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The relevance of the first two eye fixations for recognition memory processes

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------------------------------------ *Memory, in press* ----------------------------------

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Abstract

Stimuli can be recognised based on information from only one or two eye fixations. With only one fixation, item recognition is typically above chance level and performance generally saturates by the second fixation. Thus, the first two eye fixations play an important role for recognition memory performance. However, little is known about the involved processes. Therefore, two experiments were conducted to investigate hypotheses regarding the role of the first two eye fixations for specific recognition memory processes, that is, familiarity and recollection. In addition, we looked in detail at the unique contributions of (a) longer input duration and (b) additional information provided by a second fixation for familiarity- and recollection-based recognition, using a gaze-contingent stimulus presentation technique. The experiments showed that recollection- but not familiarity-based recognition increased with two compared to only one fixation, and that the second fixation boosted recollection both due to longer availability of the input and additional stimulus information gathered.

Keywords:

Recognition memory, familiarity, recollection, eye fixations, eye movements

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When we encounter a familiar other, it is beneficial to recognise this person quickly, in order to behave in a socially appropriate way. Correspondingly, Hsiao and Cottrell (2008) ascertained that performance in an old/new recognition test for faces was above chance level with only a single fixation to a test face. With a second fixation, participants already reached their maximal recognition performance. In addition, the authors disentangled two aspects that are confounded in the comparison of one versus two fixations: *input duration* of the viewed stimulus (which is or tends to be longer with two compared to one fixation) and the *amount of information* about the stimulus (which increases with a second gaze location). They showed that the availability of an additional piece of stimulus information made a unique contribution to the increase in recognition performance. Thus, the second fixation to a (face) stimulus has a functional role and in most cases we recognise a familiar stimulus already within the first second we look at it.

Usually, it is not enough to realise that we know the item (i.e., person) in front of us (i.e., familiarity-based recognition). To react in a suitable way, it is important to remember who the person is. Therefore, it is necessary to retrieve contextual information, a process that is associated with recollection-based recognition in the two-process model of recognition memory (for a review, see Yonelinas, 2002). But how does the occurrence of these processes depend on our eye fixations? Hitherto, there is no study (to our knowledge) that has investigated (1) the relevance of the first two eye fixations for familiarity- and recollection-based recognition and (2) the relative importance of input duration and amount of information gathered for the effect of an additional fixation. This was the aim of the present study.

The dual-process model of recognition and early eye fixations

According to the dual-process model by Yonelinas (1994), our recognition performance is based on two independent processes: familiarity and recollection. Familiarity is supposed to be a fast signal-detection process that is based on the assessment of processing fluency, whereas recollection is assumed to be a slower threshold process that is based on the retrieval of context information concerning the earlier encoding of the specific item (Yonelinas, 1994; for a review, see Yonelinas, 2002). The two processes are assumed to be independent, can operate in parallel and are associated with different neural networks. Whereas the perirhinal cortex is relevant for familiarity, the hippocampus contributes to recollection (for a review see Eichenbaum, Yonelinas, & Ranganath, 2007). A familiarity signal is needed to differentiate known from unknown stimuli (e.g., faces), and recollection is needed to retrieve the necessary context information to remember, for example, where we know a person or object from. Thus, the slower recollection-based recognition allows differentiation between two different familiar stimuli (e.g., our friend and our foe), enabling us to react in a suitable manner in each situation. There is evidence from studies with humans and monkeys with damage of the hippocampus that demonstrate the hippocampus as a critical part for effects of memory on eye-movement behaviour (for an overview see Meister & Buffalo, 2016).

Studies looking for memory effects in the duration of early eye fixations (Ryan, Hannula, & Cohen, 2007; Schwedes & Wentura, 2012, 2016) have suggested that first fixations might relate to familiarity-based recognition and second fixations to recollection-based recognition eye fixation. In the study by Ryan and colleagues (2007), participants had to select a familiar face out of a display of three faces. First fixations were found to be longer to known selected faces compared to unknown selected faces. However, in the studies by Schwedes and Wentura (2012, 2016), the participants' task was to select one kind of familiar face as old but to conceal the knowledge of another type of familiar face (i.e., participants were instructed to not select thus face as known). In this task, the memory effect appeared in the duration of the second fixation but not in the duration of the first fixation.

These different findings could be due to differences in task requirements: While Ryan and colleagues (2007) used an item memory task, where a familiarity signal was sufficient for correct responding, the retrieval of context-specific information (i.e., recollection) was necessary to respond correctly in the studies by Schwedes and Wentura (2012, 2016). It is known that retrieval orientation (e.g., inclusion vs. exclusion instructions) can have an influence on the relative contribution of familiarity- and recollection-based recognition (Ecker & Zimmer, 2009). Thus, it is possible that the first-fixation memory effect found by Ryan et al. (2007) was triggered by familiarity-based recognition, and the second-fixation effect in our studies reflected recollection-based recognition.

Specifically, the input provided by a second fixation may serve as an additional retrieval cue facilitating the occurrence of recollection. Support for this assumption comes from an experiment that examined the dependency of familiarity- and recollection-based recognition on the amount of available input information (Mäntylä & Holm, 2006). Mäntylä and Holm (2006) compared two conditions in a recognition memory test. In one condition, while a face stimulus was presented, participants were instructed to fixate a cross located between the eyes of the face. A second condition allowed free viewing of the face stimulus during the recognition test. In order to draw conclusions about the recognition memory processes involved, a two-step remember-know-guess procedure was used. Compared to the free-viewing condition, restriction of eye movements at recognition impaired recollection-based recognition (the proportion of "remember" responses) but had no effect on familiarity-based recognition (the proportion of "know" responses).

Although Mäntylä and Holm (2006) compared only a one-input-location condition with a many-input-locations condition, these findings, together with the findings of Hsiao and Cottrell (2008), suggest that a second fixation contributes to an increase in recollection- but not familiarity-based recognition. This assumption is in line with a more dispersed fixation pattern for "remember" compared to familiarity-based "know" responses when inter-fixation distances are analyzed in an object recognition task (Kafkas & Montaldi, 2012). When distances are larger, additional fixation locations share less information with prior sampled locations. Kafkas and Montaldi argued that with a more dispersed fixation pattern, more salient stimulus features can be attended to, and this can trigger recollection.

Additional support for a meaningful relation between a second eye fixation and recollection comes from the following observation. In event-related potentials (ERPs), the Late Positive Component (LPC) between 400 and 800 ms post stimulus onset is associated with recollection (for a review of ERPs and recognition memory, see Rugg & Curran, 2007). This time window can be mapped onto the occurrence of second fixations in recognition tasks. The time window of a second fixation in the study by Hsiao and Cottrell (2008) ranged from 300 to 610 ms post stimulus onset. In our earlier eye-tracking study (Schwedes & Wentura, 2012), we found second-fixation time windows from 267-678 ms. Hence, the time course of second fixations when recognizing stimuli was very similar across these two studies and overlap with ERPs associated with recollection-based recognition.

A finding that directly supports the assumed relation between recollection and the second fixation comes from Schwedes and Wentura (2012). In this study, we found longer second fixations to faces of “foes” (known faces that had to be selected by participants in a lineup) compared to faces of “friends” (known faces for which incriminating knowledge had to be concealed), although both types of faces were familiar to the same extent. This effect could be explained by a response-intention effect, that is, the tendency to look longer to stimuli we intend to select compared to stimuli we do not intend to select (see Ryan, Hannula, & Cohen, 2007). A prerequisite for the occurrence of this effect, however, is the differentiation between the two kinds of known faces, which can only be based on recollection. Thus, the occurrence of this effect indicates that recollection was available during the second fixation.

To sum up, one can hypothesise that a second fixation supports recollection-based recognition of a face for two different reasons: First, recollection is assumed to be a relatively slow process, and the typical duration of the first two fixations matches the time needed for recollection. Second, the additional input information gathered by a second fixation can serve as an additional retrieval cue. Therefore, it is of theoretical interest to investigate which recognition processes are responsible for the increase in recognition performance associated with a second fixation to a face (Experiment 1), and to test whether the increase depends on the longer *input duration* and/or the greater *amount of information* obtained about the stimulus (Experiment 2).

