Incidental context information increases recollection

BRIEF COMMUNICATION

Running title: *'context information increases recollection'*

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Abstract

The current study describes an ROC task for human participants based on the spontaneous recognition memory paradigms typically used with rodents. Recollection was significantly higher when an object was in the same location and background as at encoding, a combination used to assess episodic-like memory in animals, but not when only one of these task-irrelevant cues was present. The results show that incidentally encoded cue information can determine the degree of recollection, and opens up the possibility of assessing recollection across species in a single experimental paradigm, allowing better understanding of the cognitive and biological mechanisms at play.

Recognition memory is the ability to identify that something has been previously encountered. In humans, episodic memory is associated with a subjective experience of remembering (Tulving & Markowitsch, 1998). As the subjective experience of non-human animals cannot be assessed, the term "episodic-like" memory is often used when memory for an event containing information about objects in specific combinations of location and spatial/temporal context is demonstrated (what, where and when: Clayton & Dickinson, 1998; what-where-which occasion: Eacott & Norman, 2004).

Human tests of episodic memory have been used to provide insight into the distinct, independent processes of familiarity (a feeling of having previously encountered the object/event without any additional information) and recollection (the bringing to mind information from the encoded event which is not presented at test). There is a general consensus that familiarity can be considered a continuous variable, but there remains debate regarding whether recollection is a continuous rather than a non-continuous threshold variable (e.g., Wixted, 2007; Yonelinas et al., 2010).

The analysis of receiver-operating characteristics (ROCs) has been applied to recognition memory, where participants typically provide confidence ratings alongside recognition judgements. Performance is plotted as an ROC curve with hit rate (HR – the probability of a stimulus being correctly identified as 'old') against false alarm rate (FAR – the probability of a stimulus being misidentified as 'old'). The dual process signal detection model (DPSD; Aggleton et al., 2005; Fortin et al., 2004; Sauvage et al., 2008; Yonelinas, 1994; Yonelinas et al., 1998; Yonelinas et al., 2002) states that symmetrical curvilinear functions represent familiarity-based responses – a continuous signal detection process whereby recognition accuracy depends upon the strength of familiarity. Asymmetrical curvilinear functions result from both a continuous curvilinear function (familiarity), and a non-continuous linear function that may represent the threshold nature of recollection (e.g., Morris & Rugg, 2004; Yonelinas, 1994). The asymmetry from including a recollection-based linear function is the result of a high confidence hit rate with no effect of false alarm rate (Yonelinas, 1994). Theoretical-based models can be fitted to the data using a regression method or a maximum likelihood estimates method, which allow for parameter estimates of memory processes to be assessed (Yonelinas & Parks, 2007). As the degrees of recollection and familiarity can be quantified, only the need for introspective assessment of the confidence of one's memory, rather than a categorical description of it (e.g. "remember" vs. "know"), is required. This allows human and non-human animal memory to be understood in a more similar manner.

The current study used ROC analysis to obtain quantifiable measures of recollection and familiarity in a task based on recognition memory paradigms typically used with rodents, derived from the 'what-where-which occasion' episodic memory descriptor (memory for an object, its location and background context; Eacott & Norman, 2004). Participants completed a computer-based memory task, making old/new judgements about objects. The old objects could be shown at test in the same configuration of object, location and context (OLC) as previously seen, same object and location but different context (OL), same object and context but different location (OC) or the object in different location and context (object recognition: OR). As the OLC condition, by definition, is akin to the what-where-which occasion descriptor used to infer episodic-like memory in rodents, it was hypothesised that significantly greater recollection would be elicited in this condition relative to the other recognition conditions if this process underlies episodic memories.

