Canadian Journal of Experimental Psychology
2010, Vol. 64, No. 4, 241–255

1196-1961/10/$12.00 DOI: 10.1037/a0021525

Can "Pure" Implicit Memory Be Isolated? A Test of a Single-System Model of Recognition and Repetition Priming

Christopher J. Berry, David R. Shanks, Selina Li,
and Luke Sheridan Rains
University College London

Richard N. A. Henson
MRC Cognition and Brain Sciences Unit, Cambridge,
United Kingdom

Implicit memory is widely regarded as an unconscious form of memory. However, evidence for what is arguably a defining characteristic of implicit memory—that its contents are not accessible to awareness—has remained elusive. Such a finding of "pure" implicit memory would constitute evidence against a single-system model of recognition and priming that predicts that priming will not occur in the (true) absence of recognition. In three experiments, using a rapid serial visual presentation procedure at encoding, we tested this prediction by attempting to replicate some previous studies that claimed to obtain pure implicit memory. We found no evidence of priming in the absence of recognition; instead, priming and recognition were associated across experiments: when priming was absent, recognition was also absent (Experiments 1 and 2), and when priming was reliably greater than chance, recognition was similarly greater than chance (Experiment 3). The results are consistent with the prediction of a single-system model, which was fit to the data from all the experiments. The results are also consistent with the notion that the memory driving priming is accessible to awareness.

Keywords: implicit memory, priming, recognition, RSVP, unconscious

It has been argued that the defining feature of implicit memory is that its contents are not accessible to awareness.[1] However, despite over 25 years of research into the topic (for reviews, see, e.g., Mulligan, 2003; Roediger & McDermott, 1993), evidence for this defining feature has remained elusive (Butler & Berry, 2001; Shanks & St John, 1994). The majority of attempts to show that the contents of implicit memory are not accessible to awareness have compared the phenomenon of *long-term repetition priming* (henceforth priming) with recognition.[2] Priming refers to a long-term change in behavioural response to an item (e.g., a word) as a result of prior exposure to that item. This change often takes the form of facilitation in performance. For example, previously studied pictures of objects can be identified at greater levels of degradation than pictures that have not been recently presented. Because the instructions of priming tasks typically do not make reference to a specific prior study episode, the behavioural effects are often assumed to reflect implicit memory (though these "indirect" task instructions do not actually rule out conscious awareness of the study episode, for which further precautions are often taken; see Richardson-Klavehn & Bjork, 1988, for further discussion). Recognition, on the other hand, refers to the capacity to judge whether a particular item has been presented before in a particular context. For example, in a recognition test, old (studied) items are presented together with new (nonstudied) items, and participants are asked to decide whether or not each item was presented at study. The fact that the test instructions refer to a prior study episode means that recognition tests are normally assumed to tap explicit memory, that is, awareness of the study episode (though again, the use of such *direct* task instructions does not rule out contributions from implicit memory to recognition performance; Richardson-Klavehn & Bjork, 1988).

An intuitive and widely adopted method for demonstrating implicit memory is to show that a priming effect can be obtained even though concurrent recognition is no greater than chance (e.g., $d' = 0$; as proposed by Schacter, Bowers, & Booker, 1989). Such

Editor's Note. This paper was part of the Past-President's Symposium held at the joint meeting of CSBBCS and EPS in York, U.K., July, 2009.—DJKM

Christopher J. Berry, David R. Shanks, Selina Li, and Luke Sheridan Rains, Division of Psychology and Language Sciences, University College London; Richard N. A. Henson, MRC Cognition and Brain Sciences Unit, Cambridge, United Kingdom.

This research was supported by grants from the United Kingdom Economic and Social Research Council (ESRC) (RES-063-27-0127), and by the United Kingdom Medical Research Council (WBSE U.1055.05.012.00001.01).

Correspondence concerning this article should be addressed to Christopher J. Berry, Division of Psychology and Language Sciences, University College London, Gower Street, London WC1E 6BT, United Kingdom. E-mail: christopher.berry@ucl.ac.uk

---

[1] The term is actually used in several different ways: It can refer to a particular class of memory tasks (e.g., Roediger & McDermott, 1993), or to an expression of memory which is not accompanied by a phenomenological sense of remembering (e.g., Graf & Schacter, 1985; Schacter, 1987), or it can refer to a hypothesised memory store/system/source (e.g., as in the term "nondeclarative" memory, Squire, 1994). In this article, we are primarily concerned with the latter use of the term implicit memory.

[2] We are concerned with "long-term" priming effects, that is, those that exert an influence after seconds or minutes (at least), as is characteristic of traditional memory phenomena. We do not consider the implicit nature of "short-term" priming effects, which are typically demonstrated over intervals of milliseconds (e.g., Van den Bussche, Van den Noortgate, & Reynvoet, 2009).

a finding could be considered evidence for "*pure*" implicit memory because it suggests that there is an absence of explicit memory, and that the overall priming effect must therefore be driven by a different (nonconscious) source of memory (withstanding criticisms about the exhaustiveness of the explicit memory measure, see, e.g., Shanks & St. John, 1994). Such a finding would also be incompatible with a single-system model of recognition and priming that we have proposed (Berry, Henson, & Shanks, 2006; Berry, Shanks, & Henson, 2008a, 2008b) because, crucially, the model predicts that priming will not occur in the (true) absence of recognition (see ahead). In the present study, we test this prediction by attempting to obtain evidence of pure implicit memory by using a rapid serial visual presentation (RSVP) procedure at encoding.[3] The rest of the Introduction is organised as follows: We describe the model, then we place the current work into context by reviewing some previous applications of the model, then we review some recent evidence of pure implicit memory that has been produced by using RSVP procedures at encoding.

A Single-System Model of Recognition and Priming

The single-system model draws heavily upon signal detection theory (SDT), which has proven useful for understanding recognition memory (see Wixted, 2007, for a review; although it should be noted that there are studies questioning the application of SDT to recognition memory, e.g., Johns & Mewhort, 2002). Of importance, the present model extends SDT to also explain performance in priming tasks such as perceptual identification (Jacoby & Dallas, 1981) and gradual clarification/continuous identification with recognition (CID-R) paradigms. In CID-R paradigms, participants must identify an item that becomes easier to identify with time, and once identified, make a recognition judgment about its prior occurrence (e.g., Conroy, Hopkins, & Squire, 2005; Johnston, Dark, & Jacoby, 1985; Stark & McClelland, 2000). The central idea behind the extension of SDT to priming tasks is to assume that the same memory strength signal that drives recognition also drives priming effects. Thus, it is important to note from the outset that our main concern is not to model the various mechanisms and processes that are involved in different priming tasks, but rather, to model the *influence of memory* upon performance in these tasks.

The model starts with the simple assumption that each item at test is associated with a strength of evidence variable called f, where f is a normally distributed random variable with mean μ and *SD* σ_f (i.e., $f \sim N[\mu, \sigma_f]$). Because old items have been previously studied, we assume that μ(old items) is greater than μ(new items). To generate an item's recognition response, its value of f is first combined with an independent source of random noise, e_r, which has a zero-mean (and $e_r \sim N[0, \sigma_r]$) and is specific to recognition:

$$J_r = f + e_r \tag{1}$$

As in SDT, we assume that participants have some criterion of strength, C, that must be exceeded in order for an old judgment to be made. If the item's value of J_r exceeds C, then the item will be judged old (and classified as a hit if the item is old, or it will be classified as a false alarm if the item is new), and if it does not exceed C, then it will be judged new. The addition of noise e_r to f in Equation 1 can be conceptualised as trial-by-trial variability in the placement of the decision criterion (see Benjamin, Diaz, & Wee, 2009, for further discussion of variability in criteria in item recognition tasks). The proportion of hits and false alarms and a measure of discriminability between old and new items can be calculated (e.g., proportion of hits minus proportion of false alarms, or d'). Thus, when μ(old items) $>$ μ(new items), the model predicts that measures of discriminability will show recognition memory (e.g., d' will be greater than 0), and when μ(old items) $=$ μ(new items), the model predicts that measures of recognition discriminability will reveal no recognition memory (e.g., $d' = 0$).

For priming tasks, the same value of f that was used to generate an item's value of J_r is used to model its priming task response; this feature is what makes the model a single-system model. Of importance though, we assume that the f of each item is added to another independent source of noise, e_p, which is random, has a zero-mean, and is specific to the priming task (i.e., $e_p \sim N[0, \sigma_p]$). The noise can be conceptualised as representing a whole host of factors that are unrelated to the influence of memory, but can nevertheless influence a task's sensitivity to the influence of memory (e.g., the amount of perceptual information that can be extracted from a stimulus when it is presented at test, see, e.g., Ostergaard, 1992, 1998). We have previously applied the model to perceptual identification (Berry et al., 2006a), and CID-R paradigms (Berry et al., 2008a). For example, we have previously assumed that identification reaction time (RT; i.e., the latency for naming or covertly identifying an item) in CID-R paradigms is a decreasing function of f:

$$\mathrm{RT} = b - sf + e_p \tag{2}$$

where b and s are constants: b represents the RT-intercept, or baseline level of responding, and s represents the rate of change in RT with f.