Overview

In Experiment 1, we aimed to investigate which recognition memory process – familiarity or recollection – is chiefly responsible for the increase in recognition memory performance with a second compared to only one fixation to a face. Therefore, we presented face stimuli in the recognition phase for one, two, three, or four fixations. In addition to the old/new recognition decision, we applied a remember/know/guess-procedure (Gardiner, Java, & Richardson-Klavehn, 1996; Tulving, 1985) to look at the underlying recognition memory processes. Concerning overall recognition performance, we expected to replicate the findings of Hsiao and Cottrell (2008), that is, above-chance recognition performance if only one fixation is allowed at test and a significant performance improvement with two fixations compared to only one. We expected that a third or fourth fixation should not further improve performance.

Regarding the underlying recognition processes, with only one fixation we expected a larger proportion of “know” judgements to old items (corrected for FAs; typically interpreted as familiarity without recollection) than “remember” judgements (corrected for FAs; usually interpreted as recollection). We expected this outcome because only one retrieval cue might be too weak to trigger recollection (in most trials).

With two allowed fixations, we expected a significant increase in “remember” responses to old items (corrected for FAs) compared to only one fixation, due to the longer input duration of the face and, most importantly, the extra input information that can serve as an additional retrieval cue. As Mäntylä and Holm (2006) found that only recollection benefits from multiple inputs, we expected that the increase in “remember” responses to old items (corrected for FAs) with two fixations would not be accompanied by a corresponding increase in “know” responses. Thus, the expected overall increase in memory performance should be due mainly to an increase in recollection-based processes.

As an aside, one might expect that the propensity to give “know” responses – irrespective of whether they refer to old or new items – might increase with two fixations compared to only one, since a longer input duration might enhance processing fluency. Earlier studies have shown that enhanced processing fluency can lead to an increase in familiarity-based “old” responses for studied as well as new items (e.g., see Jacoby & Whitehouse, 1989; Rajaram, 1993). However, even if such an effect is found, this process cannot explain the expected performance increase, which is the focus of our research.

In Experiment 2, we disentangled the confounded second-fixation factors of longer input duration and additional stimulus information, using a specific gaze-contingent stimulus presentation to investigate the independent contributions of both aspects on recognition memory processes.

Experiment 1

Method

Participants. Forty-one undergraduate students from Saarland University took part in the experiment. They received 6 Euro for participating. One participant was excluded due to poor overall recognition memory performance (see *Results*). The data of the remaining participants (31 women, 9 men, mean age = 21 years 3 months) were analyzed. All participants had normal or corrected-to-normal vision, were native speakers of German and gave informed written consent in the beginning of the experiment.

The increase in recognition performance from one to two allowed fixations found by Hsiao and Cottrell (2008) was associated with an extremely large effect size of $d_Z = 1.67$. We planned more conservatively because we were not only interested in replication but in differentiating recollection and familiarity processes. A sample size of N = 40 allows to detect effect sizes of $d_Z = .45$ (i.e., effects a bit smaller than “medium-sized” according to Cohen, 1988) with $\alpha = .05$ and $1 - \beta = .80$ (G*Power3; Faul, Erdfelder, Lang, & Buchner, 2007).

Design and materials. The materials comprised 120 grey-scaled face images (60 men and 60 women) taken from the database of Schwedes and Wentura (2012). All faces were placed against a uniform grey background and measured 311 × 339 pixels (this corresponds to 7.3 × 8.0° of visual angle). 112 of these faces were used in the recognition test of the experiment;

the remaining eight faces (filler faces) were used for primacy and recency trials in the learning phase as well as the practice trials for the recognition test. Participants were shown half of the faces (50% men and 50% women) in the incidental learning phase (incl. two primacy and two recency filler items). These familiar faces were then intermixed with the remaining faces in the subsequent recognition test. The filler faces used in the primacy and recency trials were intermixed with the remaining 4 filler faces; these faces served as practice trials for the recognition test. To investigate the influence of the number of fixations on recognition memory performance, a quarter of the faces (half old, half new) was presented for one, two, three, or four fixations in the recognition test, respectively. This manipulation resulted in a one-factorial within-subjects design with the independent variable fixation (one, two, three, four). For the dependent variables, which served as indices of recognition memory performance and the underling recognition memory processes, see *Data Preparation*. The materials were counterbalanced across participants such that each face appeared equally often in each condition.

Apparatus. The eye movements of the participants' dominant eye were recorded with an SMI Hi-Speed Eye-Tracker with a sample rate of 500 Hz. A calibration was defined as valid if the spatial error was less than 0.5°. To manipulate stimulus presentation time dependent on the number of executed fixations, we used on-line detection of terminated fixation events, using the eye-data recording software iView X^{TM} Hi-Speed with its default parameters for fixation detection (maximal dispersion value 100 pixels and minimum fixation duration 80 ms). Stimuli were presented with a Windows-based computer on a 17" monitor with a resolution of 1280 × 1024 pixels and a refresh rate of 75 Hz, using the experimental software PsychoPy (Peirce, 2007). The viewing distance measured 64 cm.

Procedure. The experiment consisted of four phases: an incidental learning phase, a retention interval, a recognition test, and a follow-up questionnaire. Participants arrived in the laboratory and signed a consent form. Then, a standard 13-point calibration of the eye-tracker with subsequent validation was performed. The incidental learning task involved gender categorization of individually presented faces; participants were told that we were interested in the ongoing processes and viewing behaviours while categorizing faces. Before the learning phase, participants familiarised themselves with the procedure in four practice trials, which had the same structure as the main trials. Each trial began with a central fixation cross. When the cross was fixated the experimenter pressed the space bar and a frame, 311 × 339 pixel (that corresponds to 7.3 × 8.0° of visual angle) in size, appeared in one of six possible locations, indicating the position of the pending appearance of the face. The six potential positions were arranged in a circle around the center of the screen (with a radius of 100 pixels [2.6° of visual angle], and positions separated by 60° angles; for an illustration, see Figure 1A). Participants were instructed to place their gaze inside the frame. When a saccade crossed the frame border (i.e., eye position fell into the frame), the face stimulus appeared in the frame for 3000 ms. After a 50 ms blank screen, two buttons labeled “männlich” [“male”] and “weiblich” [“female”] appeared alongside a mouse cursor, and the participants had to click one of the buttons to make a gender categorization. After the categorization response, the next trial started (see Figure 1 for a trial sequence). To control for possible primacy and recency effects, we added four filler trials before and after the experimental study trials.

After a five-minute retention interval, during which participants solved some tasks of a standard intelligence test (i.e., items 21 to 40 of the *Intelligenz-Struktur-Test-Screening*; Liepmann, Beauducel, Brocke, & Nettelnstroth, 2012), an unexpected recognition test followed. Participants were informed that faces of the preceding study phase would be intermixed with lures, and that their task was to make an old/new decision for every face. Each "old" response was followed by a remember/know/guess judgment. Participants were instructed to give a "remember" response if they could recollect any aspect of the face occurring in the study phase, such as the position of the face in the sequence (i.e., early or late) or any thoughts they had when first viewing the face. If the face evoked familiarity in the absence of conscious recollection, they were instructed to give a "know" response. They were instructed to give a "guess" response whenever they had guessed the face to be "old". Participants were told that the faces would appear for a variable presentation time, but they were not informed that presentation time depended on the number of executed fixations. To familiarise participants with the procedure of the recognition test, they run through eight practice trials.

Specifically, a trial in the recognition test proceeded as follows. It started with a central fixation cross. When it was fixated, the experimenter pressed the space bar. (Whenever a drift correction was needed, a recalibration could be undertaken at this time.) After a 50 ms blank screen, a frame appeared in one of six positions, indicating where the face would appear. The possible six locations were constant (see Figure 1A), but in each trial the position was randomly chosen. As in the learning phase, participants were instructed to direct their gaze inside the frame to see the face (the center of the frame/target face appeared 6.0° of visual angle away from the fixation cross). When the corresponding saccade crossed the frame border, the face was presented. Thus, parafoveal pre-processing of the face was not possible. The face remained on screen until the end of the last permitted fixation for the particular trial (i.e., one, two, three, or four fixations) had been registered. The maximum presentation time was set to 2500 ms to avoid abnormal presentation times in the case of staring. The face was then replaced by a mask to destroy the retinal afterimage; the mask stayed on screen until 3000 ms post face onset (i.e., the minimum duration was 500 ms). Subsequently, two buttons labeled “alt” [“old”] and “neu” [“new”] and the mouse cursor appeared. The participants’ task was to indicate if the just-presented face was known from the learning phase (“old”) or not (“new”). In case of an “old” response, they were asked for a remember/know/guess judgment, which they made by clicking on the corresponding button on the next screen. After a 50 ms blank screen, the next trial started. See Figure 1B for an example trial sequence. Note, independent of the fixation conditions participants responded 3000 ms after face onset. Thus, the different fixation conditions did not reflect different response deadline conditions.

