Walking, talking and looking:

effects of divided attention on gaze behaviour and visual search performance in a real-world environment

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Introduction

Searching for an object in a cluttered environment can be complex and time consuming. Increasing evidence suggests that "inefficient" (or serial) search requires some aspect of working memory. Eye movement studies (e.g. Gilchrist & Harvey, 2000), show that people are much less likely to revisit previously fixated areas than unfixated regions in a visual search task. Dual-task studies also show that adding an "executive working memory" task (holding and manipulating items in memory) to a visual search task can significantly impair search efficiency, while a simple "memory maintenance" task (simply holding items in memory) has no effect (e.g. Han & Kim, 2004). Importantly, this seems to hold true across both spatial and nonspatial domains (Anderson et al., 2008), suggesting the involvement of a central (rather than specifically spatial) executive working memory in visual search.

Most research in visual search has been conducted in the controlled environment of the laboratory. However, accumulating evidence suggests that our perception and behaviour may be very different in more natural environments using more active, realistic tasks – perhaps because such tasks are inherently more effortful. In active foraging tasks (a "real-world" equivalent of visual search), for example, where people have to move around to locate a target, they tend to revisit previously checked locations significantly less compared with more passive, laboratory-based tasks (Smith et al., 2008). Indeed, even the simple task of walking seems to involve central cognitive resources (Yogev-Seligman et al., 2008), and can significantly alter our perception of those around us (Jacobs & Shiffrar, 2005).

Aims

We aimed to discover whether central executive, working memory processes play a role in visual search, over and above the cognitive mechanisms that are presumably required for walking or maintaining balance, in a real-world, active, visual search task. Specifically, we examined the effects of dual-task procedures requiring non-spatial, executive working memory (backwards counting) on an active visual search task in a real environment on two recorded dependent variables: (**1**) time taken to find the target; and (**2**) eye movements.

Methods

Participants

Fourteen young adult participants (8 males and 6 females, aged 19-25 years), were recruited from the student population of Edinburgh Napier University. All had normal or corrected-to-normal visual acuity and normal colour vision, and no sensorimotor or other neurological impairments.

Apparatus

A head-mounted eye tracker (Mobile Eye, Applied Science Laboratories) was used to record the eye movements of participants as they searched for a target object in a real-world environment. A lightweight pair of goggles held two small video cameras, one to capture the visual scene from the perspective of the participant, and another to record the corneal reflections from an infra-red light aimed at the eye (see figure 1).

Fig.1: *ASL Mobile Eye*

Video data from both cameras were recorded onto a modified Sony Camcorder carried in a back-pack, interlaced at a combined frequency of 25 Hz. The interlaced footage was then transformed into a combined video file showing the visual scene as viewed by the participant, with the centre of gaze fixation superimposed as a red circle.

Procedure

Participants were fitted with the eye tracker in the laboratory and gaze position calibrated using a 9-point grid, after the procedures had been explained and they provided informed consent to participate. They were then shown a copy of the target object – a white card sized 6 x 4 inches containing the type-written words "EYE TRACKING" in black – and told they would be asked to find an identical object in a shop window outside (see figure 3). Participants were asked to indicate when they had located the target by maintaining fixation on the target and issuing a verbal acknowledgement (e.g. "I've found it"). They were then escorted outside by the experimenter and into the surrounding study area, a popular district of Edinburgh, UK. At the start of the test route, the procedure was summarized again, and participants asked to set off along the pavement and find the target. The experimenter walked a short distance behind (but out of sight of) the participant throughout the test.

Experimental Conditions

In a repeated-measures design, participants completed the task under both "control" and "dual-task" conditions. In the "dual-task" condition, participants had to search for the target while counting backwards in 7s from 100 – a task widely believed to require non-spatial, working memory. A backward-counting task was chosen because it typically demands a sustained level of effort (vital during the real-world task which took minutes to complete), and can be conducted during free-walking without the use of additional materials. The sequence of conditions (control vs. dual-task) was counterbalanced to control for any order effects. All work was conducted according to the Code of Conduct of the British Psychological Society and was approved by Edinburgh Napier University's Ethics Committee.

Eye Movement Analysis

Gaze position was coded manually on each frame of the combined video file according to both "where" and "what" categories.

Results and Discussion

(1) Time taken to find the target

Participants took significantly longer, on average, to find the target in the "dual task" condition (4.8 s) compared with the control (2.4 s) [t (-2.338); df (13); p < 0.05)]; see figure 2. This supports findings from more traditional, laboratory settings (e.g. Anderson et al., 2008; Han & Kim, 2004), and suggests that searching for targets in a real-world, large-scale environment requires a non-spatial, central executive process, over and above what is also required for walking and maintaining position in outdoor space. The findings further suggest that the "real-world" approach taken here is robust, and suitably sensitive to experimental manipulation.

