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Effects of viewing time, fixations, and viewing strategies on visual memory for briefly presented natural objects

Gesche M. Huebner and Karl R. Gegenfurtner
Justus-Liebig-University of Giessen, Giessen, Germany

We investigated the impact of viewing time and fixations on visual memory for briefly presented natural objects. Participants saw a display of eight natural objects arranged in a circle and used a partial report procedure to assign one object to the position it previously occupied during stimulus presentation. At the longest viewing time of 7,000 ms or 10 fixations, memory performance was significantly higher than at the shorter times. This increase was accompanied by a primacy effect, suggesting a contribution of another memory component—for example, visual long-term memory (VLTM). We found a very limited beneficial effect of fixations on objects; fixated objects were only remembered better at the shortest viewing times. Our results revealed an intriguing difference between the use of a blocked versus an interleaved experimental design. When trial length was predictable, in the blocked design, target fixation durations increased with longer viewing times. When trial length was unpredictable, fixation durations stayed the same for all viewing lengths. Memory performance was not affected by this design manipulation, thus also supporting the idea that the number and duration of fixations are not closely coupled to memory performance.

Keywords: Visual memory; Natural objects; Eye movements; Fixations; Interleaved versus blocked design.

Visual short-term memory (VSTM) enables us to hold visual information in a mental store for a limited amount of time. It is restricted with respect to the amount of visual information that can be stored. Capacity is generally expressed as the numbers of items available to immediate memory at any given time (Miller, 1956). If the number of items that need to be represented in memory exceeds this capacity, then performance limitations are observed. A large body of evidence suggests that the capacity of VSTM is limited to about four items (Alvarez & Cavanagh, 2004; Irwin & Andrews, 1996; Luck & Vogel, 1997; Pashler, 1988; Todd & Marois, 2004). However, as summarized in the following paragraph, this might depend on the presentation time used.

The role of presentation time for memory performance

Previous work indicates that performance is relatively constant for brief stimulus durations. For

Correspondence should be addressed to Gesche M. Heubner, Justus-Liebig-Universität Gießen, Fachbereich 06, Psychologie und Sportwissenschaft, Abteilung Allgemeine Psychologie, Otto-Behaghel-Strasse 10F, 35394 Giessen, Germany. E-mail: gesche.huebner@psychol.uni-giessen.de

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viewing duration of 100 ms and 500 ms, the estimated capacity was four objects (Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001). Todd and Marois (2004) also found a capacity of four items for presentation times from 150 ms to 450 ms. Likewise, in a change detection task, Pashler (1988) found a significant but modest effect of stimulus presentation time (100 ms, 300 ms, and 500 ms) on performance. Thus, memory capacity is relatively unchanged over a range of short presentation durations. When presentation time is less than 100 ms, information is stored in iconic memory, a sensory-based memory system with a high capacity (Neisser, 1967). It is susceptible to subsequent visual input (i.e., masking) and is disrupted by eye movements (Henderson & Hollingworth, 2003). As such, it is not relevant to the questions posed in our study and thus is not further considered.

Memory performance was affected by varying stimulus presentation time in the following studies where longer display durations were used. Tatler, Gilchrist, and Rusted (2003) found a clear increase in performance with a longer presentation time even though the changes were somewhat contingent on the type of information that was asked for. Melcher and Kowler (2001) found increases in verbal recall from 1-s trials to 4-s trials. Melcher (2006) reported higher performance with increased presentation duration up to 20 s. In a study by Irwin and Zelinsky (2002) viewing times ranged from 174 ms to 4,927 ms, and performance improved with longer viewing time. In the study of Eng, Chen, and Jiang (2005) capacity increased with extended display duration from 0.5 s to 3 s.

Thus, many studies have found an effect of presentation duration, but when very short presentation times were used no effect or a weak effect emerged. In our study, we used a large range of viewing times to systematically investigate how memory performance is influenced by the time given to encode the material. It might be that it is not the length of presentation time per se that is responsible for the better performance at longer presentation times. Instead, this improvement might be due to the increased number of directly fixated objects that co-occurs with a longer viewing time. When the presentation duration is very short, there is less time to make saccades and thus to fixate objects. With longer viewing times, however, more fixations can occur.

Role of fixations for memory performance

Early evidence that fixation frequency improves memory performance came from Nelson and Loftus (1980). The number of fixations proved to be a good predictor of recognition performance. Irwin and Zelinsky (2002) showed that accuracy was much higher if the position that was probed had been foveated than when it had not been foveated. In a change detection paradigm, Hollingworth and Henderson (2002) found that performance was better when the target object had been fixated prior to change. Finally, Melcher and Kowler (2001) examined the relationship between fixation and recall performance. They found a strong link between where the participants looked and what they remembered at longer presentation durations.

However, a higher number of fixations does not necessarily improve performance. Melcher and Kowler (2001) also reported that at shorter durations when fewer objects had been fixated, participants still tended to accurately report many nonfixated items. This result was in agreement with pilot studies that had shown that eye movements were not important when viewing time was less than two seconds. Tatler, Gilchrist, and Land (2005) examined the relationship between fixations and object memory. They found that direct fixation of the target object was not needed for remembering object identity and colour.

More generally, even though the direction of attention and the direction of gaze are closely coupled (Kustov & Robinson, 1996; Moore & Fallah, 2001; Sheliga, Riggio, & Rizzolatti, 1994), they can also be decoupled (Posner, 1980; Posner, Snyder, & Davidson, 1980). There are striking examples of fixated regions that are not attended to. For example, despite a fixation in the respective region, an unexpected stimulus was not spotted (Koivisto, Hyönä, & Revonsuo, 2004) or an obvious scene change not detected (O'Regan, Deubel, Clark, & Rensink, 2000). This effect also held true when no blink-mediated visual suppression could have occurred (Caplovitz, Fendrich, & Hughes, 2008).

