task). Support for this hypothesis was found with mixed-effects model (Experience, Block, Closest Ship as predictors, and alert RT as the dependent variable), with a significant main effect of closest ship (t = -2.53) and significant interaction between Block and closest ship (t = 2.597). The main effect supported the *a prior* hypothesis that participants would be slower to respond to alert RTs (primary task) when ships were close to their ownship (secondary task). The interaction with block suggested the size of closest ship effect got smaller in later blocks.

4.1.6 Discussion

4.1.6.1 Cursor is a Good Proxy for Attention (Eye-Location)

Eye-location and cursor-location corresponded highly with each other during this task. In fact, the percentage of time eyes and cursor were together was higher during the experimental task than during the L2 calibration. This discrepancy was likely due to the fact that the L2 calibration tested the border of the displays, while the task-relevant information occurred primarily in the centre of the displays. This result, however, strongly suggests that the cursor is a very strong predictor of where the participant is looking. The one task-display in which this average correspondence was lower was the Reporting Display. The reduction for this display may have be due to the fact that the cursor task was simplest on this display (click one box which is in the same place every time) in comparison to the other displays, or due to the fact that participants had to type on this display (drawing their eyes away from the screen and to the keyboard). Although response keys (‘asd’/’qwe’) were chosen purposely in an effort to reduce the need to look at the keyboard the attempt may not have been full proof. Certainly, these variables (typing vs. simplicity of clicking) could be separated in future research. All in all, these results suggest the cursor is a good proxy/predictor of spatial attention.

4.1.6.2 The Cursor becomes a Better Predictor of Eye-Location with Practice

For both the Status and the Reporting display the trend was towards a higher relationship between participants’ eyes and cursor as they got more practice. That is, the eyes and cursor were more likely to be together on these displays the better participants got at the task. Interestingly, this relationship did not hold for the Tactical display.

4.1.6.3 Eyes are Not Ahead of Cursor

The time lag-analysis did not support our prediction that the eyes would switch-displays faster than the cursor. Perhaps participants were sufficiently practiced at this task that they could plan mouse movements in advance (causing no lag). In fact, almost all the participants (10 of 12) allowed no ships to reach the centre of the tactical display during the duration of the task (5 minutes by 6 blocks = 30 minutes). Perhaps the participants were forced to watch the cursor closely so it would not get lost on the displays. In retrospect, the cursor was mostly black on a mostly black background, possibly making it difficult to see. Results may have been different if the cursor had better contrast to the background. However, this finding, although surprising, is actually quite useful because it implies that not only are the eyes usually where the cursor is, but that they switch displays/task at approximately the same instant.

4.1.6.4 Other factors Affecting Alert RT

Notably, a significant relationship was found between reaction times to alerts (primary task) and the distance of the closest ship to the centrally located ownship (secondary task). This result suggests that, when participants were more in danger during the secondary task (a ship about to reach the centre), their vigilance on the primary task dropped (slower RTs).

In addition, participants were faster at responding to alerts when their cursor was on the Tactical display, and slowest responding to alerts when their cursor was on the Reporting display. Keeping in mind that the location of each display task (Tactical, Status, Reporting) was varied in this experiment, a possible explanation for faster alert detection on the Tactical display is that, if the secondary task can be thought of as broken into trials/events with three steps [(1) Tactical select ship, (2) Status, classify and click checkboxes and (3) Report by typing and clicking] then responses to alerts may have been fastest between trials. In other words, participants were quickest to respond to alerts when they were not already in the process of identifying ships in the secondary task. An additional reason participants may have been slower at the Reporting display is that that display required typing which may have drawn participants attention away from the screen.

4.1.6.5 Recommendations

Much was learned from this research. Most importantly, cursor-location is very strongly related to eye-location, and the eyes do not switch display/task ahead of the cursor when performing the overall task used in this study. These two results together suggest that the cursor location, for future research using tasks like this, is a more than adequate proxy for visual attention, and concurrent eye-tracking during this type of research is likely unnecessary. Also, the effect of the secondary task (ship identification) on the primary task (responding to alerts) was better characterized in the current research than in previous, related studies. Specifically, the distance ships are from the centre (in the secondary task) can significantly influence reaction times to alerts (primary task). Also, during this task, participants were faster at responding to alerts when they were on the Tactical display (i.e. between events). Future research with this task may want to more closely monitor the influence of these secondary task variables on alert reaction times.

