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Effects of Increased Cognitive Load on Field of View in Multi-Task Operations Involving Surveillance

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Abstract. Many operations, such as air traffic control which requires simultaneous surveillance and communication, involve multi-tasking. Yet, research on effects of multi-tasking on visual processing tend to revolve around driving. As such, similar effects on functional field of view in multi-tasking operations involving surveillance, while considering stimuli parameters that might be implicated, remain a gap in understanding. In this study, we investigated the effects of the presence of a secondary task and stimuli parameters (size and contrast) on the response accuracy and response time for stimuli appearing in the visual field. Mixed analyses of variance revealed that response time, but not accuracy, was affected by the engagement in multiple tasks. An interaction between the parameters of the presented stimuli signals the need to consider external factors in multi-task operations. Implications and future directions are discussed.

Keywords: Functional Field of View · Multi-Task · Size · Contrast · Visual Performance · Human Errors

1 Introduction

With technological advancements, traditional manual labour becomes more automated. Humans are thus expected to carry out different tasks from before, such as supervision of unmanned vehicles systems [1]. For example, the task of the driver in an autonomous vehicle will be switched to surveillance and standby in cases of malfunction or unknown situations of the automated systems. In various industries, such advancement presumably allows humans to engage in multiple tasks simultaneously (i.e. multi-tasking). However, multi-tasking may increase productivity, but could come with a trade-off.

Among the many industries, operational industries involving surveillance tasks are particularly implicated. Surveillance is a visual task that is often coupled with another communication task. For instance, air traffic controllers (ATCOs) monitor the airspace while concurrently managing communication with the pilots of the aircrafts in their sectors: giving instructions (to the pilots) and taking requests (from the pilots) on adjusting the aircrafts' altitude or velocity to prevent conflicts or collisions. With air

traffic density predicted to increase in the future, ATCOs' work will get more cognitively intense and complicated [2].

In the current study, we are particularly interested in the *functional field of view (FFoV)*. FFoV is the area in the human visual field where stimuli can be detected and processed [3]. Multi-tasking can degrade FFoV in two ways, resulting in either tunnel vision [4] or general interference [5]. These degradation theories have been studied in the context of usage of cellular phone while driving [6][7][8]. However, instead of testing participants on a particular driving task, we will examine the effects of multi-tasking on a more general visual task, such that the results would be generalisable to surveillance tasks in other industries, such as that of ATCOs.

This study investigates the effect of task requirements – whether one is engaging in multiple tasks or a single task – on one's visual task performance. Engaging in multiple tasks is hypothesised to result in poorer visual task performance. Extending from the context of air traffic control, we identified size and contrast as the parameters of the stimulus in the visual task as they are particularly pertinent to such contexts in surveillance. Visual task performance is expected to decrease with both stimulus size and contrast. Moreover, the questions arise whether there are interactions among these factors. We will investigate these hypotheses and questions in the current study.

2 Methods

The study is a 2 (task: multi-task vs. single-task) $\times$ 2 (stimulus size: large vs. small) $\times$ 2 (stimulus contrast: high vs. low) mixed-subject design¹. The dependent variables to measure visual task performance are the response accuracy and response time.

2.1 Participants

Twenty participants (10 females, average age: 23.35 years), with normal or corrected-to-normal vision, consented to participate the study. Each participant was compensated for their time and effort. This study was approved by the Institutional Review Board (IRB) at Nanyang Technological University, Singapore.

Participants were randomly allocated to the experimental (multi-task) and control (single-task) groups. Within each group, the participants were tested on all 4 possible combinations of large/small stimulus size and high/low stimulus contrast. The details of these conditions are explained in Procedure.

2.2 Materials

The study was ran using MATLAB [9]. Using the functions in Psychophysics Toolbox extensions [10][11][12], a fixation cross was presented at the centre of the screen. The test stimulus, a Gabor patch grating, was presented at various locations on the screen followed by a beep sound as an indication of response for the participants.

¹ Cognitive resource depletion was the between-subject variable while stimulus size and stimulus contrast were the within-subject variables.

2.3 Procedure

A randomised blocked design was adopted in the experiment. Each participant went through four different blocks; the blocks differed in terms of the parameters of the stimulus presented: large stimulus with high contrast, large stimulus with low contrast, small stimulus with high contrast, and small stimulus with low contrast (Fig. 1 shows the various stimuli). The order of the four blocks were randomised across all participants without repeat of any particular order. The test stimulus appeared at various locations on the screen, followed by a beep. Participants had to judge whether the grating was tilted to the left or the right by 45 degrees, by hitting the “<” and “>” keys on the keyboard respectively.

The experimental group, in addition to the above orientation judgment task, has to recite numbers backwards by multiples of three, starting from one hundred. If they were to make a mistake, they would have to start from the beginning. If they managed to recite smoothly till zero before the end of the trials, they will repeat the task from ninety-nine. The purpose of this secondary task was to simulate multi-tasking in various operations. Participants received sufficient training to practice the tasks before they were tested.

Fig. 1. Various Gabor patch gratings used as stimuli in the experiment. Large (21 pixels $\times$ 21 pixels) stimulus with high contrast (*top left*), large stimulus with low contrast (*top right*), small (11 pixels $\times$ 11 pixels) stimulus with high contrast (*bottom left*), and small stimulus with low contrast (*bottom right*)

3 Results

A multivariate analysis of variance (MANOVA) was ran to see the overall differences, with the response accuracy and time as the dependent variables, and task, stimulus size, and stimulus contrast as the independent variables. Main effects of Stimulus Size ($F(2, 17) = 32.99, p < .001$) and Stimulus Contrast ($F(2, 17) = 24.73, p < .001$), as well as the interaction effect of Stimulus Size $\times$ Stimulus Contrast ($F(2, 17) = 8.03, p = .004$) were significant in the multivariate analysis. However, none of the effects involving Task were significant ($ps > .05$).