Summarizing the results, it seems that direct fixation of an object increases its probability to be remembered (Hollingworth & Henderson, 2002; Irwin & Zelinsky, 2002; Melcher & Kowler, 2001). Yet, in regard to the uptake of object presence and colour information, direct fixation might not be necessary (Tatler et al., 2005). A certain length of presentation duration seems necessary to reap the benefits of fixations (Melcher & Kowler, 2001). Further support that fixation, attention, and performance are not necessarily closely linked comes from research on inattentional blindness and change detection (Caplovitz et al., 2008; Koivisto et al., 2004; O'Regan et al., 2000). With our study, we wanted to extend the findings on the role of fixations in behavioural tasks—in this case, in a memory task.

Blocked versus interleaved design

A second point of interest was whether it mattered if a blocked or interleaved design was used. A blocked design consists of a sequence of trials all having the same viewing duration whereas an interleaved design has multiple different viewing times within one block of trials. This variation could possibly affect both memory performance and eye movements. In a blocked design, participants know after the first few trials how long the following trials will last whereas an interleaved design reduces such predictability.

If the trial length is predictable, participants could possibly use this knowledge and adopt an optimal strategy for each viewing time. Such an approach might in turn minimize memory performance differences for different viewing times. However, in an interleaved design without a predictable trial length, there could be two possible outcomes: Performance could start to differ between different viewing times or it could stay the same because participants could employ the optimal strategy for the shortest time that could possibly occur. This question is of great importance and potentially large impact: If a difference emerged, it would make it necessary to limit all claims to the specific design used in any experiment. To our knowledge, this question has not been addressed explicitly in research on visual memory. Both designs have been previously used but not explicitly compared with another to see whether they differentially influence memory performance.

The role of a blocked versus interleaved design has also not been thoroughly researched with respect to eye movements. Considering that eye movements are seen as an indicator for cognitive processes, any strategic effects induced by the predictability of the viewing time might also be reflected in the fixation durations. Typical fixations during scene viewing last an average of approximately 300 ms (Hollingworth & Henderson, 2002). Several factors have been found to influence fixation durations, including: the serial position of an item (Saint-Aubin, Tremblay, & Jalbert, 2007), culture (Rayner, Li, Williams, Cave, & Well, 2007), stimulus luminance (Loftus, 1985), and the duration of the delay with which a mask appeared after fixation (Rayner, Smith, Malcolm, & Henderson, 2009). Thus, fixation durations are not fixed but are influenced by several factors, possibly reflecting top-down influences. In our study, one might speculate that without predictability, participants will tend to make shorter fixations to try to look at as many regions as possible as quickly as possible.

Aims of our study

We wanted to investigate the impact of systematically increasing the viewing time of the stimuli on memory performance. In addition, we wanted to compare performance for fixated versus nonfixated objects to clarify the role of object fixations. If the direct comparison showed an advantage for fixated objects, then a higher memory performance at longer viewing times could be ascribed to more fixations. Finally, we varied whether trials were presented in an interleaved or a blocked design to see whether the predictability of the viewing time of the stimuli had an influence on memory performance and fixation durations.

Method

Participants

A total of 15 students of the Justus-Liebig-University Giessen participated in this experiment. They received 8 euros per hour for their participation. All had self-reported normal or corrected-to-normal vision.

Stimuli

Stimuli consisted of photographs of single, natural objects. They were taken out of an existing set of 10 photographed scenes as used by Liu and Yiang (2005). Those scenes were a kitchen, a bathroom sink, a bedroom, a living room, a TV room, a city street, a farm, an office desk, a coffee table, and the inside of a refrigerator. Originally, there had been 20 plausible objects in each scene. For these experiments, 4 objects of each scene were eliminated to arrive at a collection of objects similar in shape and size. Thus, in total 160 different objects were used.

Experimental equipment

The experiment was run on Microsoft Windows XP, using a customized version of a program written in Visual C++. Images were presented on an Iiyama VisionMaster 513 (MA203DT) 21″ CRT screen. Monitor resolution was $1,280 \times 960$ pixel. The refresh rate was 100 Hz. The viewing area was 40.3 cm wide and 30.1 cm high. A chinrest to stabilize head position of the participants was placed at a distance of 47 cm from the screen, resulting in a visual field of 48.2° by 36.9°. Eye movements were measured using SR Research's EyeLinkII eye-tracking system.

Experimental procedure in the main experiment

After being seated, participants received verbal instructions about the task. The program was then started. Every participant performed three practice trials. Then the eye tracker was adjusted. After successful calibration and validation, the instructions for the task were summarized, and the participant started the first trial with a button press.

In every trial, there was a presentation phase and a test phase. During the presentation phase, 8 randomly chosen objects that had belonged to the same scene were presented evenly spaced on an invisible circle. The distance between the central fixation point and each object's centre subtended 8.7° of visual angle. Objects differed in shape and size but could all fit within a 2.4° invisible bounding box.

To start the trial, participants had to fixate on a black fixation point in the middle of the circle. If a participant deviated more than 1.5° of visual angle away from the fixation point, the trial was not started. Instead, an acoustic signal was given, and the participant had to refixate and hit the start button again.

Participants came to four testing sessions that lasted about 40–60 min each and were separated by at least 24 hours. Each session consisted of 150 trials. In the condition termed *fixed time blocked*, the stimuli were presented for 1,000, 3,000 or 7,000 ms, using a blocked design with 50 trials per block. In the condition called *fixed time mixed*, all 150 trials were shuffled and then randomly divided in three blocks. Thus, in each block, there were trials of all three presentation times. The other two conditions—called *total fixations blocked* and *total fixations mixed*—consisted also of 150 trials each, 50 for each of the three different numbers of allowed total fixations, which were, 3, 7, or 10 fixations. The trial ended when the eye moved away from the object after the critical fixation. As in the conditions with fixed viewing times, either a blocked design was used or all trials were shuffled and then divided into three blocks. The order of blocks was randomized in each session, and calibration of the eye tracker was repeated after each block.