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5 General Discussion

In Part 1, the most important finding was that flashing does not appear to matter. All flash rates appeared to be responded to equally quickly, and there was no difference between a perceived 50/50 duty cycle versus the actual 50/50 duty cycle. In part 2, the most important finding was that alert location switching does not necessarily result in reaction time cost in the participants. The appearance of a reaction time cost appeared to depend largely on the participants previous experience with the task (or video games in general), or the age of the participant. Also, the reaction time (RT) delay appeared to be manifesting a block or so later than expected. Finally, in part 3, the most important finding was that the cursor is a good proxy for attention. That is, the eyes are almost always where the cursor is, and the two (eye and cursor) switch displays at the same time. Also, this relationship appears to get stronger the more time participants spend doing the task.

A number of secondary findings were also obtained from the research. In part 1, it was determined that alerts shown on the top and bottom of the display appear to be responded to more quickly than those on the sides. In part 2, the effect of experience and age on task proved to be very evident, with experienced (and younger) participants identifying alerts more quickly (primary task) and identifying more ships (secondary task). Experienced (and younger) participants also appeared to show smaller learning effects. In part 3, a new relationship between RT to alerts and danger in the secondary task (as measured by the closest ship to the centre) was identified. Specifically, participants were slower responding to alerts when enemy ships where close to their ownship. The results also suggested faster alert RTs when participants were on the Tactical screen (between events), and slower alert RTs when participants cursor was on the Reporting display (at the end of a classification event). These findings are worth keeping in mind during future research.

5.1 Average RT to Respond to Alerts

All parts of this research involved responses to flashing or static alerts with the press of the space bar. Not surprisingly, participants RTs were fastest when they had nothing else to do (i.e. 353 ms in the single-task from Part 1, Experiment 2), and only a little bit slower when the secondary task was a simple mouse-tracking task (i.e. 400 ms in the dual-task from Part 1, Experiment 2). The next slowest average RTs were obtained from the switch location experiment (i.e. mean RTs = 832 ms for the entire group across all blocks), although RTs were again faster for the experienced participants in this group (M = 753 ms for Experience levels 2 & 3 compared to M = 898 ms for levels 0 & 1). Finally, the slowest RTs were obtained in the eye-tracking experiment (Part 3) with M = 891 ms (when considered RTs <= 4 seconds). Again, RTs were faster for the experienced participants compared to the inexperienced (M = 776 ms compared to M = 1056 ms). These slightly slower RTs in the eye-tracking experiment may have been related to the fact that in Part 3 the alerts stayed present until they were responded to. In contrast, in Part 2 the alerts would disappear after 4 seconds if they had not been responded to, leading perhaps to a greater sense of urgency (and faster RTs) in Part 2 compared to Part 3. Also, alerts appeared more regularly in Part 2 (5.33 alerts/min in Part 2 compared to 5.11 alerts/min in Part 3) which may have also contributed to these differences. Practice effects may also partially explain these differences, as participants were performing the task for longer in Part 2.

5.2 Summary of Primary Recommendations

(1) Future research can use flashing or static alerts as there seems to be no advantage, in terms of RT to respond, for favouring one over the other. (2) Moving visual alerts to a new location should be avoided, unless participants have had experience or training at the new location. (3) Future eye-tracking during this task appears to be unnecessary, as the cursor location appears to be a good predictor of where the eyes are.