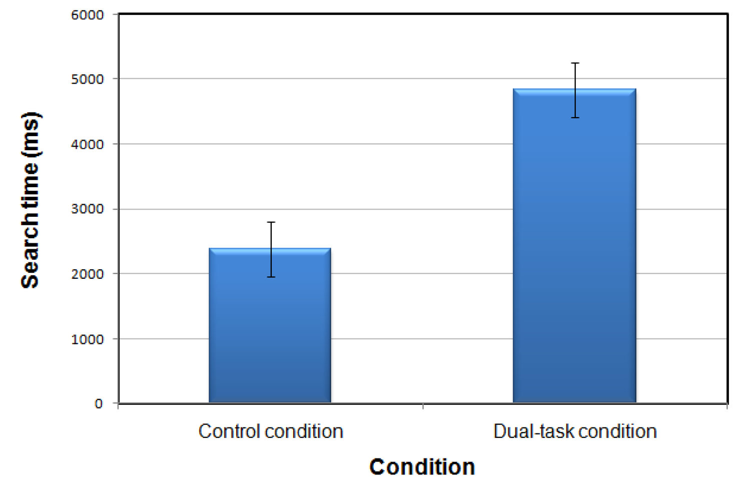

Fig. 2*: Time taken to find the target in "control" and "dual-task" conditions.*

(2a) Eye movements: where did people look?

The deficit in dual-task visual search efficacy observed here may be due, at least in part, to less effective eye movement strategies under conditions of high cognitive demand. We analysed the gaze behaviour of participants during the search tasks to examine whether or not eye movement patterns were different between the two conditions.

First, although highly variable between individuals, the distribution of fixations often appeared more widespread in the dual-task condition compared with the control (see figure 3).

Fig. 3: *Example gaze data for one participant during the course of (b) a "control" trial; and (c) a "dual-task" trial within the target window display (a).*

Analysis of "where" participants looked was carried out in terms of proportion of time fixating different regions of egocentric space, defined either *vertically* (down, central, top) or *horizontally* (left, centre, right) (see figure 4). Results suggest that on average participants tended to fixate on central regions of the shop display respective to their position in both control and "dual-task" trial. Any differences between conditions were small and not significant.

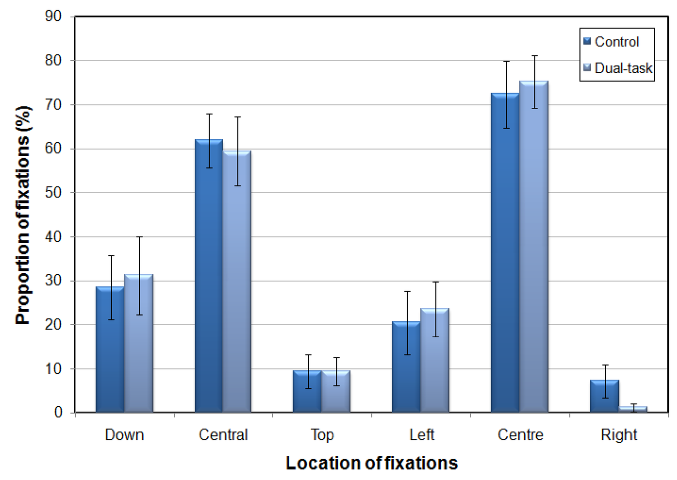

Fig. 4: *Proportion of time (%) spent fixating regions of egocentric space.*

We were also interested in whether *scanning patterns* were different between control and dual-task conditions. Because the resolution of the mobile eye tracker does not permit analysis of saccades, we coded gaze position on each frame of a given trial according to a 30 x 20 grid, corresponding to measured dimensions of real-world space (cm), and calculated the approximate distance of this location from that on the previous frame. This procedure showed, for one pair of trials from one participant, that the dual-task condition was associated with (1) smaller "saccade" distances; (2) less prolonged inspection at locations between "saccades" and (3) more prolonged inspection of target before a positive identification (see figure 5). Further analysis is needed to test if this is true in general across all participants.