A single testing block consisted of 10 encoding-retrieval phases (see Supplementary Materials for more task information). An encoding phase began with four objects presented sequentially (Figure 1). Each of the four objects was presented in a unique combination of location (left/right) and context (context A/context B), such that each context and location was experienced an equal number of times in each encoding phase with no combination repeated. An object was never repeated within the same block of encoding trials (i.e., the block of 10 encoding-retrieval phases). Participants were instructed to move their eyes to the object when it appeared, and then back to the fixation cross when the object disappeared. A retrieval phase followed wherein four objects were shown sequentially, each of these constituting a single retrieval event (Figure 1). These objects could be assigned to any one of the 'old' object conditions (OR, OL, OC or OLC) or the 'new' object condition. Participants made two responses after viewing each object in the retrieval phase: first whether the object was old (i.e., it had appeared in the previous encoding phase) or new (i.e., it did not appear in the encoding phase), and secondly, participants rated how confident they were with their judgement (1 = guessing; 2 = not very confident; 3 = quite confident; 4 = very confident). The old/new judgement was to be made entirely on the object identity, and context and location were not relevant to this judgement. Each of the objects in the retrieval phase could either be new or old, relative to the immediately preceding encoding phase. If the object was new, it was presented in a random combination of context and location. If it was old, the context and location depended on the condition for that trial (OR, OL, OC or OLC).

After four retrieval events had been completed, a tone signalled the start of the next encoding phase. Each testing block, therefore, consisted of 40 events (four events per encoding-retrieval phase pair, and 10 encoding-retrieval pairs per block). In total, participants completed 16 testing blocks over four days (four 10 minute testing blocks per day), with each block consisting of 10 encoding-retrieval phases (a total of 640 retrieval events).

Data from all 16 blocks were analysed collectively for each participant and transformed from response frequencies to accumulated probabilities that represent points on the ROC curve. FAR probabilities were derived from the new object condition, and separate HR probabilities were derived from each of the four old object conditions. The ROC function was fitted to the data using a method of least-squares (Figure 2). The best fitting ROC curve for each set of points was determined using the following dual-process equations (Yonelinas et al., 1998):

$$HR = R + (1\text{-}R)\ F_{old}$$

$$F_{old} = \Phi\ (d'/2\text{-}c_i)$$

$$FAR = F_{new}$$

$$F_{new} = \Phi\ (\text{-}d'/2\text{-}c_i)$$

Φ = cumulative normal distribution; c = calculated criterion values reflecting an individual's response bias; i = index for the different criterion levels.

For each ROC curve, the derived parameters of *d'* (a measure given by the amount of separation, in standard deviation units, between the distribution in memory strength elicited by novel items, and the distribution in memory strength elicited by familiar items) was taken as a quantifiable measure of familiarity as it is thought to reflect a signal detection process. Equally, the R probability (a measure of the threshold process of recollection given by the probability of there being a recollective experience) was taken as a quantifiable estimate of recollection, and compared across conditions rather than being taken as an absolute measure, as R probability is likely to be an underestimate of true levels of recollection. *d'* was found to vary with task conditions (OR = 1.06; OL = 1.21; OC = 1.16; OLC = 1.10; $F(3,63) = 5.152$, $p = 0.003$; Figures 3a and 3b), with the significant effect lying between the OR and OL memory conditions only ($p = 0.015$), with *d'* being higher in the OL condition. The level of R probability was also found to vary with task conditions (OR = 0.10; OL = 0.12; OC = 0.09; OLC = 0.17; $F(3,63) = 5.075$, $p = 0.003$). R probability in the OLC condition was found to be significantly greater than any of the other recognition conditions (OR and OLC: $t(21) = 3.864$, $p = 0.001$; OL and OLC: $t(21) = 2.238$, $p = 0.036$; OC and OLC: $t(21) = 3.472$, $p = 0.002$), whereas none of the other recognition conditions were significantly different from each other (all $p > 0.250$).

