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Attentional capture in stimulus rich computer interfaces[1]

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Abstract

To explore the degree which attentional set in one task interferes with performance in a secondary task, we have developed a prototype SRRI test system. This comprises a central task involving driving through a virtual maze and the presentation of an intermittent stream of competing stimuli of varying levels of salience. Centrally presented arrows are followed in the driving task and the stream of competing stimuli is presented via a head mounted display. The colour relationship between the central arrows and stimuli in the competing stream is varied. How this "task prescribed" colour relationship impinges upon attentional capture by stimuli in the competing stream is investigated. This experiment has revealed no discernible carryover effect of attentional set from one task to the other in either accuracy or reaction time for detecting the targets in the stream. Thus, the attention system seems to be adept at allocating feature based attention in a way that does not spontaneously migrate from one task to another.

Introduction

The visual world contains more information than can be processed by any real-time cognitive system. The human brain uses a multi-stage attention mechanism to deal with this problem. At the input level, the eyes can be moved around, selecting parts of the visual world around us with saccades. This visual input from the retina is then subject to a spatial form of attention, which selectively amplifies some regions of the visual field (Posner 1980). Beyond the spatial filter, the attention system can select items for processing based on certain features, such as a particular shape or color.

All of these mechanisms are under the control of top-down volitional control, allowing a person to tune their attentional filters as necessary to detect targets that are relevant to their current goals. These mechanisms are clearly critical in allowing us to function in situations of information overload. If a user is aware of the salience of a red light in a cockpit display, attention can be configured to enhance the probability that red stimuli will be selected for further processing by the attentional system.

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[1] The full reference for this article is, B. Wyble, H. Bowman, and P. Craston. "Attentional capture in stimulus rich computer interfaces." Technical Report 7-06, Computing Lab, University of Kent at Canterbury, September 2006.

Transient Attention and Contingent Capture

In addition to relatively static spatial and feature based filters, the visual system also has a reactive method of deploying attention. Within just 50 ms of the onset of a salient visual cue, target detection is enhanced at the cued location, indicating a rapid and reactive deployment of attention (Nakayama & Mackeben 1989). This may be related to the phenomenon of attentional capture (Theeuwes 1994), the theory that a window of attention can be deployed in response to salient visual objects, which makes concurrent target detection more difficult at other spatial locations because this reactive mechanism is already occupied.

A debate has centered around the degree to which this reactive attention mechanism is under top-down control. Recent work has demonstrated that the attention settings of the subject, for a particular color, makes it more likely that distractors of that color will be able to capture attention, a phenomenon known as contingent capture (Folk, Leber & Egeth 2002, Serences et al 2005).

Recent computational work has demonstrated that this form of attention plays a critical role in our ability to perceive rapidly presented stimuli, especially in the context of Rapid Serial Visual Presentation (Bowman & Wyble 2007; Wyble, Bowman & Potter, submitted).

What this work suggests is that the attentional settings of the subject (e.g. in search of a particular colour or shape) affect the ability of stimuli with those features to capture attention. This idea is critical in the present work, in which we test the ability of the attentional set specified in one task, to affect the ability to detect rapidly presented targets in another task.

Dual-Task Research

There is a large literature on the ability of subjects to switch from one task to another and the delays imposed by the switch (e.g. Arrington & Logan, 2004). The ability of the attentional system to mediate two different tasks at the same time is less well studied, as these paradigms make it difficult to isolate a single cognitive function.

However, simultaneous performance is of critical importance for complex interfaces, such as in cockpits. One critical question that arises in such research is how flexible the attentional system truly is. For example, if a subject is looking for a certain color in one task, does that affect their ability to perceive targets in a second task for which that color distinction is irrelevant or reversed? In other words, is there a single attentional filter mechanism that needs to be shared across multiple tasks? Or can each task utilize its own dedicated filter?

It is well known that there are fundamental limitations in our ability to do multiple things concurrently. For example, ideas such as central capacity theory (Kahneman 1973, Tombu & Jolicoeur 2003) are firmly established theoretical frameworks. Many of the experimental paradigms that study such central limitations report differences in response times that exist between performing two unrelated tasks. It is consistently found that doing two things at the same time results in slower performance, decreased accuracy, or both. For example, the psychological refractory period (PRP) refers to the increased time to respond to a second stimulus after having responded to a first one

(Ruthruff, Pashler, & Hazeltine 2003), a cost which can be observed even for two tasks in different modalities.