The priming task that we will be concerned with in this article is the picture fragment identification task (Snodgrass & Feenan, 1990). We can model the response for each item in this task in a similar way to RT in CID-R tasks if we assume that greater levels of strength tend to lead to identifications at greater (earlier) levels of fragmentation. Therefore, RT in Equation 2 can simply be replaced by "fragmentation identification level" (henceforth, ID). When μ(old items) $>$ μ(new items), the model predicts that there will be priming (i.e., old items will tend to be identified earlier, at greater levels of fragmentation than new items), and when μ(old items) $=$ μ(new items), the model predicts that there will be no priming (i.e., the fragment identification levels of old and new items will tend not to differ). The model makes these predictions regardless of the type of priming task.

Thus, if a reliable priming effect is found, this implies that μ(old items) $>$ μ(new items), and therefore the model predicts that

---

[3] Other methods also exist for demonstrating pure implicit memory, including the relative sensitivity approach of Reingold and Merikle (1988), in which unconscious influences of memory are demonstrated when the sensitivity of an indirect discrimination is shown to be greater than that of a direct discrimination when direct and indirect tasks are matched on all extraneous characteristics except instructions. We have addressed evidence using this approach in an earlier article (Berry, Shanks, & Henson, 2006).

recognition will be also be greater than chance.[4] If a finding of chance recognition is found, this suggests that μ(old items) = μ(new items), and the model will predict that there will also be no priming. Demonstrations of priming in the absence of recognition therefore constitute evidence against the model.

Previous Applications of the Model

The majority of research into implicit and explicit memory has investigated dissociations between recognition and priming (see, e.g., Roediger & McDermott, 1993). We have previously used the model to show that many dissociations, which at first glance appear to be indicative of independent implicit and explicit memory systems, are in fact not inconsistent with a single-system account. First, we have shown that the model can reproduce dissociations produced by manipulations of attention at study (Berry et al., 2006a). Attentional manipulations typically produce relatively large effects on recognition performance and similar, but much smaller, effects on priming (see Mulligan & Brown, 2003, for a review). This is consistent with findings showing that the reliability of priming tasks is generally lower than that of recognition tasks (e.g., as indexed by split-half correlations, see Buchner & Wippich, 2000): When a task has a relatively low reliability, an independent variable is less likely to produce effects upon it. The generally lower reliability of priming can be represented in the model by assuming that the variance of the noise associated with priming (σ_p) is greater than that associated with recognition (σ_r). When we made this assumption in the model, increases in μ (assumed to reflect greater attention) had a much greater effect upon recognition than priming, and the model produced good quantitative fits to the data. Note that this kind of dissociation is akin to those produced by other variables (e.g., semantic vs. nonsemantic processing of items at study; see Brown & Mitchell, 1994).

The model can also account for dissociations found in paradigms used to measure recognition, priming and fluency on a trial-by-trial level, such as CID-R paradigms. For example, Stark and McClelland (2000) found that even though participants did not recognise certain old items in a recognition test, a priming effect nevertheless occurred for these items. That is, even within the subset of items that participants judged new on a recognition test, identification/naming latencies for old items (misses) were still shorter than those of new items (correct rejections). This result actually falls quite naturally from the model: In SDT, the memory strength of misses is greater than that of correct rejections. In the model, because identification RTs are a decreasing function of strength (*f*), the model predicts that identification RTs to misses will tend to be shorter than those of correct rejections (Berry et al., 2008a). Also, quite counterintuitively, the model explains the variable nature of the relationship between the identification RTs to misses and false alarms when overall levels of recognition are low versus high. That is, it predicts the pattern RT(false alarm) $<$ RT(miss) when recognition is low, and RT(miss) $<$ RT(false alarms) when recognition is high, as found by Johnston et al. (1985); this variable relationship can be explained by the principle of regression to the mean (see Berry et al., 2008a).

Furthermore, the model can reproduce the dissociations found in a CID-R paradigm with amnesic individuals who have damage to the hippocampus or who have more extensive medial temporal lobe lesions (Berry et al., 2008a). Conroy et al. (2005) have shown that amnesic individuals show relatively intact priming and fluency effects (the tendency for the identification RTs of items judged old to be shorter than those of items judged new), despite relatively impaired levels of recognition. Counterintuitively, the model was able to account for this dissociation by assuming that the underlying memory representation is more variable in amnesic individuals than controls (i.e., σ_f is greater), that the variance of the noise (e.g., in the trial-to-trial placement of the decision criterion) associated with recognition is greater in amnesics relative to controls (i.e., σ_r is greater), and the amount of variability is proportional to the extent of the brain damage (greater for patients with medial temporal lobe lesions).

Finally, we have found that when estimates of the contribution of fluency to recognition are calculated from the model data, these estimates are extremely low (as have been reported by Conroy et al., 2005, and Poldrack & Logan, 1997; Berry et al., 2008a). This finding has been found in normal adults and individuals with amnesia and has previously been taken as evidence that the source of memory driving recognition is independent from that which drives priming and fluency. However, because an item's *f* is subjected to independent sources of random noise for each task, it can appear as if the contribution of fluency to recognition is weak. The random noise also gives rise to correlations between overall priming and recognition performance that are very weak, a result which has traditionally been taken as evidence for multiple-systems views (see Poldrack, 1996, for a review). Thus, there are many results that the model is able to explain without postulating independent implicit and explicit memory sources. We now turn to recent evidence for pure implicit memory that is challenging for the model.

Recent Evidence for Pure Implicit Memory

Vuilleumier et al. (2005) and Butler and Klein (2009) found evidence of pure implicit memory using RSVP procedures at encoding. Both studies found that a priming effect occurred for items that were ignored, but that recognition for these items was not reliably different from chance (for a review of previous attempts to demonstrate priming in the absence of recognition using attentional manipulations at encoding, see Mulligan, 2008). In the study phase of Vuilleumier et al.'s (2005) experiment, cyan and magenta line drawings of objects were presented simultaneously, superimposed upon one another for 250 ms on each trial of a Rapid Serial Visual Presentation (RSVP) procedure. Participants were instructed to attend to either the cyan or magenta stream of images and to press a button every time they detected the presentation of a nonsense object in that stream. At test, participants completed a recognition task with old-new judgments, or a fragment identifi-

---

[4] Of interest, the opposite finding—recognition in the absence of priming—is more easily explained by the model. The reliability of priming measures (e.g., as calculated by split-half correlations) is typically found to be lower than that of recognition tasks (Buchner & Wippich, 2000). In Berry et al. (2006a), we incorporated this characteristic of priming tasks into the model by assuming that the variance of the noise associated with priming tasks is typically greater than that of recognition tasks (i.e., $\sigma_p > \sigma_r$). This leads the model to predict that the sensitivity of recognition will typically be greater than that of priming tasks when performance in both tasks can be measured on the same response metric.

cation task in which an object was shown in progressively less fragmented forms until it was correctly identified. The key result of interest from this study was that previously ignored objects were identified at more fragmented levels than previously unseen objects (i.e., there was a priming effect for previously ignored objects), but recognition of these objects was not reliably different from chance.

The study by Butler and Klein (2009) used a similar encoding procedure to that of Vuilleumier et al. (2005). In their RSVP phase, a word was superimposed upon an object on each trial (similar to a design of Rees, Russell, Frith, & Driver, 1999). Each participant completed blocks of RSVP trials in which they either attended to words or attended to objects. Using a perceptual identification task, Butler and Klein (2009) found a reliable priming effect for words that had been ignored, but found that recognition memory for these words was not different from chance.

If the pure implicit memory effects in Vuilleumier et al. (2005) and Butler and Klein (2009) are robust and replicable, then this would pose a serious problem for the single-system model. Thus, the main aim of this study is to test the model by attempting to reproduce these effects (see also Berry et al., 2006a; et al., 2006b).

Experiment 1

In Experiment 1, we aimed to test the single-system model by attempting to replicate the pure implicit memory effect found in Vuilleumier et al. (2005). As in Vuilleumier et al. (2005), objects were presented in cyan or magenta using an RSVP procedure. Participants attended to one of the two colors and were instructed to press a button whenever they detected a nonsense object. At test, one group of participants completed a recognition task (with old/new judgments) (as in Vuilleumier et al., Experiment 1A) and another group completed a fragment identification task (as in Vuilleumier et al., Experiment 1B).

Method

Participants. Ninety-one individuals were recruited (42 male; mean age = 24.1 years; *SD* = 7.7 years). Participants were randomly assigned to either the fragmentation condition ($n = 41$) or the recognition condition ($n = 50$).[5] All participants in this and subsequent experiments reported normal or corrected-to-normal eyesight and no colour blindness.

RSVP phase procedure. All participants initially completed an RSVP phase. All stimuli were presented using an LCD monitor with a refresh rate of 60 Hz. On each RSVP trial a cyan line drawing and a magenta line drawing were superimposed on top of one another and presented at central fixation (the entire display was approximately 5 cm × 5 cm, subtending approximately 3.8 degrees of visual angle horizontally and vertically). A line drawing was either an outline of a real object (taken from Snodgrass & Vanderwart, 1980), or of a nonsense object (taken from Kroll & Potter, 1984). On each trial, the display was presented for 250ms and was followed by a 250ms blank interval. Participants' attention was oriented to either the cyan or magenta stream (counterbalanced across participants) by telling them that they must press a button when they detected a nonsense object in the attended stream (and that this would occur on approximately 10% of trials). For each participant, 50 line drawings of real objects were randomly selected from a pool of 260 line drawings of objects to be presented in the attended colour; another 50 drawings were randomly selected from the same pool to be presented in the ignored colour. Each object was presented four times in a random order within the same stream. Fifty nonsense objects were selected from Kroll and Potter (1984); 25 were randomly selected to be presented in the attended colour and 25 were randomly selected to be presented in the ignored colour. Thus, there were 225 RSVP trials in total.