The $2 \times 2 \times 2$ mixed analysis of variance (ANOVA) was then followed, with task as the between-subject variable, and stimulus size and stimulus contrast entered as the

within-subject variables. The ANOVA were run separately for each dependent variable – response accuracy and response time. The response accuracy and time were negatively correlated but not significant ($r = -.290, p = .215$).

3.1 Response Accuracy

The ANOVA on response accuracy found significant main effects of stimulus size ($F(1, 18) = 69.26, p < .001, \eta^2 = .794$) and stimulus contrast ($F(1, 18) = 49.53, p < .001, \eta^2 = .733$), but not task ($F(1, 18) = .114, p = .740, \eta^2 = .006$). Response accuracy in detecting large stimulus ($M = .848, SE = 0.029$) was significantly higher than in detecting small stimulus ($M = .674, SE = 0.022$). Similarly, the accuracy in detecting high contrast stimulus ($M = .809, SE = 0.025$) was significantly higher than in detecting low contrast stimulus ($M = .712, SE = 0.024$).

The interaction between stimulus size and stimulus contrast was also significant ($F(1, 18) = 15.03, p = .001, \eta^2 = .455$). The significant interaction between stimulus size and stimulus contrast may be related to the different effects of contrast in large vs. small stimulus size. For large stimulus size, there was a non-significant difference in accuracy, $t(19) = .527, p = .604, d = .117$, between stimulus of high contrast ($M = .854, SD = .119$) and stimulus of low contrast ($M = .841, SD = .161$). On the other hand, for small stimulus size, there was a significant difference in accuracy, $t(19) = 7.05, p < .001, d = 1.58$, between stimulus of high contrast ($M = .764, SD = .126$) and stimulus of low contrast ($M = .583, SD = .092$). No other interactions were found to be significant.

The participants' response accuracy are summarised in Fig. 2.

Fig. 2. Summary of participants' response accuracy

3.2 Response Time

All three main effects (task, stimulus size and contrast) are significant in response time. Participants in the experimental group showed a significantly higher response time ($M = 1.05, SE = 0.092$) compared to participants in the control group ($M = .716, SE = 0.092$), $F(1, 18) = 6.52, p = .020, \eta^2 = .266$. Furthermore, there was a significantly lower response time in detecting large stimulus ($M = .786, SE = 0.065$) compared to small stimulus ($M = .976, SE = 0.081$), $F(1, 18) = 7.35, p = .014, \eta^2 = .290$.

Similarly, response time for detection of stimulus with high contrast ($M = .812$, $SE = 0.062$) was significantly faster than for stimulus with low contrast ($M = .951$, $SE = 0.074$), $F(1, 18) = 10.69$, $p = .004$, $\eta^2 = .373$. None of the interactions were found to be significant.

The participants' response time are summarised in Fig. 3.

Fig. 3. Summary of participants' response time

4 Discussion

We found significantly poorer visual task performance when multi-tasking than when single-tasking in terms of response time but not accuracy. Such a finding implies that participants engaging in multiple tasks may not divide their attention among the requirements of the tasks simultaneously, but are instead alternating their attention between the tasks. The implications to multi-task operations is critical; it signifies that multi-tasking may not necessarily result in erroneous processing of visual stimuli (accuracy), but it does take a toll on timely response to incidences (response time).

Apart from multi-tasking, other factors may affect response accuracy. For example, the interaction between stimulus size and stimulus contrast on accuracy was significant. It suggests that erroneous processing becomes a concern when a heterogeneous variation of visual stimuli needs to be detected. Specifically, contrast has less effect on accuracy when the stimulus is large, but impairs performance when the stimulus is small. This carries implications in multi-task operations when the environment of the area under surveillance varies. For instance, external factors such as weather (e.g. rainy or foggy) can influence contrast of the surrounding objects in air traffic control.

Some limitations may be present in this study. Firstly, visual task performance (accuracy and response time) with distance from the point of fixation were not examined in this paper as there was a lack of a meaningful trend in the threshold of the FFoV. In other words, visual task performance of the participants did not seem to decrease consistently with increasing distance from the point of fixation. This might be because the task performance reaches plateau without much variations in this aspect. Secondly, as the cognitive load required by the secondary task used in this study was not measured, it is plausible that the task was not sufficiently difficult to reveal other impacts of multi-tasking. Therefore, the secondary task should not be regarded as representative

of the actual tasks (which might utilise a greater cognitive load) that such operations might require their operators to engage in.

Moving forward, future studies should address these limitations, to (1) aim to determine how the threshold of the FFoV vary with task requirements and stimulus parameters and (2) replicate the study using secondary tasks that are more representative for the context in which the results would be applied in. Such findings can go a long way in reducing human errors that can potentially result in dire consequences in multi-task operations in surveillance, such as that of the air traffic controllers.

5 Conclusion

As technology advances, human beings are presumed to be able to multi-task [13]. This research demonstrated the potential impact of multi-tasking on visual task performance. . Even for a simple visual orientation judgment task, imposing a secondary task can impair one's visual task performance. When we consider the multitude of possible tasks in multi-task operations, this issue could only be further complicated. Further research in the future can inform us the necessary adjustments to task requirements in multi-task operations.

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