The area under the ROC curve (AUC) for each task condition was used as a single measure of performance (and thus an index of task difficulty), ranging from chance (0.50) to perfect performance (1.00). Here, ROC performance is reduced to a single scalar value measured as a portion of the area of the unit square. Generally, this means that increases in performance will result in a greater measured area (Fawcett, 2006). This measure does not discriminate between different memory processes. The AUC was calculated using the trapezoidal rule for approximating the definite integral. The level of AUC varied with task condition (OR = 0.78; OL = 0.81; OC = 0.80; OLC = 0.81; AUC: $F(3,63) = 8.082$, $p = < 0.001$), with the OR condition significantly more difficult than the OL ($p = 0.002$) and OLC ($p = 0.010$) conditions. Crucially, the OLC condition was not significantly less difficult than the OL or OC conditions (both $p > 0.3$); therefore, the results cannot be attributed purely to differences in task difficulty.

To assess whether the combination of location and context in the OLC condition elicited a degree of recollection that is greater than that predicted by the summation of the separate degrees of recollection associated with location and context alone, the observed R probability in the OLC condition was compared to a hypothetical expected value predicted by the combined probability of the location and context components (see Supplementary Material for calculations). The observed R probability value (0.17; Figure 3) was significantly greater than that predicted by the summation of the OL and OC probability values (0.11; $t(21) = 2.642$, $p = 0.015$). Similarly, the observed *d'* for the OLC condition (1.10) was compared to a hypothetical expected *d'* (1.30; Figure 3), and was found to be significantly lower than the hypothetical expected value ($t(21) = 3.133$, $p = 0.005$). Recollection in the OLC condition appears to be distinct from the simple summation of additional cue information.

The results show that recollection was greater for objects presented in the same combination of location and background context as seen at encoding. Importantly, this pattern of results was not found for the measure of familiarity, indicating that only the OLC condition leads to participants being more likely to use recollection to successfully recognise the object. This interpretation relies on the assumption that R and d' are measures of recollection and familiarity respectively. It should be noted that both recollection and familiarity may contribute towards performance when it is highly confident, as the ROC method leaves open the possibility that familiarity underpins highly confident responses, either instead of, or alongside, recollection. Nonetheless, the difference observed in the experiment shows clearly that whatever the underlying mechanism, the OLC condition produces a step-wise change relative to other conditions. For the reasons outlined below we believe the result is best understood in terms of an increase in levels of recollection, rather than an increase in confidence of a single familiarity process, but acknowledge that the ROC method can only ever be one line of evidence in support of this interpretation.

The results are unlikely to support the notion of a dependent relationship between recollection and familiarity. Although recollection significantly increases for OLC relative to OL/OC, the decrease in familiarity for OLC relative to OL/OC conditions is not significant, which we might expect to see if the relationship was dependent, or if recollection in this instance reflected high confidence familiarity. In addition, the increase in recollection from OL/OC to OLC cannot be attributed to performance change between OL/OC and OLC conditions, because although there is a slight performance increase between OC and OLC, this is not significant and therefore not sufficient to account for the significant increase in recollection for OLC.

Participants may have attended to the contextual and location information despite only being instructed to remember the object. However, levels of recollection were not significantly different in the OL and OC conditions relative to the OR condition, where only the object was the same as at encoding, suggesting that the location and context information continue to be incidentally encoded.

Each piece of information may act as an independent cue for recollection. These cues are incidental – participants may be aware of them changing, but are not made aware that they are relevant when responding whether an object is old or new. During encoding, participants do not know which condition the objects will be assigned. Therefore, even if they explicitly encode the location and context information for the encoded objects, this should benefit performance across all conditions as they will not be able to encode cues differently across conditions.

The provision of two features that match encoding (location and context) might merely provide cues to recall, that summate to produce the observed increase in recollection in the OLC condition. However, the amount of recollection in the OLC condition was found to be significantly greater than the hypothetical expected value found through combining the recollection probabilities associated with the location and context components alone. The correct combination of object, location and context elicits a degree of recollection-based memory that is distinct from the summation of those individual components. This strongly suggests that the increased recollection in the OLC condition is not merely a result of summative effects arising from presentation of additional cues for recall.

