
Is visual search really like foraging?

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Abstract. The visual-search paradigm provides a controlled and easy to implement experimental situation in which to study the search process. However, little work has been carried out in humans to investigate the extent to which traditional visual-search tasks are similar to more general search or *foraging*. Here we report results from a task in which search involves walking around a room and leaning down to inspect individual locations. Consistent with more traditional search tasks, search time increases linearly with display size, and the target-present to target-absent search slope is 1 : 2. However, although rechecking of locations did occur, compared to more traditional search it was relatively rare, suggesting an increased role for memory.

1 Introduction

The last 30 years have seen an enormous research effort devoted to studying visual search. There are a number of justifications for this focus. First, visual search provides a convenient method to study low-level perceptual processes by using a reaction time measure. Such a justification has resulted in a large number of studies that attempt to identify visual properties that can be extracted in parallel as distinct from those that require some serial-like processes (eg Rensink and Enns 1995; Gilchrist et al 1997; Davis and Driver 1998).

A second justification is that visual search provides a constrained experimental paradigm in which to study a more general and ubiquitous behaviour. Indeed, many review papers in this area start with examples of everyday foraging tasks such as finding car keys or finding a book on the bookshelf (eg see Wolfe 1994, page 202). Klein and MacInnes (1999) have recently explicitly argued that inhibition of return acts in visual search as a “foraging facilitator”.

This second justification for carrying out visual-search experiments begs the question to what extent *is* visual search a good model for foraging in general? As far as we know, no systematic study has been carried out to investigate this. The experiment reported here is a first attempt at testing this relationship.

In order to test the extent to which visual search is a valid model for foraging we constructed a foraging task in which participants search for a marble hidden in a film canister in a room (see figure 1).

There are a number of well-established properties of visual search. First, when search becomes more difficult, search time increases linearly with display size for both target-absent and target-present displays. In addition the target-present slope is half the target-absent slope (Treisman and Gelade 1980). In the current study, we aimed to see whether these features of visual search also characterised foraging.

We were also interested in the memory mechanisms that support foraging. Gilchrist and Harvey (2000) used a visual-search paradigm and recorded eye movements to investigate memory in search. They argued that, if search was supported by a perfect memory for which locations had been visited, then participants should never return to refixate a distractor. In the current study, in an analogous manner, we measured the extent to which rechecking occurs in foraging.



Figure 1. An example display with a participant reaching down to check if the film canister contains a marble.

2 Method

2.1 Participants

There were ten participants with a mean age of 26 years (range 22–33 years). All participants were right-handed and were recruited with posters placed in the Psychology Department.

2.2 Displays

A 10 by 10 (3 m × 3 m) grid was marked on the carpeted floor of a room with map pins of the same colour as the carpet. For each trial, black film canisters with grey lids were placed at random locations on the grid. On half the trials, one of the film canisters contained a marble which could only be located by reaching down and shaking the canister. The displays also varied in the number of canisters—there could be 4, 12, 20, 28, or 36.

Each participant carried out a total of 20 trials: 2 trials at each display size for both target-present and target-absent. Trial types were randomised in a block for each participant.

2.3 Procedure

All participants were run individually and continuously on the 20 trials, with a between-trial interval to reset the display during which the participant was in another room. Participants were asked to search for a ball in one of the canisters, which could be identified by shaking a canister. All began the search from a point $\frac{1}{2}$ metre below one side of the grid. Participants were instructed that the target would not always be present, and that the number of canisters would change across trials. Only two constraints were placed upon participants: (i) to be careful not to knock any of the canisters over in the process and return any they did knock over to their original positions; and (ii) to use one hand only. Participants indicated when they had completed their search. Each participant was recorded onto digital video and subsequently analysed. We recorded two key variables from these videos: (i) the search time, defined as the time from the first to last touch of canisters; and (ii) rechecking frequency, defined as the number of times in a trial that a given canister was returned to.

2.4 Results

One participant was consistently unable to restrain from using two hands and so has been excluded from subsequent analysis. All other participants used their right hand.