Test phase procedures. After the RSVP phase was completed, instructions were presented for the test phase; participants completed either a fragmentation phase, or a recognition phase. In the recognition phase, the 50 attended and 50 ignored objects from the study phase were presented together with an additional 50 unseen real objects (selected from the same stimuli pool) to act as new items. All objects at test were presented in black outline. The instructions informed the participants that on each trial a previously attended, previously ignored or previously unseen (new) object could be presented and they were to decide whether the object had been presented in the first stage by pressing the 'Z' or 'M' key to indicate a "yes" or "no" response (the assignment of keys to the response was counterbalanced across participants).

For a subset of participants in the recognition stage, objects were presented until the recognition response was made ($n = 16$), and for another subset of participants, each object was presented for only 500 ms ($n = 18$). Finally, for some participants, payment was performance related such that participants received 5 pence for every correct recognition response that they made, and 5 pence was deducted for every incorrect response made ($n = 16$). Vuilleumier et al. (2005) only presented items for 500 ms in the recognition stage and performance was not pay related. In our study, performance between the three different subsets of participants did not significantly differ (though there were some marginal effects; see Appendix A), and moreover, these procedural differences did not affect our ability to replicate the key recognition findings in their study. For the sake of clarity, we present the recognition data as being from one group of participants.

The instructions for the fragmentation procedure informed participants that they would initially see a very fragmented form of a drawing of an object on each trial. Their task was to try to correctly identify the item. If they did not know the identity of the item, they were told to press the spacebar to reveal a slightly less fragmented version of the object, and that a less fragmented form of the item would be presented with each successive spacebar press. As with the recognition stage, there were 150 trials in total (50 previously attended items, 50 previously ignored items, and 50 new items). There were eight possible levels of fragmentation for each item. The stimuli were presented in black, and the degree of fragmentation on each successive presentation was determined in a similar manner to that described by Snodgrass and Feenan (1990). Participants were instructed that when they were confident that they

---

[5] One reviewer was concerned with the unequal group sizes in our experiments. The unequal *n*s arose because of the random manner in which participants were assigned. We repeated all the analyses equating group sizes by removing participants at random from groups with a greater number of participants. All qualitative patterns of results were the same as reported in the text.

could identify the item correctly, they were to press the enter key and then type the name of the object into a white text box which appeared. Thus, the task requires identification of an item and is typically thought to rely largely upon perceptual processes (Roediger & McDermott, 1993). The fragment identification stage instructions made no reference to the initial RSVP phase. Only objects which were correctly identified were later analysed. If an object in the fragmentation or recognition test phase had been paired with a nonsense object in the RSVP phase, then it was not analysed (as in Vuilleumier et al., 2005). An alpha level of .05 was used for all statistical tests in all experiments, and all *t* tests were two-tailed unless indicated.

Results and Discussion

RSVP. The responses made in the RSVP stage across all participants are given in Table 1. In this stage, a false alarm was classified as a response on a nontarget trial. If a greater proportion of responses on these trials were to objects (in the ignored or attended stream) than to nonsense objects in the ignored stream, this would be an indication that participants were attending to the correct stream. This trend was found in the data, $t(76) = 5.71$, $p < .001$, suggesting that participants allocated attention appropriately. Comparing RSVP performance in the recognition and fragment identification groups, there was no difference in the overall percentage of correct responses, $t(89) = 0.51$, or percentage of false alarms, $t(89) = 1.05$, but the percentage of correct nonsense object detections in the recognition group (50.8%) was greater than in the fragmentation group (41.0%), $t(89) = 2.07$, $p = .041$ (there is no a priori reason why this difference should occur—the assignment of participants was random and participants were naive to the subsequent test stage, and so we do not consider this result further). Two participants in the recognition group performed quite poorly on the RSVP task: one responded correctly on only 58.7% of trials and one only responded correctly on 20.9% of trials; importantly, however, the inclusion of these participants did not affect the qualitative pattern of recognition and priming results, and the results we report include all participants. All other participants responded correctly on more than 75% of RSVP trials. It is worth noting that the detection of the nonsense targets in the attended stream was not as good as that of Vuilleumier et al.'s (2005) participants (83.2%), suggesting that it was more difficult to detect the nonsense shapes that we presented in our study. (The other RSVP results reported in Vuilleumier et al. were as follows: 97.4% correct responses on all trials, 0.9% of nontarget trials were false alarms.)

Recognition. Recognition discrimination performance was measured by d' (the difference between the *z*-transformed proportion of hits and false alarms, where a hit is an old response to an old word, and false alarm is an old response to a new word; separate hit rates were calculated for attended and ignored stimuli).[6,7] The measures of d' are shown in the left panel of Figure 1A, the associated measures of response bias (C) are shown in Table 2, and the hit and false alarm rates for previously attended, ignored and new items are shown in the left panel of Figure 2A. Recognition for attended objects was significantly better than that of objects in the ignored stream, $t(49) = 11.23$, $p < .001$. Recognition for attended objects was greater than chance (i.e., $d' = 0$) levels, $t(49) = 10.57$, $p < .01$, and crucially, recognition for previously ignored objects was not reliably different from chance, $t(49) = 1.28$, $p = .21$, replicating Vuilleumier et al.'s (2005) crucial result for ignored objects, and confirming that the RSVP study phase procedure can be an effective method for eliminating recognition memory. Given this absence of recognition memory for ignored items, we then asked whether there was a priming effect for these items, which would constitute evidence for pure implicit memory.

Fragment identification. For every participant, the priming effect for previously attended and ignored objects was calculated by subtracting the mean fragment identification threshold for attended/ignored objects from that of new objects. As in the recognition data, there was an effect of attention on priming: The mean priming effect for attended objects was significantly greater than that of previously ignored items, $t(40) = 6.12$, $p < .001$ (see Figure 1A, right panel, for priming effects, and Figure 2A, right panel, for the respective fragment identification thresholds for previously attended, ignored and new items). Furthermore, priming of attended objects was reliable (i.e., greater than zero), $t(40) = 7.72$, $p < .001$, but priming of ignored objects was not, $t(40) = 0.97$, $p = .34$. Comparisons between participants who attended to cyan and those who attended to magenta at study revealed no reliable differences between priming and recognition for attended or ignored objects.

Thus, Experiment 1 found effects of attention upon recognition and priming, and also that recognition memory was absent for ignored objects (as in Vuilleumier et al., 2005). However, we did not find any evidence of priming for previously ignored objects (unlike Vuilleumier et al., 2005). The power of our experiment to detect a priming effect for ignored items is obviously an important consideration here: power was ample, and for the sake of clarity, we present the power analysis for Experiments 1–3 in a single section at the end of Experiment 3.

Modelling

We fit the single-system model to the data using the procedures described in Appendix B. As shown in Figures 1 and 2, the expected model results (open circles) are within the empirical range of results observed (with the exception of recognition d' for

---

[6] To permit the calculation of d' for participants who made zero hits or zero false alarms, we applied the correction recommended by Snodgrass and Corwin (1988) when calculating each participant's hit and false-alarm rate: The hit rate for attended items was calculated as (number of hits to attended items + 0.5)/(number of attended items + 1); similarly, the hit rate for ignored items was calculated as (number of hits to ignored items + 0.5)/(number of ignored items + 1); finally, the false-alarm rate was calculated as (number of false alarms + 0.5)/(number of new items + 1). In Experiment 1, there were three unity hit rates for attended items, one zero hit rate for ignored words, and one zero false-alarm rate that required this correction. No scores in Experiment 2 required this correction. In Experiment 3, two zero false-alarm rates required this correction.

[7] We chose to analyze our recognition data using d', whereas Vuilleumier et al. (2005) (and Butler & Klein, 2009) analyzed their recognition data by comparing the hit rate for attended/ignored items with the false-alarm rate. The conclusions of Experiments 1 to 3 are unaffected by using d': the qualitative pattern of results was the same when we compared the attended/ignored hit rates with the false alarm rate (where the Snodgrass & Corwin, 1988, correction was not applied to any of the scores).

Table 1

Rapid Serial Visual Presentation (RSVP) Phase Performance (Means) Collapsed Across Participants in Experiments 1 to 3 (SDs Are in Parentheses)

	% of correct responses	% of target items responded to in attended stream	% of false alarm trials (trials on which a response to a nontarget occurred)	% of false alarm trials that were to non-target items in the ignored or attended stream	% of false alarm trials that were to target items in the ignored stream
Experiment 1	91.0 (9.0)	46.4 (23.0)	3.5 (10.5)	68.5 (29.5)	30.2 (30.4)
Experiment 2	93.5 (3.6)	69.7 (18.2)	3.5 (3.3)	63.8 (28.6)	36.2 (28.6)
Experiment 3 (attend objects group)	86.6 (17.0)	44.3 (24.6)	8.1 (20.5)	100 (0)	—
Experiment 3 (attend words group)	95.1 (2.1)	71.2 (11.7)	1.9 (2.1)	100 (0)	—

Note. A correct response was counted as either responding to a target on an RSVP trial or not responding to a nontarget. A dash indicates that calculation is not appropriate because target items do not appear in the ignored stream (the attended and ignored streams in Experiment 3 contained items of different classes).

ignored objects, which fell just outside the confidence interval). The model predicts that *both* priming and recognition for ignored items will be very weak and very close to chance levels. Thus, the fact that the attentional manipulation failed to produce evidence of pure implicit memory in Experiment 1 is consistent with the single-system model: priming for ignored items did not occur in the absence of recognition, nor was this pattern predicted by the model.