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Annex A Summary of Processing Steps and Datafiles

General note: The program Python was used to present stimuli in Part 1 & Part 3. This is a free program that can be installed on any computer, and the install files for a PC are provided in folder '\Python & R install files\Python_Install'. Further, the program R used for many steps of the data processing and analysis, preferentially over Excel and SPSS. This is because (1) R is a free program, (2) it can do analyses not possible (or at least no easily accomplished) by Excel/SPSS such as a mixed-effects analysis, (3) it can handle, process, and analyze data more quickly and efficiently than Excel and SPSS. This last point was especially important in the case of Part 3 in which the data files were so large they exceeded the maximize size allowed for spreadsheets in Excel AND some of the processing steps required hours of computing/processing time on an optimized modern (fast) computer. The files needed to install R on a PC-computer are located in '\Python & R install files\R-project_Install'. Documentation for both Python and R syntax is readily available free of cost on the internet, but I have included an invaluable R-resource the Baayen book 'Analyzing Linguistic Data: A practical introduction to statistics' in which chapter 1 is an introduction to R in general, and chapter 7 to mixed-effects models ('Baayen2008.pdf').

Part 1, Experiment 1. FlashRate Research

1. Read all of the data (.txt) files into Excel and save them as excel documents, files in folder: 'PART1_FlashResearch\FlashResearch_Data\FlashRate_Exp'
2. Sort the data period, color, and position, then calculate the means with a formula.
3. Alternatively, these means can be calculated by running the commands in the R-code: FlashRate_Analy.r – which also contains the code to run the mixed-effects analysis on the data.
4. Means were pooled together in the Excel file 'FlashRate_GroupData.xls' and used to construct the figure for the report.

Part 1, Experiment 2. FlashRT Research

1. File 'FlashRT_Demographics.xls' contains demographic information for participants #'s 1-19. But only p6-p19 had data in which false alarm trials were rejected, so only these were used. Some of the earlier datafiles are stored in 'FlashRT_Data1_noFA' but the datafiles that were analyzed are in: 'PART1_FlashResearch\FlashResearch_Data\FlashRT_Exp\R&Analysis_files\FlashRT_Data2'
2. R-code was used to collate the data, and conduct the ANOVAs: 'FlashRT_Data2new.r'
3. Analysis of Mouse Error was conducted using R-code: 'FlashRT_MouseAnaly.r'
4. Part of the group data for the Mouse Error analysis is stored in the file 'GroupData_MouseError.xls'. The 'FlashRT_MouseAnaly.r' file was used to calculate '_errorSave.txt' files for each participant which is a recording of average mouse error time locked to the onset of each stimulus. The Mouse Error analysis in general was not very fruitful, and all of the files are stored in: '\PART1_FlashResearch\FlashResearch_Data\FlashRT_Exp\R&Analysis_files\MouseError_Analysis'

Part 2. Location Switch Experiment.

Data Storage

1. All E-prime files and output are contained in the folder: '\PART2_LocSwitch(DRDC)\E-prime BackUp Files\Phase4 Jan_2010'
   The data for participants in the static condition are in: '\PART2_LocSwitch(DRDC)\E-prime BackUp Files\Phase4 Jan_2010\Data'
   The data for participants in the flashing condition are in: '\PART2_LocSwitch(DRDC)\E-prime BackUp Files\Phase4 Jan_2010\Cond2flash\Data'

E-prime Changes

2. The primary change to the program was changing the number of blocks (to 20), and changing the types of alerts per block to meet the conditions (alerts top, alerts bottom, flashing or non-flashing). In the filenames: condition AB = top then bottom, BA = bottom then top, and s = static, f = flashing.
3. The program also changed so that alerts would be shown on all 3 displays simultaneously on every trial.
4. A small bug in the program was also fixed: alerts on the bottom right display were being drawn a few pixels in the wrong location causing the alert removal to leave some of the alert up – this was fixed.
5. Practice condition was modified to include a random variable that would sometimes draw the alert on the top of the screen, and sometimes draw the alert on the bottom of the screen.

