Fixations durations on familiar items are longer due to attenuation of exploration

Tal Nahari (tal.nahari@mail.huji.ac.il)
Eran Eldar
Yoni Pertzov

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Abstract

Previous studies have shown that fixations on familiar stimuli tend to be longer than on unfamiliar stimuli, putatively due to ongoing retrieval of memory about familiar stimuli. Here, we hypothesized that extended fixations are in fact due to a lesser need to explore an already familiar stimulus. Participants gaze was tracked as they tried to encode or retrieve a familiar face displayed either alone or alongside other unfamiliar faces. Regardless of the memory task (encoding\retrieval), longer fixation durations were observed when a single familiar face was presented alone, and not when presented among unfamiliar ones. Thus, fixations were not prolonged when it was possible to explore other, unfamiliar stimuli. We conclude that prolonged fixations on familiar stimuli reflect a lesser need to explore an already familiar percept. The results underscore how memory representations influence active sensing, yielding fresh insights into efficient deployment of attention resources.

Significance statement

Analyzing eye movement patterns when observing a familiar versus unfamiliar face reveals distinct behaviors. Past research has established that fixation duration is prolonged when viewing a familiar face. This study investigates three potential explanations for this phenomenon. Firstly, we explore the hypothesis that any retrieval from memory inherently consumes time, thereby delaying subsequent eye movements and extending fixation duration. This delay may occur automatically when encountering a familiar image (first hypothesis) or only when there is an intention to retrieve information from memory (second hypothesis). Alternatively, we consider whether the lengthening of fixation arises from the need to explore (third hypothesis). For instance, individuals might prefer to attend and gaze at novel stimuli rather than focusing on something already known. Through manipulation of memory task demands and the number of items presented, our findings support the notion that extended fixations are driven by the need to explore. This not only enhances our understanding of the interplay between memory and attention but also has practical implications, offering insights for the application of eye tracking in scenarios like concealed information tests.

Introduction

The quest for understanding how memories are reflected in behavior has been the target of many scholars. It has been addressed not only as a theoretical question about the structure of memory and the bodily manifestations of it, but also as an applicative tool – valuable both for detection of conscious awareness of individuals in different awareness states (Owen & Coleman, 2008); and in forensic scenarios in which crime related knowledge is concealed (Verschuere et al., 2011). Recent studies have started to examine eye-tracking as a tool for detection of concealed information showing its' promise to the field, relying on the way gaze behavior is affected by memory (Lancry-Dayan et al., 2023).

Several studies have shown that observers tend to employ longer fixations (the relatively stable periods between eye movements) on familiar stimuli (Lancry-Dayan et al., 2018a; Millen & Hancock, 2019; Nahari et al., 2019a; Peth et al., 2013, 2013; Ryan et al., 2007a; Schwedes & Wentura, 2019b), and attributed this phenomena to retrieval of information from memory (Schwedes & Wentura, 2016, 2019a) or holistic processing of familiar stimuli (Millen et al., 2020). Interestingly, studies were inconsistent in their findings: whether it was the first fixation that was longer (Ryan et al., 2007), the second fixation (Ryan et al., 2007a; Schwedes & Wentura, 2012, 2016), or the average fixation duration (Millen & Hancock, 2019; Peth et al., 2013). Some studies did not find either of the fixation durations to be significant (Millen et al., 2020). Thus, a lingering question remained regarding the conditions in which fixation durations become longer, and the mechanism behind it.

Longer fixations on familiar stimuli may appear somewhat counter-intuitive, as one might anticipate that we should invest more time fixating on unfamiliar stimuli, which offer more new visual information for us to gather and process. For familiar stimuli, by contrast, we typically already have a fully formed representation in mind.

Therefore, it is interesting to examine what is the mechanism driving the longer fixation durations effect, which is what the current study is sought to explore. We considered two different hypotheses: first, as suggested by prior work, it could be that an internal retrieval from memory takes time, and therefore retrieval during fixation on familiar stimuli delays the next saccade. This hypothesis further divides into two different sub-hypotheses, since the retrieval that extends fixations could be either automatic (i.e, happens whenever a memory representation appears) or activated only when there is an intention to retrieve items from memory (e.g., when instructed to do so))hypotheses 1 and 2; Fig. 1). Second, we raised a novel hypothesis, which proposes that longer fixations are related to a decrease in the need to visually explore a familiar stimulus because a representation of it already exists in memory, and therefore a lesser need to execute the next saccade (hypothesis 3, Fig. 1).

In the lesser need to explore case, longer fixations would be evident on familiar stimuli only when no alternative stimuli are available to explore. That is, if there is only one image to explore, and the viewer is already familiar with it, fixations should be longer as a result of an attenuated exploratory behavior. However, if there are additional unfamiliar stimuli besides the familiar stimulus, no prolonged fixations are expected – as the observer can explore the other stimuli. If this hypothesis is correct, we expect to find that observers generally tend to look at the familiar stimulus less, and direct their gaze toward unfamiliar stimuli more often and for longer periods of time (Fig. 1, right panel).

The alternative hypothesis for the longer fixations on familiar stimuli regards automatic retrieval/different processing. It was previously proposed that familiar faces are processed differently due to their memory representations, presumably duo to more holistic type of processing (Millen et al., 2020). A related explanation depict that the process of retrieval from memory delays the next saccade and therefore the durations of the fixation become longer (Schwedes et al., 2020). Schwedes et al argued that while the first fixation is mostly based on information gathering, and planning of the next behavior, the second fixation is lengthened due to the memory retrieval process (Hsiao & Cottrell, 2008; Schwedes et al., 2020; Schwedes & Wentura, 2016a), while Millen regarded the familiar pictures as processed in a different manner (Millen & Hancock, 2019). These two hypotheses yield similar predictions in the current study, and are therefore joined together. If these two explanations are correct, we expect to find longer fixations on familiar stimuli regardless of task and the number of stimuli on the display (see Fig. 1, left-panel).