Experiment 2

The primary aim of Experiment 2 was to determine whether the results of Experiment 1 generalised to word stimuli. Given that we did not replicate the pure implicit memory effect found by Vuilleumier et al. (2005), we thought that a demonstration that the results of Experiment 1 generalise to a completely different class of stimuli would help to strengthen the conclusions drawn. Accordingly, we repeated Experiment 1 but with word outline stimuli. In the RSVP phase, participants were instructed to detect nonwords in the attended stream. The procedures of Experiment 2 were otherwise identical to those of Experiment 1.

Method

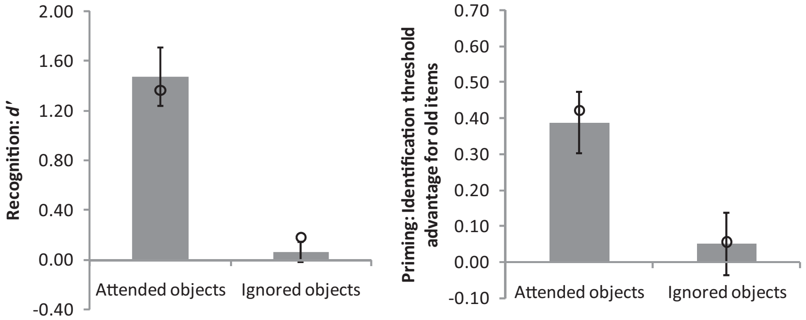
Participants. Forty individuals were recruited (23 female; $M = 26.0$ years; $SD = 6.5$). Twenty-four were randomly assigned to the fragmentation condition and 16 were randomly assigned to the recognition condition.

Materials. The word stimuli were 335 four-letter words, selected from the MRC psycholinguistic database (Coltheart, 1981). All words had a low frequency of occurrence (1–10 per million; Kucera & Francis, 1967) and archaic and colloquial terms were excluded. The outlines of each word were presented in lowercase Courier 90pt font, and occupied an area of approximately 1.5 cm in the vertical (1.2°) and 7.5 cm in the horizontal (5.7°) on the screen. The thickness of the outline was 1.8 pt. The nonword stimuli were 50 four-letter nonwords, selected from Stark and McClelland (2000).

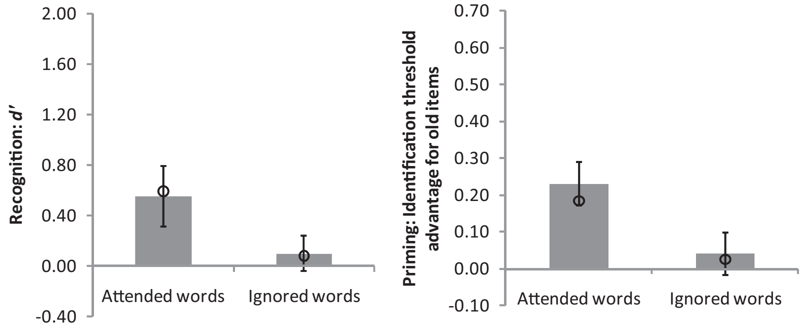
Procedure. The RSVP procedure was the same as that of Experiment 1 (i.e., in terms of frequencies of trials, colors of streams, general instructions, presentation duration of each trial), except that outlines of words were superimposed upon one another on each trial rather than outlines of objects, and participants were instructed to detect the occurrence of nonwords (e.g., "nzxq") in the attended stream, and to press the spacebar whenever they detected one. Words in the attended stream were always presented at fixation. Words in the ignored stream were randomly offset from the fixation point by 50 pixels to the left or right and 50 pixels above or below (approximately 1° of the visual angle). This was done to prevent complete overlap between the attended and ignored words, and to allow each word to be discernable.

The procedure in the fragmentation and recognition phases was the same as Experiment 1, and the same method that was used to fragment the pictures in Experiment 1 was used to fragment the word stimuli in Experiment 2. Thus, the fragmentation of each word outline was such that any part of the outline of a word could be fragmented.

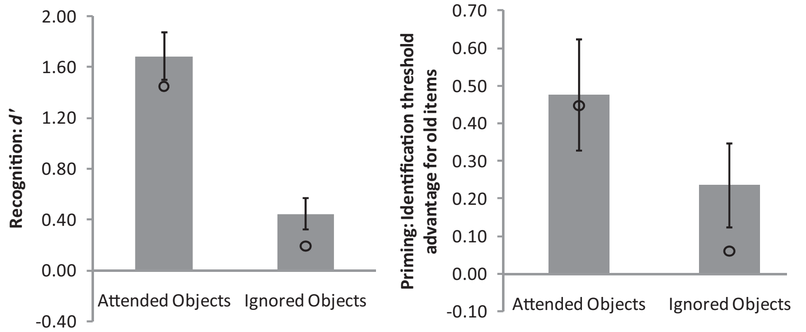
A. Experiment 1: Objects



B. Experiment 2: Words



C. Experiment 3: Objects



D. Experiment 3: Words

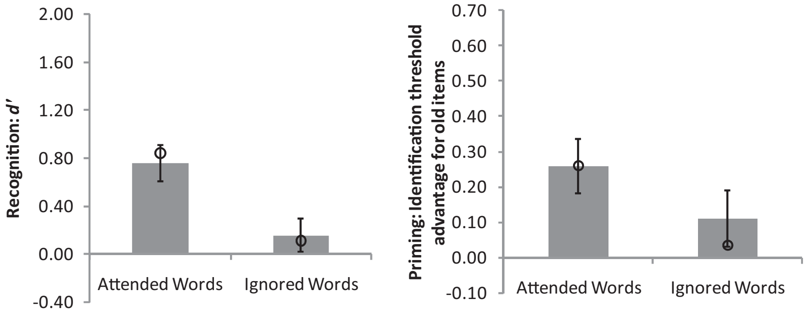


Figure 1. Recognition discriminability (d') (left panels) and priming (right panels) for attended and ignored objects in Experiment 1 (A), words in Experiment 2 (B), objects in Experiment 3 (C), and words in Experiment 3 (D). Priming is shown if an old item (attended or ignored) is identified at a lower identification threshold than new (unseen) items. Error bars denote 99% confidence intervals of the mean. Open circles indicate the expected values of the single-system model once its parameters had been estimated using maximum likelihood estimation, as described in Appendix B.

Table 2
Mean Response Criterion (C) Values in Experiments 1 to 3 (SDs Are in Parentheses)

	Criterion	
	Attended	Ignored
Experiment 1	0.05 (0.44)	0.76 (0.57)
Experiment 2	0.03 (0.50)	0.26 (0.61)
Experiment 3 (attend objects)	−0.08 (0.40)	0.41 (0.51)
Experiment 3 (attend words)	−0.24 (0.60)	0.52 (0.55)

Note. C is calculated as $-0.5^{*}(z(H) - z(F))$, where H is the hit rate for attended items or the hit rate for ignored items; F is the false alarm rate.

Results and Discussion

RSVP phase. The results of the RSVP phase are presented in Table 1. As in Experiment 1, a greater percentage of the false alarm trials were to real words in the attended or ignored streams than to nonwords in the ignored stream, $t(37) = 2.99$, $p < .01$, suggesting that participants allocated attention appropriately. The recognition and fragment identification groups did not differ in the percentage of correct RSVP trials, percentage of correct nonword detections, or percentage of false alarm trials (all ts < 1.74). All participants performed with accuracy above 75% correct on all RSVP trials (in fact, the minimum was 83% correct). The RSVP performance in this experiment was more comparable to that obtained by Vuilleumier et al. (compared with Experiment 1).

Recognition. Recognition (d') for attended words was significantly better than that of ignored words, $t(15) = 4.44$, $p < .001$ (see the left panel of Figure 1B; the left panel of Figure 2B shows the hit and false alarm rates, and Table 2 shows associated measures of response bias, *C*). Recognition for attended words was reliably greater than chance levels, $t(15) = 4.05$, $p = .001$, but, like Experiment 1, recognition for previously ignored words was not reliably different from chance, $t(15) = 1.24$, $p = .24$.

Fragmentation. As in the recognition data, priming for attended words was significantly greater than that of previously ignored words, $t(23) = 3.71$, $p = .001$. Furthermore, as was found in Experiment 1, there was a reliable priming effect for attended words, $t(23) = 6.58$, $p < .001$, but not for ignored words, $t(23) = 1.19$, $p = .25$. Comparisons between participants who attended to cyan and those who attended to magenta at study revealed no reliable differences between priming and recognition measures for attended or ignored objects.

Thus, we replicated all of the main findings from Experiment 1 and showed that the results generalise to word stimuli: Effects of attention were found on recognition and priming, and recognition and priming were reliable for attended but not ignored items. Furthermore, as in Experiment 1, the single-system model fit the data well (Figures 1 and 2).