In the partial report procedure (compare Figure 1), the randomly chosen target object appeared after presentation of the stimulus array in the middle of the circle. Participants had to

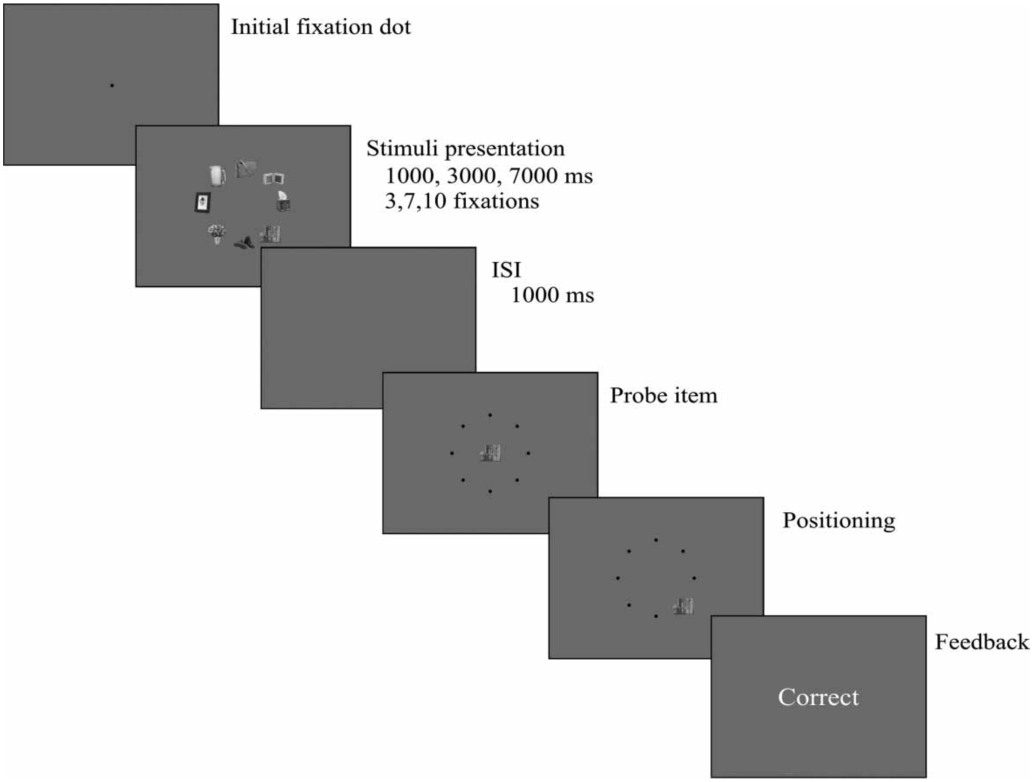


Figure 1. *Memory performance was tested with a partial report procedure. A previously shown object had to be assigned to the correct position. To view a colour version of this figure, please see the online issue of the Journal.*

assign the target, which had always been present during the presentation phase, to one of the eight positions on the circle. Using two keys (the left and right arrow), participants moved the target object around on the eight different positions of the circle. When the target object was at the position that participants believed to be the correct one, they confirmed their choice by pressing the "End" key. After making a choice, participants received feedback about their decision in form of a text displayed on the screen. There was no time limit during the test phase. Participants started the next trial with a button press once they had received the feedback.

Fixation experiment

We conducted an additional experiment to contrast a condition without any eye movements with a free viewing condition. The methods for this additional experiment were very similar to those for the main experiment. The largest difference was that in one block, participants had to fixate the centre of stimulus display during the trial—that is, no eye movements and thus no fixations on objects were possible. During the presentation of the stimuli, the fixation point in the circle centre had to be fixated continuously. If during the trial a deviation of more than 1.5° was detected, a sentence prompting the participant to fixate properly was shown in blinking red letters after the trial. The trial was then excluded in later analysis. Only one presentation time was used—namely, 1,000 ms—and the stimulus size was 4.8° to ensure its visibility in the periphery. A total of 10 students participated. Half the participants began with 100 trials in the condition of central fixation, followed by 100 trials in the condition of free viewing. The condition order was reversed for the other half of participants.

General experimental issues

In both experiments, great care was taken to ensure that the light conditions were the same for all participants. The experimenter was present during the experiments. The experiments were carried out in accordance with the rules of the local ethics committee.

Results

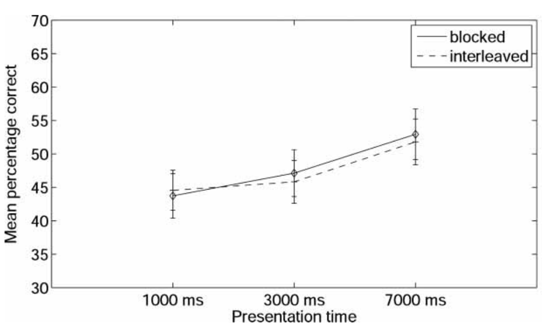
In the following analyses of variance, the degrees of freedoms were adjusted according to Greenhouse–Geisser. When pairwise comparisons were performed, a Bonferroni adjustment of α was made. Performance in the memory task was defined as the percentage of correct answers. To make the result easier to grasp, we also calculated performance in terms of the number of visual items held in memory. First, to correct for guessing, the following formula was applied: $p = (x - g)/(1 - g)$ where x is the raw proportion correct, g is the guessing probability, and p is the corrected proportion correct (Busey & Loftus, 1994); g was $1/8 = .125$. The result p was then multiplied by the number of objects presented—that is, 8.

Overall memory performance

We first looked at performance in the memory task, for both the fixed presentation times and the varied numbers of total fixations. We first report the memory performance for the conditions with a fixed presentation time, followed by the results of the analysis of variance. The same is then done for the condition where the numbers of fixations were set.

In the fixed presentation time condition using a blocked design (compare left graph of Figure 2), mean percentage correct was $M = 43.73\%$ ($SD = 12.89$) for a presentation time of 1,000 ms, $M = 47.12\%$ ($SD = 13.56$) for 3,000 ms, and $M = 52.93\%$ ($SD = 14.64$) for the longest presentation time of 7,000 ms. When the trials were interleaved (fixed time mixed), performance was very similar in the two shorter conditions, $M = 44.56\%$ ($SD = 11.64$) for 1,000 ms, and $M = 45.81\%$ ($SD = 12.45$) for 3,000 ms, and, again, was highest for 7,000 ms ($M = 51.80\%$, $SD = 13.22$). Taking the estimated marginal means for the different presentation times, the performance for 1,000 ms corresponded to the retention of 2.89 objects, for 3,000 ms to 3.11 objects, and for 7,000 ms to 3.65 objects.