Data preparation. Overall recognition memory performance was assessed with the discrimination measure *Pr*, calculated by subtracting the probability of an “old” response to a new face (false alarm [FA]), *p*(FA), from the probability of an “old” response to a learned face (hit), *p*(hit). The corresponding measure for the response bias *Br* was calculated by dividing *p*(FA) by 1- *p*(hit)- *p*(FA) (see Snodgrass & Corwin, 1988)[1].

For the analyses of the underlying recognition memory processes, we estimated the probability of remember, know, and guess responses that followed a hit or FA, separately for each fixation condition. The probability of a hit followed by a "remember" response, *p(hitR)*, was calculated by dividing the number of old faces with a "remember" response by the total number of old faces. In an analogous manner, we proceeded for the probability of know, *p(hitK)*, and guess, *p(hitG)*, responses. The same was done for the probability of FAs, using the number of new faces instead of old ones, followed by a remember, know, or guess response to calculate *p(FAR)*, *p(FAK)*, and *p(FAG)*.

The proportion of "remember" responses to old items (corrected for FAs) was used as an estimate of recollection-based recognition performance. Correspondingly, we decided to use the proportion of "know" responses to old items (corrected for FAs) as an estimate of familiarity-based recognition performance instead of using the independence remember/know (IRK) method introduced by Yonelinas and Jacoby (1995). This decision was based on the known problems of the IRK method to produce reliable estimates of familiarity under experimental conditions that primarily affect recollection – as in our case – with only a small or no effect on familiarity (see, e.g., Gardiner & Richardson-Klavehn, 2000; Richardson-Klavehn et al., 1996, for a detailed discussion of this point).

[1] We used the correction introduced by Snodgrass and Corwin (1988) to deal with the problem of a division by zero in some cases when calculating the response bias. That is, the probabilities for a hit, FA, CR, and miss were calculated by adding .5 to the numerator and 1 to the denominator. To be consistent, we applied the correction to all data reported here, as recommended by Snodgrass and Corwin.

Results

The result section is divided into two parts. First, we present recognition memory performance data (*Pr* and *Br*) separately for each fixation condition. In the second part, the data of the remember/know/guess (RKG) procedure are analyzed in detail to look at the underlying recognition memory processes in the different fixation conditions. The mean duration of first, second, third, and fourth fixations to old and new faces across fixation conditions are listed in Table A1 (*Appendix*). We excluded trials that contained a blink (i.e. 5.2 % of trials in total; with no exclusion in the one fixation condition, 1.9 % in the two fixation condition, 6.1 % in the three fixation condition and 12.9 % in the fourth fixation condition). Unless otherwise noted, all effects referred to as statistically significant throughout the text are associated with *p* values less than .05, two-tailed.

Recognition memory performance. Figure 2 shows mean recognition memory performance, *Pr,* separately for each fixation condition. We conducted a 4 (fixation: one vs. two vs. three vs. four) repeated measures MANOVA with *Pr* as the dependent variable to compare performance in the four fixation conditions. The main effect of fixation reached significance, $F(3,37) = 6.65$, $p = .001$, $\eta_p^2 = .350$. To test our specific hypotheses, we ran a priori planned orthogonal contrasts (Helmert) on the fixation factor. The first contrast compared performance with one fixation with the mean performance in the remaining three fixation conditions; this contrast was significant, $F(1,39) = 20.48$, $p < .001$, $\eta_p^2 = .344$, indicating a better performance with two or more fixations. The other contrasts—two fixations versus three/four fixations collapsed and three versus four fixations—were not significant,

$F(1,39) = 1.24$, $p = .272$ and $F(1,39) < 1$, $p = .783$, denoting no further increase in performance with more than two fixations to a face.[2] As in Hsiao and Cottrell (2008), performance with only one fixation was already above chance level, $t(39) = 7.50$, $p < .001$, $d_Z = 1.19$.

To understand whether the increase in performance with a second fixation is due to an increase in hits and/or a decrease in FAs, we ran post-hoc tests (with Bonferroni-Holm-adjusted alpha) for the proportion of hits and FAs. The means and standard deviations (*SD*) for all four fixation conditions are summarised in Table 1. The increase in performance from one to two fixations was due to a significant increase in hits, $t(39) = 2.91$, $p = .006$, $d_Z = .46$, as well as a significant decrease in FAs, $t(39) = 2.57$, $p = .014$, $d_Z = .41$.

To explore the response bias *Br* (see Figure 2), we conducted a one-way MANOVA for repeated measures with fixation as the factor and centered *Br* scores ($Br_{adj} = Br - 0.5$; see below) as the dependent variable. The effect of fixation, $F(3,37) = 1.17$, p = .333, as well as all orthogonal contrasts (Helmert) did not reach significance, *F*'s < 3.27, *p*'s > .078. Thus, there were no differences in *Br* across the four fixation conditions. Since we used centered *Br* scores, the constant test of the analysis indicated whether there was on average a conservative or liberal response bias (i.e., $Br \neq .5$; .5 indicates an unbiased *Br* score). However, since this test was non-significant, $F(1,39) = 2.54$, $p = .119$, $\eta_p^2 = .061$, it can be assumed that *Br* was unbiased.

Recognition memory processes. To look at the underlying recognition memory processes responsible for the performance in the different fixation conditions, we analyzed the probabilities of “remember” and “know”

[2] To directly compare with Hsiao and Cottrell (2008): There was a significant increase in performance with two fixations compared to only one, $F(1,39) = 13.11$, $p = .001$, $\eta_p^2 = .252$.

responses that followed a hit or a FA (see Figure 3). As there was no further increase in performance with a third or fourth fixation, we ran the analyses only on the conditions with one and two fixations.

We first ran a 2 (fixation: one vs. two) × 2 (stimulus type: old vs. new) repeated measures ANOVA on "remember" response probabilities. This analysis revealed a significant main effect of stimulus type, $F(1,39) = 99.68$, $p < .001$, $\eta_p^2 = .719$, as well as a significant effect of fixation, $F(1,39) = 23.65$, $p < .001$, $\eta_p^2 = .377$. These effects were qualified by a significant Stimulus Type × Fixation interaction, $F(1,39) = 23.39$, $p < .001$, $\eta_p^2 = .375$, indicating a recollection-based increase in performance from the first to the second fixation. Learned faces received more "remember" responses than new faces and the proportion of a "remember" response to a learned face increased with two fixations compared to only one, $t(39) = 5.22$, $p < .001$, $d_Z = .825$. This was not the case for new faces, $t(39) < 1$.

In contrast, the 2 (fixation: one vs. two) × 2 (stimulus type: old vs. new) repeated measures ANOVA on "know" response probabilities revealed a significant main effect of stimulus type, $F(1,39) = 61.58$, $p < .001$, $\eta_p^2 = .612$, but all other effects were non-significant, *F*'s < 1. Thus, learned faces received more "know" responses than new faces but there was no increase in the number of "know" responses with two fixations to a face compared to only one.

To investigate our specific hypothesis of a larger proportion of "know" judgments compared to "remember" judgments when only one fixation was allowed to a face, we ran a 2 (response type: know vs. remember) × 2 (stimulus type: old vs. new) repeated measures ANOVA for the one-fixation condition on the probabilities of “know” and “remember” responses. Both main effects reached significance, $F(1,39) = 52.24$, $p < .001$, $\eta_p^2 = .573$ for response type and $F(1,39) = 101.09$, $p < .001$, $\eta_p^2 = .722$ for stimulus type, whereas the interaction effect did not, $F(1,39) < 1$. When only one fixation was allowed to a face, participants in general made more hits than FAs (again reflecting above-chance performance), and as predicted, more “know” compared to “remember” responses were made to learned as well as new faces.

Discussion

First of all, we replicated the findings of Hsiao and Cottrell (2008) regarding the moderation of recognition memory performance by the number of fixations allowed to a stimulus. That is, we found that recognition memory performance was above chance level with only one fixation at test, and that there was a significant increase in performance when a second fixation was allowed. Additional fixations did not increase performance further; thus, maximal recognition memory performance of incidentally learned faces was reached with two fixations to a face. The rise in performance from one to two allowed fixations was due to an increase in hits as well as a decrease in FAs.