Data Processing (Excel Document with Add-Ins)

6. All data was read into the special Excel workbook (parser) designed by Don Coady at DRDC Atlantic. Data for the 12 static condition participants were read into 'Exp4_Static_(N=12)_v03.xls'. Data for the 12 flash condition participants were read into 'Exp4_Flash_(N=12)_v04.xls'. These files are stored in '\PART2_LocSwitch(DRDC)\LS(DRDC)_data_standard_longXLS'
7. The built-in SPSS commands/macros were then run: 'Prepare Data for SPSS' and 'Cursor Screen Summary (Josh)'.
8. Smaller versions of these excel files were then created by deleting the data tabs and only maintaining the summaries to create files 'Exp4_Flash_(N=12)_v04_short.xls' and 'Exp4_Static_(N=12)_v03_short.xls'
9. In both these new files, a new tab called 'RTbyBlock' was created, and RTs for each of the 20 blocks was copied to this page (from the summary tabs) and a simple figure was created. Some values for 'TotalCorrectIDs' were also copied to these tabs.
10. These values (RTs per block and number of correct ship IDs) were then copied into SPSS to do the repeated measures ANOVAs that were reported. SPSS files 'Exp4_avgRT.sav' and 'Exp4_NumShipCorrect.sav' respectively. These SPSS files are saved in: '\PART2_LocSwitch(DRDC)\LS(DRDC)_DataAnalysis_Age_Experience'
11. These RTs were then copied into excel files 'DRDC_ExpAnaly_v02.xls' and 'DRDC_AgeAnaly2.xls' to create the age and experience figures seen in the report. 'DRDC_ExpAnaly_v02.xls', in particular, contains additional information about each participant, including how the experience measure was calculated.

Mixed-Effects Analysis

12. The mixed-effects model was conducted in R using the code 'DRDC_EprimeSwitch.r' contained in: '\PART2_LocSwitch(DRDC)\R_files_&_data' on the full raw data contained in: '\PART2_LocSwitch(DRDC)\R_files_&_data\DRDC_switchData'

Part 3. Eye-tracking Experiment.

Data Storage

1. The eye-tracking data was merged with the cursor location information and stored as .csv files in '\PART3_EyeTracking\ JET_Data&_Rfiles\EyeTracking_MergedData', in the fet folder. 'FET' stands for faceLAB eye-tracking (data generated by faceLAB), and only data for participants 5-16 were analyzed. The R-files used to construct these .csv files are saved in '\PART3_EyeTracking\ JET_Data&_Rfiles\Key_R-AnalysisFiles\R_MergeDat_Files'. Note: the faceLAB data used as input was not provided (because these datafiles are huge), but the R-files are provided as a record to show what processing steps were done to create these.
2. The behavioural-only data (cursor and alert-responses) were saved as .txt files, and are stored in the JET folders in:
'\PART3_EyeTracking\ JET_Data&_Rfiles\EyeTracking_BehavData'.
JET stands for 'Josh Eye-tracking' or 'Josh Eye-tracking behavioural'.

R-Analysis Processing Steps/Files

3. R was used for a lot of the processing steps because it handles big datafiles better/faster than Excel or SPSS (some of these processing steps required hours to run on a fast computer). The steps for computing the 'correlation analysis' or rather the percent correspondence between cursor and eye described as *'Correlation between Eye and Cursor During Task'* are present in R-file 'JET_CorrelAnaly_p05-16.r'.
4. The steps for computing data necessary for the behavioural analyses are present in the R-file 'JET_Behave_p05-16.r'.
5. The file for the time-lag analysis described in '*Task-Switching, Eye versus Cursor*' is 'JET_AllDat_LagAnaly2.r' located in '\PART3_EyeTracking\JET_Data&_Rfiles\Key_R-AnalysisFiles'. The R-file generated the text files located in '\PART3_EyeTracking\JET_Excel&SPSS\Data_Analysis_XLS_SPSS\JET_LagAnaly' which were then combined to create a figure for the report in 'FET_LagAnaly.xls'
6. The other R-files were also used to get descriptive statistics for the data that were saved in text files provided in '\PART3_EyeTracking\JET_Data&_Rfiles\JET_R_output_TXT _files'