In addition, we examined what we call the *instructed retrieval* explanation for prolonged fixations. It is possible that lengthened fixations are not due to an automatic process, but rather appear only when people are required to retrieve information from memory. If that is the case, we expect to find longer fixations when participants are required to retrieve information from memory but not when required to encode information into memory, regardless of the number of images displayed (see Fig. 1, mid-panel).

In order to test these hypotheses, we designed a study that includes several factors manipulated in a within-subject design: One factor relates to the number of stimuli displayed: a familiar stimulus was presented either alone, or together with other unfamiliar stimuli. The purpose of these two conditions was to examine the lesser exploratory need hypothesis (see Fig. 2 for an illustration of the task, and Fig. 1 for the three different hypotheses examined). The other, orthogonal, factor relates to the requirement to either encode or retrieve a stimulus from memory – enabling separation between the instructed- and automatic-retrieval hypotheses.

The distinction between these hypotheses will shed light on the mechanism responsible for elongation of fixations on familiar items, arbitrating between distinct mechanisms: whether it is related to different processing, and retrieval of information from memory that stalls the fixations, or a need to conserve our valuable muscular saccadic eye movement. This question is important not only to the study of visual attention but also has applicative significance with regards to eye-movement-based Concealed Information Tests (CIT), as it can guide the experimental design and constrain the obtained gaze parameters.

Methods

All experiments were approved by the ethics committee of the social science faculty in the Hebrew University.

Participants. The sample included 59 university students (32 women; Average age 27.7, sd 3.9). Sample size was determined according to the effect size of 0.42 reported in Schwedes & Wentura, 2016. Given this effect size, a power of 0.8 requires a sample size of 46 participants, computed as in Schwedes & Wentura, 2019 using WebPower package. We kept running participants until the end of the semester in order to reach the desired sample size after exclusions. After exclusion (see criteria below), the sample consisted of 48 participants with normal or corrected-normal vision and valid eye movements data from the entire experiment. All participants signed an informed consent before the experiment. They were granted either course credits or 40 NIS (~ 10$). The experiment was approved by the psychology department ethics committee.

Stimuli. We used 64 pictures of past years' students of the Hebrew University that were held in the University database. All pictures were of neutral expressions, front facing the camera. We normalized the pictures for brightness using Matlab (find the code in: https://osf.io/wgfb4/). The stimuli were displayed on a 24" BenQ 3d monitor, with a 120-Hz refresh rate BenQ monitor and a 1024 × 768 screen resolution, corresponding to a screen size of 47.6° × 28°, situated at a distance of 60 cm from the participants' eyes.

Procedure

Familiarization stage. The pool of face images was divided randomly into four sets of faces, each composed of eight pictures, four males and four females. At the beginning of the session each participant memorized one set of images, with sets counterbalanced across participants, such that the familiar faces of one participant would be the unfamiliar of other participants. This ensured that the only difference between familiar and unfamiliar faces was the familiarization stage. In this stage, each image was shown for at least 5 seconds. Participants could self-pace additional viewing time from the first 5 seconds onwards if they wanted to spend more time encoding the picture. Next, the 8 familiar faces, along with 8 unfamiliar faces (that were not used later in the experiment) were displayed serially in a random order. To validate that participants remembered the faces, they were asked to indicate by clicking one of two keys if the face is familiar or not. If they were wrong, the face was repeated later in the session.

The memory task. The short-term memory task included two blocks in random order, one with 64 trials of the single-first condition and the other with 64 trials of the multiple-first condition. Each trial began with a drift check, allowing a deviation of only 0.75 degree of visual angle between the predicted gaze position and the center of fixation point. Larger deviations were accompanied by an error beep and led to a repeated calibration process.

In the multiple-first condition participants saw a display of four faces (5000 ms), followed by a fixation cross on a blank screen (3000 ms), a single display (2000 ms) and a blank screen with a central fixation cross (1000 ms). During the single face display, participants were required to press one of two keys indicating whether the current face had been presented in the previous multiple display or not.

In the single-first condition, participants saw a single face (2000 ms), followed by a delay with a blank screen and a fixation cross (3000 ms), a multiple display of four faces (5000 ms) and a blank screen with a central fixation point (1000 ms). During the multiple display, participants were required to press one of two keys indicating whether one of the faces had been presented in the previous single display or not.

Each familiar face appeared in the multiple display in four trials, once in each location of the display (top right, top left, bottom right, bottom left). In the single display, each familiar face appeared twice, once when it had appeared in the multiple display and once when it had not. Since each participant had 8 familiar faces, a familiar face appeared in half of the multiple displays (32 trials) and in quarter of the single displays (16 trials). The faces in both displays (i.e., the multiple and the single ones) were from the same sex, and the correct answer in half of the trials was "yes" and in the other half "no", in a random order in both conditions.

At the end of the experiment, participants were rewarded based on their accuracy – if they were correct (accurately reporting if a face in the retrieval display was also displayed in the encoding display) in over 90% of the trials, they were rewarded a bonus (10 NIS, ~ 2.5$).