Evidence from source memory accuracy (Harlow & Donaldson, 2013) shows that recollection is a threshold event. Using this framework, it is possible that in our experiment there may be a threshold level of object, location and context information required to trigger recollection. In our OR, OL and OC conditions the information may sit on one side of this threshold with the OLC condition sitting on the other side, producing the observed step change in recollection in the OLC task. Alternatively, the results might be a result of additive effects of additional cues, but that these additive effects are supra-linear with all three cues (OLC) providing much more recollection than expected from the difference between one cue (OR) and two cue (OL or OC) conditions. However, both these interpretations rely on each individual cue providing additional information for recall of the encoded memory. Rather than recollection being for the associations between the individual components, it may instead be recollection for the 'scene' or 'snapshot' at the time of the event, and that this 'scene' is much more than the sum of its parts (Gaffan, 1992; 1994). This interpretation is in line with studies of OLC memory in animals, showing that this type of memory is quantitatively different from memory for individual or pairs of components (Eacott & Gaffan, 2005; Eacott & Norman, 2004; Easton et al., 2011; Gaffan, 1994; Norman & Eacott, 2005).

In summary, manipulating incidental information at retrieval produces a step wise change in the ROC curve only when all of object, location and context are congruent with their presentation at encoding. This change does not occur in a linear manner with the addition of recall cues, but instead represents a shift only in the OLC condition. Making the assumption that R is a measure of recollection (rather than a mixture of recollection and familiarity), we believe this reflects an increased likelihood to recollect information in this condition, above all other conditions. In combining our understanding of episodic-like memory (object-location-context) in animals with the ROC approach in humans we provide a novel insight into the way in which this type of information is remembered. Only through such linking of animal and human work can we produce improved translation of recognition memory research from animals to humans.

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Fig. 1.

Experimental procedure. A single testing block consisted of encoding and retrieval phases. Example object presentation for an encoding phase (a). Four objects are sequentially presented for 2s each, separated by a fixation cross presented for 2s (not shown in the image). The objects are presented in a unique combination of location and context such that in each encoding phase the left and right locations and contexts A and B would be experienced an equal number of times, but presented in a randomly selected order. Example object presentation for a retrieval phase (b). Four objects (preceded by a 2s fixation cross) are sequentially presented for 2s, each that may be old or new relative to the objects that appeared in the encoding phase, with each of these retrieval object presentations constituting a single trial. New objects would be presented in a random combination of location and context. Participants were instructed to respond whether the presented object was old or new, relative to the immediately preceding encoding phase, and their confidence rating. The next object was not presented until these responses had been collected. Example object presentation for a retrieval phase (c) that illustrates the possible location and context configurations for a single object from encoding, depending on the old object condition in which it may feature. For old objects, the potential locations and contexts are determined by condition; object recognition (OR) objects are presented in a novel location and context relative to their appearance in the encoding event; object-location (OL) objects are presented in the same location but novel context; object-context (OC) objects are presented in the same context but novel location; and object-location-context (OLC) objects are presented in the same location and same context relative to their appearance in the encoding event.

Fig. 2.

ROC curves with hit rate (HR) plotted against false alarm rate (FAR) for all subjects. Standard object recognition (OR) memory (a). Object-location (OL) memory (b). Object-context (OC) memory (c). Object-location-context (OLC) memory (d). The horizontal SEM bars show the variance for FAR, and the vertical SEM bars show the variance for HR.

Fig. 3.

ROC analyses. Mean *d'* estimates for each recognition condition (a): Object recognition (OR); object-location (OL); object-context (OC); object-location-context (OLC). Mean recollection probability estimates for each recognition condition (b). Predicted and observed *d'* (c) for the object-location-context (OLC) recognition memory condition. Predicted and observed R probability values (d) for the OLC condition. Vertical bars show the standard error of the mean. * = < 0.05; ** = < 0.01; *** = < 0.001.

