

The influence of instructions on object memory in a real-world setting

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The representations that are formed as we view real environments are still not well characterized. We studied the influence of task instructions on memory performance and fixation allocation in a real-world setting, in which participants were free to move around. Object memories were found to be task sensitive, as was the allocation of foveal vision. However, changes in the number of fixations directed at objects could not fully explain the changes in object memory performance that were found between task instruction conditions. Our data suggest that the manner in which information is extracted and retained from fixations varies with the instructions given to participants, with strategic prioritization of information retention from fixations made to task-relevant objects and strategic deprioritization of information retention from fixations directed to task-irrelevant objects.

approached this question in an ecologically valid setting: We tested object memory performance after participants had spent 60 seconds moving freely in a natural environment. Memory was tested under three task conditions.

Memory representations are intimately linked to the places we select for scrutiny with our high-acuity foveal vision. The amount of time spent fixating an object predicts change detection performance (Hollingworth & Henderson, 2002), and the number of fixations on an object predicts memory performance (Pertzov, Avidan, & Zohary, 2009; Tatler, Gilchrist, & Land, 2005), indicating that the efficacy of stored object representations improves as information is accumulated across fixation time. The places we select for foveal scrutiny are themselves intimately linked to our behavioral goals (e.g., Buswell, 1935; Yarbus, 1967; for a review, see Tatler, Hayhoe, Land, & Ballard, 2011). Thus, memory representations are inevitably related to behavioral goals. Objects that are relevant to the task are remembered better than objects that are not task relevant (e.g., Castelano & Henderson, 2005; Williams, Henderson, & Zacks, 2005). Similarly, object properties are retained in memory as long as they remain relevant to an ongoing task (e.g., Droll & Hayhoe, 2007; Droll, Hayhoe, Triesch, & Sullivan, 2005; Triesch, Ballard, Hayhoe, & Sullivan, 2003).

Given the intimate link between task goals and fixation allocation, and between fixation allocation and memory, task specificity of memory representations may arise solely from differences in the allocation of foveal processing between task-relevant and -irrelevant objects. In support of this possibility, simply looking at an object does seem to result in memory formation even for task-irrelevant objects (e.g., Castelano & Henderson, 2005; Hollingworth, 2006). However, task may also influence the extent to which information is encoded and retained from fixations. Võ and Wolfe

Introduction

Real-world environments typically extend well beyond our field of view. To avoid resorting to searching for objects outside the field of view, representations of the surroundings are required. Low-acuity peripheral vision further means that representations may aid us when locating targets outside central vision. Information about what we see is encoded and stored as we engage in active behavior in real-world environments (for reviews and discussion, see Hayhoe, 2008; Tatler & Land, 2011). However, the characteristics and composition of representations remain the topics of continued research. A key unanswered question, and the primary aim of this study, is whether task-related differences in memory representations are due solely to strategic differences in the allocation of fixations to objects or whether task also influences the extent of encoding and retention from fixations. In the present study, we

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(2012) found a search benefit for having fixated an object in a previous exposure to the scene, but only if the previous exposure was for the purpose of search; if the object was previously fixated during a scene memorization task, no benefit was found for subsequent search for that object. Thus, the purpose of fixation on an object appears to modulate the encoding and retention of information. Similarly, Williams and colleagues (2005) showed that for a given number of fixations on an object, memory for search targets was better than memory for distractors, suggesting that more was encoded or retained from fixations on task-relevant items. In contrast, Hollingworth (in press) conducted an experiment similar to that of Võ and Wolfe (2012) but found that fixating an object for the purpose of judging semantic relationships between objects and scenes did result in better subsequent search performance. Thus, Hollingworth (in press) concluded that task specificity in memory is due to task-related differences in fixation allocation, but once fixation is allocated to a target, memory representations are encoded irrespective of task goals.

Task-based influences on memory representations are particularly evident in studies of natural behavior (for reviews, see Hayhoe, 2008; Tatler & Land, 2011). A key difference between natural behavior and the tasks typically employed in laboratory studies of memory is that natural behavior typically involves motion through the environment. Moving through an environment has a crucial effect on the nature of the spatial representations formed. Simons and Wang (1998) showed that spatial memory was impaired by changes in the retinal projection of a scene, if these changes arose from movements in the scene. However, if the same changes were generated by the participant's egomotion, spatial memory was unimpaired. Moreover, when carrying out active tasks in natural environments, spatial representation is likely to require coordination across a number of frames of reference (Burgess, 2006, 2008), including transformations between egocentrically encoded information and allocentric maps of the surroundings (Tatler & Land, 2011). Thus, to understand the manner in which task influences how we represent natural environments, it is important to test memory under ecologically valid settings in which participants are free to move around the environment.

Studying representation under natural settings, in real environments, offers greater potential for an ecologically valid account of representation, but there is limited scope for how the representations can be characterized without interfering with natural behavior: If participants become aware that the aim is to characterize memory, this may interfere with natural behavior. Where representation has been studied in more natural contexts, most studies characterize

representations by inferring the likely nature of scene memory from fixation patterns and task performance (e.g., Hayhoe, 2008; Land, Mennie, & Rusted, 1999) or compromising between ecological validity and experimental manipulation by using virtual reality (e.g., Droll et al., 2005; Droll & Hayhoe, 2007; Triesch et al., 2003). Although inference-based insights may avoid the problems of jeopardizing ecological validity, direct tests of representation—in the form of object memory probes or explicit change detection—allow the underlying patterns of information accumulation and storage to be explored in detail. For example, it is possible to look for links between the number of fixations on a particular object and the subsequent efficacy of memory for that object and to consider memories of specific properties of objects. It is much harder to infer the extent to which a range of object properties, such as color, are represented based on fixation patterns in a natural task. Such direct testing paradigms have revealed links between fixation allocation and memory (Hollingworth & Henderson, 2002; Pertzov et al., 2009) and subtle differences in the accumulation of different types of object information over fixations (Tatler, Gilchrist, et al., 2005) that cannot be revealed easily without employing direct testing paradigms.