Most importantly, Experiment 1 is the first study to reveal the influence of the number of fixations on the underlying recognition memory processes. Specifically, it was found that the proportion of “know” judgments, that is, an index of familiarity without recollection (according to standard interpretations), was already at a high level with only one fixation and did not increase with a second fixation to the face. In contrast, the proportion of “remember” judgments, that is, an index of recollection, was at a lower level than "know" judgments when only one fixation was allowed but increased significantly with a second fixation. Importantly, this effect of fixation number was not found for new faces (i.e., for FAs). The strong increase in "remember" judgments (using hits adjusted for FAs) with two fixations, in the absence of a corresponding effect for "know" responses, is in line with the findings of Mäntylä and Holm (2006). It seems that the amount of input provided by a second fixation plays a significant role for recollection-based but not for familiarity-based recognition. The extra information gathered by a second fixation may serve as an additional retrieval cue, causing an increase in recollection. Alternatively, recollection could be boosted by the longer input duration, which may serve to increase the fidelity of the retrieval cue.

Thus, the second-fixation recollection boost found in Experiment 1 could be due to both the longer input duration and/or the additional input provided by a second fixation. In order to differentiate the contributions of both these confounded factors and their unique influences on the recognition memory processes, especially on recollection, we conducted Experiment 2.

Experiment 2

To disentangle the confounded factors of input duration and amount of stimulus information, we used a specific gaze-contingent stimulus presentation in Experiment 2. In addition to a one-fixation condition, which provides the participant with information from one fixation location (L) for the duration (D) of one fixation ($D_{one}L_{one}$), we created two new conditions (see also Hsiao & Cottrell, 2008). First, we constructed a condition with an input duration of two fixations (i.e., the average duration of two fixations in

Experiment 1) but information from only the first fixation location (condition $D_{two}L_{one}$). Second, we created a condition with an input duration of two fixations and information from two fixation locations (condition $D_{two}L_{two}$).

The comparison of condition $D_{one}L_{one}$ with condition $D_{two}L_{one}$ allows conclusions about the effect of input duration on the recognition memory processes. Contrasting condition $D_{two}L_{one}$ and $D_{two}L_{two}$ allows conclusions about the influence of additional information about the stimulus. Furthermore, compared to Experiment 1 we optimised the parafoveal indication of the location of the upcoming face. We used a facial pre-stimulus mask that specified the position of the eyes and the nose of the subsequently presented face, thus allowing for a spatially optimal first fixation.

We expected to replicate the findings of Hsiao and Cottrell (2008) concerning an increase in performance due to additional information about the stimulus, holding input duration constant. Beyond that, we hypothesised to find an increase in performance with a longer input duration. Regarding the involved recognition memory processes, we expected (as in Experiment 1) a greater proportion of “know” judgments compared to “remember” judgments to old items (adjusted for FAs) when only one fixation to the face was allowed. We expected an increase in the proportion of “remember” judgments to old items (adjusted for FAs) with a longer input duration. Recollection (i.e., “remember” responses) should increase as a longer input duration may provide more time to use the first input as a retrieval cue. Thereby, this first input probably provides a more valid first cue with a longer input time. Finally, based on the findings of Mäntylä and Holm (2006) as well as Kafkas and Montaldi (2012), we expected an increase in “remember” judgments to old items (adjusted for FAs), but no such effect on familiarity-based “know” responses, when information from a second location was available, compared to the condition with the same input duration but information about only one stimulus location.

Method

Participants. A total of forty-eight undergraduate students from Saarland University took part in the experiment. They received 6 Euro for their participation. Two participants had to be excluded due to an extreme blink rate. The remaining forty-six participants (27 women, 19 men; median age = 24 years) had normal or corrected-to-normal vision, were native speakers of German and gave informed written consent in the beginning of the experiment.

The minimal required sample size to replicate the increase in recognition memory performance with additional input information (and input duration held constant) found by Hsiao and Cottrell (2008)—an effect size of $d_Z = 0.65$, with α set to .05, power set to $1 - \beta = .80$—was calculated as $N = 21$ (using G*Power3; Faul et al., 2007). To replicate the Fixation (one vs. two) × Stimulus Type (old vs. new) interaction effect for remember responses from Experiment 1 with an effect size of $d_Z = 0.81$, the minimal required sample size — with α set to .05, power set to $1 - \beta = .80$ — was calculated as $N = 15$ (using G*Power3; Faul et al., 2007).

We decided to increase the number of participants to forty-eight as we aimed to investigate the impact of both input duration and amount of stimulus information on the proportion of familiarity (“know”) and recollection (“remember”) judgments. A sample size of $N = 48$ allows to detect effect sizes of d_Z = .41 (i.e., effects somewhat smaller than “medium-sized” according to Cohen, 1988) with α = .05 and 1 – β = .80.

Design. To investigate the pure impact of input duration and amount of stimulus information on recognition memory processes, we implemented three fixation conditions; faces were presented (1) for the duration of one fixation at one fixation location ($D_{one}L_{one}$), (2) for the average duration of two fixations, but with information uptake constrained to one location ($D_{two}L_{one}$), (3) for the average duration of two fixations with information uptake from two different fixation points of the stimulus ($D_{two}L_{two}$).

This manipulation in the recognition test resulted in a one-factorial (fixation: $D_{one}L_{one}$, $D_{two}L_{one}$, $D_{two}L_{two}$) within-subject design. We added a condition with three allowed fixations as buffer trials, since pilot testing indicated that the sole use of very restricted presentation conditions (i.e., low number of allowed fixations) increases the probability of abnormal fixation times (“staring”).

Materials. The material comprised 112 gray-scaled images of faces (56 men and 56 women) taken from the FACE database (Ebner, Riediger, & Lindenberger, 2010). All faces were placed against a uniform gray background and measured 310 × 365 pixels (this corresponds to 8.6 × 10.2° of visual angle). In addition, we made sure that the eyes of all used faces were placed on the same horizontal axis and the nose on a fixed vertical axis. This was important to ensure that the used facial pre-stimulus mask indicated the actual position of the eyes and the nose of the subsequent face (for details see *Procedure*). Participants were shown half of the faces (28 men and 28 women) in the incidental learning phase. These familiar faces were intermixed with the remaining 56 faces in the recognition test. The assignment of faces to the different fixation conditions was counterbalanced across participants, such that each face appeared equally often in each condition.

The facial pre-stimulus mask was constructed in a sequence of steps. First, a morph stimulus was created from all 112 equally-weighted face stimuli, using the software WinMorph 3.01. The next two steps were conducted in Photoshop 8.0. We first selected only the inner facial parts (eyes, nose, and mouth) of the morph and placed them against the same uniform gray back-ground as the other face stimuli, thus ensuring that the eyes were in the same vertical position as the eyes of the face stimuli and the nose in the same horizontal position. In a last step, we applied a “Gaussian blur” filter to blur the contours.

Apparatus. The eye movements of the participants’ dominant eye were recorded with an SMI Hi-Speed Eye-Tracker with a sample rate of 500 Hz. A calibration was defined as valid if the spatial error was less than 0.5°. As in Experiment 1, to manipulate the number of permissible fixation locations, we used on-line fixation detection using iView X^{TM} Hi-Speed with the default parameters. Stimuli were presented with a Windows-based computer on a 27” monitor with a resolution of 1920 × 1080 pixels and a refresh rate of 120 Hz, using the experimental software PsychoPy (Peirce, 2007). The viewing distance measured 64 cm.

Procedure. The learning phase and retention interval were identical to Experiment 1. Compared to Experiment 1, we improved the procedure of the recognition test. After a central fixation cross and a 50 ms blank screen, the facial pre-mask (i.e., eye, mouth, and nose region of the blurred morph) appeared either on the left or right side of the fixation cross, indicating where the target face would be presented (see Figure 1B). The center of the mask/target face appeared 8.5° of visual angle to the right or left of the fixation cross. The position of the eye and nose region in the mask was identical to these regions in the subsequent target face. That is, when the participant programmed a saccade to the right eye of the face mask, for example, the right eye of the target face appeared at this position as soon as the participant's gaze passed the invisible frame of the facial pre-mask.

The conditions of interest were implemented in the following way: The $D_{one}L_{one}$ condition was comparable to the "one fixation" condition of Experiment 1. That is, a post-mask appeared as soon as the first fixation was terminated. For the remaining conditions, the input duration was fixed to 571 ms, which was the average duration of the first two fixations (when two fixations were allowed) in Experiment 1. During this presentation time, participants were allowed to gather stimulus information from one (condition $D_{two}L_{one}$) or two ($D_{two}L_{two}$) fixation locations. Stimulus presentation was followed by the post-mask.