Figure 1

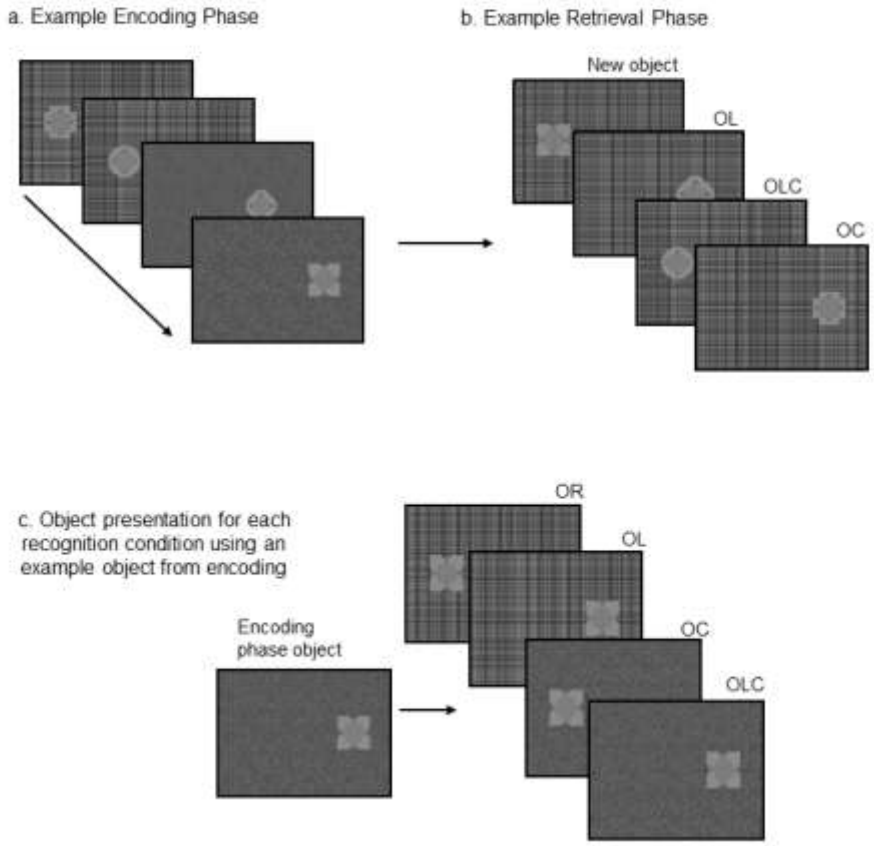

a. Example Encoding Phase
b. Example Retrieval Phase
New object
OL
OLC
OC
c. Object presentation for each recognition condition using an example object from encoding
Encoding phase object
OR
OL
OC
OLC