A 3 (viewing time: 1,000, 3,000, 7,000 ms) × 2 (design: mixed vs. blocked) repeated measures analysis of variance (ANOVA) showed a significant main effect of time, $F(2, 28) = 6.108$, $p = .008$. Neither the effect of design, $F(2, 28) = 0.054$, $p = .820$, nor the Time × Design interaction, $F(2, 28) = 0.162$, $p = .851$, was significant. Pairwise comparisons revealed a significant difference between the condition of 1,000 ms and



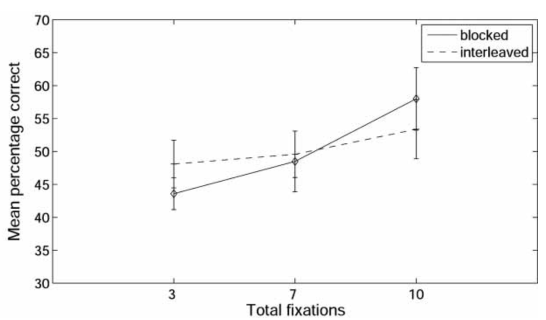


Figure 2. *Mean percentages of correct trials and standard error of the mean for the condition of fixed presentation times (left figure) and of varied fixation numbers (right figure).*

7,000 ms ($p = .030$) and of 3,000 ms and 7,000 ms ($p = .041$).

When participants were allowed a certain number of total fixations in the blocked design, the results were as follows (compare right graph of Figure 2): Mean percentage correct for 3 fixations was $M = 45.58\%$ ($SD = 9.34$), for 7 fixations $M = 48.48\%$ ($SD = 17.90$), and for 10 fixations $M = 58.00\%$ ($SD = 18.37$). In the mixed conditions, the respective results were $M = 48.09\%$ ($SD = 14.01$) for 3 fixations, $M = 49.57\%$ ($SD = 13.66$) for 7 fixations, and $M = 53.38\%$ ($SD = 17.43$) for 10 fixations. Taking the estimated marginal means of performance for the different numbers of fixations, the performance for 3 fixations corresponded to the retention of 3.05 objects, for 7 fixations to 3.34 objects, and for 10 fixations to 3.95 objects.

A 3 (fixation number: 3, 7, 10) × 2 (design: blocked vs. mixed) repeated measures ANOVA showed that the main effect of the number of fixations was significant, $F(2, 28) = 9.998$, $p = .002$. The effect of design was not significant, $F(2, 28) = 0.010$, $p = .923$, and also the interaction was not significant, $F(2, 28) = 3.301$, $p = .076$. Pairwise comparisons showed that the difference between 3 and 10 fixations was significant ($p = .009$), as was the difference between 7 and 10 fixations ($p = .002$). Thus, when it came to performance defined as the percentage of correct answers, there was a significant effect of viewing duration both when a fixed time had been set and when different numbers of total fixations were allowed, with the difference between the two shorter times and the longest one being significant.

Performance for fixated objects

We examined whether memory performance was affected by the number of fixations that an object had received within one trial. We compared performance for objects that been fixated once with performance for nonfixated objects, or performance for objects fixated once with performance for objects fixated twice. If there were fewer than five cases for a certain combination of viewing time and target fixation, the respective value was left out in the following analyses leading to 12 data sets for the 1,000-ms condition. The data were analysed using a 2 (target fixation: fixated vs. nonfixated or fixated twice vs. fixated once) × 2 (design: blocked vs. mixed) repeated measures ANOVA for each viewing time. The results are shown in Figure 3. For 1,000 ms, both the main effect of target fixation, $F(1, 12) = 21.087$, $p = .001$, and that of design, $F(1, 12) = 5.758$, $p = .034$, were significant, as was the interaction, $F(1, 12) = 5.406$, $p = .038$. In the mixed design, the difference in performance for fixated and nonfixated objects was more pronounced (38.85% vs. 66%) than in the blocked design (40.23 % vs. 49.94%) but the difference was clearly present in both. For the longer viewing times of 3,000 ms (comparison of nonfixated and once fixated objects) and of 7,000 ms (comparison of once and twice fixated objects), none of the possible main and interaction effects were significant (all $p > .475$).

When varying the number of total fixations, the pattern of results was similar to the one obtained when varying the presentation time (see Figure 4). For 3 total fixations, again there was a significant main effect of target fixation, $F(1, 14) = 34.388$, $p < .000$. Target objects that had been fixated were remembered better than those not fixated. The design effect, $F(1, 14) = 2.090$, $p = .170$, and the interaction effect, $F(1, 14) = 2.534$, $p = .134$, were not significant.

For 7 total fixations, there was no significant main effect of target fixation, $F(1, 14) = 3.334$, $p = .089$, no main effect of design, $F(1, 14) = 0.966$, $p = .342$, and no interaction effect, $F(1, 14) = 1.349$, $p = .265$. In fact, performance for nonfixated target objects tended to be better, with estimated marginal means of 53.04 for nonfixated and 46.37 for fixated items. Thus, even if we tested more participants in this condition, a beneficial effect of fixations would not emerge considering that the trend is going in the opposite direction.

For 10 fixations, we compared performance for objects fixated once with objects fixated twice. The main effect of target fixation was not significant, $F(1, 13) = 3.940$, $p = .069$. Yet, performance for objects fixated twice tended to be higher, with an estimated marginal mean of