2.4.1 Search-time data. Overall search times are plotted in figure 2. Search time increased linearly for both target-absent and target-present. For target-present the search slope, which indicates the average increase in search time per additional items, was 0.67 s per item ($t = 6.61$, $p < 0.001$) with an intercept of 1.25 s ($t = 0.534$, ns). For target-absent, the search slope was 1.57 s per item ($t = 11.4$, $p < 0.001$) with an intercept of -0.98 s ($t = 0.302$, ns). The target-present to target-absent search slope ratio was 1 : 2.33. To test if the search slope ratio differed significantly from 1 : 2 we carried out a further linear regression with the target-absent search times divided by 2. There was no effect of target-present/target-absent in this regression ($t = 0.363$, ns), indicating that the search slope ratio did not differ significantly from 1 : 2.

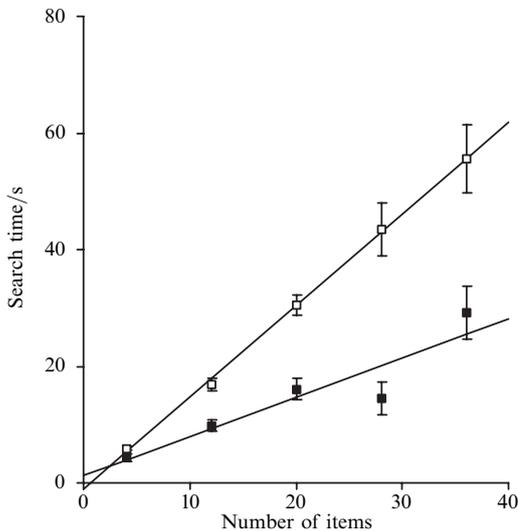


Figure 2. Search time plotted against the number of items in the display. The filled symbols relate to target-present and the unfilled symbols to target-absent. Error bars are standard error of the mean.

2.4.2 Rechecking data. Rechecking frequency is plotted against display size for target-absent and target-present in figure 3. Rechecking rates were typically between 0 and 2 rechecks per trial. Overall, there was more rechecking in target-absent trials ($N = 60$) than in target-present trials ($N = 11$). This probably reflects the overall time spent searching in these two conditions (see figures 2 and 3). The extent of rechecking also increased with display size.

Compared to the number of movements made, these rechecking rates are low. For example for the largest display size (36) participants made on average 20.3 inspections for target-present and 35.3 inspections for target-absent, with an average of only 0.61, 1.72 rechecks per trial.

3 Discussion

Foraging time increased linearly with number of items and the target-present to target-absent slope ratios did not differ significantly from 1 : 2. This is consistent with visual search. A number of authors have argued that this property of the search functions is a hallmark of serial self-terminating search in which each item is sampled in turn until the target is located (eg Treisman and Gelade 1980). However, such an interpretation is far from being noncontroversial as such functions can result from noisy parallel systems (Humphreys and Müller 1993). In this foraging task, it is clear that search does occur in a serial manner. Participants can only sample one item at a time and

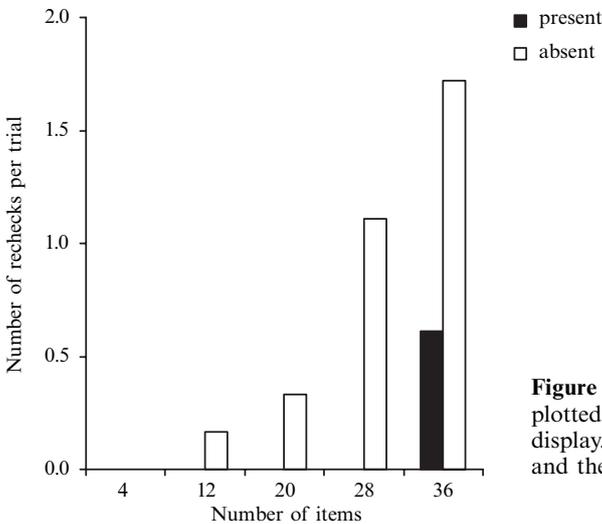


Figure 3. The number of rechecks per trial plotted against the number of items in the display. The filled bars relate to target-present and the unfilled bars to target-absent.

then move on to the next item. Serial self-terminating models of visual search also assume that once an item is sampled it is excluded from the search set. In this sense, these data do not fit the strictest of serial self-terminating models as revisits do occur.