Excel and SPSS processing Steps

7. Data for the correlation, or % correspondence question were saved in 'CorrelAnaly_Question.xls' and used to create the figure for the report. Statistics was conducted for this data using SPSS files 'CorrelScreen_Analy.sav' and 'CorrelScreen_AnalyCorrectX.sav' and the syntax file 'Syntax1_CorrelAnaly_rmANOVA.sps'. The difference between these two SPSS files is that 'CorrelScreen_AnalyCorrectX.sav' contains the data post X-correction (as described in the report) and this was data used in the final analysis. All the file corresponding to this analysis are location in:
'\PART3_EyeTracking\JET_Excel&SPSS\Data_Analysis_XLS_SPSS\JET_CorrelAnaly'
8. The SPSS files necessary for doing the remaining behavioural (not eye-tracking) analyses on the eye-tracking data are located in the folder
'\PART3_EyeTracking\JET_Excel&SPSS\Data_Analysis_XLS_SPSS\JET_BehavData'.
The figures were again created in the excel document, 'JET_DataAnaly.xls'.

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Annex B List of Folders and Variable Names

<u>*Level I folders*</u>

Ethics	- Ethic protocols from the various elements of this research.
FULL_REPORT_(EarlierVersions)	- Backup copies of earlier versions of the report.
PART1_FlashResearch	- All necessary files and folders pertaining to Part 1.
PART2_LocSwitch(DRDC)	- All necessary files and folders pertaining to Part 2.
PART3_EyeTracking	- All necessary files and folders pertaining to Part 3.
Python & R install files	- Files needed to install Python and/or R on a PC.
SOW & Work Description	- SOW, Work Description copies

<u>*Part 1 folders (level II)*</u>

FlashResearch_Data	-Contains Python program, Data, and R-files for Exp 1 & 2.
FlashResearch_WriteUp	-Contains reports for Exp1 and Exp 2 (Part 1).
Python_BackUp_files	-Contains other versions of Python (stimulus presentation) files.

<u>*Part 1 Variable Names, Exp 1*</u>

Primary Data files Named: SUBJ_FlashRate.txt or SUBJ_FlashRate.xls

Variable Names:

trial#	- Trial number (order of presentation)
startT	- Time the trial started (in ms from start of Python program)
stopT	- Time the trial ended (in ms from start of Python program)
period	- The period (time for complete cycle) of the flashing 100 = 100 ms, 200 = 200 ms, etc.
startOn	- The starting time ON for the alert (add 5 ms to get the ACTUAL time on).
startOFF	- The starting time OFF for the alert (*period – startOn*)
endON	- The time ON that the participant adjusted the alert to within the trial.
endOFF	- The corresponding time OFF at the end of the trial (*period – endON*)
color	- The color of the alert (red or white)
position	- The position of the alert, Bot = bottom, Top = top, N = near, F = far.

<u>*Part 1 Variable Names, Exp 2*</u>

Primary Data files Named: SUBJ_DATE_TIME_FlashRT.txt

Variable Names:

trial#	- Trial number (order of presentation)
dualTask?	- Whether or not it was the dualtask condition 0 = single, 1 = dual-task
trial_startT	- Time the trial started (in ms from start of Python program)
trial_stopT	- Time the trial ended (in ms from start of Python program)
period	- The flash period (time for complete cycle), 100 = 100 ms, 200 = 200 ms, etc.
FlaRate_ON	- The time the alert was on (add 5 ms to get the ACTUAL time on).
FlaRate_OFF	- The time the alert was OFF (*period – FlaRate_OFF*)
color	- The color of the alert (red or white)
position	- The position of the alert, 1-8. 1= TopFar, 2=BotFar, 3=TopNear, 4=BotNear, 5=LeftFar, 6=RightFar, 7=LeftNear, 8=RightNear
AlertON_T	- The time the alert came on (in ms from start of exp)
ResponseT	- The time the participant responded (in ms from start of exp)
RT	- The reaction time (RT) of the participant (*AlertON_T – ResponseT*)
False_pos	- Whether or not trial was a false positive (whether response before alert appeared).