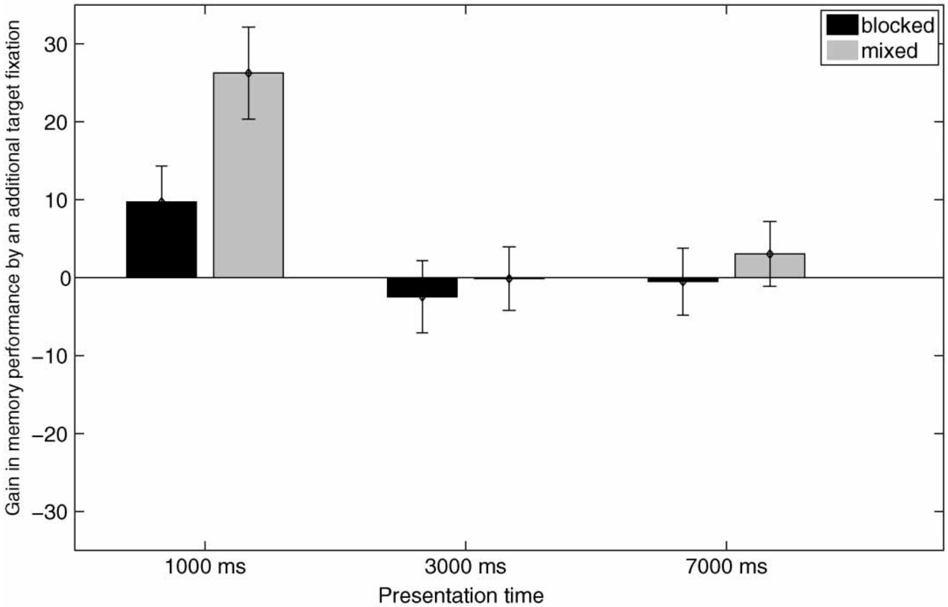


Figure 3. *Mean percentage correct and standard errors of the mean when subtracting performance for nonfixated objects from performance for fixated objects (1,000 ms and 3,000 ms) or when subtracting performance for objects fixated once from objects fixated twice (7,000 ms). Positive values reflect a benefit for an additional target fixation.*

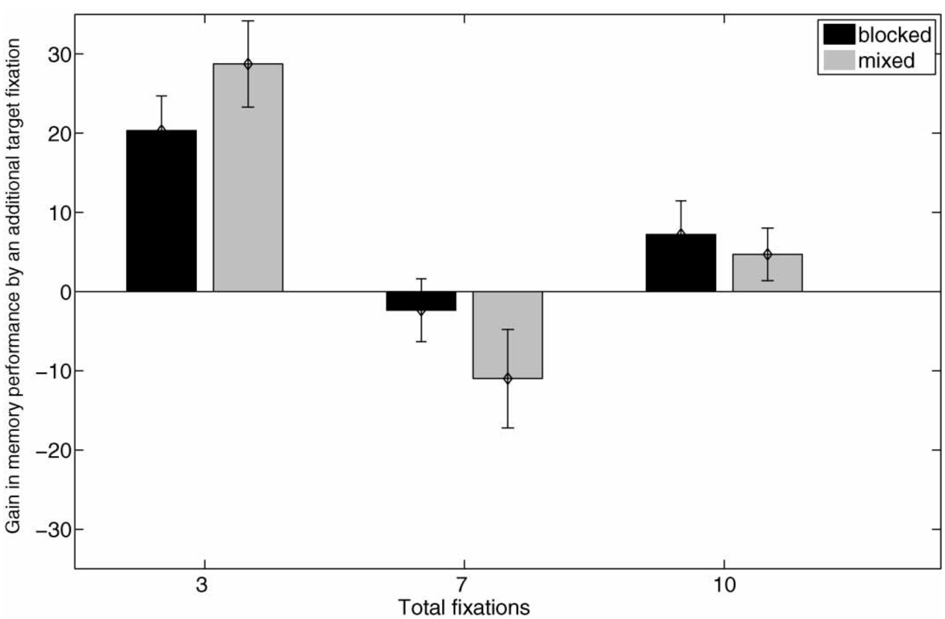


Figure 4. *Mean percentage correct and standard errors of the mean when subtracting performance for nonfixated objects from performance for fixated objects (3 and 7 fixations) or when subtracting performance for objects fixated once from objects fixated twice (10 fixations). Positive values reflect a benefit for an additional target fixation.*

$M = 59.00\%$ as compared to $M = 53.05\%$. The effect of design and the interaction effect were not significant (both $p > .602$).

Thus, the results show that fixating an object aided in remembering it only when the viewing time was short. When viewing times were longer, there was no benefit of one or two target fixations.

Results of the fixation experiment

In the additional experiment, we contrasted a condition in which no eye movements and thus no fixations on objects were allowed with a condition of free viewing. Performance was virtually identical in both conditions, with a mean percentage of correct trials of $M = 41.09\%$ ($SD = 11.25$) in the central fixation condition and $M = 41.7\%$ ($SD = 6.80$) in the free viewing condition. A t test for paired samples revealed no significant difference in accuracy in the memory task for the two conditions, $t(9) = -0.18$, $p = .862$. Performance was thus comparable irrespective of whether any fixations were made, lending further support to the idea that fixations play a limited role with respect to memory performance.

Effect of fixations in time-course

We also investigated whether the relative time of object fixation within a trial affected memory performance. We compared performance for objects that had been fixated at different time points within one trial. We focused on the data from those sessions where we had manipulated the number of allowed fixations. This ensured that the time of fixation was not confounded with the number of fixations made. For example, in the condition of 7 fixations, in each trial, exactly 7 fixations could be made, and the most recent one was always the 7th fixation. In a condition with a fixed viewing time, the last fixation might have been the last of 7, 8, or 9 fixations.

To get as many cases as possible to allow statistical testing, we combined the data from the mixed and blocked modes for all participants. We then selected all trials in which the target object had been fixated. Trials in which the target object had been fixated last or second to last in the sequence of fixations were counted as *recent*. Trials in which the target object had been fixated first or second were counted as *first*. All other trials were counted as *else*. Inclusion in the categories was mutually exclusive; if an object fulfilled the criteria for recent (e.g., fixated last or second to last in the sequence) and for first (e.g., fixated first or second), then the respective trial was excluded. Because of this restriction, 7.10% of the trials in the condition of 10 fixations and 4.4% of the trials in the condition of 7 fixations were excluded. For the condition with 3 fixations, we only compared recent trials versus all other ones because only 3 fixations made it very unlikely that performance would be different between the first and the second fixation. In fact, performance for the first fixation and second was rather similar with respective means of 59.64% and 55.88% (for this condition, most recent included only those cases when the target had been fixated last in the sequence). Thus, a combination of performance for the first and second fixations in a trial seemed justified.