What is less well studied is the specific pattern of interference between tasks that use the same perceptual system. The question we ask here is to what degree do filters in one perceptual system (e.g. vision) cross tasks that rely on the same system; see Figure 1. This question is of vital importance for the design of any complex interface. If one display requires users to attend to red and ignore green, while another requires the opposite, what costs do these conflicting instructions incur if the user is to process both of these displays simultaneously?

Some work has been done that is relevant to this question. Olivers & Watson (In Press) had subjects monitor an RSVP stream of characters for letters of a particular colour. Immediately following this task, subjects had to rapidly count the number of dots of a particular colour in a display. It was found that if the colour of the dots to be counted matched the colour of the distractors in the RSVP task, performance was impaired, indicating that the colour filter established for one task had carry over effects onto a secondary task, even though that distinction was entirely irrelevant. However these two tasks were performed sequentially, not simultaneously.

Most & Astur (Under Revision) addressed this question directly, by having subjects maneuver a virtual car through a city, attending to signposted arrows of one colour, while ignoring arrows of another colour. While driving, subjects would occasionally have to break to avoid hitting a motorcyclist, appearing suddenly in front of the car. It was found that subjects were faster at braking in response to cyclists of the same color as the arrows to which they were attending.

These results are suggestive of cross-task interference although it could be argued that this is not a true case of dual-task performance, as steering and braking could be considered parts of the same task.

What we address here is the degree to which the visual system exhibits interference between concurrent, and unrelated tasks fed from the same modality. The question proposed is whether the same kind of interference demonstrated by Most & Astur will be found for independent tasks.

Combining Rapid Presentation and Driving Tasks

To test the interference between independent tasks that use a common sensory modality, we combine a colored-arrow guided navigation task, as in Most & Astur, with a task requiring rapid identification of digits presented concurrently in a heads-up display. The colour of each digit is randomly chosen, but subjects are to ignore the color.

If the interaction between the colors of the arrows and the motorcyles in the Most & Astur task was due to the fact that subjects were sharing the same visual input between the tasks, we should expect to observe the same effect here. On the other hand, it is possible that if the visual system is being used for two distinct tasks, that a visual filter can be applied to the visual input to one of the tasks without strongly affecting the other.

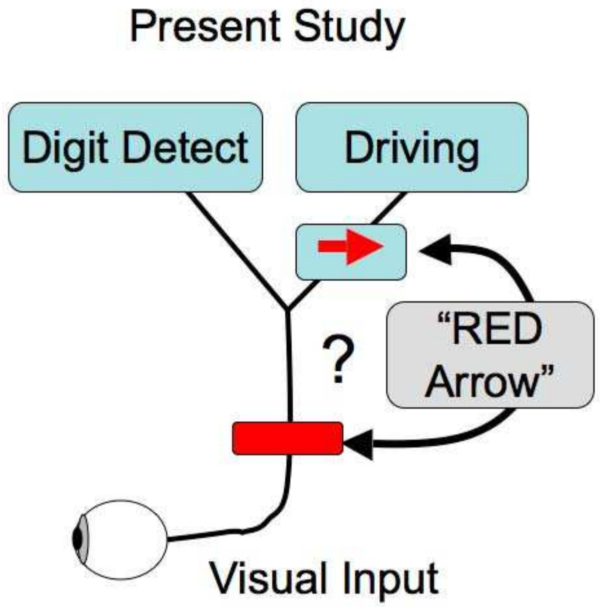

Figure 1. The question addressed by the current study. Can visual attention selectively apply a colour filter to the visual input of one of two independent tasks without influencing the other?

In our experiment, one group of subjects navigate the maze guided by black arrows and the other guided by white. Meanwhile, in a secondary display, they attempt to detect digits that are white, black or coloured.

A critical aspect of the current task is that, on average, subjects in both the black and the white arrow groups are seeing the same visual stimulus. The only difference between them is the instructions that they are given at the start of the experiment (e.g. to attend to white or to black arrows). Thus, any differences observed would necessarily be the result of top-down task set.