Participants performed a practice session before each condition block, and had to complete at least three correct practice trials out of five, otherwise, they underwent another session of five training trials.

Debriefing questionnaire. After the main memory task participants completed a debriefing questionnaire in which they viewed images of all the faces displayed in the experiment, numbered from 1 to 64, and were asked to indicate the faces that were included in the familiarization stage prior to the memory task.

Exclusion criteria. Based on the final debriefing, and similarly to our previous studies (Lancry-Dayan et al., 2018c; Nahari et al., 2019b), we removed from the analyses trials that included misclassified faces, based on the following criteria: (1) familiar faces that participants did not report as familiar (2.4% of all the pictures rated) and (2) unfamiliar faces that participants reported as familiar (18.75% of all the pictures rated). If more than 16 pictures were removed from the data of a single participant (equivalent to a quarter of the total number of pictures), or more than 1 standard deviation above the mean of the rest of the participants, the data of the participant was excluded from the analysis (11 out of 59 participants). The final sample consisted of 48 participants

Eye tracking. The experiment began with a standard 9-point calibration and validation procedure provided by Eyelink 1000+ (SR Research Ltd., Mississauga, Ontario, Canada). Average accuracy in the validation procedure ranged between 0.25º – 0.82º of visual angle.

In each trial, four identical rectangle interest areas (size: 360 on 360 pixels; 16.7° on 16.7°) surrounded each one of the four faces in the multiple display, separated horizontally by 55 pixels (2.5°) and vertically by 48 pixels (2.23°). In the single display, an interest area was outlined around the presented face (size: 480 on 480 pixels; 22.3° on 22.3°).

Data Analysis

Fixation parsing. The eye-tracking measures are based on EyeLink’s standard parser configuration: samples were defined as a saccade when the deviation of consecutive samples exceeded 30 °/s velocity or 8,000 °/s² acceleration. Samples gathered from time intervals between saccades were defined as fixations.

Preprocessing. In the fixation analysis, the duration of the first, second, and mean fixations directed to each image were extracted for familiar and unfamiliar faces and averaged across all presentations of the face. In the dwell time analysis, all the durations of fixations on familiar and unfamiliar faces were summed, and then averaged first within trial to control for the multiple unfamiliar faces present, and then across all trials for each participant.

Bayesian analysis. To further test the likelihood of the competing hypotheses, we computed Bayes Factors (BF) for the statistical analyses of the fixation and total durations measures by a repeated measures Bayesian ANOVA. In the Bayesian ANOVA, we report the $BF_{inclusion}$, based on all models that include the effect of interest (whether one of the main effects or the interaction) compared to all models without these effects (Rouder et al., 2017). We additionally examined the student t-tests contrasts with Bayesian t-tests. All Bayesian analyses were conducted using JASP (JASP team, 2017), using the default priors of the software. They are reported after each of the frequentist statistics as the likelihood of the alternative hypothesis relative to the null, given the data.

Results

Task performance. Participants accuracy in the short-term memory task was better than chance in both conditions (single-first: $t_{48} = 89.28, p < .001, d = 12.75$, BF = 14600$\times 10^{48}$; multiple-first: $t_{48} = 17.98, p < .001, d = 2.57, BF = 6819 \times 10^{14}$; Fig. 3). Performance in the single-first condition was better ($t_{48} = 9.03, p < .001, d = 1.29, BF = 1404 \times 10^{5}$), and slower ($t_{48} = 8.81 p < .001, d = 1.26, BF = 6872 \times 10^{5}$) than in the multiple first condition. In the single-first condition, accuracy levels were higher when a familiar face was the target of the short-term memory task (repeated in the consecutive displays) than when it was an unfamiliar face, without significant differences in reaction times (see supplementary materials for further details; Figure s1).

Fixations analysis.

The duration of the first fixation was examined using repeated measures analysis of variance on the effects of memory task (encoding\retrieval) * familiarity (familiar\unfamiliar) * display (single\multiple). No significant difference was found either between encoding and retrieval (memory-task main effect: $F_{1,47}$=1.53,p=.222, $\eta_p^2 = .03, BF_{inclusion} = .023$), nor between single and multiple displays (Display main effect: $F_{1,47}$=.352,p=.556, $\eta_p^2 = .007, BF_{inclusion} = .19$), nor between familiar and unfamiliar faces (Familiarity main effect: $F_{1,47}$=.921,p=.342, $\eta_p^2 = .019$, $BF_{inclusion}$= .08). Only the interaction between memory task and display was significant, but did not yield higher likelihood than the null model: ($F_{1,47}$=5.93, p=.019, $\eta_p^2 = .112$, $BF_{inclusion}$ =.42). The rest of the interactions, between memory-task and familiarity ($F_{1,47}$=2.63,p=.111, $\eta_p^2 = .053, BF_{inclusion} = .07$), and the display and familiarity ($F_{1,47}$=1.97,p= .167, $\eta_p^2 = .04, BF_{inclusion} = .05$) were not significant. Neither was the three-way interaction between the memory-task, display and familiarity ($F_{1,47}$=0.07,p=.794, $\eta_p^2 = .001, BF_{inclusion} = .016$) (see Figure s4 in supplementary materials).