For 3 fixations, the mean percentage correct for recent trials was $M = 68.98\%$ ($SD = 21.70$) and $M = 57.92\%$ ($SD = 19.80$) for the remaining trials with target fixation (that is, target fixated first or second) . The difference did not reach significance in a paired-samples t test, $t(14) = 1.897$, $p = .079$ but there was a strong tendency for a recency effect. For 7 fixations, performance was highest in the recent trials with $M = 56.28\%$ ($SD = 12.62$). For first trials, the mean percentage correct was $M = 45.12\%$ ($SD = 15.54$) and for the else trials, $M = 41.69\%$ ($SD = 17.48$). A repeated measures ANOVA showed a significant main effect of the fixation point in time (recent vs. else vs. first), $F(2, 28) = 7.006$, $p = .005$. Pairwise comparisons showed that the difference between recent versus else trials ($p = .016$) was significant. The difference between recent versus first trials did not quite reach significance ($p = .069$). Thus, with 7 total fixations, target objects that had been fixated last or second to last in the fixation sequence were remembered at a higher rate.

For 10 fixations, performance was high and nearly identical for both the recent trials with $M = 61.77\%$ ($SD = 18.98$) and for the first trials with $M = 61.00\%$ ($SD = 23.22$). For the else trials, the mean percentage of correct answers was distinctly lower with $M = 49.15\%$ ($SD = 15.88$). Again, a repeated measures ANOVA showed a significant main effect of time of fixation within the trial (recent vs. else vs. first), $F(2, 28) = 4.522$, $p = .032$. Pairwise comparisons showed that the difference between recent versus else trials ($p = .017$) was significant, as was the difference between else versus first ($p = .034$). Thus, we found evidence for both a primacy and a recency effect (compare Figure 5 for a graphic presentation of the results). This result fits well with our finding above, indicating that performance in the longest viewing condition (e.g., 10 fixations) differed significantly from that in the shorter ones.

As is presented in detail in the Discussion section, we propose that the better performance and primacy effect in the 10-fixation condition are ascribable to the involvement of a long-term memory component that comes into play when viewing duration is sufficiently long. To get further support for this idea, we performed an additional analysis for the first trials of the 7-fixation condition. If longer viewing times are associated with the involvement of a long-term memory component, one might expect that those participants with longer trial lengths in the 7-fixation condition might already show this involvement. This should then be reflected in a stronger primacy trend. Thus, we constructed two subgroups depending on trial length in the 7-fixation condition. The subgroup of participants with shorter trials ($N = 8$) had an average trial length of $M = 2{,}847$ ms ($SD = 64$). The mean trial duration for the subgroup with longer trials durations ($N = 7$) was $M = 3{,}163$ ms ($SD = 27$). For the two groups, we then compared performance in those trials that were counted as first. Performance in the first trials was lower in the group with shorter trials, with a mean percentage correct of $M = 37.20\%$ ($SD = 9.85$), as compared to the group of participants taking longer for the trials, with $M = 54.17\%$ ($SD = 16.47$). This difference was significant, $t(13) = -2.380$, $p = .040$. Thus, a longer trial length was associated with a stronger primacy effect. We compared overall performance between the two groups to ensure that it was not the case that those participants who had shorter trial lengths generally performed worse. The difference in performance was not significant, $t(13) = -1.549$, $p = .147$. This analysis supports the idea that longer viewing times are associated with a long-term memory involvement reflected in a primacy effect.

We also compared performance for the recent, else, and first trials for the conditions with a fixed presentation time. We found a very similar pattern of results (not plotted) even though there was the potentially confounding factor of different numbers of fixations made. Recent, else, and first were defined as above. In the condition of 7,000 ms, 6.32% of the trials and for 3,000 ms, 7.8% of the trials had to be excluded as objects were fixated first and last. For 1,000 ms, no results are reported because only 3 participants had at least five cases for both recent and else trials. For 3,000 ms, performance was highest for the most recent trials, $M = 51.22\%$ ($SD = 16.01$), and was at $M = 35.78\%$ ($SD = 10.09$) for the else trials and at $M = 46.92\%$ ($SD = 19.09$) for the first trials. A repeated measures ANOVA showed a significant main effect of time of fixation within the trial, $F(2, 28) = 3.647$, $p = .045$. Pairwise comparisons indicated a significant difference between the recent performance and the else performance, $p = .017$.

For the presentation time of 7,000 ms, there were again recency and primacy effects. The mean percentage correct for the recent trials was $M = 55.36\%$ ($SD = 17.28$) and for the first trials was $M = 58.50\%$ ($SD = 15.31$). Performance was lowest for the else trials with a mean of $M = 46.36\%$ ($SD = 14.13$). A repeated measures ANOVA showed a significant main effect of time of fixation within the trial, $F(2, 28) = 5.254$, $p = .016$. Pairwise comparisons showed a significant difference in the comparison of the recent and else trials ($p = .031$) and the first and else trials ($p = .026$).

Fixation durations and trial lengths

To examine whether the predictability of the viewing time had an impact on memory