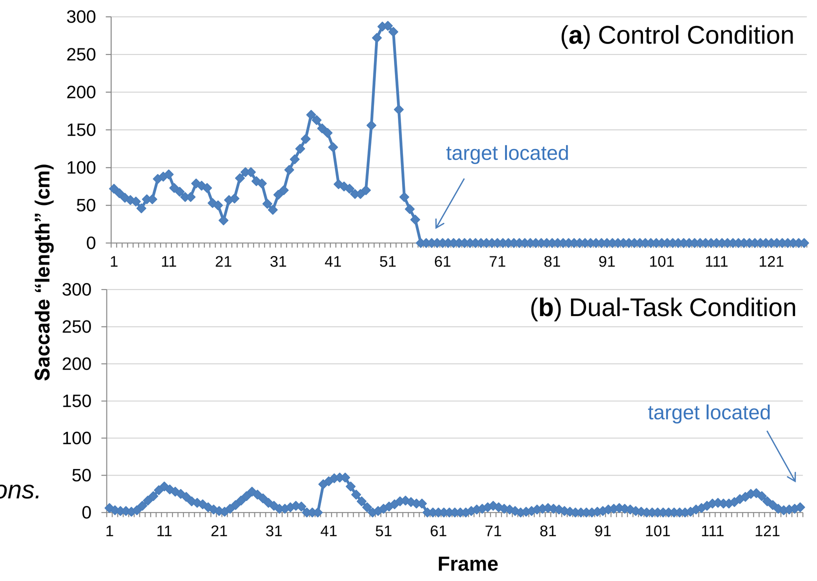

Fig. 5*: Approximate length of "saccades" for one participant in (a) control and (b) dual-task conditions.*

(2b) Eye movements: what did people look at?

The proportion of time fixating different object-based regions of interest did not differ significantly between control and dual-task conditions across the original seven categories (see figure 6a). However, when the categories were collapsed into "task-relevant" (shop display, target, objects that were similar in size and shape to the target) and "task-irrelevant" (buildings, people, other), we found that participants in the dual-task condition fixated significantly less on task-relevant compared to task-irrelevant objects (81% vs. 89%; t (2.16); df (13); p = 0.05). These findings suggest that maintaining focus on task-relevant objects requires the activity of central, non-spatial cognitive processes.

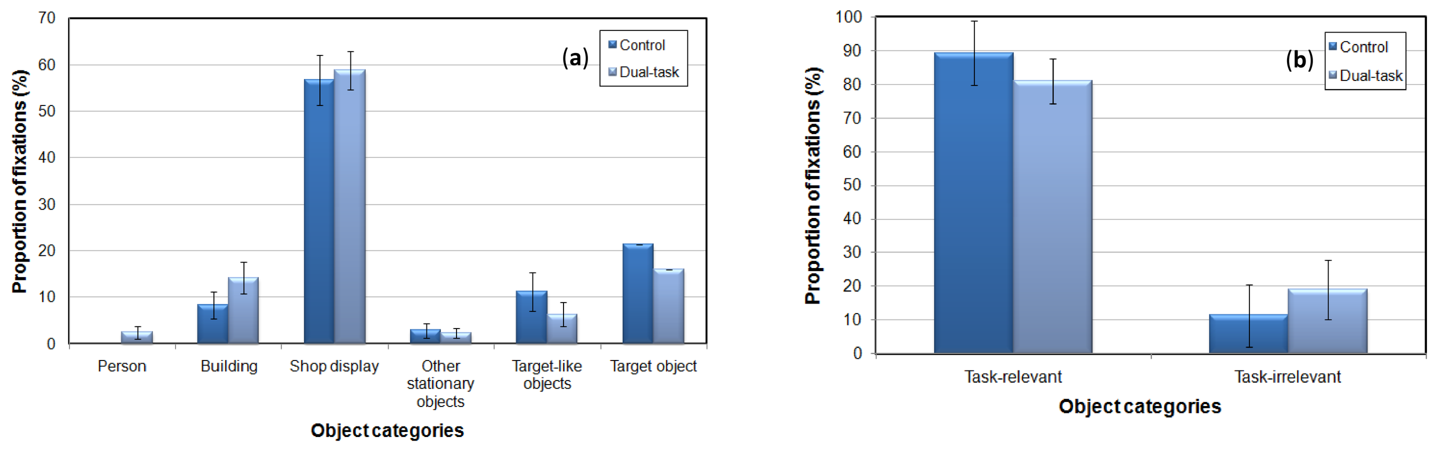

Fig. 6*: Average proportion of time fixating object-based regions of interest under control and dual-task conditions according to (****a****) six-category framework; (****b****) two-category framework (task-relevant and task-irrelevant).*

Conclusions

1. Active visual search tasks in large-scale environments require the operation of a limited-capacity, non-spatial, central executive process, over and above what is required for walking and maintaining position in space.

2. Longer search times in dual-task conditions may be explained, at least in part, by differences in eye movement strategies – for example, scanning a wider area (figure 3), scanning in a more "flat" manner, with shorter saccades and shorter fixations (figure 5) and fixating less relevant objects for longer periods of time (figure 6). Further analyses (ongoing) are needed to examine whether these findings are applicable to a wider sample.

References

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