Experiment 3

In Experiment 3, to increase the generality of our results even further, we aimed to replicate the results of Experiments 1 and 2 again, but with a modified RSVP procedure in which an object was superimposed upon a word on each RSVP trial. This modified RSVP procedure is similar to that of Butler and Klein (2009), who presented a word and object on each trial. Thus, Experiment 3 was very similar to Experiments 1 and 2 (and used the same object and word stimuli), except that a word was superimposed upon an object on every RSVP trial and one group of participants was instructed to attend to words, and another group to attend to objects.

Method

Participants. One hundred two individuals participated as part of a first year UCL psychology laboratory class (82 women; $M = 19.5$ years; $SD = 3.4$). All participants were run simultaneously, but each participant completed the experiment in an individual sound-dampened cubicle. A 2 × 2 between-participants design was used: participants attended to words or objects in the RSVP stage, and subsequently completed either a recognition task or a fragment completion task: n(attend-objects/recognition) = 29; n(attend-words/recognition) = 20; n(attend-objects/fragment-identification) = 27; n(attend-words/fragment-identification) = 26. Participants were randomly assigned to each group.

Procedure. The same object and word stimuli from Experiments 1 and 2 were used as stimuli in this experiment. The RSVP procedure was the same as that of Experiment 1 except that on each trial a word and object were presented at fixation, superimposed upon one another. Participants were either instructed to detect the occurrence of nonobjects in the attended stream, or to detect the occurrence of nonwords in the attended stream. For every participant, on 25 trials a nonobject was presented in the stream containing objects, and on 25 trials a nonword was presented in the stream containing words. Items in the ignored stream that were paired with a target in the attended stream were not subsequently analysed at test. The colour of the attended stream (magenta or cyan) was randomised across participants within each group.

The procedure in the fragmentation and recognition tasks was the same as in Experiment 2, except that on each trial a black outline of a word or an object was presented. The 50 new item trials were comprised of 25 object trials and 25 word trials. All types of trial were randomly interleaved. The object/word new item trials served as the relevant baseline for each type of stimuli within each group; thus, to calculate recognition and priming, attended/ignored objects were always compared with new objects, and attended/ignored words were always compared with new words. Also, unlike Experiments 1 and 2, response reminders were presented at the bottom of the screen for the first three trials of the recognition and priming stages. In the recognition stage, the reminder was the old-new response key mappings, and in the fragment identification task, the response reminder was to press space to reveal more of the picture, and to press enter at the earliest point that the item could be identified. The reminders were included in this experiment because a large number of participants were being run simultaneously and, unlike previous experiments, the experimenter was not at hand to answer any queries immediately.

Results and Discussion

RSVP phase attend objects group. The results of the RSVP phase are shown in Table 1. The false alarm rate is greater than in previous experiments: five participants performed below 75% cor-

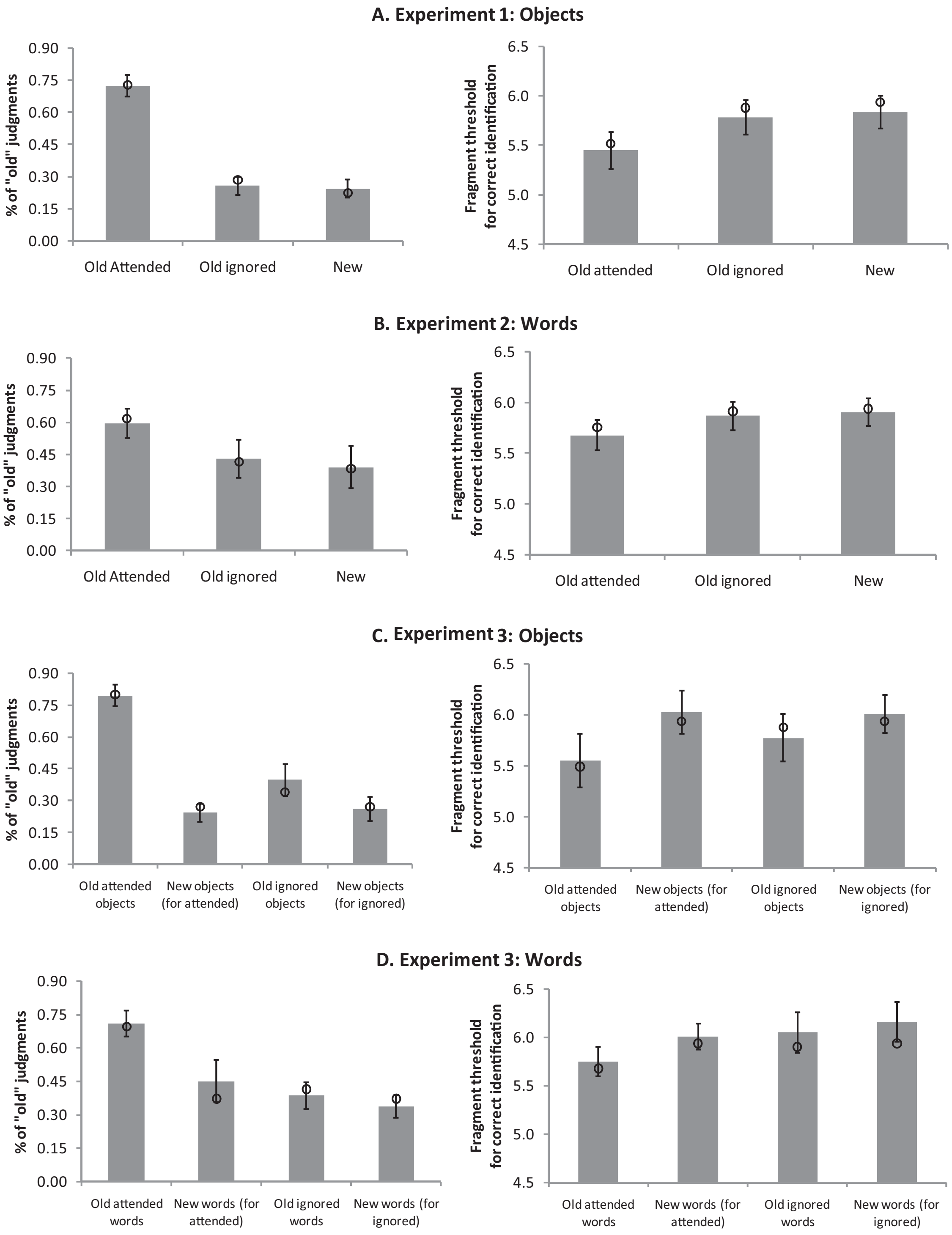


Figure 2. Proportion of old judgments to previously attended, previously ignored and new items in Experiments 1 to 3 (left panels). In Experiment 3 there are separate new item baselines for attended and ignored items. Error bars denote 99% confidence intervals of the mean. Open circles indicate the expected values of the single-system model obtained via maximum likelihood estimation, as described in Appendix B.

rect on the RSVP task (three in the recognition group and two in the priming group); the false alarm rate when these participants were excluded was only 2.4% (*SD* = 3.9). The inclusion of these participants did not affect the qualitative pattern of priming or recognition results. Furthermore, the fragment identification and recognition groups did not differ in terms of the percentage of correct RSVP trials, percentage of correct nonsense object detections, or percentage of false alarm trials (all *t*s < 1).

RSVP phase attend words group. The results of the RSVP phase are shown in Table 1. Evidently, participants in this experiment found it easier to detect nonwords than nonobjects. The fragment identification and recognition groups did not differ in terms of the percentage of correct RSVP trials, percentage of correct nonword detections, and percentage of false alarm trials (all ts < 1). We did not analyse recognition and priming (in this group of participants and also the group that attended to objects) when broken down according to the colour attended to at study in this experiment because of the low number of participants that would have resulted in some of the cells of the analysis.

Recognition. Recognition (d') for attended objects was significantly better than that of ignored objects, $t(47) = 8.49$, $p < .001$ (recognition data are shown in the left panels of Figure 1C and 2C and in Table 2) (note that the recognition scores for attended and ignored objects (or words) are from different groups of participants: the attend words (objects) group and attend objects (words) group, respectively). Recognition performance for attended objects was reliably greater than chance levels, $t(28) = 15.24$, $p < .001$, and recognition for previously ignored objects was also reliably different from chance, $t(19) = 6.23$, $p < .001$.

Recognition for attended words was significantly better than that of ignored words, $t(47) = 4.96$, $p < .001$ (see the left panels of Figures 1D and 2D, and Table 2). Recognition performance for attended words was greater than chance levels, $t(19) = 8.82$, $p < .001$, and recognition for previously ignored words was also reliably different from chance, $t(28) = 1.92$, $p = .032$ (one-tailed) (59% of participants had $d' > 0$).

Fragmentation. The mean priming effect for attended objects was significantly greater than that of ignored objects, $t(51) = 2.57$, $p = .01$ (see Figure 1C and 2C, right panels). Furthermore, priming for attended and ignored objects was reliably greater than chance: $t(26) = 6.38$, $p < .001$, and $t(25) = 4.02$, $p < .001$, respectively.

The mean priming effect for attended words was significantly greater than that of ignored words, $t(51) = 2.35$, $p = .023$ (see Figure 1D and 2D, right panels). Furthermore, the priming effect for both attended and ignored words was reliably different from chance, $t(25) = 5.68$, $p < .001$, and $t(26) = 2.41$, $p = .023$, respectively.

The results of Experiment 3 differed in an important way from those of Experiment 2: Once again we found that recognition and priming for previously attended items (objects or words) was greater than for previously ignored items; however, unlike Experiments 1 and 2, both recognition and priming were reliable for ignored items. This represents another failure to demonstrate a pure implicit memory effect for both words and objects, and is consistent with the single-system model prediction that priming for ignored items does not occur in the absence of recognition.