To constrain the permissible number of information uptakes in the $D_{two}L_{one}$ condition, the stimulus was moved during a saccade such that the picture-relative x and y coordinates of the first and second fixation remained the same. That is, participants in the $D_{two}L_{one}$ condition had the same retinal projection in their second fixation as in the first fixation, whereas participants in the $D_{two}L_{two}$ condition got a new input with their second fixation (if they made a third fixation within the time frame of 571 ms, they got the same input as in the second fixation). The post-mask stayed on screen until 3000 ms post face onset. After this, the remaining procedure was the same as in Experiment 1. Participants were prompted to make an old/new decision and each “old” response was followed by a “remember”, “know”, or “guess” judgment. After a 50 ms blank screen the next trial started.

Data preparation. As in Experiment 1, we calculated the overall recognition memory performance *Pr*, with *Br* as an index of response bias.

For the analyses of the underlying recognition memory processes, we again estimated the probability of “remember”, “know”, and “guess” responses that followed a hit or FA separately for each fixation condition. For details of these calculations, see *Data preparation* of Experiment 1.

Results

The result section is again divided into two parts. First, we present recognition memory performance data across the three fixation conditions ($D_{one}L_{one}$, $D_{two}L_{one}$, and $D_{two}L_{two}$) to test our specific hypotheses. In the second part, the proportion of hits and FAs followed by “remember” and “know” responses are analyzed to test our hypotheses regarding the underlying recognition memory processes. We excluded trials that contained a blink (i.e. 3.6 % of trials in total; with 2.5 % in the $D_{one}L_{one}$ condition, 4.7 % in the $D_{two}L_{one}$ condition, and 3.6 % in the $D_{two}L_{two}$ condition). The mean duration of first, second, and third fixations to old and new faces across fixation conditions are listed in Table A2 (*Appendix*).

Recognition memory performance. Figure 4 shows mean recognition performance, *Pr*, separately for each fixation condition. We conducted a 3 (fixation: $D_{one}L_{one}$ vs. $D_{two}L_{one}$ vs. $D_{two}L_{two}$) repeated measure

MANOVA with *Pr* as the dependent variable to compare performance in the three fixation conditions. There was a significant main effect of fixation, $F(2,44) = 15.34$, $p < .001$, $\eta_p^2 = .411$, revealing differences in recognition memory performance between the fixation conditions.

We ran a priori simple contrasts to look separately at the effect of input duration and amount of information on recognition performance. The first simple contrast regarded the influence of input duration—contrasting condition $D_{one}L_{one}$ and $D_{two}L_{one}$—and revealed better performance with longer presentation duration, $F(1,45) = 8.99$, $p = .004$, $\eta_p^2 = .166$. The second simple contrast regarded the amount of information—contrasting condition $D_{two}L_{one}$ and $D_{two}L_{two}$—and indicated significantly better performance with a second input location, $F(1,45) = 4.04$, $p = .05$, $\eta_p^2 = .082$, replicating Hsiao and Cottrell (2008).[3]

To better understand the increase in performance associated with longer input durations as well as greater informational input, we ran separate post-hoc *t*-tests (with Bonferroni-Holm-adjusted alpha) on the hit and FA rates. Mean rates and *SD*s for all three fixation conditions are summarised in Table 2. The increase in performance with a longer input duration was due to a significant increase in hits, $t(45) = 4.93$, $p < .001$, $d_Z = .727$, without an effect on FAs, $t(47) < 1$. In contrast, the increase in performance with a second input was only due to a decrease in FAs, $t(45) = 2.83$, $p = .007$, $d_Z = .417$ ($t(47) < 1$, for hits). That is, a second input made it easier to reject new faces without any effect on the correct identification of learned faces.

[3] As expected, based on the findings of Hsiao and Cottrell (2008) and Experiment 1, the comparison between $D_{two}L_{two}$ and $D_{three}L_{three}$ revealed no further increase in performance with a third fixation, $t(45) = 1.26$, $p = .213$.

To analyze the response bias *Br* (shown in Figure 4), we conducted a MANOVA with a fixation factor ($D_{one}L_{one}$ vs. $D_{two}L_{one}$ vs. $D_{two}L_{two}$) and centered *Br* (see Experiment 1 and see below) as the dependent variable. This analysis revealed a marginally significant main effect of fixation, $F(2,44) = 2.70$, $p = .079$, $\eta_p^2 = .109$. A simple comparison of condition $D_{one}L_{one}$ and $D_{two}L_{one}$ revealed a more conservative bias with a shorter presentation time, $t(45) = 2.27$, $p = .028$. A simple comparison of condition $D_{two}L_{one}$ and $D_{two}L_{two}$ showed that amount of information resulted in a tendency to a more conservative response bias, $t(45) = 1.84$, $p = .072$. Since we used centered *Br* scores, the constant test of the MANOVA indicated whether there was on average a conservative or liberal response bias (i.e., $Br \neq .5$). This test was significant, $F(1,45) = 5.47$, $p = .024$, $\eta_p^2 = .108$; there was a conservative bias in the $D_{one}L_{one}$ and $D_{two}L_{two}$ fixation condition, as corroborated in post-hoc tests (with Bonferroni-Holm-adjusted alpha), $t(45) = 3.13$, $p = .003$, $d_Z = .46$ and $t(45) = 2.70$, $p = .010$, $d_Z = .40$, and no significant bias in the $D_{two}L_{one}$ condition, $t(45) = 0.44$, $p = .659$, $d_Z = .065$.

Recognition memory processes. To look at the underlying recognition memory processes that are responsible for the increase in performance with both a longer input duration and a second input, we again analyzed the proportion of "remember" and "know" responses that followed a hit or FA, across the three fixation conditions (see Figure 5). For details of the calculations, see *Data preparation* of Experiment 1.

The impact of input duration. First, we looked at the impact of input duration on the underlying recognition memory processes. To test our specific hypothesis of a significant increase in recollection-based recognition performance with a longer input duration, we conducted a 2 (fixation: $D_{one}L_{one}$ vs. $D_{two}L_{one}$) × 2 (stimulus type: old vs. new) repeated measures ANOVA on the rate of “remember” responses. All effects were significant, $F(1,45) = 10.26$, $p = .002$, $\eta_p^2 = .186$ for fixation, $F(1,45) = 99.23$, $p < .001$, $\eta_p^2 = .688$ for stimulus type, and $F(1,45) = 9.11$, $p = .004$, $\eta_p^2 = .168$ for the interaction effect. The increase in “remember” responses was due to a significant increase in hits, $t(45) = 3.35$, $p = .002$, $d_Z = .494$, without a change in FAs, $t(45) < 1$ (Bonferroni-Holm adjusted alpha).

To analyze the effect of a longer input duration on the proportion of a familiarity-based response, we conducted a 2 (fixation: $D_{one}L_{one}$ vs. $D_{two}L_{one}$) × 2 (stimulus type: old vs. new) repeated measures ANOVA on the rate of “know” responses. Only the main effects reached significance, $F(1,45) = 31.95$, $p < .001$, $\eta_p^2 = .415$ for stimulus type and $F(1,45) = 10.25$, $p = .003$, $\eta_p^2 = .185$ for fixation ($F(1,47) < 1$, for the interaction effect). Thus, a longer input duration caused an increase in familiarity-based responses to both old (hits) and new faces (FAs). In other words, familiarity-based recognition performance was not affected by input duration.

The impact of a second input. In a second step, we analyzed the influence of the amount of input information on the recognition memory processes. A 2 (fixation: $D_{two}L_{one}$ vs. $D_{two}L_{two}$) × 2 (stimulus type: old vs. new) repeated measures ANOVA on the rate of “remember” responses revealed a significant main effect of stimulus type, $F(1,45) = 131.97$, $p < .001$, $\eta_p^2 = .746$, and a marginal significant effect of fixation, $F(1,45) = 3.36$, $p = .074$, $\eta_p^2 = .069$. These effects were qualified by a significant Fixation × Stimulus Type interaction effect, $F(1,45) = 4.82$, $p = .033$, $\eta_p^2 = .097$. The effect was due to a increase in hits, $t(45) = 2.16$, $p = .036$, without a change in FAs, $t(45) < 1$ (with Bonferroni-Holm adjusted alpha). In contrast, the corresponding analysis of “know” responses revealed only main effects of fixation, $F(1,45) = 7.31$, $p = .010$, $\eta_p^2 = .104$, and stimulus type, $F(1,45) = 33.27$, $p < .001$, $\eta_p^2 = .425$. The interaction effect did not reach significance, $F(1,45) < 1$. Thus, with an additional input, the rate of familiarity-based “know” responses decreased, but it did so for both learned and new faces, as indicated by the non-significant interaction effect.