The aim of the present study was to consider the link between task instructions and memory representation in a real environment. As our environment, we used a large laboratory containing an array of objects typically found in lab/office workspaces (see the Method section and Figure 1). Participants were free to move around the environment, thus providing a situation that had the same spatial reference frame challenges that are present in active behavior in natural environments. To characterize the link between task instructions and memory processes, we used a direct memory-testing paradigm much like that used in laboratory-based investigations of scene and object memory. This testing method allowed us to characterize memory for particular object properties and consider whether task-dependent processes in memory representations differ between object properties (Tatler, Gilchrist, et al., 2005). Our experimental setting therefore allowed us to use memory-testing procedures typically employed in studies of static scene viewing to explore the characteristics of memory encoding under a more ecologically valid setting in which participants are free to move around the environment. However, we did not allow participants to interact with the objects in the environment. This was because we wanted to ensure that any retained information could have come only from visual inspection of the object rather than any other modality. Restricting behavior in this way reduces the ecological validity of the experiment but does allow us to make comparisons more directly between the characteristics of representations suggested

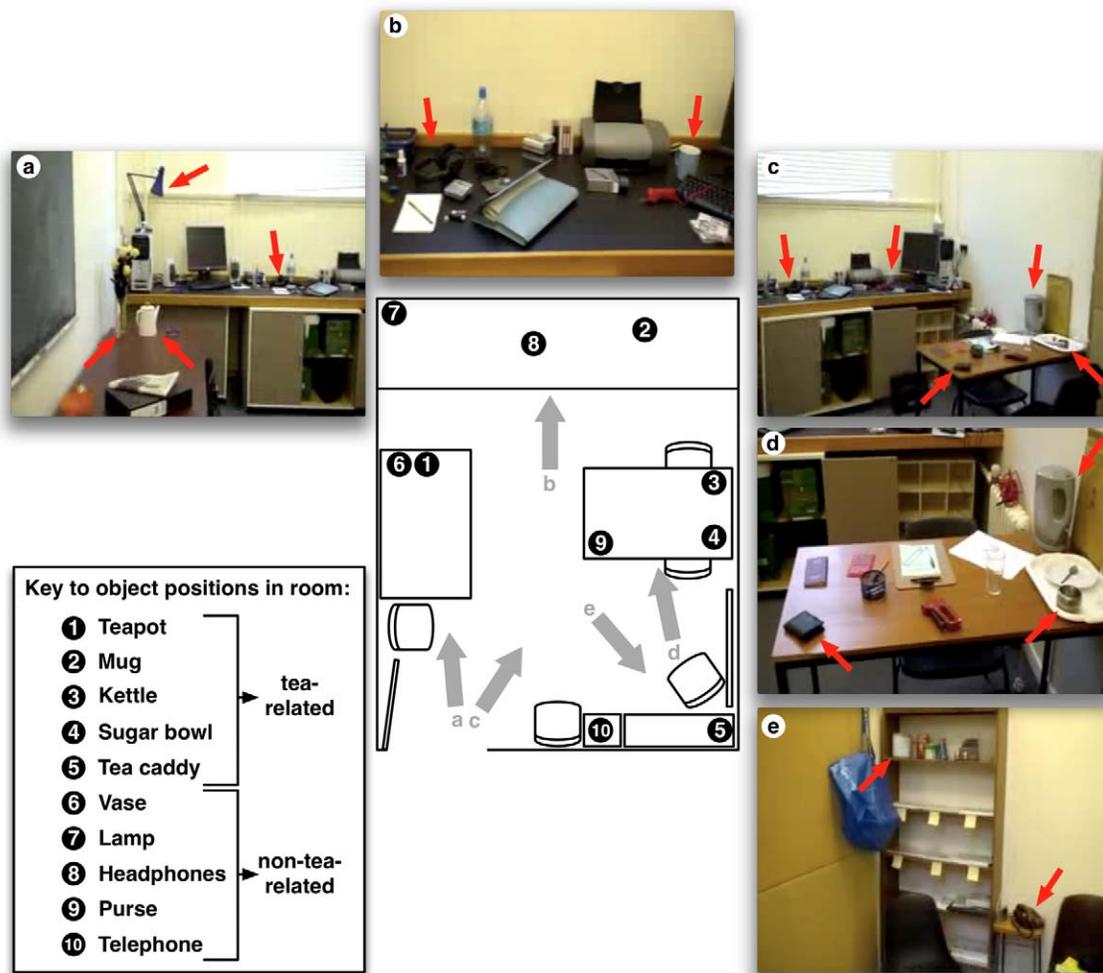


Figure 1. The room in which the experiment was conducted. The central plan view shows the layout of the room and the placement of the 10 target objects. Images a–e show views of the room (taken from positions a–e in the plan). In these images, red arrows indicate target objects.

by the present study and those suggested by previous studies using images of real-world scenes. This paradigm therefore offers a bridge between methods typically used in static scene-viewing experiments and in studies of natural tasks.

We used three different sets of task instructions to explore memory in this real-world environment: a free viewing condition in which the participant did not expect a memory test afterward,¹ an undirected memory condition in which participants were asked to remember as much as they could about all objects in the room, and a directed memory condition in which participants were asked to remember only certain objects in the room.

The first condition allowed us to consider what is encoded and retained in memory when participants are not expecting to be tested on their memory for objects in the scene. This allowed us to consider incidental encoding of object memories (Castelhamo & Hender-

son, 2005; Williams et al., 2005) in a more natural setting than has been employed previously. It should be noted that although we describe this condition as the “free viewing” condition, we do not claim or expect that participants viewed the scene in a task-free manner. Indeed, so-called “free viewing” conditions are likely to be anything but task-free; rather, the participants are given free reign to select their own priorities during inspection (for full discussions of this point, see Tatler, Baddeley, & Gilchrist, 2005; Tatler et al., 2011). This is not a problem for the current study: The aim was to provide a condition in which the participant did not expect memory to be tested, rather than to provide a task-free condition. The second experimental condition (undirected memory) is very similar to that typically found in many studies of memory for objects in static scene-viewing paradigms (e.g., Melcher, 2001, 2006; Pertzov et al., 2009; Tatler, Gilchrist, et al., 2005; Tatler, Gilchrist, & Rusted, 2003)

and allowed us to compare our results with those gathered in previous studies. The third condition (directed memory) reflects the selective nature of typical natural tasks, in which only a subset of the objects in the surroundings need to be encoded and retained (e.g., Hayhoe, Shrivastava, Mruczek, & Pelz, 2003), and provides an interesting and important comparison to the undirected memory condition.