Methods:

Subjects:

26 volunteer subjects were selected from the University of Kent Campus. All were between 18 and 40 years of age, right handed and had normal or corrected vision.

Task 1: Subjects attempted to pilot a vehicle through a virtual maze which contained a large number of black and white arrows. Upon successful escape from the maze, subjects were instructed to drive to the edge of the arena, at which point they would be teleported back into the center of the maze. Subjects were instructed to escape from the maze by following either black or white arrows, and to ignore the opposite color. Movement was controlled entirely by mouse, with forward and backward speed controlled by moving the mouse forward or backward, and turning controlled by left/right movement.

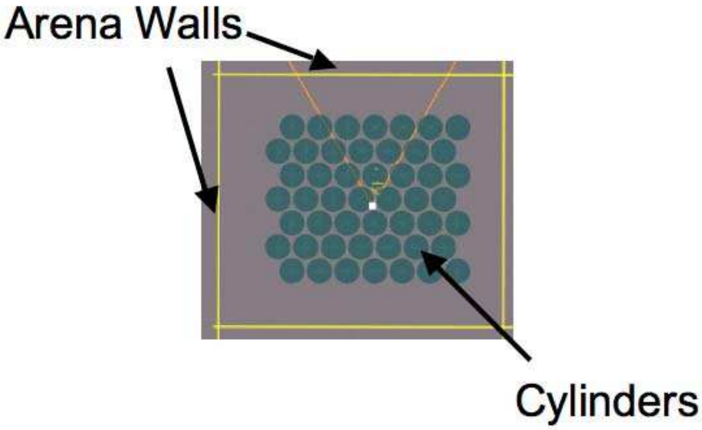

Figure 2. The shape of the arena navigated by subjects. Each clylinder was a solid object and subjects navigated between them to escape from the square.

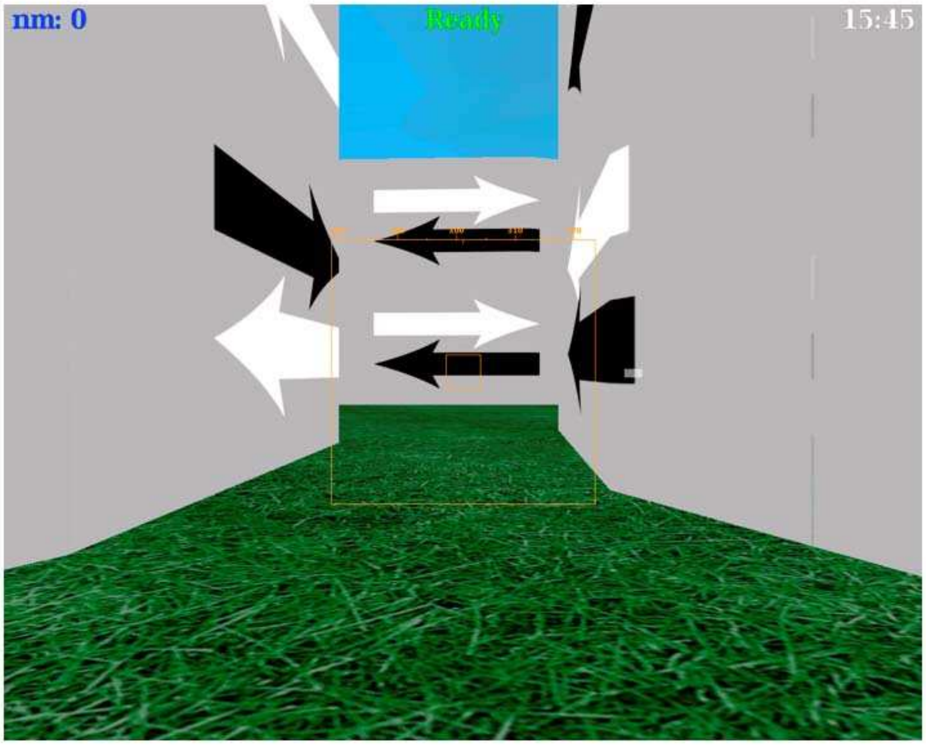

Figure 3. The view subjects saw of the arena, looking between two cylinders at the next. At each such T intersection, subjects were to follow one of the colours of arrow, ignoring the other.