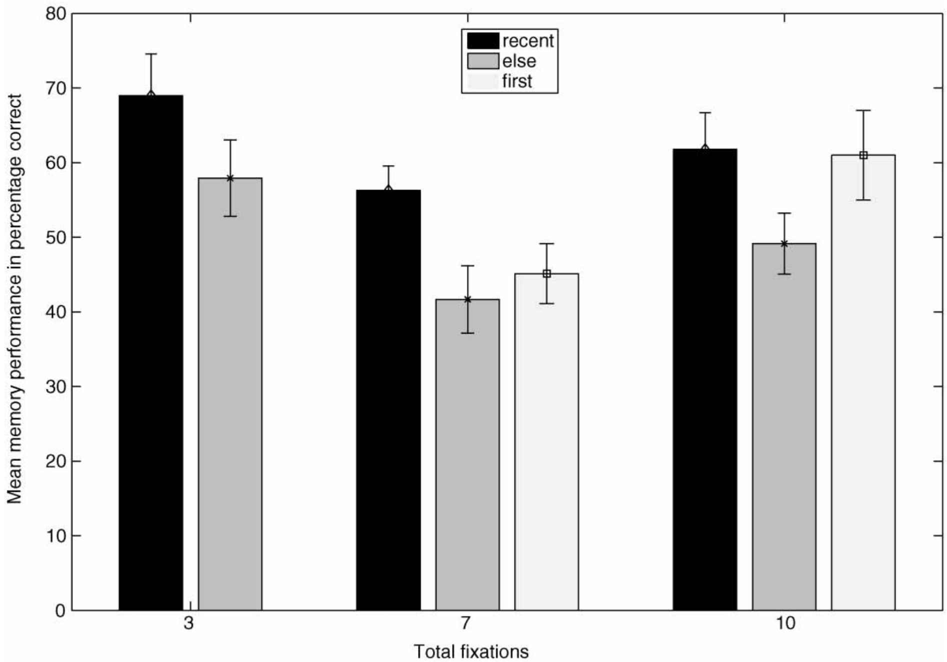


Figure 5. *The mean percentage of correct answers and standard error of the mean depending upon when the target object had been fixated. For three total fixations, no differentiation between else and first has been made, resulting in only two bars.*

performance, we compared fixation durations and trial lengths in the blocked versus interleaved designs. For every participant, we calculated the duration of the first target fixation and compared the mean across conditions. We used the duration of the target fixation to be able to relate fixation durations to memory performance. We used the duration of the first fixation, not the sum of all fixations, because in the latter case differences between the different viewing times would have emerged because at longer times there were more cases of multiple fixations. To compensate for this problem by taking the average duration would not have been feasible because a refixation cannot be seen as equivalent to an initial fixation.

A 3 (viewing time: 1,000, 3,000, 7,000 ms) × 2 (design: blocked vs. mixed) repeated measures ANOVA showed a significant main effect of time, $F(2, 28) = 19.151$, $p < .000$, and a highly significant interaction effect, $F(2, 28) = 12.727$, $p = .001$. The effect of design was not significant, $F(1, 14) = 0.015$, $p = .906$. As also shown on the left graph of Figure 6, in the blocked design, fixation durations increased with longer presentation times (from 251.45 to 355.18 to 423.62 ms), whereas they remained constant in the interleaved design (331.69, 336.15, 358.48 ms).

The same pattern of fixation behaviour occurred when varying the number of total fixations, as the right graph of Figure 6 shows. There was a highly significant effect of the number of fixations made, $F(2, 28) = 20.260$, $p < .000$, and a significant interaction effect, $F(2, 28) = 5.823$, $p = .023$. The effect of design was not significant, $F(1, 14) = 0.152$, $p = .702$. In the blocked condition, fixation durations increased the more fixations were made (mean fixation durations: 254.57, 339.98, 402.38 ms), but in the interleaved condition they were very similar for all trials (mean fixation durations: 300.08, 331.71, 328.99 ms).

This implies that the design had an important influence on the viewing strategy of the participants: When they were not able to predict the

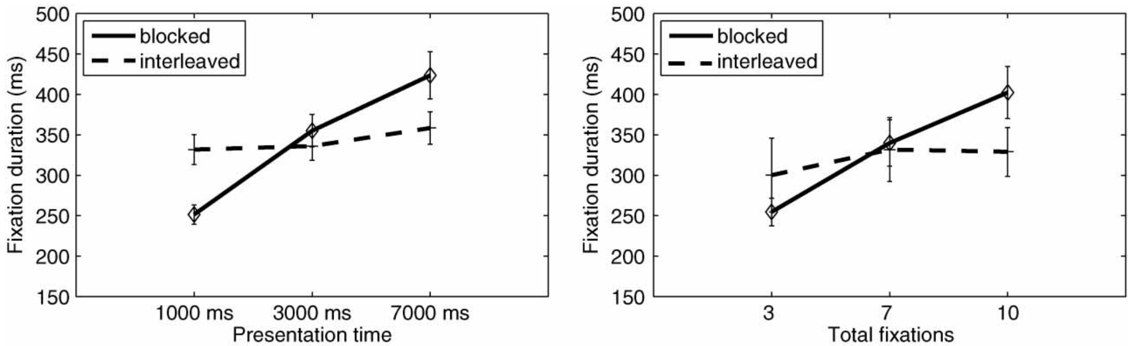


Figure 6. *The mean presentation durations and standard error of the mean of the first target fixation in the mixed and the blocked design.*

duration of the stimulus array, they tended to make fixations of about the same length. But when they knew about how much time they had, they adjusted the duration of their fixations accordingly. Interestingly, this was not reflected in the memory performance, indicating that the fixation duration is not of major importance when it comes to remembering an object. To analyse the relationship between fixation durations and performance further, we created three subsets of data, by binning fixation durations for each participant in each condition into thirds, yielding short, medium, and long fixation durations. We looked at the percentage of correct answers in the respective bin and then calculated in a repeated measures ANOVA whether there was an effect of fixation duration. There was no significant effect, all $p > .132$. Thus, performance and fixation durations were not linked showing that extended looking at an object did not increase its probability of being remembered.

The variable fixation behaviour was also reflected in the average trial lengths. We calculated the median of all trial durations for each participant. In the condition of 3 fixations, the average trial length was $M = 1{,}300$ ms ($SD = 96$) in the blocked condition and $M = 1{,}494$ ms ($SD = 166$) in the mixed condition. For 7 fixations, the average trial length was very similar for the blocked ($M = 3{,}028$ ms, $SD = 202$) and the mixed condition ($M = 2{,}960$ ms, $SD = 306$) as were the respective average target fixation durations (compare above). For 10 fixations, the average trial was longer in the blocked condition with $M = 5{,}305$ ms ($SD = 704$) than in the mixed condition ($M = 4{,}640$ ms, $SD = 499$) reflecting the finding of the longer fixation duration in the blocked condition.