Critically, we explored whether task-based effects on memory representation can be explained solely in terms of task-based differences in the allocation of fixations (Hollingworth, in press) or whether encoding and retention from individual fixations appear to be task dependent (Võ & Wolfe, 2012). To address this question, we characterized the relationship between the number of fixations on an object and subsequent memory performance (e.g., as in Tatler, Gilchrist, et al., 2005; Williams et al., 2005).² This relationship was characterized for each question type to consider whether any task dependence in encoding and retention from fixations differs for different forms of object information.

Method

Participants

Thirty-six undergraduate students took part in this study, which was approved by the Ethics Committee of the University of Dundee, for course credit or monetary reward. Participants had normal or corrected-to-normal vision and were naive to the purposes of the experiment. Participants were randomly allocated to one of three experimental conditions (see below).

Environment

A laboratory (approximately 20 m²) in the University of Dundee was furnished with a large number of everyday objects that would be expected to be found in a typical lab/office workspace (Figure 1). All objects were placed in locations where they might be expected to occur naturally, to avoid potential effects of unusual placement on inspection behavior (Võ & Henderson, 2009). Ten objects were selected as targets for the experiment. These included five objects typically used when making a cup of tea (kettle, teapot, tea caddy, cup, and sugar bowl) and five objects not used for making tea (lamp, telephone, vase, purse, and headphones). Target items were distributed around the room (Figure 1). The layout of the room was the same for all participants.

Eye movement recording

Eye movements were recorded using a lightweight portable eye tracker. The eye tracker headset was custom built by Jason Babcock and is similar to that described in Babcock and Pelz (2004): Two cameras mounted on a plastic spectacles frame were used to record simultaneously the scene and the participant's eye. The data from the eye and scene cameras were synchronized and recorded to miniDV using ISCAN Ltd. hardware at 30 frames per second. Eye position was calculated offline using the Yarbus software package (version 2.2.2) supplied by Positive Science LLC (Figure 2 shows sample frames from the fitted eye movement video). Gaze estimation was based on pupil detection. The model fit by the Yarbus software was estimated by using a nine-point calibration procedure at the start and end of each recording session. The accuracy of this system is sufficient to allow spatial estimates of gaze direction to within a degree of visual angle.

Procedure

In all conditions, participants were told that they would have 60 seconds in the room during which they could walk around freely but not touch anything; the eye tracker was worn by all participants. Further instructions depended on the condition to which the participant was randomly allocated. For the free viewing condition, participants were simply instructed to walk around in the room. As explained in the Introduction, this condition was not intended as a task-free viewing condition, because participants are likely to adopt their own “tasks” in the absence of more specific instructions (see Tatler et al., 2011), but instead to serve as a condition in which participants did not expect a subsequent memory test. Anecdotally, participants in this condition confirmed that they did not anticipate the memory test that followed the 60 seconds in the room (see below for details of the memory test). In contrast, a memory test was expected in the other two experimental conditions. For the undirected memory condition, participants were instructed to remember as much as possible about every object in the room. For the directed memory condition, participants were instructed to remember as much as possible about the objects in the room that could be used to make a cup of tea.

Participants stood with eyes closed in front of the door while the experimenter opened the door. They were given 60 seconds in the room before being instructed to close their eyes, and being led out of the room with eyes closed, by the experimenter. Partici-



Figure 2. Sample frames from the fitted eye-tracking movie. Both frames are taken from the same participant. The frames here show the participant looking at two of the target objects from the present experiment: the teapot (left) and the sugar bowl (right). The eye video (with fitted model) is shown in the upper right of each frame.

pants then completed a questionnaire presented one question at a time on a PC laptop.

The questionnaire tested object memory for the 10 items designated as targets in the experiment. For each object, four questions were asked. These tested memory for the identity, color, and position of the object and its relative distance to other objects (as in Tatler et al., 2003; Tatler, Gilchrist, et al., 2005). Each question was presented as 4AFC with plausible foils. For identity questions, grayscale photographs were used with foils drawn from the same object class. For color, verbal color labels were used, with viable color foils for the target object. For relative distance, verbal labels of other objects were used. For position, an outline plan view of the room was shown with four possible locations, from which the participant had to select the correct position of the target object; foil locations never coincided with the locations of the other target objects. Each target object was tested in random order. For each object, the questions were shown in one of two orders: (a) relative distance, position, color, identity or (b) color, identity, relative distance, position. This is because the grayscale images in the identity question could potentially offer clues to the color question. Similarly, the possible locations shown in the position question could influence answers to the relative distance question.

Analysis

We analyzed response data for all 36 participants to consider the link between task instructions, object type, and the different object properties tested. For eye

movement analyses, data from two participants had to be discarded because of failure to obtain reliable estimates of eye position during the model-fitting procedure (one participant from the undirected memory task and one from the directed memory task). For each participant, the movie with the eye position model fitted was coded manually, frame by frame, for the full 60 seconds of each viewing session. This procedure was used to score how many times each target object was fixated during the 60-second viewing period. Saccade detection was manual using deflections of the iris in the video overlay of the eye in the eye-tracking video record (Figure 2; for details, see Land & Lee, 1994). The minimum detectable saccade size using this method was 0.5° to 1° . There was no minimum fixation duration criterion.

In the sections that follow, we use the term *task* to refer to the different experimental conditions. As such, when we discuss task-related effects, we refer to effects associated with differences in instructions, rather than differences that might arise from any changes to behavior (such as the amount of movement) that occur as a result of these differences in instructions. Using the term *task* to refer to different instructions is consistent with prior studies that have looked for task-related effects on object memory.