Part 2 folders (level II)

E-prime BackUp Files	- Copies of E-prime files, and data
LS(DRDC)_data_standard_longXLS	- Excel files of the flash and static data (special Macro files)
LS(DRDC)_DataAnalysis_Age_Experience	- Age & Experience analysis Excel and SPSS files
LS(DRDC)_WriteUp	- Report for Part2 (.doc files)
R_files_&_data	- Datafiles (in .txt format) and R-script for Mixed Effects analysis
Recruitment	- Consent, debriefing, instructions & other recruitment forms

Part 2 Variable Names

Primary Data files Named: DataJosh-AAS_Phase5_*COND*.txt, where *COND* was s=static, f=flash, order: AB or BA, and then subject number.
Variable names in these files were generated by E-prime, and were the same as those used in previous experiments.

Computed Variables (in Excel):

block#_alarmtype	- Block alarm type 1 or 4=Top, 3 or 6 =Bottom.
Block1_AvgRT_all to *Block20_AvgRT_all*	- Average RT per block.
Block1_Total_Correct_IDs to *Block20_Total_Correct_IDs*	- The number of correct ship IDs by block
Cursor_LeftScn, Cursor_LeftScn, Cursor_LeftScn	- # of times cursor on the respective screen

SPSS (Exp4_avgRT.sav) Variable Names:

Subj	- Subject number
age	- Subject age
Experience	- Experience level of subject/participant, from 0 to 3[1].
ageGroup	- First Age Grouping of participants (unequal groups)
ageGroup2	- Second age grouping of participants (median split = equal Ns)
AlrmType	- Alarm type (1 or 4=Top, 3 or 6 =Bottom)
FlashStatic	- Flashing or Static Alert (s = static, f = flashing)
Cond	- Condition order AB = Top then Bottom, BA = Bottom then Top
Block#_AvgRT_all	- Average RT for each block
Blck11_Cost	- The cost (in RT) of switching location (*Block11_AvgRT* - *Block11_AvgRT*)

SPSS (Exp4_NumShipCorrect.sav) Variable Names:
Subj, Experience, age, ageGroup, ageGroup2, AlrmType – All the same as before (above)
Block#_Total_Correct_IDs - The number of correct ship IDs (secondary task) by block

Part 3 folders (level II)

EyeTracking_WriteUp	- Report for Part 3, as well instructions, procedure, & storyboard
JET_Data&_Rfiles	- Data and R-file used for processing / pre-processing
JET_Excel&SPSS	- Demographics, Condition orders, SPSS and Excel files (with figures)

Part 3 Variable Names

Primary Behavioural Data files Named: jet##_*COND*_AlertFacelabExp.txt
Primary Eye-tracking Data files Named: zFET_MergData##_*COND*.csv
… where ## = Subj Number, and *COND* = condition order (a-f) and block number (1-6).

[1] The values used to compute these numbers are contained in the file 'DRDC_ExpAnaly_v02.xls'

Behavioural (.txt) data Variable Names (example file name: 'jet05_d3_AlertFacelabExp.txt')

Type	- Type of trial. startE = start Experiment, calibr = calibration phase, refres = regular screen refresh, mouseP = mouse button pressed, moveSH = move ships on the screen, alertO = alert ON, spaceP = space bar pressed correctly, spaceF = space bar pressed when no alert on screen (FA), finish = end experiment.
pyTime	- Time (in ms) since pygame (Python module) started
GMTs	- Time (in sec) since 01-01-1970 00:00:00 (Jan 1st, 1970)
GMTms	- Time (in ms) over and above GMTms (0 to 999)
MouseX	- Mouse X position on screen.
MouseY	- Mouse Y position on screen.
Display	- Display mouse/cursor is on 9 = out of bounds, 0 =left, 1=centre, 2=right.
Textbox	- Text currently showing in the textbox '___' = nothing / blank
ScrnArrange	- Arrangement of screens from left to right, with S = status, T=tactical, R=reporting
Block	-Block # (changes during calibration but kept constant for the rest of the expeirment)
NoIdent	- Number of correct ship identifications so far (secondary task)
NoMiss	- Number of ships missed (got to the centre before identified)
AlertON	- Time an alert came on (in *pyTime* = ms since pygame started)
AlertRespT	- Time an alert was responded to (in *pyTime* = ms since pygame started)
AlertRT	- Reaction time (RT) to alert (= *AlertRespT* – *AlertON*)
AlertOFF	- Time an alert went off (in *pyTime* = ms since pygame started)
t1	- GMT time on L2 (laptop #2) when ping was sent to L1 (laptop#1)
ts	- GMT time reported from L1
t2	- GMT time on L2 when ping was received back from L1.
tripT	- Total trip/ping time (= *t2 – t1)*
ClosestSH	- Distance of the ship closest to the ownship (absolute values of X & Y distances added together.) This variable was used for an exploratory analysis.