Next, we examined the duration of the second fixations (see Fig. 4). All three main effects were significant: the memory-task ($F_{1,47} = 16.67, p < .001, \eta_p^2 = 0.262, BF_{inclusion} = 13961$),display ($F_{1,47} = 26.22, p < .001, , \eta_p^2 = 0.358. BF_{inclusion} = 916419$), and familiarity

$F_{1,47} = 5.95, p = .019, , \eta_p^2 = 0.112, BF_{inclusion} = 3.518$. The interaction between the display type and memory-task ($F_{1,47} = 17.834, p < .001, , \eta_p^2 = 0.275, BF_{inclusion} = 501.67$), and between the display and familiarity were significant ($F_{1,47} = 10.44, p = .002, , \eta_p^2 = 0.182, BF_{inclusion} = 5.94$), but the interaction between memory and familiarity was not ($F_{1,47} = .726, p = .399, \eta_p^2 = 0.015, BF_{inclusion} = .74$). The three-way interaction between the memory-task, display and familiarity was not significant ($F_{1,47} < .001, p = .978, , \eta_p^2 =< .001, BF_{inclusion} = .784$).

Planned contrasts to compare the effect of familiarity when multiple faces were displayed were not significant for either encoding ($\psi = 4.16, t_{175} = 0.44, p = .658, BF = .086$) or retrieval ($\psi = 4.81, t_{175} = 0.51, p = .609, BF = .268$). On the other hand, when a single face was displayed, significantly longer fixation durations were observed on the familiar face (Encoding: $\psi = 19.14, t_{175} = 2.04, p = .043, BF = 3.44$, retrieval: $\psi = 28.63, t_{175} = 3.05, p = .003, BF = 1.97$; see Fig. 4).

Next, we examined the mean fixation duration across all fixations on the stimulus (Figure s5 in the supplementary materials). The main effects of memory task (encoding\retrieval): ($F_{1,47}$=8.11,p = .007 $, \eta_p^2 = .157, BF_{inclusion} = 60.1$) and display (multiple\multiple: $F_{1,47}$=24.57,p = < .001, $\eta_p^2 = .343, BF_{inclusion} = 15683.49$) were significant, but not familiarity (familiar\unfamiliar: $F_{1,47}$ =3.725,p=.06, $\eta_p^2 = .07, BF_{inclusion} = .37$). The interaction between memory task and display was significant: ($F_{1,47}$=10.93,p=.002, $\eta_p^2 = .19, BF_{inclusion} = 38.3$) but the rest of the interactions were not (memory-task x familiarity $F_{1,47}$=1.83,p=.201, $\eta_p^2 = .03, BF_{inclusion} = .36$; display x familiarity $F_{1,47}$ =0.22,p= .64, $\eta_p^2 = .005, BF_{inclusion} = .24$). Neither did the three-way interaction between the memory task, display and familiarity ($F_{1,47}$=1.02,p=.318, $\eta_p^2 = .02, BF_{inclusion} = .17$).

Dwell time analysis.

The fixation duration analysis shows that second fixations were elongated on familiar relative to unfamiliar faces only when a single face was displayed, supporting the less exploratory need hypothesis. If the effect of fixation duration disappears in the multiple display because there are other, unfamiliar, faces to explore, this should be evident also in the overall dwell time gaze is directed to the faces. We expected to find shorter overall dwell times spent on the familiar face during encoding as there is higher need to encode the other unfamiliar faces in order to succeed in the short-term memory task. In addition, we expect the same phenomena but with a lesser effect during retrieval too, as there is a greater need to explore the other faces in the display which are unfamiliar.

The main effects of familiarity ($F_{1,47} = 0.004, p = .948, \eta_p^2 < .001, BF_{inclusion} =< .001$) and memory task ($F_{1,47} = 2.242, p = 0.141, \eta_p^2 = .04, BF_{inclusion} =< .001$) were insignificant, however the interaction between the two was significant ($F_{1,47} = 89.576, p < .001, \eta_p^2 = .65, BF_{inclusion} = 1407 \times 10^{10}$; see Fig. 6). Direct contrasts revealed significant differences between the total dwell time on familiar and unfamiliar faces within each memory task: (Encoding: $\psi = 170.9, t_{90} = 6.02, p < .001$, BF = 2341×10^4, retrieval: $\psi = 189.9, t_{90} = 5.92, p < .001, \mathrm{BF} = 1348.9$). This was evident also when excluding the time following the key press (see supplementary material Figure s3).

A similar pattern was reflected also in the number of fixations. Fewer fixations during encoding of a familiar face were observed, in comparison to unfamiliar faces, as shown by the three-way interaction between the memory-task, display and familiarity was significant ($F_{1,47} = 44.04, p < .001, \eta_p^2 = .484, BF_{inclusion} = 5521 \times 10^6$). For further details on the number of fixations analysis see supplementary materials (Figure s2).

Discussion

Consistent with previous studies, when participants looked on familiar faces presented alone their second fixations were longer (Hsiao & Cottrell, 2008), but not when other unfamiliar faces were displayed simultaneously. It may indeed be the case that during retrieval, the second fixation duration on single displays reflect a recollection processes, and\or holistic perception, as suggested previously (Schwedes et al., 2020, Millen et al., 2020). However, the lack of a difference in fixation duration when unfamiliar faces were displayed together with the familiar face, suggests that the differences in durations are dependent not only on familiarity, but also on the need and opportunity to explore, shaped by the availability of other stimuli in the display. We speculate that previous studies have found lengthened fixations because the stimuli were singly presented, or because the task explicitly required their retrieval from memory. In the current study, in which task was unrelated to the long-term familiarity, no elongation was observed when multiple faces were displayed.