The performances in the Results section are reported as proportion correct, where 0.25 is chance performance (4AFC questions). Based on our previous work, we selected objects that had properties that were not particularly guessable in order to minimize the potential for participants to base their answers on the properties of objects of the same class that they have previously encountered (see Tatler, Gilchrist, et al.,

2005, for a full discussion). However, we did not explicitly account for guessability in our analyses.

We first analyzed responses in the memory questions using a mixed-design analysis of variance (ANOVA) with question type, task, and object type as factors. Because difficulty cannot be equated across question types (for a discussion, see Tatler et al., 2003), it is not valid to interpret any main effect of question type. However, we were interested in whether task influenced memory recall and whether task had different effects on memory for different object properties. As such, analyzing the responses from questions testing different object properties in the same ANOVA was valid as it allowed us to consider the possibility of interactions involving task instructions and the type of object memory. Where significant effects were found in the ANOVAs, partial η^2 (η^2_p) is reported as a measure of effect size. Significant interactions were broken down with Bonferroni-corrected t tests. All p values for t tests are reported after Bonferroni correction for multiple comparisons.

When analyzing the link between fixation and memory, we considered both the allocation of fixations to target objects and the link between the number of fixations on the object and subsequent performance in the memory questions. For fixation allocation, we considered (a) the proportion of target objects fixated and (b) the number of fixations made on fixated objects. Differences in fixation allocation between our experimental conditions were assessed using independent measures t tests, Bonferroni corrected for multiple comparisons.

To explore the possibility that task influences information extraction and retention from fixations and thus the link between the number of fixations and memory performance, separate analyses were run for each question type. When dividing data according to the number of fixations on objects, there were insufficient data for subject averages in each condition. Therefore, data were pooled across participants, and we compared performance for a given number of fixations between tasks using chi-square analyses. To ensure that enough samples were present in each cell of the chi-square table, data were pooled across fixation counts where necessary (see Results for details). Where significant effects were found, ϕ is reported.

Results

Task and object memory

A 4 (question type) \times 2 (object category) \times 3 (task instruction) mixed design ANOVA confirmed that task influenced memory performance, $F(2, 33) = 11.60$, $p <$

0.001, partial η^2 (η^2_p) = 0.413. Independent samples t tests showed that performance was higher in the directed memory task ($M = 0.506$) than in the free viewing task ($M = 0.342$), $t(22) = 4.70$, $p < 0.001$. Performance in the undirected memory task ($M = 0.458$) was higher than the free viewing task, $t(22) = 3.29$, $p = 0.010$. There was no overall difference in performance between the directed and undirected memory tasks, $t(22) = 1.37$, $p = 0.555$. One-sample t tests showed that overall performance was above chance in all three tasks: free view, $t(11) = 3.66$, $p = 0.011$; undirected memory, $t(11) = 8.31$, $p < 0.001$; directed memory, $t(11) = 10.48$, $p < 0.001$.

There was a main effect of question type, $F(3, 99) = 26.11$, $p < 0.001$, $\eta^2_p = 0.442$. However, given the problems in comparing different question types, it is not appropriate to break down or interpret this main effect (see the Method section for further details). Performance in all questions was above chance: identity, $M = 0.547$, $t(35) = 12.52$, $p < 0.001$; position, $M = 0.503$, $t(35) = 10.23$, $p < 0.001$; color, $M = 0.367$, $t(35) = 4.10$, $p < 0.001$; relative distance, $M = 0.325$, $t(35) = 3.00$, $p = 0.020$.

The main effect of object category approached significance, $F(1, 33) = 3.83$, $p = 0.059$, $\eta^2_p = 0.104$, with a tendency toward better performance for tea-related ($M = 0.458$) than non-tea-related objects ($M = 0.413$).

The only significant interaction was the expected two-way interaction between task and object category, $F(2, 33) = 32.43$, $p < 0.001$, $\eta^2_p = 0.663$ (Figure 3). Performance was no different between tea-related and non-tea-related objects in the free viewing task, $t(22) = 1.90$, $p = 0.213$, or in the undirected memory condition,

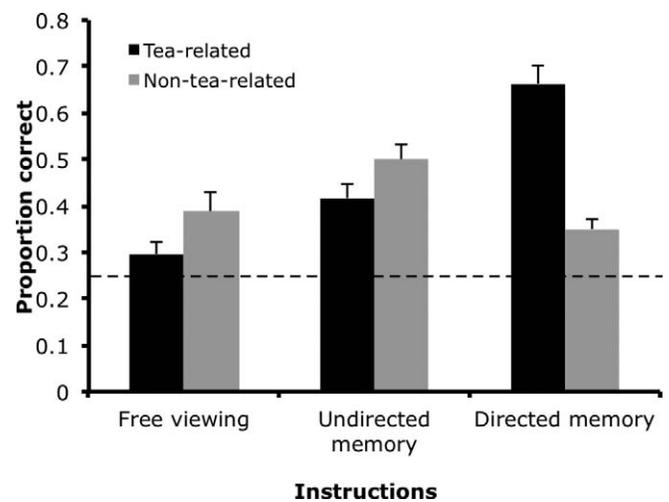


Figure 3. Memory performance on tea-related and non-tea-related objects for participants in each of the three instruction conditions. Performance data are pooled across the four questions for each object and show the mean proportion of correct responses ($+1$ SEM). The dashed line indicates chance performance.

$t(22) = 1.85$, $p = 0.232$. However, in the directed memory task, performance was better for the tea-related objects than the non-tea-related objects, $t(22) = 7.32$, $p < 0.001$.

Unsurprisingly, for tea-related objects, performance was better in the directed memory condition than either the undirected memory, $t(22) = 5.01$, $p < 0.001$, or free viewing conditions, $t(22) = 7.85$, $p < 0.001$, and was marginally better in the undirected memory condition than in the free viewing condition, $t(22) = 2.87$, $p = 0.053$. For non-tea-related objects, there was no difference in performance between the free viewing condition and either the undirected memory condition, $t(22) = 2.21$, $p = 0.225$, or the directed memory condition, $t(22) = 0.84$, $p > 0.999$. However, performance for non-tea-related items was worse in the directed memory condition than in the undirected memory condition, $t(22) = 3.95$, $p = 0.004$. In each condition, and for each class of object, performance was above chance, $t(11) \geq 3.48$, $p \leq 0.031$, in all cases, apart from tea-related objects in the free viewing condition, $t(11) = 1.65$, $p = 0.768$.