The maze was composed of large cylinders in a hexagonal packing arrangement in a grid of size 7 by 7, as shown in Figure 2. Each cylinder was surrounded by a repeating pattern of black and white arrows as shown in Figure 3. A cylinder had one black and one white arrow, which would vary from cylinder to cylinder in a random fashion. Each possible combination of the three factors: top/bottom, same /different orientation, and left/right was represented, leading to a total of 8 possible patterns.

The arrangement of arrows was such that following either black or white arrows would eventually lead to the edge of the maze but subjects were not made aware of this fact, nor did they report any such suspicion at the end of a trial. Subjects in both black and white groups saw exactly the same maze, only instructions differed.

When subjects managed to escape from the block of cylinders, they were instructed to head straight to the nearest wall, which would teleport them back to the center of the maze.

Task 2: Subjects wore a head mounted display (Data Glass 2 by Shimadzu, Figure 4). The display was centered over the right eye, and ran at 800 x 600 resolution, and a 60 hz refresh rate. In the center of the black display, a gray square, approximately 1.5 x 1.5 degrees of visual angle, contained the rapidly presented targets.

Figure 4. The Data Glass 2 wearable display.

On each trial, subjects were shown a single target item, randomly drawn from the digits 1, 2 or 3. This target was present for 117ms and masked by an immediately following symbol drawn randomly from the set #, %, §, £, @, ±, ? or **Ω**, presented with a duration of 117 ms. Targets were either black, white or a randomly selected color from the set (cyan, yellow, purple, green) with an equal number of each of the three possibilities per subject. Masks were the same colour as the target they followed.

Subjects were instructed to look for digits and to enter them into a number pad on a keyboard as rapidly as possible. Subjects were also encouraged to focus on the maze navigation task and to move as fast as possible, and to report any digits that they could, without worrying about missing some of them. All subjects were monitored to ensure that they were following the correct colour of arrow throughout the task.

Results

Raw accuracy scores for detection of digits are displayed in figure 5, broken down by the color of the arrow that the subject was seeking, as well as the color of the digit. There is a trend towards increased detection of white digits for subjects in the white arrow condition (61% vs 57%). Furthermore, reaction times are slightly shorter for responding to white letters in the white arrow condition (Figure 6, 707ms vs 709ms). An ANOVA revealed neither of these effects to be significant. (F(1,24) = .48, p > .4; F (1,24) = .005, p > .9).

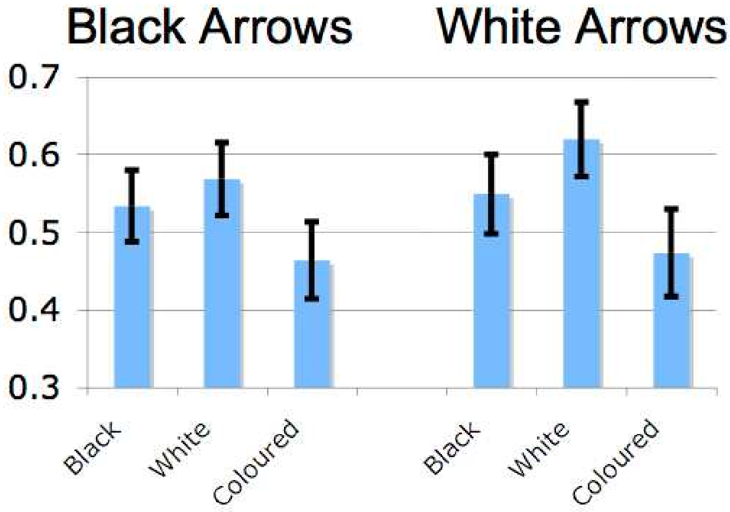

Figure 5. Accuracy of digit report for subjects in the two conditions.