Eye-tracking (.csv) data Variable Names (example file name: 'zFET_MergData05_d4.csv)
Note: Variables ALL IN CAPS come from faceLAB eye-tracking software.

FRAME_NUM	- Number of frames (screen refreshes) since faceLAB started
EXPERIMENT_TIME	- Time in ms since faceLAB started (?)
GMT_S	- Time (in sec) since 01-01-1970 00:00:00 (Jan 1st, 1970)
GMT_MS	- Time (in ms) over and above GMTms (0 to 999)
DELAY	- ** not sure
GAZE_ITEM_NAME	- The name of the item (display) that the participant was looking at
GAZE_WORLD_X	- X-location of where person is looking
GAZE_WORLD_Y	- Y-location of where person is looking
GAZE_WORLD_Z	- Z-location of where person is looking (depth in and out of screen)
HEAD_ITEM_NAME	- The name of the item (display) that the participant's head was pointed at
HEAD_WORLD_X	- X-location where the participant's head was pointing
HEAD_WORLD_Y	- Y-location where the participant's head was pointing
HEAD_WORLD_Z	- Z-location where the participant's head was pointing
etime	- Calculated time for merged with cursor data (= *GMT_S* + (*GMT_MS*/1000))
JBehavTime	-Time from behaviourally data merged with etime (eye-tracking time)
Jtype	- Type of trial on behavioural task (same as above). Specifically, calibr = calibration phase, refres = regular screen refresh, mouseP = mouse button pressed, moveSH = move ships on the screen, alertO = alert ON, spaceP = space bar pressed correctly, spaceF = space bar pressed when no alert on screen (FA)
JScnArrange	- Screen Arrangement from left to right, S = Status, T=Tactical, R=Reporting
JMouseX	- Mouse (cursor) X-location
JMouseY	- Mouse (cursor) Y-location
JDisplay	- Display the cursor was on, 9 = out of bounds, 0=left, 1=centre, 2= right display

JBlock	- Block Number (changes during calibration, but set = to correct block # for the normal trials)
tDiff	- Difference between eye-tracking time and behavioral time
SameScrn2	-Whether or not eyes and cursor on the same display (TRUE or FALSE)
SameScrn	-Same variable coded as numeric (0=not on same display, 1=same display)

Annex C Global Set-Up of Equipment (Part 3)

C.1 Eye-tracking Set-Up: Participant & Experimenter

Figure A-10: Entire set-up from a distance (calibration step). Participants were in a raised chair in front of faceLAB cameras. Experimenter at desk in front of laptops (the 'experimenter' in this photo was not the actual experimenter but an RA posing as the experimenter).

C.2 Eye-tracking Set-Up: Experimenter Computers

Figure A-11: The two laptops used. L1 on left (controlled faceLAB). L2 on right controlled presentation software (Python). Computer in back (LCD) was used for data analysis (but not used during the experiment).

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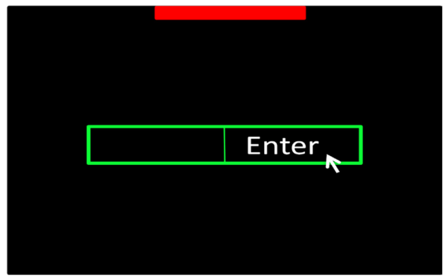
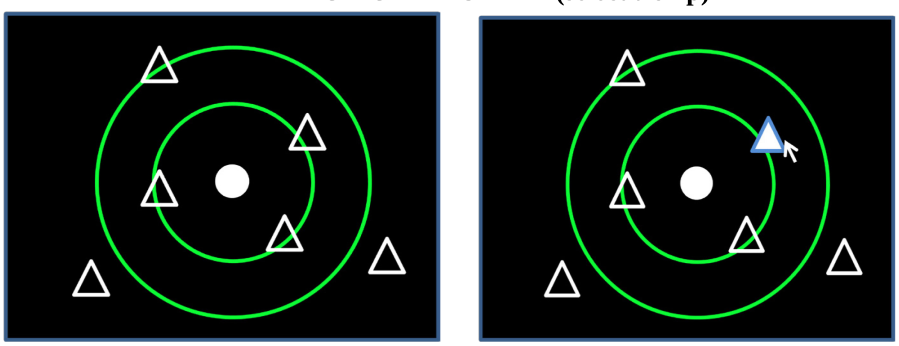
Annex D Instructions for Task (Part 3)