How task influences memory: fixation allocation and information extraction

In this section, we consider whether the task-related differences identified above arose from differences in the allocation of fixations to the target objects or from differences in the information extracted and retained from fixations. Fixation allocation can be considered in terms of whether the task influences the likelihood of selecting an object for fixation and, once selected, whether task influences how many fixations are made on the object. Thus, we can test three hypotheses for explaining task-related differences in object memory: (a) that task influences how likely an object is to be fixated, (b) that task influences how many times an object is fixated, and (c) that task influences the information extracted within each fixation. All p values for t tests conducted below are reported after correction for multiple comparisons.

Memory when expecting or not expecting a memory test

There was no difference in the proportion of target objects fixated in the undirected memory ($M = 0.79$) task and the free viewing condition ($M = 0.80$), $t(21) = 0.17$, $p > 0.999$. However, objects that were fixated received more fixations in the undirected memory task ($M = 2.50$) than in the free viewing condition ($M = 1.63$), $t(21) = 2.83$, $p = 0.030$.

To consider whether information extraction within fixations differed between the undirected memory and free viewing conditions, we compared the relative efficacy of memories for objects fixated a similar number of times in each of the task conditions. As such, we are able to consider whether for a given number of fixations on an object the amount of information extracted and retained (as indicated by performance in the memory questions) was the same or different depending on the task instructions.

In analyses that follow, we excluded cases in which objects were fixated more than seven times (a single case across these two task conditions). After pooling data across fixation numbers to ensure that no cells in the chi-square tables had expected frequencies less than 5, we were able to analyze performance for objects fixated once or twice or three to seven times³ (Figure 4). There were no differences in performance between the two tasks on any of the question types for objects fixated once or twice (all $\chi^2 \leq 1.26$) or for objects fixated three to seven times (all $\chi^2 \leq 2.63$).

By comparing performance for objects fixated once or twice to those fixated three to seven times, we were able to consider evidence for information accumulation across fixations. Only position questions showed evidence for significant improvement in either the free viewing condition, $\chi^2 = 9.94$, $p = 0.002$, $\phi = 0.322$, or the undirected memory task, $\chi^2 = 3.97$, $p = 0.046$, $\phi = 0.215$ (Figure 4). In the free viewing task, there was a tendency toward better performance in the identity question for objects fixated three to seven times than for objects fixated once or twice, although this trend failed to reach significance, $\chi^2 = 3.41$, $p = 0.065$. No other questions showed any evidence for accumulation across fixations in either task (all $\chi^2 \leq 1.84$, $p \geq 0.175$).

Memory for task-relevant and -irrelevant objects

In the directed memory condition, performance was better for task-relevant (tea-related) objects but worse for task-irrelevant (non-tea-related) objects than for the same objects in the undirected memory condition. In the analyses that follow, data were pooled across the free viewing and undirected memory task to provide more power for the analyses (and because of the lack of differences between these two conditions in the above analyses).

A higher proportion of tea-related objects were fixated in the directed memory task ($M = 0.95$) than in the other two task conditions ($M = 0.76$), $t(32) = 3.25$, $p = 0.008$. Tea-related objects that were selected for fixation received more fixations in the directed memory task ($M = 4.82$) than in the other two task conditions ($M = 2.02$), $t(32) = 5.24$, $p < 0.001$.