Discussion

Experiment 2 was run to gain a deeper understanding of the interplay between recognition memory processes and eye fixations. We analyzed the individual influences of the increased input duration and the increased informational input associated with a second fixation on recognition performance and the underlying recognition memory processes. The aspects of input duration and informational input are normally confounded with the variation of one fixation versus two fixations.

We found that both a longer input duration and a second information input resulted in a significant increase in performance. More importantly, with a longer input duration we found an increase in correct “remember” responses without an effect on FAs, whereas “know” responses increased for learned as well as new faces. For this reason, the increase in overall performance with longer input duration can be attributed to enhanced recollection-based recognition.

Moreover, the availability of a second input led to an increase in recollection-based hits without an effect on FAs, whereas it caused a decrease in familiarity-based responses to learned as well as new faces (roughly to the level of the $D_{one}L_{one}$-condition; see Figure 5). Thus, additional input information has only an effect on the proportion of familiarity-based responses, not on the familiarity-based recognition memory performance. Therefore, better recognition performance with an additional input is due to a rise in recollection-based recognition.

The increase in familiarity-based hits as well as FAs with a longer input duration corresponds to a relaxed response criterion ($D_{one}L_{one}$: Br = .42 vs. $D_{two}L_{one}$: Br = .48). This fits with the observation that a more liberal response criterion usually goes along with an increase in familiarity-based responses (to old as well as new items) with only little effect on recollection-based responding (Yonelinas, 2002). The change in response criterion for “know” responses could be explained by enhanced processing fluency when the face is presented for the duration of two compared to only one fixation (see, e.g., Winkielman & Cacioppo, 2001).

The increased rate of hits accompanied by “remember” responses with a longer input duration could be explained by the additional time the information from the first input location is available. The longer availability of the input information may increase the fidelity of the available information and thereby leads to a more valid first retrieval cue.

Regarding the influence of the amount of informational input on the recognition memory processes, the analyses of “know” and “remember” responses revealed a significant increase in recollection-based recognition, but no effect for familiarity-based recognition (only the proportion of familiarity-based know responses, hits as well as FAs, decreased). A second fixation provides our system with new information about the presented stimulus, which can serve as an additional retrieval cue. These results are in line with the findings of Mäntylä and Holm (2006), who found a significant drop in “remember” responses without an effect on “know” responses when they restricted viewing to only one input location compared to free viewing. The results of Experiment 2 extended these findings by showing the influence of additional input in finer and better controlled conditions that disentangled the confound of the longer input duration and the extra information provided by an additional fixation.

In conclusion, a second fixation plays a significant role in face recognition performance. More precisely, a second fixation provides a longer input duration as well as extra informational input, and both these aspects cause a unique and significant increase in performance. The change in performance can be explained by an increase in recollection, as for familiarity-based responses there was only a shift in bias.

General Discussion

We examined the relevance of early eye fixations for recognition memory performance and especially for the underlying recognition memory processes. Experiment 1 used a gaze-contingent stimulus presentation that prevented parafoveal stimulus processing. Experiment 2 refined this technique and implemented conditions that allowed us to investigate the unique effects of input duration and amount of informational input on recognition memory performance in general and the involved recognition memory processes in particular. Replicating Hsiao and Cottrell (2008), we found an increase in overall recognition performance with two compared to only one fixation to a face (Exp. 1). Additional fixations did not increase performance further. Both aspects of a second fixation—longer input duration and additional informational input—made independent and significant contributions to this rise in performance (Exp. 2). Regarding the underlying recognition memory processes, the results of Experiment 1 and Experiment 2 showed that the rise in performance from one to two fixations was due to an increase in recollection.

In contrast, familiarity-based recognition performance remained at a constant level across fixation conditions in both experiments. Instead, in Experiment 2 (but not Experiment 1) we found that response bias for “know” responses depended on fixation condition: The proportion of familiarity-based responses (i.e., “know” responses) for hits and FAs increased with a longer input duration (in the absence of additional input). This change in familiarity-based responses with a longer input duration could be explained by enhanced processing fluency. The fact that the change in response bias only affected familiarity-based but not recollection-based responses is in line with previous findings (for a review see, Yonelinas, 2002).

As neither aspect of a second fixation (i.e., increased input duration, increased amount of information) improved familiarity-based recognition performance, a presentation duration of 172 ms (Exp.1) to 228 ms (Exp.2)—the mean duration of the first fixation—seems to suffice to reach maximal recognition memory performance based on familiarity.

By contrast, recollection played a crucial role for the increase in overall recognition performance when a second fixation was allowed. With a longer input duration as well as an additional input, the proportion of hits followed by a “remember” response increased, without an effect on FAs. In the two-fixation conditions, the input information was available for an additional time of about 343 ms compared to the condition with only one allowed fixation. The longer availability of the input might supply additional time to use the information provided by the first fixation as a retrieval cue. The retrieval cue presumably becomes more valid the longer the input is available, resulting in a higher proportion of recollection-based responses.

The time window of the second fixation—on average 228-571 ms post stimulus onset in Experiment 2—matches the temporal range of early recollection-related ERPs in face recognition studies. For example, associative memory studies using experimentally learned associations, such as face-name pairs, have detected recollection-related ERP effects (i.e., the anterior old/new effect) as early as 300-700 ms post face onset (MacKenzie & Donaldson, 2007, 2009; Yick & Wilding, 2014; Yovel & Paller, 2004). Moreover, the temporal occurrence of early expressions of recollection in eye movements, such as longer second fixations (Schwedes & Wentura, 2012, 2016) or the emergence of longer viewing times to recollected faces relative to familiar but non-recollected faces after about 500 ms post stimulus onset (e.g., Hannula & Ranganath, 2009) are in line with the increase in recollection with increased input duration found in Experiment 2.

However, the results of Experiment 2 revealed that recollection-based effects in the ERP and eye movement studies could also be related to the effect of additional input provided by a second fixation. The increase in “remember” responses to old items (adjusted by FAs) with a second input location in Experiment 2 highlights the functional role of a second fixation and its relevance for recollection-based recognition. The effect of additional input on the recollective experience is in line with previous findings of increased recollection-based responding (i.e., “remember” responses) if fixations to different input locations were allowed (Mäntylä & Holm, 2006) or if a more dispersed fixation pattern was observed (Kafkas & Montaldi, 2012). Compared to these previous studies, our Experiment 2 is the first to investigate the unique contributions of input duration and amount of information on familiarity- and recollection-based recognition. It seems that the additional input provided by a second fixation serves as an additional retrieval cue and triggers recollection. In the terms of Bruce and Young’s (1986) multi-stage face recognition model, it could be assumed that the structural code generated by the input from the first fixation overlaps sufficiently with the stored face representation to activate the relevant face recognition unit. Thus, familiarity-based recognition can already be maximal with only one fixation. However, the additional information and the longer availability of the stimulus associated with a second fixation may result in the optimization and extension of the structural code. This more valid code will have a greater overlap with the stored face representation and may thus suffice to activate the person identity node that give access to episodic information. Future experiments that combine Experiment 2 with the ERP technique could ascertain whether the occurrence of ERP effects associated with the different processes varies with the fixation conditions realised in Experiment 2.

The proposed relationship between recollection and access to a second retrieval cue provided by a second fixation has been neglected in most previous studies that make assumptions about the temporal occurrence of recollection after stimulus onset. It is possible that a second fixation to a stimulus plays a significant role for the occurrence of ERPs associated with recollection. If this is the case, it should be possible to predict the temporal occurrence of recollection-based ERPs based on the temporal execution of the second fixation. The timing of the second fixation is influenced by a variety of factors (e.g., bottom-up influences such as the luminance of the fixated stimulus, e.g., Henderson, Nuthmann, & Luke, 2013; top-down influences such as the probability of the stimulus, Loftus & Mackworth, 1978; for a review see Nuthmann, 2016). Hence, the resulting variance in the temporal availability of an additional retrieval cue might explain variance in the temporal occurrence of recollection and therefore in the ERP effects typically associated with recollection. For this reason, studies using fixation event-related potentials (e.g., Rämä & Baccino, 2010; Thierry, 2011), which allow measuring brain activity in response to eye fixations, will play an important role in future research into the relationship between eye fixations and the neuronal correlates of recognition memory.