Figure 2

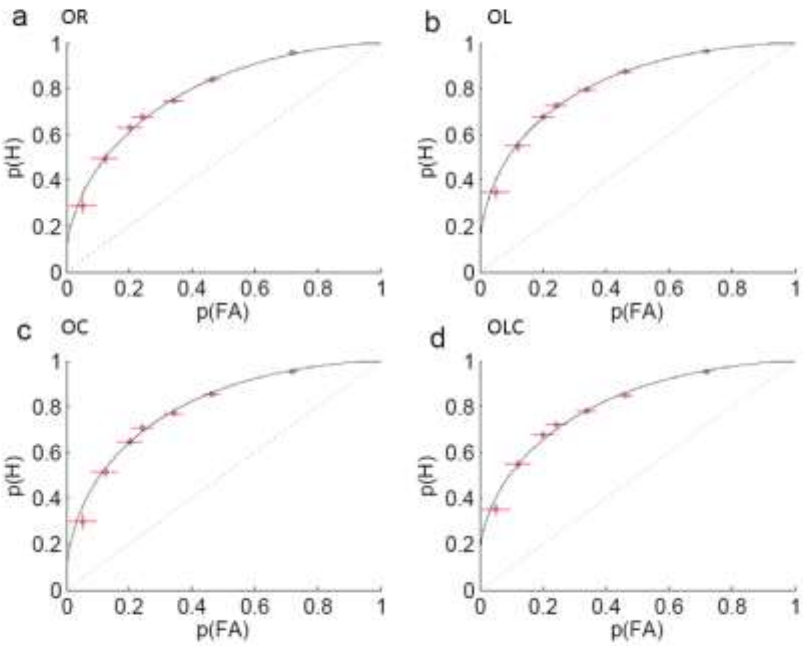
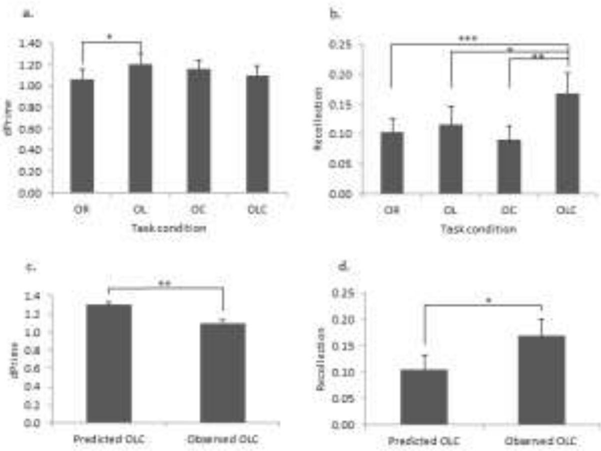


Figure 3


a.
b.
c.
d.
dPrime
Recollection
OR
OL
OC
OLC
Task condition
Predicted OLC
Observed OLC

Supplementary Materials

Methods

Twenty-two participants were recruited to the study (the total number that responded to the study advertisement and completed all testing sessions), and thus the stopping rule was merely the total number recruited within a given time-frame. All participants were naïve to the purpose of the study, and informed consent was acquired before testing took place. Participants were undergraduate and postgraduate students from the Psychology Department, Durham University, and were compensated for their time with either course credit of financial compensation. This study was covered by approval from the Durham University Psychology Department Ethics Committee.

A custom set of 64 2D virtual objects were generated using Matlab (MathWorks). Each object was a unique permutation of three components (object back surface, front surface and peripheral feature), of which there were four variations of each. Two background contexts were used which were also generated in Matlab. Context A was a chequered pattern and context B was a granulated surface pattern; both defined by grey-scale variations in luminance. Stimuli were presented on a CRT monitor using a Cambridge Research Systems (Rochester, England) ViSaGe graphics system. The monitor had a resolution of 1280x1024 pixels and ran with a refresh rate of 85Hz. The viewing distance was set at 45cm with participants resting their head on a chin rest. Each object had a width subtending 6.4° of visual angle and each object was presented 12.8° (either to the left or right) from the centre of the screen.

A single testing block consisted of 10 encoding-retrieval phases. An encoding phase began with an auditory tone lasting 1s, after which a fixation cross would appear in the centre of the screen lasting 2s. This was then followed by four objects presented sequentially for 2s each (Figure 1), and separated by periods of 2s fixation. Each of the four objects was presented in a unique combination of location (left/right) and context (context A/context B), such that each context and location were experienced an equal number of times in each encoding phase with no combination repeated. An object would never be repeated within the same block of encoding trials (i.e., the block of 10 encoding-retrieval phases). Participants were instructed to move their eyes to the object when it appeared, and then back to the fixation cross when the object disappeared. A retrieval phase followed after an auditory tone lasting 1s. In the retrieval phase four objects were shown sequentially, each of these constituting a single retrieval event (Figure 1). Again, these objects were presented for 2s each, and preceded by 2s fixation. These objects could be assigned to any one of the 'old' object conditions (OR, OL, OC or OLC) or the 'new' object condition. Participants made two responses after viewing each object in the retrieval phase: first whether the object was old (i.e., it had appeared in the previous encoding phase) or new (i.e., it did not appear in the encoding phase), and secondly, participants rated how confident they were with their judgement (1 = guessing; 2 = not very confident; 3 = quite confident; 4 = very confident). Note that the old/new judgement was to be made entirely on the object identity and that context and location were not relevant to this judgement. The next object in the retrieval phase was not presented until the participant's responses had been recorded. Each of the objects in the retrieval phase could either be new or old, relative to the immediately preceding encoding phase. If the object was new, it was presented in a random combination of context and location. If it was old, the context and location depended on the condition for that trial (OR, OL, OC or OLC).