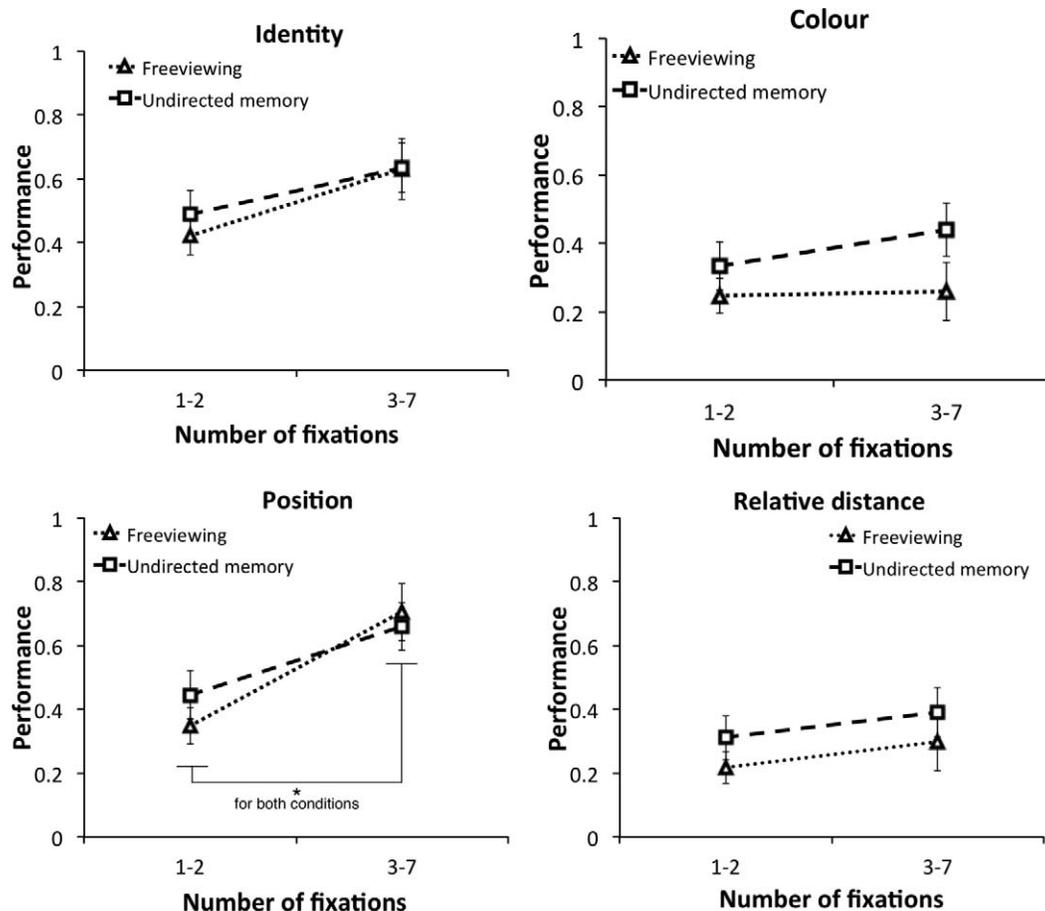


Figure 4. Mean performance in each question type as a function of the number of times the object was fixated for the free viewing and undirected memory tasks. Error bars indicate standard errors. Significant differences are denoted by asterisks.

For tea-related objects fixated once or twice⁴ (Figure 5), performance was better in the directed memory task than the other two tasks for recognition memory, $\chi^2 = 9.35$, $p = 0.002$, $\phi = 0.360$; color memory, $\chi^2 = 5.83$, $p = 0.016$, $\phi = 0.284$; position memory, $\chi^2 = 4.68$, $p = 0.031$, $\phi = 0.255$; and relative distance memory, $\chi^2 = 4.80$, $p = 0.028$, $\phi = 0.258$. For tea-related objects fixated three to seven times (Figure 5), performance was better in the directed memory task than the other two tasks for recognition questions, $\chi^2 = 6.28$, $p = 0.012$, $\phi = 0.323$, and position questions, $\chi^2 = 4.85$, $p = 0.028$, $\phi = 0.284$. However, performance was no better in the directed memory task than in the other two tasks for questions testing memory for relative distance, $\chi^2(1) = 2.44$, $p = 0.118$, and there was a nonsignificant trend toward better performance in the directed memory task than in the other two tasks for color questions, $\chi^2 = 3.30$, $p = 0.069$.

For non-tea-related objects, there was no difference in the proportion of these objects fixated in the directed memory task (where they were task irrelevant, $M = 0.73$) and in the other two tasks ($M = 0.83$), $t(32) = 1.52$, $p = 0.416$. There was also no difference in the number of fixations made to fixated non-tea-related objects in

the directed memory task ($M = 2.14$) and in the other two tasks ($M = 2.28$), $t(32) = 0.37$, $p > 0.999$.

For non-tea-related objects, there was no difference in performance between the directed memory task and the other two tasks for objects fixated once or twice for any of the questions (all $\chi^2 \leq 0.37$; Figure 6). For non-tea-related objects fixated three to seven times, performance was no different in the directed memory task than the other two tasks for color questions, $\chi^2 = 0.043$, $p = 0.836$, or relative distance questions, $\chi^2 = 2.48$, $p = 0.115$. However, for non-tea-related objects that were fixated three to seven times, performance was significantly worse in the directed memory condition than in the other two tasks for recognition questions, $\chi^2 = 4.74$, $p = 0.029$, $\phi = 0.299$, and for position questions, $\chi^2 = 5.83$, $p = 0.016$, $\phi = 0.332$.

Discussion

We considered memory performance for objects encountered when walking around a real environment under three different task instructions. Participants