It is worth noting that overall levels of performance were generally higher in Experiment 3 than Experiments 1 and 2 (i.e., compare Figure 1C with Figure 1A, and compare Figure 1D with Figure 1B). One speculative explanation for this difference is that there may have been a greater amount of slippage of attention to ignored items in this experiment. The size of each word stimulus was relatively homogenous across RSVP trials, whereas that of objects was relatively heterogeneous. It is possible that this combination produced greater slippage of attention to the ignored stream in this experiment (this could also be true for the Butler and Klein (2009) study too, although recognition for ignored words was not reliable in that study). Another possibility is that the participants in this experiment were generally more motivated at test. Regardless of the cause of the greater levels of performance, the action of this cause was to elevate *both* recognition and priming.

The model fits to the recognition and priming data for the object and word conditions are shown in Figures 1C and 1D, respectively (Figures 2C and 2D show the hit and false-alarm rates). The model results fell within the empirical range except for the expected recognition and priming results for ignored objects (and recognition d' for attended objects), which were slightly underestimated. This is likely to have arisen because we assumed when fitting the model that (for the sake of simplicity) the strength of the attentional manipulation at encoding was the same across experiments. That is, the strength of ignored items is always weaker than that of attended items by a fixed proportion β across experiments (Appendix B). However, the strength of the attentional manipulation in Experiment 3—specifically when words are attended to and items are ignored—may not necessarily be as strong as in Experiments 1 and 2. Indeed, when we fit the model to the data again, but allowed β to freely vary in this condition (and have the value $\beta = 3.4$ when the estimate of $\mu = 1.51$), then all model predictions in this condition fell within the confidence limits. In any case, the important point is that the model successfully reproduces the same qualitative effect of the attentional manipulation on recognition and priming, and it successfully predicts that both recognition and priming for ignored items is greater than chance.

Power Calculations for Experiments 1 and 2 Based Upon Experiment 3

Given the reliable priming (and recognition) for ignored objects and words in Experiment 3, we can ask what the power of Experiments 1 and 2 was to detect effects of comparable size. (All the following power values are for a two-sided test unless indicated.) In Experiment 1, using $M = 0.24$ ($SD = 0.29$) (i.e., the priming effect for ignored objects in Experiment 3) as an estimate of the population effect, the power to detect a priming effect for ignored objects with $N = 41$ was 0.99. Furthermore, the power to detect an effect of half this size (i.e., $M = 0.12$, $SD = 0.29$) was still ample (0.83, one-sided). Similarly, we can also ask what the power of Experiment 1 was to detect a recognition d' for ignored objects of $M = 0.44$, $SD = 0.32$ with $N = 50$; again, power was ample (0.99). Experiment 1 even had sufficient power (0.81; one-sided) to detect a much smaller recognition d' equal to that of ignored words in Experiment 3 ($M = 0.16$, $SD = 0.44$, $N = 50$).

The power of Experiment 2 to detect a priming effect equivalent to that of ignored words in Experiment 3 was not as high (0.58, based upon $M = 0.11$, $SD = 0.24$, $N = 24$). Similarly, the power to detect a recognition effect in Experiment 2 of $M = 0.16$, $SD = 0.44$, with $N = 16$, was low and was equal to 0.28.

Thus, although it is possible that a failure to detect recognition and priming for ignored items in Experiment 2 was because of low power, it is unlikely that the failure to find reliable priming (or recognition) for ignored items in Experiment 1 (which was a closer replication of Vuilleumier et al., 2005) is because of a lack of power. Considering both experiments together, the probability of falsely failing to find a true priming effect in both Experiments 1 and 2 is $(1 - .99) \times (1 - .58) = .004$.

General Discussion

The primary aim of this study was to test a prediction of the single-system model of recognition and priming. The model predicts that priming will not occur in the absence of recognition. A finding of priming in the absence of recognition would therefore be evidence against the model; it would also constitute evidence for pure implicit memory. In three experiments we found no such evidence. Instead, all the results were consistent with the model, which also fit the data well. Priming and recognition were generally associated across experiments: In Experiment 1, priming and recognition for objects that were previously attended in a RSVP study procedure were greater than for objects that had been ignored. Both recognition and priming for ignored objects were abolished entirely. The lack of priming for ignored objects meant that our study failed to replicate the pure implicit memory effect of Vuilleumier et al. (2005; Experiment 1). In Experiment 2, we replicated the results of Experiment 1, but with a completely different class of stimuli (words). In Experiment 3, we again found that recognition and priming for attended items were greater than for ignored items (objects and words); however, in this experiment both priming and recognition were reliable for previously ignored items. The reliable recognition observed for ignored words meant that our study failed to replicate the pure implicit memory effect found by Butler and Klein (2009).

An important question is why our study failed to replicate the pure implicit memory effects of Vuilleumier et al. (2005) and Butler and Klein (2009). We do not think that low power is the cause: In Experiment 1, there was ample power to detect a priming effect for ignored objects that was at least half the size of the priming effect we found for ignored objects in Experiment 3 (though this was not the case in Experiment 2). It is possible that Butler and Klein (2009) failed to obtain recognition for ignored words because of low power: the power of their study to detect a recognition effect for ignored words that was equal in size to the one we found in Experiment 3 ($d' = 0.16$, $SD = 0.44$) with $N = 24$ was only 0.40 (although it should be noted that there are other procedural differences between our study and Butler and Klein's study).

We performed a similar power analysis for Vuilleumier et al.'s study: They had sufficient power to detect a recognition effect for ignored objects equivalent to the one we found in Experiment 3 ($d' = 0.44$, $SD = 0.32$) with $N = 15$ (0.99), but the power of their study to detect an effect equal to the one we found for ignored words in Experiment 3 ($d' = 0.16$, $SD = 0.44$) with $N = 15$ was only 0.26. Thus, if there was a small amount of recognition memory for ignored objects in Vuilleumier et al.'s study, then their study may not have had sufficient power to detect it. Indeed, the magnitude of the priming effect that they observed for ignored objects was approximately $M = 0.14$, which is more comparable to the priming effect we found for ignored words ($M = 0.11$) than ignored objects ($M = 0.44$) in Experiment 3, suggesting that recognition d' for ignored words in Experiment 3 is an appropriate estimate of the effect in their study.

A methodological difference between the Vuilleumier et al. study and ours was the type of nonobject stimuli used. The nonobject stimuli we used in Experiment 1 (and Experiment 3) were taken from Kroll and Potter (1984), whereas Vuilleumier et al. (2005) used nonobjects from a different (unknown) source. Although it is possible that this procedural difference could have led to a difference in findings between studies, we are reassured by the results of our Experiment 2, in which we were able to replicate the results of Experiment 1 with a completely different class of stimuli (words). This mitigates concerns about differences in nonobject stimuli. Another procedural difference is the visual angle subtended by the stimuli. In our Experiment 1, all stimuli subtended approximately 4° of visual angle, whereas in the Vuilleumier et al. study, all stimuli subtended approximately 10° of visual angle. Although this is a difference between studies, it is unclear how this procedural difference could have contributed to the difference in findings. Thus, given that our failure to replicate Vuilleumier et al.'s (2005) results across three experiments is unlikely to be because of low power or procedural differences, we are led to conclude that the priming effect in the absence of recognition seen in the Vuilleumier et al. (2005) study is an error (i.e., that their priming effect for previously ignored items is a Type I error, and/or that their failure to find recognition for these items is a Type II error).

We are assured by the results of other studies that have manipulated attention at encoding and have found similar results to ours. For example, the chance recognition and priming results in Experiments 1 and 2 are similar to the findings of Subramaniam, Biedeman and Madigan (2000). They found that up to 31 repetitions of a nontarget picture in a RSVP stream did not facilitate detection of the picture when it subsequently became a target in the RSVP sequence. They also found that recognition memory for these items was similarly not different from chance. Reliable levels of priming and recognition only emerged in their study under conditions which allowed a greater amount of time to process the stimuli. Furthermore, there are many studies that have found that priming cannot be detected when recognition is close to chance levels (Berry et al., 2006a; Berry et al., 2006b; Hawley & Johnston, 1991, Experiment 2; MacDonald & MacLeod, 1998; Moscovitch & Bentin, 1993; Mulligan, 2002; for a review of previous attempts to demonstrate priming in the absence of recognition using attentional manipulations at encoding, see Mulligan, 2008).

The evidence in favour of pure implicit memory is certainly controversial, and the replicability of many other findings has been questioned: These include those from subliminal mere exposure studies (Kunst-Wilson & Zajonc, 1980, vs. Fox & Burns, 1993, and Newell & Shanks, 2007), and also other studies using manipulations of selective attention at study (Merikle & Reingold, 1991, vs. Berry et al., 2006b; Eich, 1984, vs. Wood & Cowan, 1995, and Wood, Stadler, & Cowan, 1997). Furthermore, the question of whether (long-term) unconscious memory or unconscious knowledge exists continues to be a contentious issue in other research areas, and many studies showing implicit effects have been shown to have methodological or theoretical flaws, or have not been successfully replicated (e.g., in human conditioning: Lovibond & Shanks, 2002; in implicit learning tasks such as the sequential reaction time task: Wilkinson & Shanks, 2004; artificial grammar learning: Tunney & Shanks, 2003; the contextual cuing task: Smyth & Shanks, 2007; the Iowa Gambling Task: Maia & McClelland, 2004; and the weather prediction task: Lagnado, Newell, Kahan, & Shanks, 2006; see also Shanks & St John, 1994). Until convincing, replicable evidence of pure implicit memory can be provided—because no one doubts that we can have memories which are conscious and are accessible to awareness—it seems more parsimonious to regard the memory that drives priming as being accessible to awareness. Indeed, others have also questioned whether memory does divide along conscious and unconscious lines, or have questioned the usefulness of such a distinction (e.g., Berry et al., 2008a; Butler & Berry, 2001; Kinder & Shanks, 2003; Reder, Park, & Kieffaber, 2008).