Regarding the generalisability of the effect to other materials, we think the effect should also be found with objects or scenes. As mentioned before, the finding that second fixations are especially relevant for recollection-based recognition is in line with a memory effect in second fixation durations in tasks that require recollection (see Schwedes & Wentura, 2012, 2016). The early fixation-based memory effect was found with faces as well as object material. Since we think that the early fixation-based memory effect in second fixation durations and the effect that second fixations are especially relevant for recollection-based recognition are related, our hypothesis is that the effect is not limited to face stimuli. However, it is well known, that faces are special in several regards (for a review see McKone & Robbins, 2011). Thus, further studies should investigate this question.

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Appendix

Table A1

Mean duration of the first, second, third, and fourth fixation (standard deviation in parentheses) to old and new faces in Experiment 1.

	Executed Fixation							
	First		Second		Third		Fourth	
Allowed Fixations	Old	New	Old	New	Old	New	Old	New
One	172 (36)	180 (35)						
Two	168 (22)	173 (26)	391 (104)	412 (128)				
Three	166 (19)	177 (29)	423 (157)	412 (123)	611 (158)	591 (153)		
Four	176 (30)	182 (52)	427 (128)	422 (166)	575 (174)	607 (214)	473 (119)	456 (115)

Note: The average duration of the first two fixations that was used for Experiment 2 (that is, 571 ms; see *Procedure*) deviated by 1 ms from the summed average durations of a first and second fixation (when two fixations were allowed) in this table. This is caused by slight differences in data handling when we planned Experiment 2, which had no impact on the reported results.

Table A2

Mean duration of the first, second, and third fixation (standard deviation in paraphrases) to old and new faces separately for each fixation condition in Experiment 2.

	Executed Fixation					
Fixation	First		Second		Third	
Condition	Old	New	Old	New	Old	New
$D_{one}L_{one}$	217 (52)	223 (61)				
$D_{two}L_{one}$	195 (37)	196 (40)				
$D_{two}L_{two}$	198 (45)	201 (36)	260 (48)	240 (74)		
$D_{three}L_{three}$	221 (72)	228 (69)	586 (232)	590 (249)	488 (152)	489 (163)

Note: The duration of first fixations in the $D_{two}L_{one}$ condition reflect the duration of the first fixation before the stimulus got gaze-contingent.

Tables

Table 1

Mean probability (standard deviations in parentheses) of hits and FAs in Experiment 1 as a function of fixation condition.

	Allowed Fixations							
	one		two		three		four	
p(hit)	.57	(.19)	.66	(.16)	.71	(.15)	.72	(.18)
p(FA)	.34	(.19)	.26	(.16)	.28	(.16)	.28	(.19)

Table 2

Mean probability (standard deviations in parentheses) of hits and FAs in Experiment 2 as a function of fixation condition.

	Allowed Fixations					
	$D_{one}L_{one}$		$D_{two}L_{one}$		$D_{two}L_{two}$	
p(hit)	.55	(.17)	.66	(.18)	.66	(.14)
p(FA)	.32	(.14)	.34	(.21)	.26	(.15)

Figures

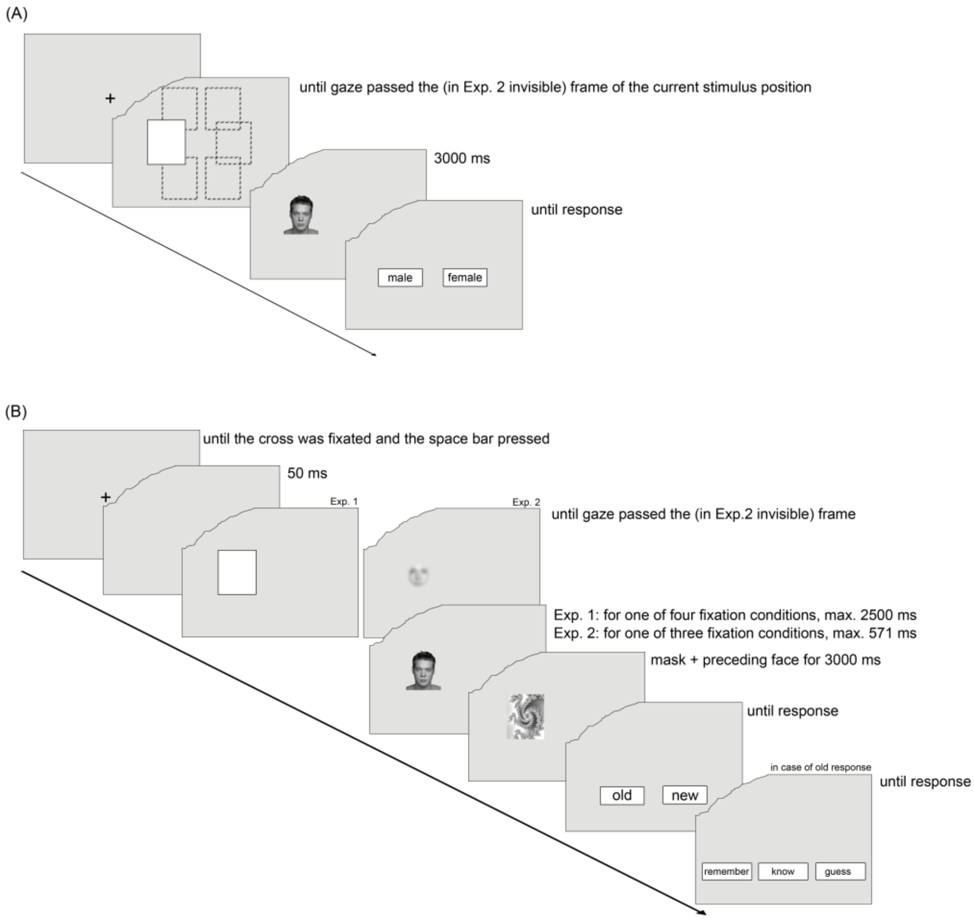

Figure 1. Examples of (A) the trial sequence in the learning phase and (B) the trial sequence in the recognition test of Experiment 1 and Experiment 2. Note: the background color was white in Experiment 1.

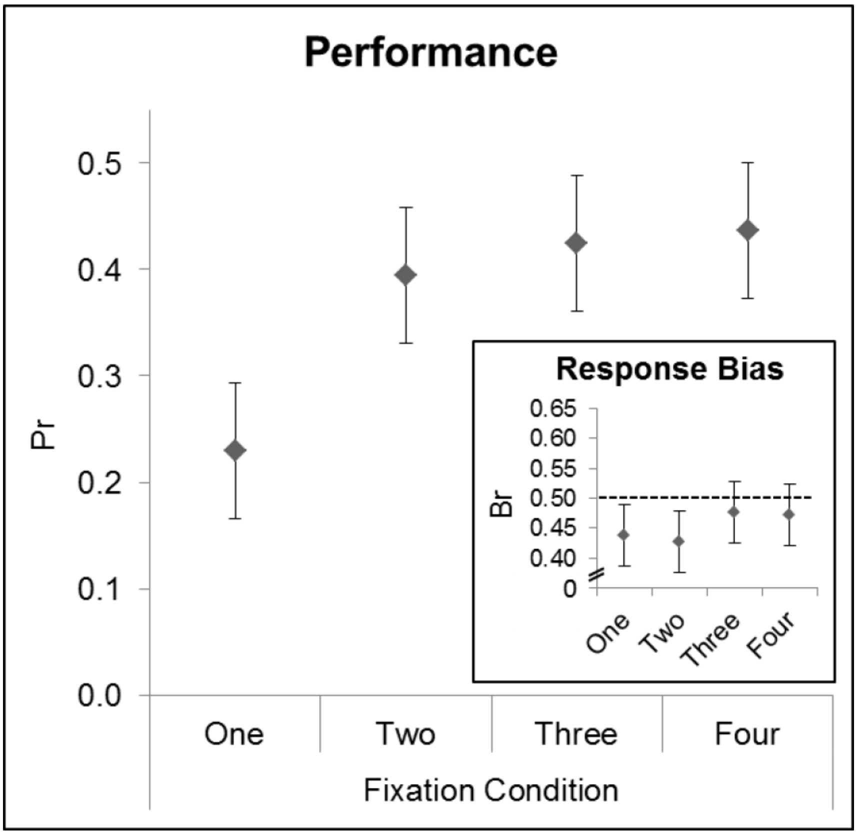

Figure 2. Main Figure: performance (*Pr*) across fixation conditions (Experiment 1). Small figure: response bias (*Br*) across fixation conditions. The dashed line indicates neutral bias. Error bars are 95 % within-subject confidence intervals (Jarmasz & Hollands, 2009) for the main effect of the fixation factor.