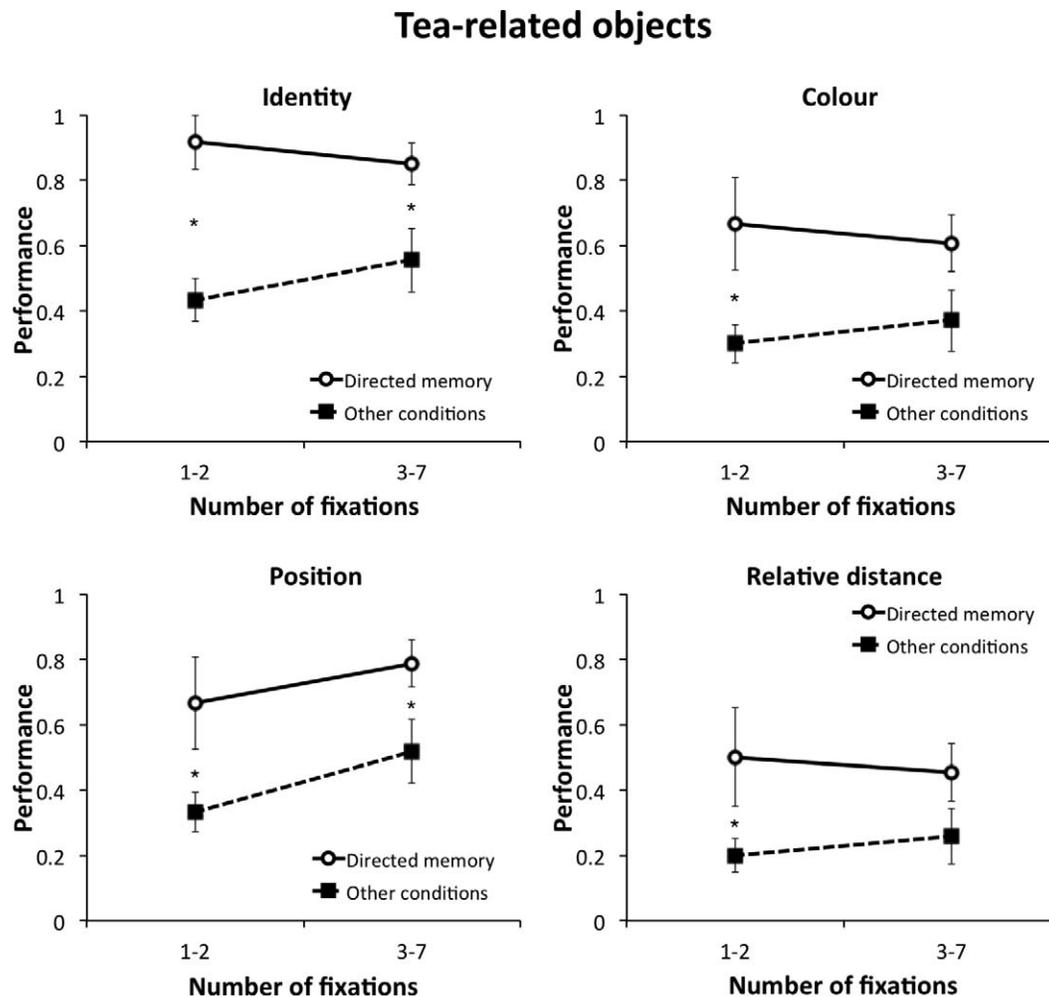


Figure 5. Mean performance as a function of the number of times an object was fixated for tea-related objects in the directed memory task and the combined data from the other two tasks (free viewing and undirected memory). Given that in the directed memory task, participants were instructed to locate and remember the objects they would need to make a cup of tea, the tea-related objects can be considered as task-relevant objects in this task. Error bars indicate standard errors. Significant differences are denoted by asterisks.

performed above chance for all question types, confirming that memories for a variety of object properties were extracted and retained in this natural setting, and memory was modulated by task instructions. Task instructions modulated memory performance via a combination of strategic differences in fixation allocation and strategic differences in the extraction and retention of information from fixations.

When not expecting to be tested on object memory, participants recalled objects better than chance. This result is consistent with previous suggestions that object memory encoding is incidental and not restricted to situations in which memorizing the object is central to the participant's task (Castelhano & Henderson, 2005; Hollingworth, 2006; Williams et al., 2005). Like Castelhano and Henderson (2005), we found that although objects were remembered at above-chance levels for nonmemorization conditions, memory for

objects was better in the memorization condition. Here we were able to extend these previous findings by considering how the performance benefit in the memorization task might be achieved. We found that whether or not participants were expecting a memory test did not influence how likely it was that a target object would be selected for fixation. However, once selected, objects received a higher number of fixations in the memorization task than in the free viewing condition. For a given number of fixations, memory performance was no different between free viewing and the undirected memory task. The memory difference between these two conditions therefore most probably arose from the strategic increase in the number of fixations on objects when expecting a memory test and not via modulations to information extraction and retention from fixations.

Non-tea-related objects

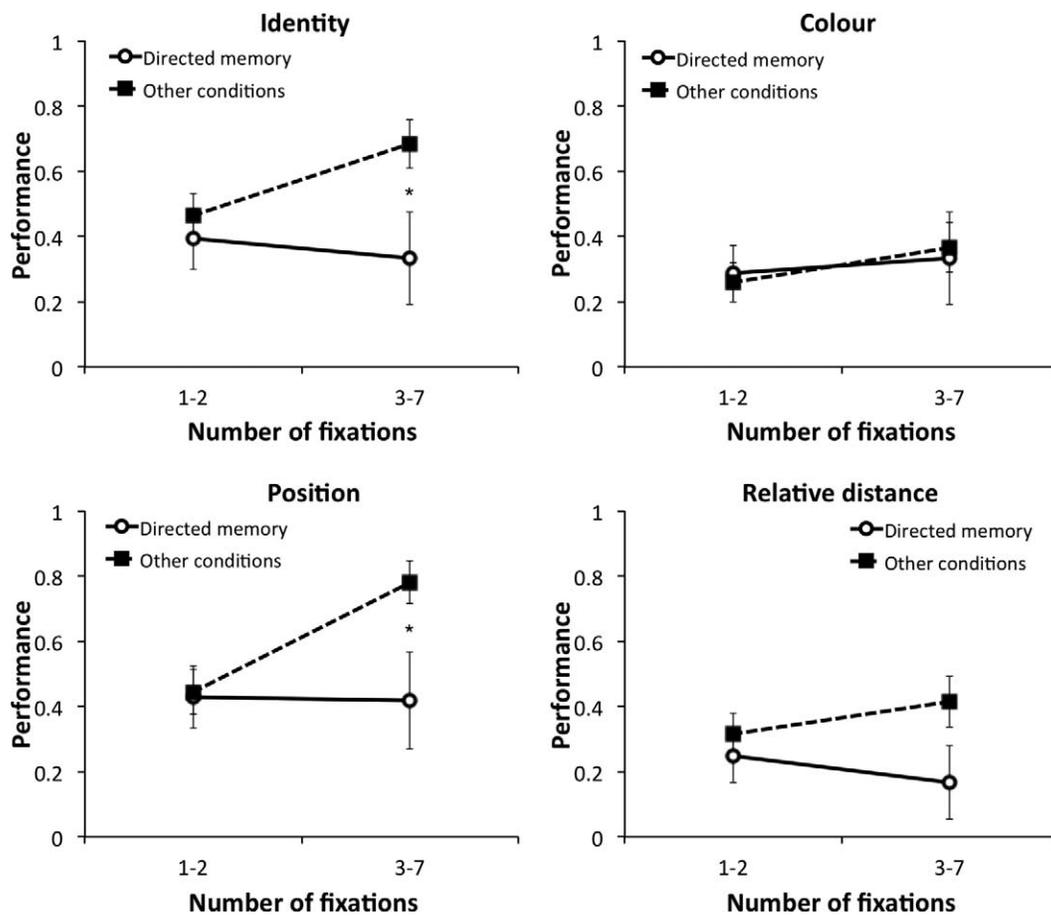


Figure 6. Mean performance as a function of the number of times an object was fixated for non-tea-related objects in the directed memory task and the combined data from the other two tasks (free viewing and undirected memory). Given that in the directed memory task, participants were instructed to locate and remember the objects they would need to make a cup of tea, the non-tea-related objects can be considered as task-irrelevant objects in this task. Error bars indicate standard errors. Significant differences are denoted by asterisks.

An important caveat when interpreting the above finding is that it is not possible to know how the objects in the room align with the participant's priorities because providing no instructions to the participants allows them to adopt their own priorities for viewing. As such, this condition does not necessarily inform us whether there is incidental encoding of memories for task-irrelevant objects (as in Castelhamo & Henderson, 2005; Williams et al., 2005), but it does inform us that there may be some encoding and memory of objects when there is no explicit memory task for the participants.