Rechecking in this foraging task was rare, suggesting an important role for memory. Memory here allows the participant to avoid locations that have been visited and facilitate search. When rechecking did occur it was systematically related to the display size. This suggests that, rather than being random, these rechecks represent the limits of the mechanisms that were determined by either the display size or search time.

In a similar manner to the current study, Gilchrist and Harvey (2000) investigated refixation frequency in visual search. The closest direct comparison that can be made between the current data and the data from Gilchrist and Harvey (2000) is between the larger display size here (36 items) and the fixed display size used in the saccade study (31 items). Note, first, that the overall search times are radically different: in the search task the average overall search time was 1.9 s for target-present and 4.2 s for target-absent. In contrast, in the current experiment, average search times were 29 and 56 s for target-present and target-absent, respectively. One of the fundamental properties of memory systems is the drop in memory performance over time (eg Ebbinghaus 1885/1913). As a result, such a large increase in overall search time should reduce the efficiency of any store for visited locations. This difference in search time between the two studies also co-occurs with an increase in the number of visits or fixations that occur. In the saccade study, participants made on average 5.7 fixations for target-present trials and 14.1 for target-absent trials. In the current study, participants made on average 20.3 inspections for target-present and 35.3 inspections for target-absent. The number of locations or items that have to be retained also has an influence on memory performance (eg Miller 1956). It would appear then that memory plays a more important part in determining foraging behaviour in the current study compared to search as reported by Gilchrist and Harvey (2000). This suggests that foraging and search differ in the *extent* to which they rely on memory to prevent revisits. However, this may not reflect the memory *capacity* of either search process, but rather the extent to which the memory capacity is exploited in any given task.

The estimates of the extent and importance of memory mechanism in visual search vary widely (eg Horowitz and Wolfe 1998; Klein and MacInnes 1999; Gilchrist and Harvey 2000; Shore and Klein 2000). Gibson et al (2000) offered one possible resolution to this issue. They argued that the extent of memory for 'tagging' locations depends

on the extent to which the benefits of tagging each location outweigh the costs of holding in memory a number of locations. Such a cost–benefit model may include the difficulty in returning to the previously visited locations to recheck them. In the current foraging experiment, there is a substantial cost associated with revisiting a location that has been previously inspected: the participant has to walk across the room, lean over, and shake the canister. As a result, the foraging task may be an example of a search task in which memory is important because of the cost of forgetting.

The difference in revisiting frequency reported here and refixation frequency reported by Gilchrist and Harvey (2000) may not simply reflect differences in the extent of ‘tagging’ of locations. Multiple types of memory are probably important in search (Shore and Klein 2000): from remembering which items have been visited to the identity of the target. Search may also be supported by a long-term memory of a strategic route followed consistently on each trial (for example “search left to right”). Such strategic scanning appears to be an important characteristic of eye-movement patterns in visual search (Gilchrist et al 1999) and refixation frequency in search is presumably modulated by the extent to which such a mechanism is employed. Refixation frequency may be influenced by the extent to which each individual item is tagged *and* the extent to which strategic scanning occurs. This has implications for the current study, the relatively small revisiting frequencies in foraging could represent an increase in strategic scanning or an increase in the use of a memory for which individual items have been inspected on any given trial. Which type of memory leads to this difference across the two types of ‘search’ is an exciting topic for further study.

The present study illustrates some important similarities between search and foraging, but also highlights a difference. This difference is explained in terms of the different task demands. Further studies will be required to make a more detailed comparison between search and foraging, but the methodology developed has the potential to be an ideal testing ground for investigating whether results from visual search can genuinely provide predictions about more general foraging (eg Klein and MacInnes 1999).

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