DISCUSSION

Our study addressed three main issues. First, we investigated how increasing the viewing time of the stimulus material affected memory performance. We operationalized a longer display time in two ways: first, by setting the trial length to 1,000, 3,000, or 7,000 ms and, second, by allowing participants to make 3, 7, or 10 fixations. We found that that memory performance, defined as the percentage of correct answers, was significantly better in the respective longest trials (that is, for 7,000 ms or 10 fixations) than in the shorter trials. We also examined whether memory performance differed for fixated and nonfixated objects. We found that at the two shortest conditions (1,000 ms or 3 fixations, respectively) fixated objects were remembered better. At medium trial durations, there was no difference in performance for fixated and nonfixated objects. At the longest viewing durations, where we contrasted performance for objects fixated once and fixated twice, we also did not find any significant differences. Our third aim was to compare the effects of a blocked versus interleaved design. We found that this manipulation did not significantly change memory performance but instead affected fixation behaviour. In the blocked design, fixation durations increased with longer trial durations whereas they stayed constant in the interleaved design.

Memory performance

As reported above, memory performance was significantly higher for 7,000 ms or 10 fixations than for 3,000/1,000 ms and 7/3 fixations, respectively. Thus, the longest viewing time led to significantly more objects being remembered. The memory increase corresponded to the retention of one additional object. The estimated memory capacity of our study fits well into the framework of the object-file theory, which postulates that about three to five object files containing position and identity information are stored in VSTM (Irwin & Zelinsky, 2002; Kahneman & Treisman, 1984). The significantly higher performance at the longest viewing duration in our study was accompanied by a primacy effect, which we take as indication of the involvement of a qualitatively different memory component. Generally speaking, a recency effect is considered a reliable marker of short-term memory whereas the primacy effect is ascribed to a long-term storage component (Atkinson & Shiffrin, 1968; Glanzer, 1972; Glanzer & Cunitz, 1966). Hollingworth (2004) reported that object memory was consistently superior for the two most recently fixated objects, which he ascribed to a visual short-term memory component. He also found that objects looked at earlier within a trial were still remembered well above chance indicating a visual long-term component. This partition into a short-term and a long-term memory component is central in Hollingworth's and Henderson's visual memory theory of scene representation (Hollingworth, 2003, 2004, 2005a, 2005b; Hollingworth & Henderson, 2002). We propose that in our study memory performance in the two shorter conditions is attributable to a short-term memory component, and the significant improvement at the longest viewing time to a long-term memory component. Alternatively, the hypothesized different memory component could match the medium-term component as proposed by Melcher (2001) instead of a long-term memory component. He found no evidence for a discontinuity in the rate of accumulation that he expected during transition from short-term to long-term memory. But he did find evidence for a loss of information over a period of 24 hours and suggested that scene memory might involve a proto-long-term memory. Thus, with respect to memory performance, our results are easily integrated into the existing theoretical framework. Our reported finding of a primacy effect brings novel support for a long-term-memory involvement. We interpret the fact that there were no performance differences in the two shorter conditions as an indication that the short-term component of visual memory is filled after brief viewing. Improvements can then only be expected when a long-term component comes into play—that is, when using longer stimulus durations.

Role of fixations

Our study also showed that fixations on objects only play a limited role with regard to memory performance. Fixated objects were only remembered better at the shortest viewing times. At the medium viewing times, there was no difference between nonfixated and fixated objects. At the longest viewing times, there was no beneficial effect of a second target fixation. In earlier research a beneficial effect of fixations for memory performance had been found (e.g., Hollingworth & Henderson, 2002; Irwin & Zelinsky, 2002; Melcher & Kowler, 2001; Nelson & Loftus, 1980); however, this was not true for all object properties (Tatler et al., 2005). Research on inattentional blindness and change detection also supports the idea that fixating a location does not mean that what is present at that location is necessarily perceived (Caplovitz et al., 2008; Koivisto et al., 2004; O'Regan et al., 2000). Using a flicker change-blindness paradigm without blink-mediated suppression, Caplovitz et al. showed that despite directive attentive fixations, participants often failed to detect obvious scene changes. This clearly indicates that fixating a location is not always equal to attending to that location, and thus a beneficial effect on memory performance is not necessarily expected.

Our results indicate that peripheral viewing of an object, which supposedly occurs repeatedly when viewing time is beyond a critical duration, is sufficient for encoding as well as that of direct fixation. The duration of a fixation was not coupled to performance, arguing in favour of a limited effect of fixations in the current experiment. Considering that we have found only a very limited advantage for fixated objects, one might argue that participants fixate those objects that are hard to see and thus initially harder to remember. However, there are two arguments against this claim: First, we conducted an additional experiment where we compared a central fixation condition with a free viewing condition. The level of performance should have been lower in the central fixation condition if fixations serve to boost performance for otherwise unrecognizable items. However, we found that performance was the same in both conditions. Second, recognizing which objects are more difficult to recognize already requires attending to all positions. Considering the short viewing time used, it does not seem sensible to expect that participants can preprocess the stimulus array in such depth before making the first saccade. From our results, we deduce that fixations only help under specific circumstances. We reject the general claim that fixations are beneficial for memory performance.

Blocked and interleaved design

Our third main finding concerned the use of a blocked versus interleaved design. Absolute memory performance did not change across these conditions, but viewing behaviour was affected. In an interleaved design where viewing time was unpredictable, the average fixation duration was the same for all trials and thus for all viewing times. In the blocked design, fixation durations became longer with longer viewing times. The total trial durations varied accordingly. This result shows that participants adjusted their strategy of looking according to the design. Thus, we have shown a novel influence on fixation durations. It has been reported that fixation durations are sensitive to a number of factors, like the serial position of an item (Saint-Aubin et al., 2007), culture (Rayner et al., 2007), stimulus luminance (Loftus, 1985), and mask onset delays (Rayner et al., 2009), but to our knowledge it has not been previously shown that the use of blocked versus interleaved design plays a role.

Conclusions

We suggest that the stimulus presentation time only plays a limited role for performance in a visual memory task. Variations within a brief range of durations that only involve the short-term component of the visual memory system do not alter memory performance. When viewing times increase such that a long-term memory component is involved, performance increases beyond the initial level. Fixations only had a limited impact on performance: They aided in remembering when viewing time was short. Thus, peripheral viewing can be sufficient for memory performance as high as that of directly fixated objects. The use of a blocked versus interleaved design did not impact memory performance but did affect fixation durations, showing the importance of the task design, and highlighting the potential of fixation durations as a marker of cognitive processes and strategies.

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