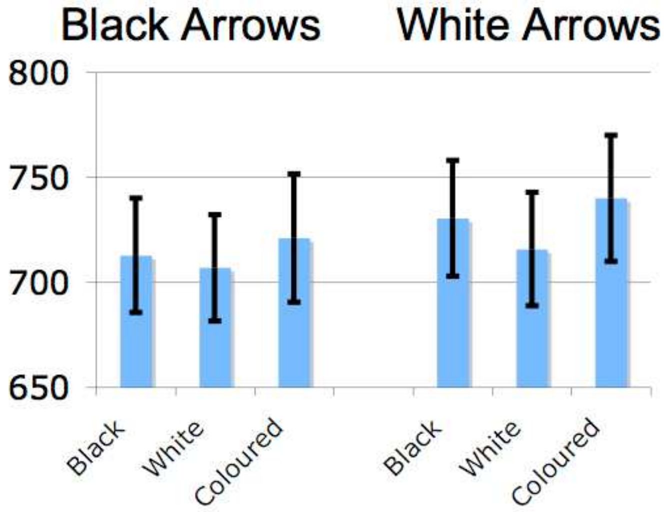

Figure 6. Reaction times of subjects reporting digits of different colours in the two conditions.

We also compared the ratio of black to white digits reported for each subject in the two conditions. This ratio was .89 (std err of .05) for subjects in the white arrow group and .94 (std err of .05) for subjects in the black arrow group. This difference was not significant (F(1,24) = .57, $p > .4$).

Therefore it seems that subjects were remarkably insensitive to the congruency between the colour of digit targets and the arrows that were guiding their behavior. The colours of the digits were not without some effect on performance. White digits were detected more readily than coloured digits (F(1,24) = 4.6, $p < .05$) but this is likely to be the result of differences in contrast between black, white and coloured digits. Furthermore, this test would not stand up after correction for multiple comparisons.

Discussion

The results of our study are interesting for what they say about the flexibility of the visual attention system. Apparently, we have the ability to process different tasks independently, even if they overlap in features. The task described here, despite being application oriented, is very sensitive to differences in processing different colours, both in accuracy and reaction time. The fact that subjects from the different groups were statistically identical across several different analyses is strong evidence that the visual system can segregate processing very effectively.

This is not to imply that cross task colour-interference in previous research, such as Most & Astur or Olivers & Watson (In Press) has not been replicated. Rather, our experiment may more effectively isolate the two tasks. There is no overlap of motor task set in our experiment. Subjects see two different displays simultaneously, each of which displays a different kind of information. Furthermore, there is no overlap between the responses that subjects are to produce. Driving is performed with wrist and hand motions of the right arm, while digit responses are finger key presses from the left hand. The only commonality is that the same visual input is used in both. The attentional set, defined by the arrows, must be imposed beyond the point at which input from the two signals diverges (see Figure 1).

What our results suggest is that the effect observed by Most & Astur, may have been specific to situations in which the interference is between components (e.g. braking and navigation) of a single task (e.g. driving), rather than across components of two completely independent tasks (e.g. driving and detecting digits) as we have considered here.

The effect of Olivers and Watson is notable for the small size of the effect elicited by changing the congruence between the secondary task, and the distractors of the RSVP stream. Small changes in the number of dots to be counted (e.g. from 2 to 3) caused large changes in the number of errors, indicating that the counting measurement was a sensitive measure. Despite this sensitivity, whether the dots were target or neutral colours made no difference. Dots of the distractor colour were harder to count accurately, but the effect was small in contrast to the increased difficulty of counting 3 instead of 2 dots. Increasing the set from 2 to 3 dots in a neutral colour increased the number of errors from 32% to 61%, while the effect of presenting the dots in the distractor colour only increased errors to 45%.

This research was undertaken to explore limitations of the visual attention system's ability to perform multiple concurrent tasks. The results of this experiment suggest that attention is less susceptible to interference between tasks than previous research has suggested. This could indicate that attention can create a number of filters consisting of specific form-colour conjunctions, rather than applying more generalized colour filters to all visual input.

Future Work

A number of unanswered questions remain. In our experiments, the target set in one task was irrelevant to the other task and we observed no interference. Would the same be true if the attention system had to maintain mutually incompatible task sets? That is, what if subjects were to follow black arrows while selecting white digits from a concurrent stream?

Does this same flexibility apply to shape discriminations? Often in reading a complex display, our attention is tuned to look for a particular shape or word. Our research suggests that reactive attention can be configured to respond selectively to a particular category, such as letters or digits (Wyble, Bowman & Potter, submitted). Can this system be configured to attend to letters while ignoring digits in one display, while concurrently attending to the opposite combination (attending digits, ignoring letters) in a separate display?

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