To consider how task-irrelevant objects are remembered, we can compare the tea-related and non-tea-related objects in the directed memory condition, in which participants were asked to remember only the tea-related objects. Here we found (as expected) better performance for tea-related objects than for non-tea-related objects, but performance was above chance for

both classes of object. Thus, although task prioritizes relevant information in memory representations (e.g., Hayhoe, 2008; Vö & Wolfe, 2012), incidental memories for irrelevant objects are also formed (Castelhamo & Henderson, 2005; Hollingworth, 2006, in press; Williams et al., 2005). When comparing memory for tea-related and non-tea-related objects in the directed and undirected memory conditions, our data are consistent with a tradeoff in memory as a result of our directed memory task, with prioritization of task-relevant information at the expense of task-irrelevant memory representations. This tradeoff appears to be achieved via a combination of strategic allocation of fixations to task-relevant objects and a strategic change in the information extracted and retained from fixations.

As expected, task-relevant objects in the directed memory condition were more likely to be fixated, and once fixated, they received more fixations than the same objects in the undirected memory task. In addition,

there was evidence that memory performance for task-relevant objects was better for objects fixated once or twice in the directed memory condition than the same objects in the undirected memory condition. This finding suggests that when the task specifies only a subset of objects in the environment as being task specific, more information is extracted or retained from the first two fixations of these objects than when the same objects are viewed under less specific instructions. Interestingly, there were no significant differences in performance for tea-related objects fixated three to seven times in the directed memory task than in the other two tasks for questions testing color and relative distance. It may therefore be that preferential extraction and retention from fixations is not the same for all object properties when considering objects fixated several times.

For task-irrelevant objects in the directed memory condition, we found no difference in the likelihood of fixation or the number of fixations compared with the same objects in the other two conditions, yet we did find that memory for these objects was worse in the directed memory condition than in the undirected memory condition. Thus, the decrease in memory for non-tea-related objects in the directed memory task compared with the undirected memory task cannot be accounted for by changes in fixation allocation. For these objects, we found that for a given number of fixations on the objects, performance was either no better or in some cases worse in the directed memory task (where these objects were irrelevant to the task) than in the other two tasks. Moreover, worse performance was found on these objects for identity and position information when fixated three to seven times. This finding clearly implies that when objects are explicitly task irrelevant, information about the properties of these objects is not encoded or retained to the same extent that it would be under different task conditions. It is interesting to note that this apparent deprioritization of information for objects fixated several times is specific to identity and position information. This implies again not only that strategic control of memory representations may vary between object properties but also that the two properties that showed significant benefit for task-relevant objects fixated three to seven times were those properties that showed significant deficit for task-irrelevant objects.

Our findings suggest that task influences not only strategic allocation of fixations but the extent to which information is encoded and retained to form memory representations of the objects we view, with prioritization of task-relevant information but deprioritization of task irrelevant information. This suggestion is consistent with Vö and Wolfe's (2012) finding that task modulates information extraction within fixations and with Williams et al.'s (2005) finding that task-relevant

objects are remembered better than distractors for a given number of fixations on an object. However, in our data, we are unable to differentiate the possibility that task effects on the link between memory and the number of fixations arise from strategic differences in information extraction within fixations (Vö & Wolfe, in press), or from strategic protection of task-relevant information in memory representations (Maxcey-Richard & Hollingworth, in press).

We are able to extend previous suggestions of strategic modulation in information extraction (Vö & Wolfe, 2012, in press) or retention (Maxcey-Richard & Hollingworth, in press) from fixations by suggesting that such task-based modulation varies for different types of object information. All of our tested information types received benefit for task-relevant objects that were fixated once or twice, suggesting an initial task-based benefit for memory representations. However, for objects fixated three to seven times, the influence of task appeared different for position and recognition memory than it was for color and relative distance memory. These sources of information were selectively prioritized for task-relevant objects and selectively deprioritized for task-irrelevant objects when compared with recognition and position memory for the same objects in the other two tasks. No significant prioritization or deprioritization was evident for color or relative distance memory for objects fixated three to seven times. These findings suggest that for objects that were fixated several times during viewing, task-based influences on memory representation appeared to be achieved primarily via modulation in recognition and position memory. We have previously argued that different object properties are encoded differently over time and across fixations in a memorization task (Tatler et al., 2003; Tatler, Gilchrist, et al., 2005). Here we extend this proposal to suggest that the components of memory representations are differentially sensitive to task requirements: Particular object properties are differentially prioritized or deprioritized according to the requirements of the task.

Collectively, our findings indicate that when moving freely in a natural environment, there is an intricate relationship between task, fixation, and object memory. Memory representations are formed for both task-relevant and task-irrelevant objects, but there is strategic prioritization of task-relevant objects. This prioritization is achieved via modulations in fixation allocation and in the information encoded and retained from fixations. Moreover, the contents of memory representations are differentially sensitive to task requirements, with strategic prioritization and deprioritization of particular types of information encoded into object memory.

Keywords: task, instruction, object memory, representation, real world, natural, prioritization

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Footnotes

¹ Participants were informally asked after the experiment whether they had expected there to be a memory test in order to ensure that this manipulation was effective. All participants reported that they had not expected to be tested regarding their memory for objects in the scene.

² We considered the number of fixations on objects in our analyses but not their durations. Previous studies of memory accumulation (Tatler, Gilchrist, et al., 2005) and task-specific effects on information extraction from fixations (Williams et al., 2005) have shown that analyses using fixation numbers or durations show the same patterns.

³ Note that whether fixations on an object followed each other or were separated by fixations to other objects in the room was not considered in these analyses, an approach that mirrors previous studies of fixation number or time on memory performance (e.g., Hollingworth & Henderson, 2002; Tatler, Gilchrist, et al., 2005).

⁴ As before, cases in which objects were fixated more than seven times were excluded. Across the three task conditions in these analyses, this resulted in the exclusion of eight cases (of 275 nonzero fixation counts).

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