We should note that priming in the absence of recognition has been demonstrated in the amnesic patient E.P. (e.g., Hamman & Squire, 1997), and this patient has been found to consistently perform no better than chance in recognition tests (Stefanacci, Buffalo, Schmolock, & Squire, 2000). In previous modelling studies, we have shown that the model can simulate the dissociation between recognition and priming in amnesia (Berry et al., 2008a). However, the pattern shown by E.P. is clearly problematic for the present single-system model (though other single-system models have been shown to give a very close approximation to this pattern, see Kinder & Shanks, 2001). Even if it can be convincingly shown that E.P.'s recognition memory has been completely eliminated by his amnesia, and yet his priming performance has been untouched (as some have argued), we are still wary about drawing strong conclusions from individual cases and would ideally like to see replications of this pattern in other patients.

Finally, the results of our experiments were consistent with the single-system model, which also gave close fits to the data. However, a limitation of the test of the model in this study is that confirmation of the prediction that priming is absent when recognition is absent depends upon finding evidence for the null. Clearly a far more persuasive test of the model is to show that it can make positive predictions in advance that are born out experimentally, and also to show that these predictions are distinct from those of a multiple-systems version of the model. We have recently adopted such an approach using a CID-R paradigm, and have found some positive evidence in favour of the single-system model. Whatever the outcome of these and future tests of the model, we believe there is much to be gained from specifying and testing formal models of recognition and priming.

Résumé

La mémoire implicite est souvent vue comme une forme inconsciente de mémoire. Cependant, les données appuyant cette caractéristique fondamentale discutable de la mémoire-stipulant que son contenu est inaccessible à la conscience-demeurent nébuleuses. La mise en évidence d'une mémoire implicite « pure » s'opposerait à un modèle de reconnaissance et d'amorçage à système unique prédisant que l'effet d'amorçage ne se produira pas en l'absence (réelle) de reconnaissance. Dans trois expériences reposant sur une procédure de présentation visuelle sérielle rapide, nous avons testé cette prédiction en tentant de répliquer des études antérieures dans lesquelles les auteurs affirment obtenir une mémoire implicite pure. Nous n'avons trouvé aucune preuve d'amorçage en absence de reconnaissance; au contraire, l'amorçage et la reconnaissance ont été associés au fil des expériences : quand l'amorçage était absent, la reconnaissance l'était aussi (Expériences 1 et 2) et quand l'effet d'amorçage était significativement supérieur à la chance, la reconnaissance était aussi supérieure à la chance (Expérience 3). Ces résultats appuient un modèle à système unique, qui a été testé sur les données de toutes les expériences. Les résultats appuient aussi la notion selon laquelle la mémoire responsable de l'amorçage est accessible à la conscience.

Mots-clés : mémoire implicite, amorçage, reconnaissance, RSVP, inconscient

References

Benjamin, A. S., Diaz, M. L., & Wee, S. (2009). Signal detection with criterion noise: Applications to recognition memory. *Psychological Review, 116,* 84–115.

Berry, C. J., Henson, R. N. A., & Shanks, D. R. (2006a). On the relationship between repetition priming and recognition memory: Insights from a computational model. *Journal of Memory and Language, 55,* 515–533.

Berry, C. J., Shanks, D. R., & Henson, R. N. A. (2006b). On the status of implicit memory: Merikle & Reingold (1991) revisited. *Journal of Experimental Psychology*: *Learning, Memory, and Cognition, 32,* 925–934.

Berry, C. J., Shanks, D. R., & Henson, R. N. A. (2008a). A single-system account of the relationship between priming, recognition, and fluency. *Journal of Experimental Psychology*: *Learning, Memory, and Cognition, 34,* 97–111.

Berry, C. J., Shanks, D. R., & Henson, R. N. A. (2008b). A unitary signal-detection model of implicit/explicit memory. *Trends in Cognitive Sciences, 12,* 367–373.

Brown, A. S., & Mitchell, D. B. (1994). A revaluation of semantic versus nonsemantic processing in implicit memory. *Memory & Cognition, 22,* 533–541.

Buchner, A., & Wippich, W. (2000). On the reliability of implicit and explicit memory measures. *Cognitive Psychology, 40,* 227–259.

Butler, B. C., & Klein, R. (2009). Inattentional blindness for ignored words: Comparison of explicit and implicit tasks. *Consciousness and Cognition, 18,* 811–819.

Butler, L. T., & Berry, D. C. (2001). Implicit memory: Intention and awareness revisited. *Trends in Cognitive Sciences, 5,* 192–197.

Coltheart, M. (1981). The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology, 33,* 497–505.

Conroy, M. A., Hopkins, R. O., & Squire, L. R. (2005). On the contribution of perceptual fluency and priming to recognition memory. *Cognitive, Affective, and Behavioural Neuroscience, 5,* 14–20.

Eich, E. (1984). Memory for unattended events: Remembering with and without awareness. *Memory & Cognition, 12,* 105–111.

Fox, S. E., & Burns, D. J. (1993). The mere exposure effect for stimuli presented below recognition threshold: A failure to replicate. *Perceptual and Motor Skills, 76,* 391–396.

Graf, P., & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal and amnesic patients. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 501–518.

Hamann, S. B., & Squire, L. R. (1997). Intact perceptual memory in the absence of conscious memory. *Behavioral Neuroscience, 111,* 850–854.

Hawley, K. J., & Johnston, W. A. (1991). Long-term perceptual memory for briefly exposed words as a function of awareness and attention. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 807–815.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340.

Johnston, W. A., Dark, W. J., & Jacoby, L. L. (1985). Perceptual fluency and recognition judgments. *Journal of Experimental Psychology: Learning Memory & Cognition, 11,* 3–11.

Kinder, A., & Shanks, D. R. (2003). Neuropsychological dissociations between priming and recognition: A single-system connectionist account. *Psychological Review, 110,* 728–744.

Kroll, J. F., & Potter, M. C. (1984). Recognizing words, pictures, and concepts: A comparison of lexical, object, and reality decisions. *Journal of Verbal Learning and Verbal Behavior, 23,* 39–66.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Kunst-Wilson, W. R., & Zajonc, R. B. (1980). Affective discrimination of stimuli that cannot be recognized. *Science, 207,* 557–558.

Lagnado, D. A., Newell, B. R., Kahan, S., & Shanks, D. R. (2006). Insight and strategy in multiple cue learning. *Journal of Experimental Psychology: General, 135,* 162–183.

Lovibond, P. F., & Shanks, D. R. (2002). The role of awareness in Pavlovian conditioning: Empirical evidence and theoretical implications. *Journal of Experimental: Animal Behavior Processes, 28,* 3–26.

MacDonald, P. A., & MacLeod, C. M. (1998). The influence of attention at encoding on direct and indirect remembering. *Acta Psychologica, 98,* 291–310.

Maia, T. V., & McClelland, J. L. (2004). A re-examination of the evidence for the somatic marker hypothesis: What participants know in the Iowa gambling task. *Proceedings of the National Academy of Sciences, USA, 101,* 16075–16080.

Merikle, P. M., & Reingold, E. M. (1991). Comparing direct (explicit) and indirect (implicit) measures to study unconscious memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 224–233.

Moscovitch, M., & Bentin, S. (1993). The fate of repetition effects when recognition approaches chance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 148–158.

Mulligan, N. W. (2002). Attention and perceptual implicit memory: Effects of selective versus divided attention and number of visual objects. *Psychological Research, 66,* 157–165.

Mulligan, N. W. (2003). Memory: Implicit versus explicit. In L. Nadel (Ed.), *Encyclopedia of cognitive science* (pp. 1114–1120). London: Nature Publishing Group/MacMillan.

Mulligan, N. W. (2008). Attention and memory. In H. L. Roediger (Ed.), *Learning and memory: A comprehensive reference* (pp. 7–22). Oxford: Elsevier.

Mulligan, N. W., & Brown, A. S. (2003). Attention and implicit memory. In L. Jiminez (Ed.), *Attention, consciousness, and learning* (pp. 297–334). Amsterdam: John Benjamins Publishing.

Newell, B. R., & Shanks, D. R. (2007). Recognizing what you like: Examining the relation between the mere-exposure effect and recognition. *European Journal of Cognitive Psychology, 19,* 103–118.

Ostergaard, A. L. (1992). A method for judging measures of stochastic dependence: Further comments on the current controversy. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 413–420.

Ostergaard, A. L. (1998). The effects on priming of word frequency, number of repetitions, and delay depend on the magnitude of priming. *Memory & Cognition, 26,* 40–60.

Poldrack, R. A. (1996). On testing for stochastic dissociations. *Psychonomic Bulletin and Review, 3,* 434–448.