Another consistent difference in gaze pattern was found in the multiple-faces displays. There, overall dwell time was shorter on the familiar face compared to unfamiliar faces during encoding, but longer during retrieval. The shorter overall dwell time on familiar faces is consistent with our lesser need to explore hypothesis and reflects the need to explore unfamiliar stimuli. This effect is also consistent with previous studies (Lancry-Dayan et al., 2018b) and is adaptive as it is easier to encode familiar stimuli into short term memory, encouraging deployment of resources to unfamiliar faces (Nahari et al., 2019c). Unlike our prediction, during retrieval, gaze was directed more towards familiar faces than unfamiliar faces. We speculate that this effect is due to a confusion between long-term and short-term memory, in which participants may not be sure what is the encoding source of the current face – the previous encoding stage from five seconds ago, or the initial familiarity stage that occurred at the beginning of the experiment. Such confusion may hamper the short-term memory reports and lead to longer dwell time on the face.

From an applied perspective, our results support the potential contribution of fixation duration to memory detection, provided that the familiar and unfamiliar stimuli are displayed serially. It also signifies the importance of using multiple measurements when testing for concealed information (Klein Selle et al., 2016; Millen et al., 2020). Many measurements have been proposed before, as well as combinations between them, in order to create a more accurate detection score (Meijer et al., 2014). Notably, when trying to detect concealed information it is better to use multiple measures (Lancry-Dayan et al., 2021; Meijer et al., 2014; Millen et al., 2020). Our study shows that the second fixation duration could be used as another marker of recognition depending on the task and display.

A limitation in the current study is the relatively large number of misclassified pictures. At the end of the experiment participants were asked to indicate which faces they had learned at the beginning of the experiment. This final memory test had a relatively large error rate (21.15%), with unfamiliar faces either misclassified as previously learned or learned faces classified as unfamiliar (see Figure s6 in the supplementary materials). We believe that this confusion is due to the relatively long task, which lasted about an hour and included 128 trials of short-term memory queries. Future research can address this issue by employing a longer familiarization phase, a deeper encoding method (Schwedes et al., 2020; Sporer, 1991), or a between-subject design that will allow showing only one condition, either multiple-first or single-first, thus shortening in half the experiment duration. In any case, the effects reported here are robust and can be seen even when the analyses include all faces without exclusion (see Figures s7-s9). Another thing to consider is that the faces in the multiple displays were smaller than the single faces, which may mask the effects of holistic processing. Future studies should examine the effect of stimuli size on fixation durations on familiar stimuli.

There are numerous future research directions that emerge from the theoretical hypothesis supported by the current results. An interesting question regards the limits to the need of exploration. For example, by manipulating the number of total stimuli on display (by extending the range between 1–6, as been previously used), and the number of familiar pictures amongst them. This would allow further clarification of when exactly reduced exploration is exhibited. In addition, examining individual differences within this effect would elaborate on how different individuals engage in visual exploration differently. If individuals differ in their exploratory gaze behavior in a consistent manner, it would be interesting to examine the association of this behavior with other related personality traits, such as curiosity. Curiosity it expected to generate stronger exploratory urges regardless of familiarity, and is therefore would lead to shorter fixations on the familiar items. It would also be of importance to understand whether the strength of the memory representation determines the magnitude of the effect, for both theoretical and applicative reasons (i.e, in cases of detection of information). Another way to examine the lesser need of exploration would be to generalize it in a more ecological setup, for instance using virtual reality. Virtual reality set-ups enable participants to change their head position, see full body figures and even different scenes. It's not clear if such experimental differences would influence the time that participants engage in looking at familiar and unfamiliar faces. Lastly, comparing directly between tasks that require explicit recognition and tasks that do not demand memory at all, like target detection (Nahari et al., 2019c) is warranted, as all current tasks engaged memory, thus implicitly demanding its involvement in the deployment of visual exploration.

To conclude, the finding that the second fixation on a familiar stimulus is longer only when it is displayed alone, points to a mechanism that factors in not only the current visual stimulus and its presence in memory, but also competition from other stimuli around it. These findings highlight the role of memory in shaping active sensing and bring forward constraints in using fixation duration as a marker for recognition in concealed memory tests.

Declarations

The authors declare no conflict of interest.

Availability of data and materials

The datasets generated and analysed during the current study will be made available in the OSF repository upon publication.

Author contribution

T. Nahari and T. Pertzov conceptualized the study concept and methodology. Data curation, formal analysis, visualization, software, project administration and investigation were done by T. Nahari under the supervision of Y. Pertzov and E. Eldar. Y. Pertzov was in charge of resources and funding acquisition. Y. Pertzov and E. Eldar supervised all of the above. T. Nahari drafted the manuscript, and Y. Pertzov and E. Eldar provided critical revisions, review and edits. All authors approved the final version of the manuscript for submission.