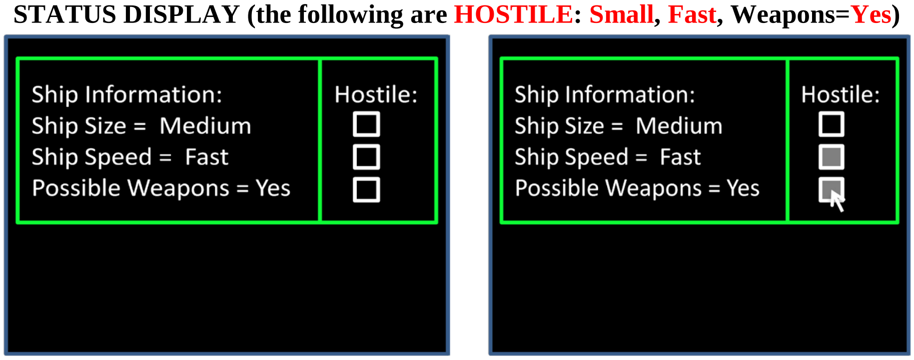
PRESS SPACE BAR every time you see the RED ALERT (top of the screen)!!



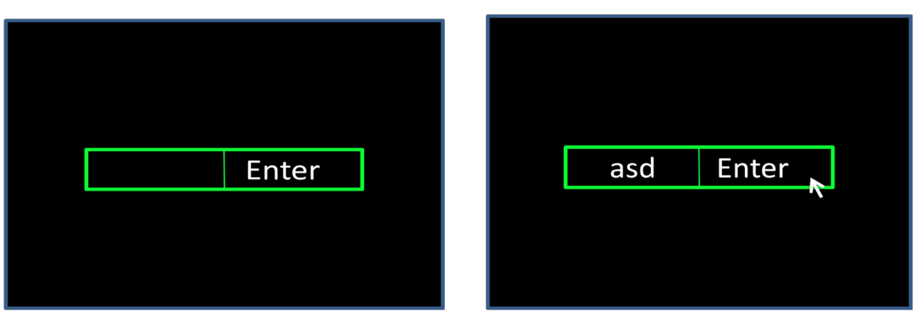
TACTICAL DISPLAY (select a ship)



STATUS DISPLAY (the following are HOSTILE: Small, Fast, Weapons=Yes)



REPORTING DISPLAY (2 or more = HOSTILE, HOSTILE = asd, NEUTRAL = qwe)



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Aspects of visual alerts were explored to determine what type of visual alerts best captured attention, as measured by reaction time (RT) to the alerts. In part 1, flash rate of alerts was explored to determine the most effective detection. The results suggested that flashing at any of the flash rates was no better than a non-flashing alert. In part 2, the cost of moving an alert from one location to another was investigated. The results showed an alert location-switching cost (slower RTs after switch) that was only present for inexperienced and older participants. In part 3, the relationship between eye-location and cursor location was explored. The goal of this research was to determine if cursor-location was a good proxy for eye-location during a multi-display task that had been used in previous experiments. The results suggested that, for this task, the cursor was in fact an excellent proxy for eye-location with a very high display correspondence between eye and cursor location. Both eye and cursor were found to move from one display to another at the same time. The results have implications for future visual alerting research and the design of automated alerting.

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alerting; vision; maritime; human factors; psychology; eye-tracking

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