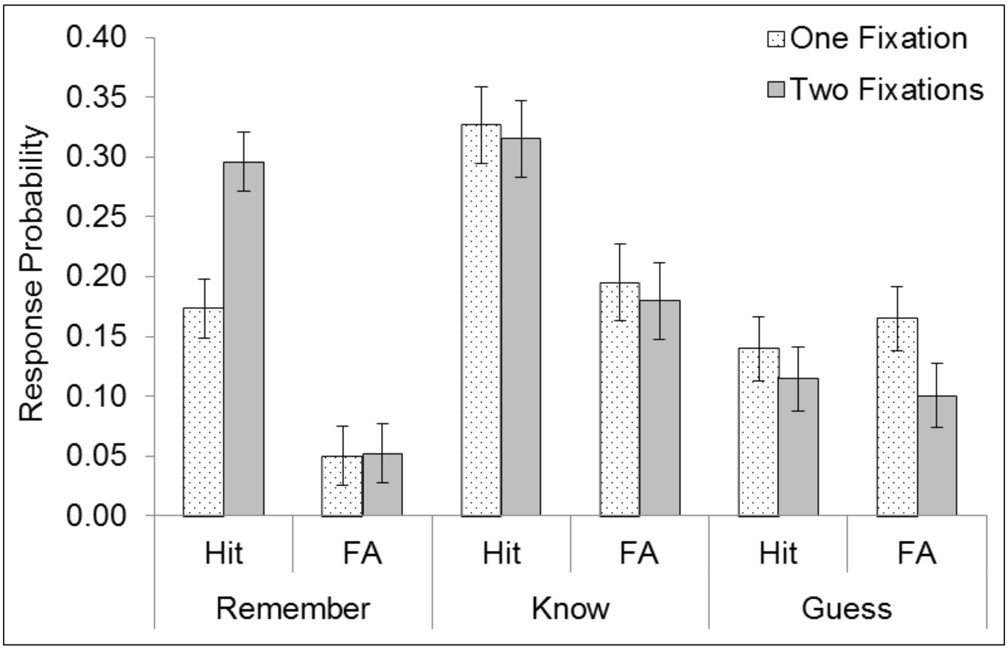

Figure 3. The probability of remember, know, and guess responses following a hit or FA, separately for one and two allowed fixations. Error bars are 95% within-subject confidence intervals (Jarmasz & Hollands, 2009) for the Fixation (one vs. two) × Stimulus Type (old vs. new) interaction effect, for remember, know, and guess responses respectively.

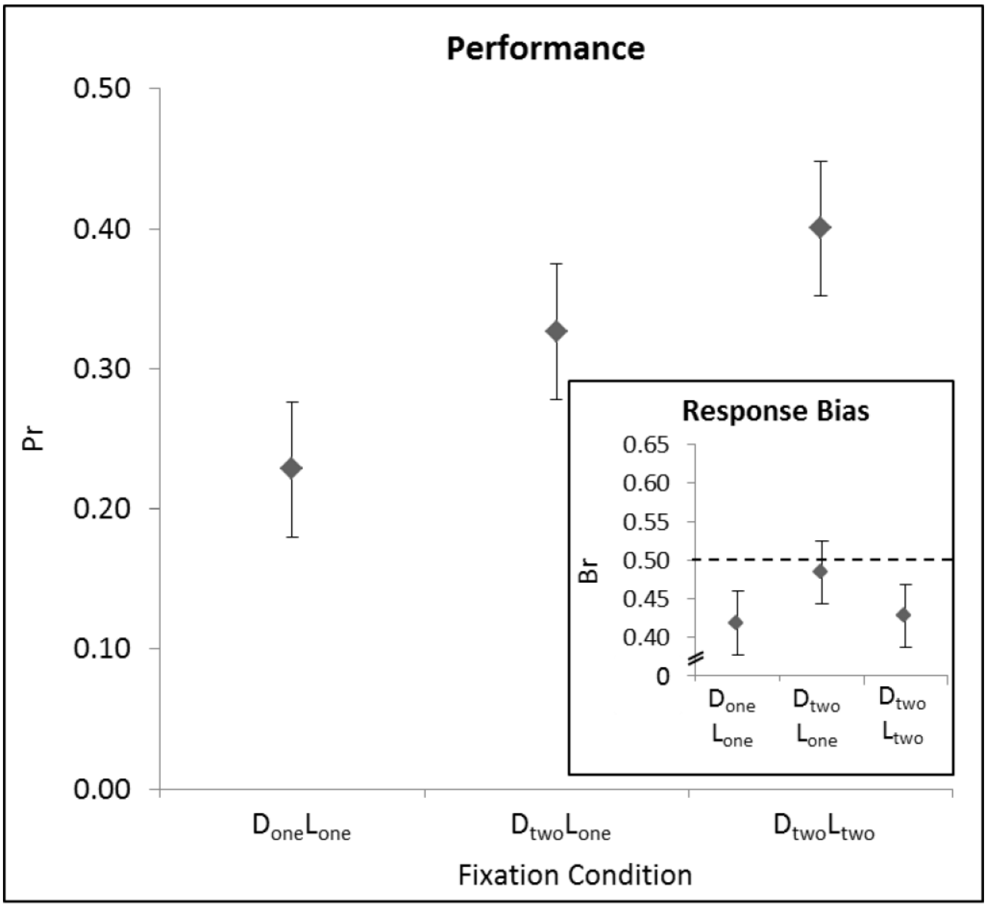

Figure 4. Main Figure: Performance (*Pr*) as a function of fixation condition (Experiment 2). Small figure: Response bias (*Br*) as a function of fixation condition. The dashed line indicates neutral bias. Error bars are 95% within-subject confidence intervals (Jarmasz & Hollands, 2009) for the main effect of the fixation factor.

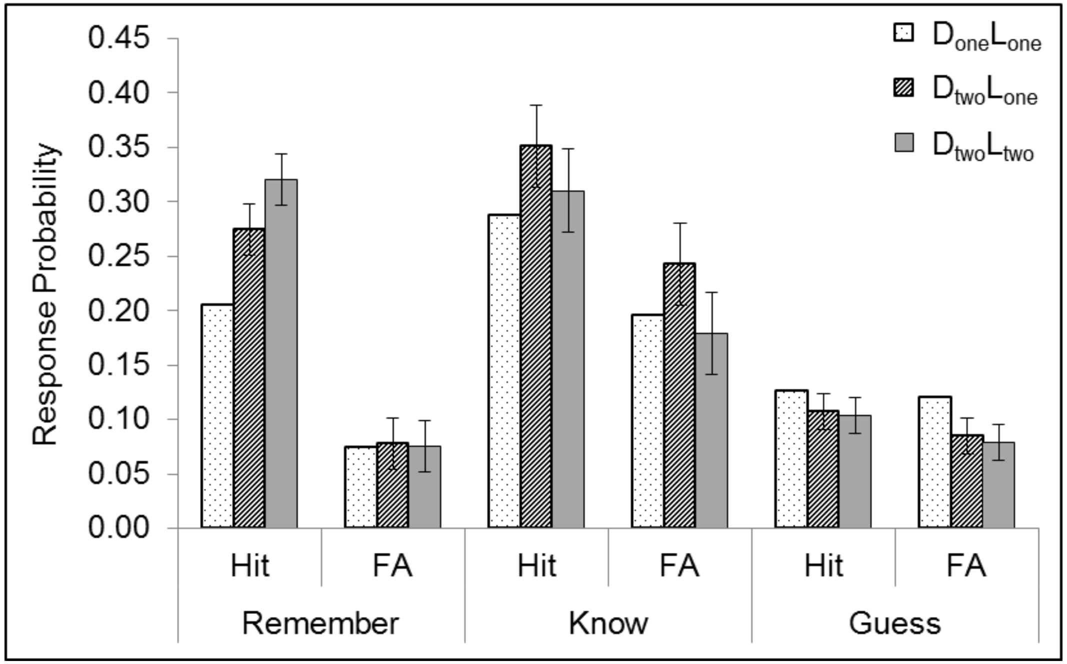

Figure 5. The probability of “remember”, “know”, and “guess” responses following a hit or FA as a function of fixation condition. Error bars are 95% within-subject confidence intervals (Jarmasz & Hollands, 2009) for the Fixation × Stimulus Type interaction effect regarding the influence of the amount of available information, for remember, know, and guess responses respectively.