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Figures

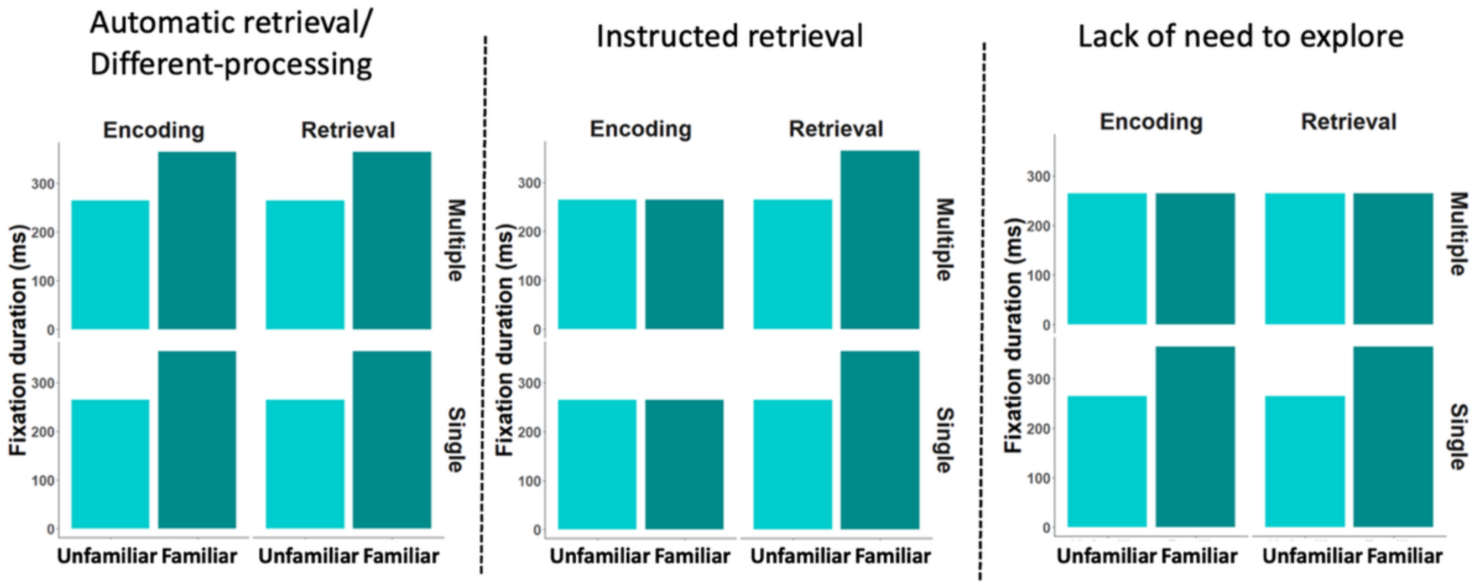

Figure 1

Predicted results of the three hypotheses regarding the mechanism behind the increase in fixation durations on familiar stimuli. In the case of automatic retrieval (left panel), fixation durations would be longer on the familiar stimulus relatively to the unfamiliar stimuli, regardless of encoding/retrieval and the number of stimuli. The instructed retrieval hypothesis predicts longer fixation durations in the retrieval conditions only (mid-panel). The lesser exploratory need hypothesis (right panel) predicts longer fixations only when a single familiar stimulus is displayed, but not when it is embedded within other unfamiliar stimuli.