After four retrieval events had been completed, a tone signalled the start of the next encoding phase. Each testing block, therefore, consisted of 40 events (four events per encoding-retrieval phase pair, and 10 encoding-retrieval pairs per block). Of these events, there was an equal number (8) of events from the novel, OR, OL, OC and OLC conditions. This design required 48 unique objects for each testing block, which were determined randomly from the 64 available at the start of each block. This meant that some objects would be seen in multiple blocks but never within the same block. In total, participants completed 16 testing blocks over four days (four 10 minute testing blocks per day), with each block consisting of 10 encoding-retrieval phases (a total of 640 retrieval events). This design, therefore, yielded a total of 128 trials per experimental condition (new object condition and four recognition conditions).

In the OR condition, the objects in the retrieval phase were presented in a novel location and context relative to their appearance in the encoding phase. This is in contrast to OR trials with rodents (though based on the same principles), whereby objects are not presented in novel contexts or locations, relative to encoding in a sample phase. In such tasks, recognition is signalled by object exploration driven by novelty of the object alone, due to rodents' innate novelty-seeking behaviours. With humans, there is no need to rely on novelty preference; as such, for the OR condition, the only familiar feature is the object. In the OL and OC recognition conditions, the objects were presented either in the same location but novel context (OL), or the same context but novel location (OC). Again, this is different to the rodent tasks in which novel configurations of object and location, or object and context, drive exploration and signal recognition. With no need to rely on novelty preference, the OL and OC conditions are designed so that familiarity is defined only by the object and location (OL), or the object and context (OC). Finally, in the OLC condition, following the same principles, the objects were presented in the same location and the same context relative to their appearance in the encoding phase rather than a novel configuration of these features, being equivalent to rodent tests of episodic memory (Eacott and Norman, 2004).

The response frequencies were tabulated at each of the eight response levels (old or new, each with four confidence levels) and converted to cumulative response probabilities by dividing the frequencies by the total number of responses in each condition. The probabilities from the highest criterion (“definitely old”) to the lowest (“definitely new”) were cumulatively added. A set of *n* categories, in this case 8, gives n-1 points on the ROC curve. There were, therefore, seven points plotted on these ROC curves. In total, four individual sets of seven ROC points were derived, each one representing either OR, OL, OC or OLC memory.

Every participant completed 16 blocks of trials, with a single block consisting of 10 encoding-retrieval phases, and each encoding-retrieval phase consisting of four encoding events and four retrieval events. The 16 testing blocks completed by each participant consisted of 160 encoding-retrieval phases in total, or 640 individual retrieval events. These 640 individual retrieval events were equally divided across the five conditions; ‘new’, OR, OL, OC or OLC, that occurred equally often (i.e., there was a total of 128 new events and 128 of each recognition condition retrieval events) that were presented randomly across each testing session. Therefore, not every retrieval phase featured a novel object.

The parameters of *d’*, c (calculated criterion values that reflect an individual’s response bias) and R probability were free to vary to provide the most suitable account of the data, with the only constraint being that $0 \leq R \leq 1$.

Additional analyses

The mean sum of squared errors (SSE) between the observed and predicted data was extremely low for each condition, indicating the best fitting parameters were obtained for each condition and that the ROC curves provided a close fit to the data (OR: mean SSE = 0.003; OL: mean SSE = 0.002; OC: mean SSE = 0.003; OLC: mean SSE = 0.002).

In addition to the least-squares method, we also performed a maximum-likelihood fit using the open-source toolbox at https://github.com/jdkoen/roc_toolbox. The results from the two methods are similar and only those from the least-squares method are reported in the paper.

Predicted OLC performance

An important question to consider is whether the correct combination of location and context in the OLC condition elicited a degree of recollection that is greater than that predicted by the summation of the separate degrees of recollection associated with location and context alone – i.e., is the greater recollection merely the result of summative effects of additional cue information? The observed R probability in the OLC condition was compared to a hypothetical expected value predicted by the combined probability of the location and context components.

First the R probability values for just the location (L_R) and just the context (C_R) were calculated. These values are not necessarily equal to the recollection probability values observed in the OL and OC conditions, respectively, because the recollection probability observed in the OL condition, for example, is the combined probability of that found for OR and some other unknown probability associated solely with presenting the object in the same location. The same is true for the recollection probability associated with context in the OC condition. Following the laws of adding independent probabilities, we can express this in the following way. The recollection probability observed in the OL condition (OL_R) is equal to the recollection probability observed in the OR condition (OR_R) plus some unknown degree of recollection probability associated with presenting an object in a familiar location (L_R), minus the intersection of the two. The variables OL_R and OR_R are known probabilities observed from the experiment, but L_R is unknown and will be derived from the following formula:

$$OL_R = OR_R + L_R - OR_R*L_R$$

This equation can be rearranged to find L_R:

$$OL_R - OR_R = L_R - OR_R*L_R$$

$$OL_R - OR_R = L_R\ (1 - OR_R)$$

$$(OL_R - OR_R) / (1 - OR_R) = L_R$$

$$L_R = (OL_R - OR_R) / (1 - OR_R)$$

The recollection probability observed in the OC condition (OC_R) is equal to the recollection probability observed in the OR condition (OR_R) plus some unknown degree of recollection probability associated with presenting an object in a familiar context (C_R), minus the intersection of the two. The variables OC_R and OR_R are known probabilities observed from the experiment, but C_R is unknown and will be derived from the following formula:

$$OC_R = OR_R + C_R - OR_R*C_R$$

This equation can be rearranged to find C_R:

$$OC_R - OR_R = C_R - OR_R*C_R$$

$$OC_R - OR_R = C_R\ (1 - OR_R)$$

$$(OC_R - OR_R) / (1 - OR_R) = C_R$$

$$C_R = (OC_R - OR_R) / (1 - OR_R)$$

The probability of observing recollection in the OLC condition was estimated by adding individual probabilities from the three other recognition conditions. This is equivalent to estimating the probability that at least one of the three independent events occurs. The probability of either *A*, *B*, or *C* happening is equal to the addition of the probability of *A* happening, the probability of *B* happening, and the probability of *C* happening, minus the combined probability of *A* and *B* happening, minus the combined probability of *A* and *C* happening, minus the combined probability of *B* and *C* happening, plus the combined probability of *A*, *B*, and *C* happening. The formula for calculating the probability of at least one of the three independent events occurring is the following:

$$p(AuBuC) = p(A) + p(B) + p(C) - p(AnB) - p(AnC) - p(BnC) + p(AnBnC)$$

We are considering the three factors that can induce recollection (OR, L, and C) as independent events, and therefore we could substitute them in to this equation to replace *A*, *B*, and *C*, to calculate the probability of at least one of these factors inducing recollection. The derived values for L_R and C_R were used to derive an expected R probability value for the OLC condition (eOLC) using the following formula:

$$eOLC = OR_R + L_R + C_R - OR_R*L_R – OR_R*C_R – L_R*C_R + OR_R*L_R*C_R$$

The observed *d'* for the OLC condition was compared to a hypothetical expected *d'* derived from the combination of the separate context and location cues. The estimated *d'* value for the OLC condition was calculated for each participant that could be compared to the observed value. This estimated *d'* value was calculated using the following formula:

$$eOLC = SOR + (OL\text{-}SOR) + (OC\text{-}SOR)$$