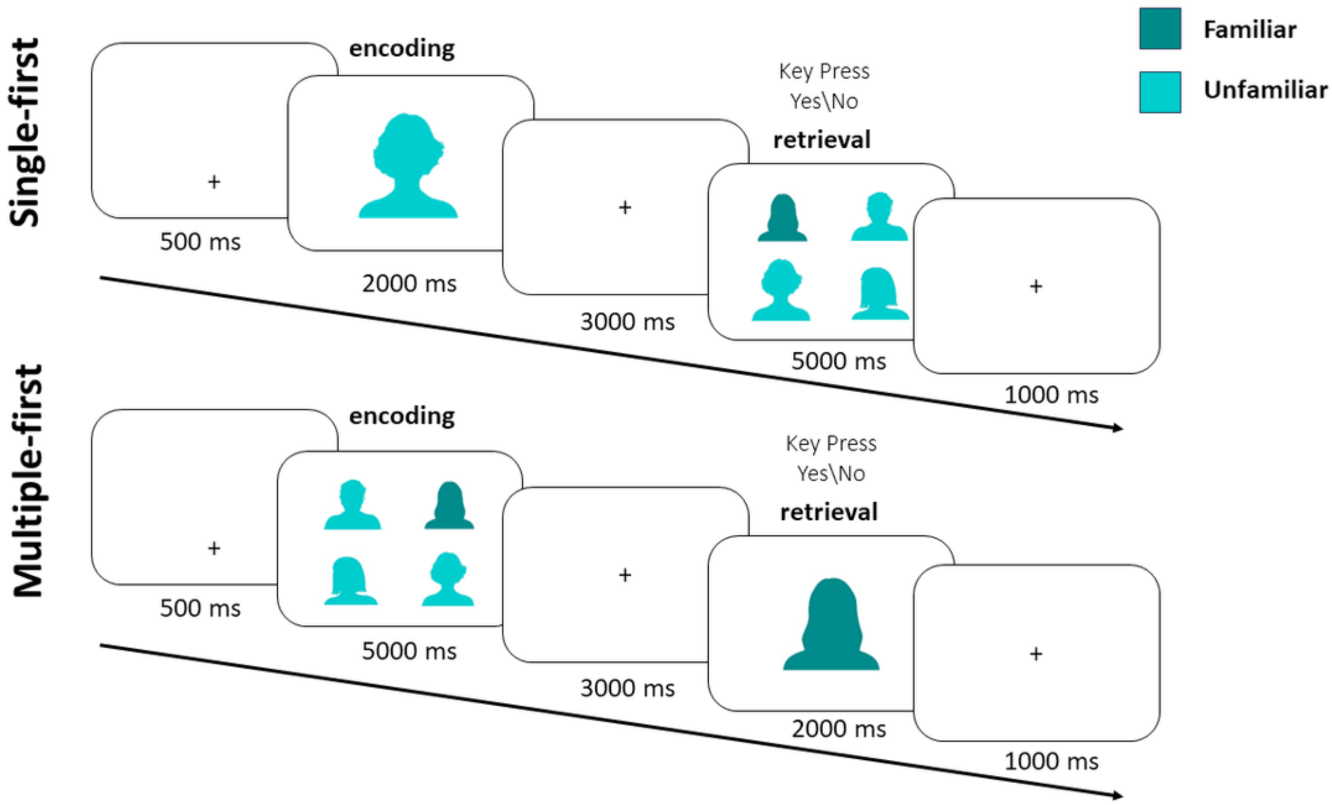

Figure 2

Depiction of the two experimental conditions in the memory task. In the single-first condition participants were requested to encode a single face, and later report if one of four faces matches the single face they saw before. In the Multiple-first condition participants were requested to encode four faces, and later report if a single face was displayed before as one of the four. For privacy reasons the silhouettes of the faces are presented instead of the real faces. A familiar face could be presented either during encoding, during retrieval (as in the single-first example) or during the encoding and retrieval (as in the multiple-first example).

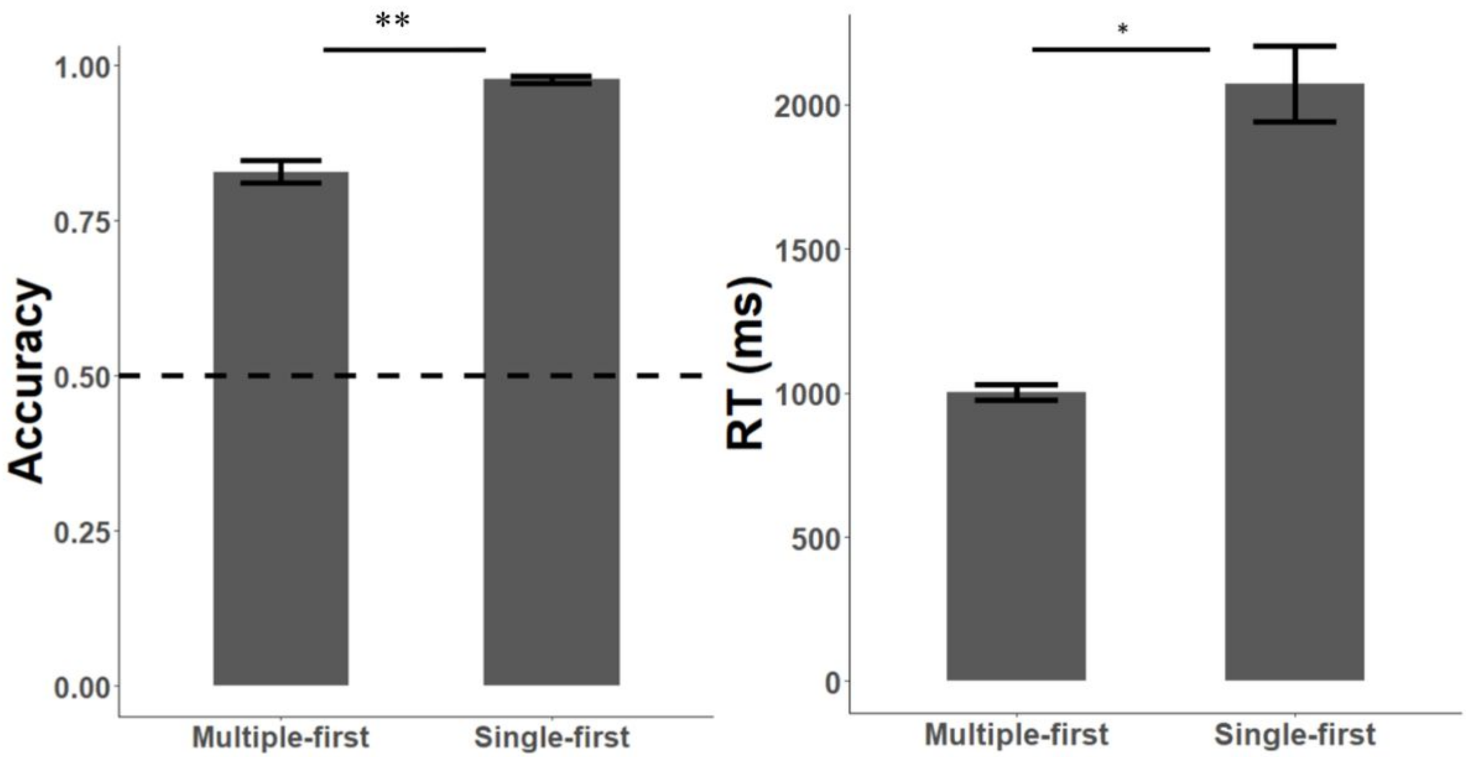

Figure 3

Performance in the short term memory task. Accuracy rates and reaction times of determining if a face in the first display repeated in the second display. Error bars indicate 1 standard error above and below the mean. ***<.001

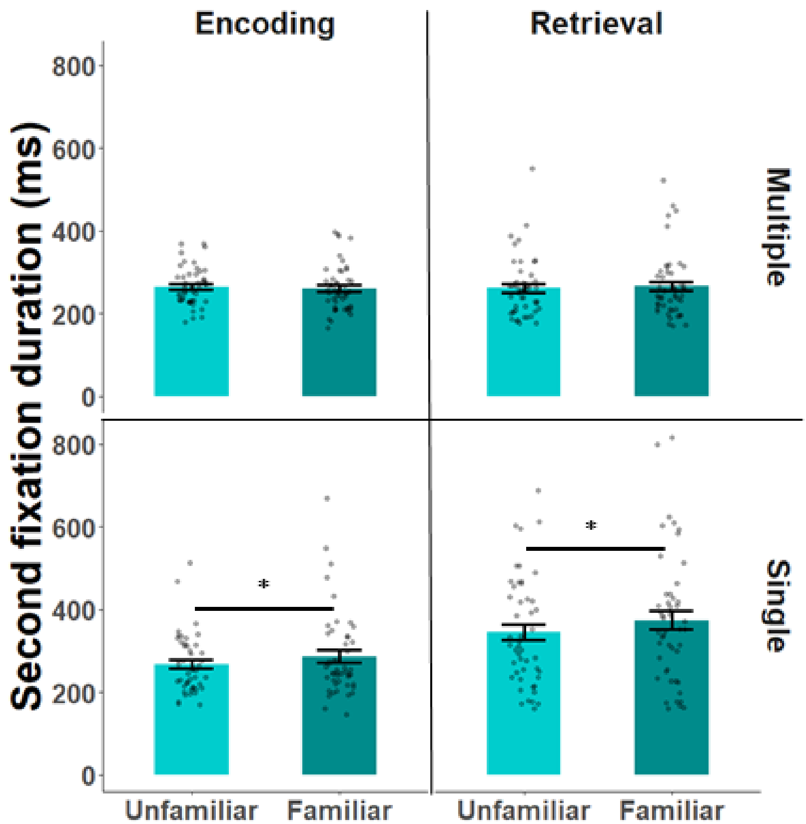

Figure 4

Duration of the second fixation in each of the conditions. Every dot signifies a subject's mean second fixation duration across all trials of a specific condition: Familiar\Unfamiliar face Single\Multiple display and Encoding\Retrieval. Error bars signify 1 standard error above and below the mean. *:<.01

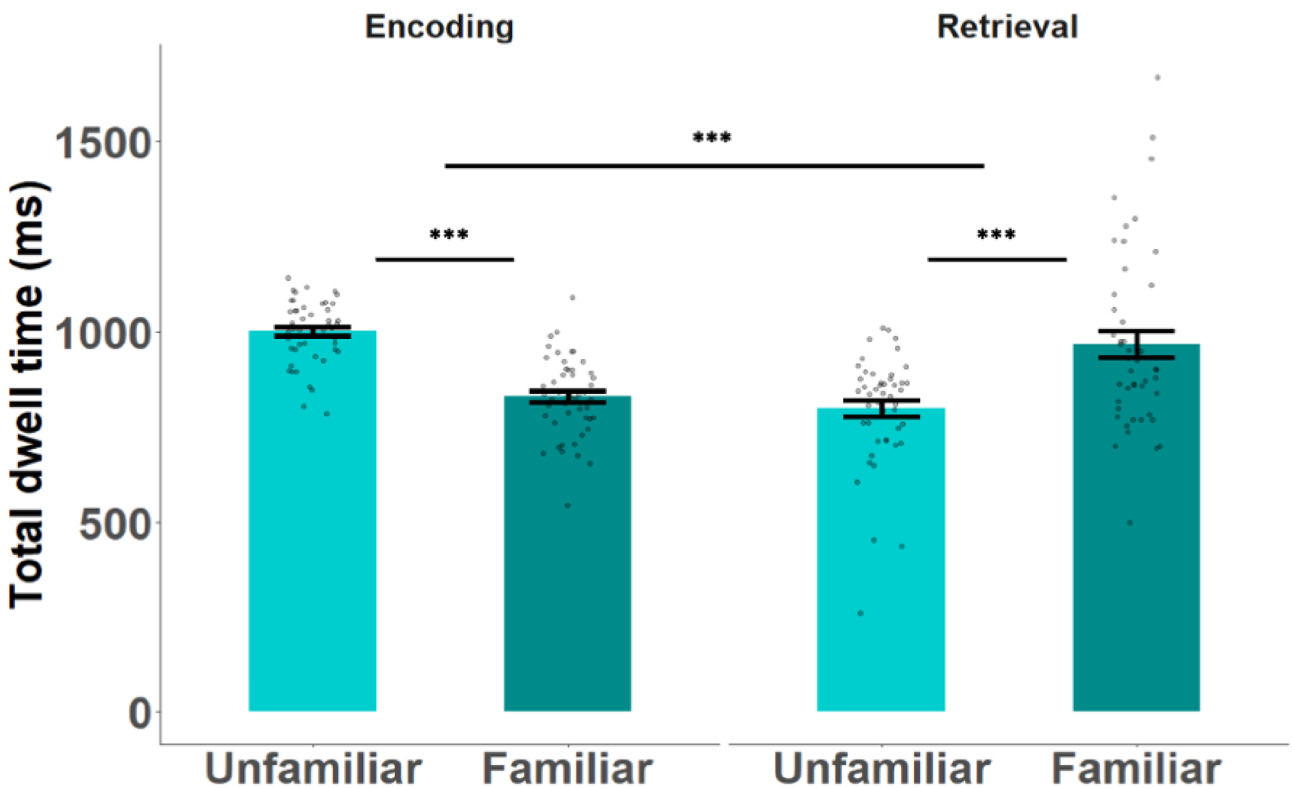

Figure 5

Total dwell time on the different faces during the multiple four face display. Error bars indicate 1 standard error above and below the mean. ***: <.001.

Supplementary Files

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- FixationdurationSupplementarymaterials.docx