Poldrack, R. A., & Logan, G. D. (1997). Fluency and response speed in recognition judgments. *Memory & Cognition, 25,* 1–10.

R Development Core Team. (2008). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing.

Reder, L. M., Park, H., & Kieffaber, P. D. (2009). Memory systems do not divide on consciousness: Reinterpreting memory in terms of activation and binding. *Psychological Bulletin, 135,* 23–49.

Rees, G., Russell, C., Frith, C. D., & Driver, J. (1999). Inattentional blindness versus inattentional amnesia for fixated but ignored words. *Science, 286,* 2504–2507.

Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception and Psychophysics, 44,* 563–575.

Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Review of Psychology, 39,* 475–543.

Roediger, H. L., & McDermott, K. B. (1993). Implicit memory in normal human subjects. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 8, pp. 63–131). Amsterdam: Elsevier.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 501–518.

Schacter, D. L., Bowers, J., & Booker, J. (1989). Intention, awareness and implicit memory: The retrieval intentionality criterion. In S. Lewandowsky, J. C. Dunn, & K. Kirsner (Eds.), *Implicit memory: Theoretical issues* (pp. 47–65). Hillsdale, NJ: Erlbaum.

Shanks, D. R., & St. John, M. F. (1994). Characteristics of dissociable human learning systems. *Behavioral and Brain Sciences, 17,* 367–447.

Smyth, A., & Shanks, D. R. (2007). Awareness in contextual cuing with extended and concurrent explicit tasks. *Memory & Cognition, 36,* 403–415.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General, 117,* 34–50.

Snodgrass, J. G., & Feenan, K. (1990). Priming effects in picture fragment completion: Support for the perceptual closure hypothesis. *Journal of Experimental Psychology: General, 119,* 276–296.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning, 6,* 174–215.

Squire, L. R. (1994). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. In D. L. Schacter, & E. Tulving, (Eds.), *Memory systems* 1994 (pp. 203–231). Cambridge, MA: MIT Press.

Stark, C. E. L., & McClelland, J. L. (2000). Repetition priming of words, pseudowords, and nonwords. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 945–972.

Stefanacci, L., Buffalo, E. A., Schmolock, H., & Squire, L. R. (2000). Profound amnesia after damage to the medial temporal lobe: A neuroanatomical and neuropsychological profile of patient E. P. *The Journal of Neuroscience, 20,* 7024–7035.

Subramaniam, S., Biederman, I., & Madigan, S. (2000). Accurate identification but no priming and chance recognition memory for pictures in RSVP sequences. *Visual Cognition, 7,* 511–535.

Tunney, R. J., & Shanks, D. R. (2003). Subjective measures of awareness and implicit cognition. *Memory & Cognition, 31,* 1060–1071.

Van den Bussche, E., Van den Noortgate, W., & Reynvoet, B. (2009). Mechanisms of masked priming: A meta-analysis, *Psychological Bulletin, 135,* 452–477.

Vuilleumier, P., Schwartz, S., Duhoux, S., Dolan, R. J., & Driver, J. (2005). Selective attention modulates neural substrates of repetition priming and "implicit" visual memory: Suppressions and enhancements revealed by fMRI. *Journal of Cognitive Neuroscience, 17,* 1245–1260.

Wilkinson, L., & Shanks, D. R. (2004). Intentional control and implicit sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 354–369.

Wixted, J. T. (2007). Dual-process theory and signal-detection theory of recognition memory. *Psychological Review, 114,* 152–176.

Wood, N. L., & Cowan, N. (1995). The cocktail party phenomenon revisited: Attention and memory in the classic selective listening procedure of Cherry (1953). *Journal of Experimental Psychology: General, 124,* 243–262.

Wood, N. L., Stadler, M. A., & Cowan, N. (1997). Is there implicit memory without attention? A re-examination of task demands in Eich's (1984). procedure. *Memory & Cognition, 25,* 772–779.

(*Appendices follow*)

Appendix A

Within Recognition Group Comparisons in Experiment 1

The attended hit rates, ignored hit rates, false-alarm rates, attended d' and ignored d' measures for the three recognition subgroups are shown in Table A1.

One-way ANOVAs were conducted to compare performance in the three subgroups: There was no reliable difference in the hit rates to attended items, $F(2, 47) = 2.76$, $p = .074$, the hit rates to ignored items, $F(2, 47) = 0.34$, $p = .72$, the false-alarm rates, $F(2, 47) = 1.17$, $p = 32$, d' for attended items, $F(2, 47) = 3.06$, $p = .057$, or d' for ignored items, $F(2, 47) = 2.12$, $p = .13$. Because two of the above results were marginally significant, pairwise comparisons of performance in each subgroup were conducted. The only significant results found were that the hit rate, d' for attended items, and also d' for ignored items was greater in sub-Group B than sub-Group C: $t(32) = 2.41$, $p = .022$; $t(32) = 2.73$, $p = .01$; and $t(32) = 2.03$, $p = .05$, respectively (all other ts < 1.58).

Recognition d' for attended items was reliably greater than chance in all three groups (ts > 4.25). Recognition d' for ignored items was not reliably different from chance in sub-Groups A, $t(15) = 1.16$, $p = .27$, or C, $t(17) = 0.93$, $p = .36$, but was marginally significant in sub-Group B, $t(15) = 1.81$, $p = .09$. Thus, although the results from this analysis appear give some indication that the performance-related-payment condition led to better recognition performance, they do not change our conclusions regarding the failure of Experiment 1 to demonstrate a pure implicit memory effect.

Table A1
Performance Within the Recognition Group

Sub-Group	Payment	Recognition stimuli exposure duration	*M* Att H	*M* Ig H	*M* FA	*M* Att d'	*M* Ig d'
A	Flat-rate	Until judgment	0.72	0.27	0.25	1.21	0.08
B	Performance-related	Until judgment	0.81	0.23	0.19	1.90	0.17
C	Flat-rate	500 ms	0.65	0.27	0.29	1.10	−0.06

Note. Att = previously attended objects; Ig = previously ignored objects; H = hit rate; FA = false-alarm rate.

Appendix B

Fitting the Single-System Model to the Data

The parameters of the model were estimated using maximum likelihood estimation. To fit the data from Experiments 1 to 3, the parameters of the single-system model were as follows: μ, which represents the mean difference between the attended and new distributions of f; β, which represents the proportional decrease in the mean of ignored items relative to attended items; σ_f, the *SD* of the old and new distributions of f; σ_r, the *SD* of the noise associated with the recognition task; σ_p, the *SD* of the noise associated with the identification task; b, the fragment identification level (ID) intercept; s, the scaling parameter that represents the rate of change in ID with f; and C_{ON}, the criterion of J_r that must be exceeded for an old judgment to occur.

Certain parameter values were fixed across experiments in order to reduce the number of free parameters: The *SD* of the overall distribution of the recognition strength variable, σ_{Jr}, was fixed to 1, as in standard SDT of recognition judgments. In previous applications of the model, for the sake of simplicity, we have assumed that $\sigma_f = \sigma_r$, and we make the same assumption here, and so, $\sigma_f = \sigma_r = 1/\sqrt{2}$ (because $\sigma^2_{Jr} = \sigma^2_f + \sigma^2_r$). Furthermore, the β, s, and b parameters were constrained to take on one value across all experiments. Thus, to model the data across all experiments, there were 12 free parameters in total: μ (for Experiments 1, 2, 3[objects and words conditions]), C_{ON} (Experiments 1, 2, 3 [objects and words conditions]), β, b, s and σ_p. Also note that, for the sake of simplicity, we assumed that there was only one false-alarm rate for the objects condition and one false-alarm rate in the words condition in Experiment 3, and also only one mean identification threshold for new items in each of these conditions.

The likelihood function for each recognition judgment, where Z denotes the recognition judgment ("new" or "old") on a given recognition trial, is given as

$$L(Z|\mathrm{Y}) = [\Phi(C_j|\mu_{\mathrm{Y}}, \sigma^2_{Jr}) - \Phi(C_{j-1}|\mu_{\mathrm{Y},}\sigma^2_{Jr})] \qquad \text{(B1)}$$

where Y denotes the type of item and Y = attended, ignored, new; $\mu_{new} = 0$, $\mu_{attended} = \mu$, and $\mu_{ignored} = \mu/\beta$; Φ is the cumulative normal distribution function; $j = 1$ when $Z =$ "new", and $j = 2$ when $Z =$ "old"; $C_0 = -\infty$, $C_1 = C_{ON}$ and $C_2 = \infty$.

(*Appendices continue*)

The likelihood function for each identification level (ID) is given as

$$L(\mathrm{ID}|\mathrm{Y}) = \phi(\mathrm{ID} \dashv |b| \ \llbracket s\mu \rrbracket_{\downarrow} \mathrm{Y}, \llbracket \sigma \rrbracket_{\downarrow} \mathrm{ID}^{\uparrow} 2) \qquad \text{(B2)}$$

where Y = attended, ignored, new; $\mu_{\mathrm{new}} = 0$, $\mu_{\mathrm{attended}} = \mu$, and $\mu_{\mathrm{ignored}} = \mu/\beta$; ϕ is the normal density function, and $\sigma^2_{\mathrm{ID}} = s^2\sigma^2_f + \sigma^2_{\mathrm{p}}$ (from Equation 2).

General Fitting Procedure

For each data point, the relevant function in Equations B1 or B2 was used to determine the likelihood of every single valid trial, given some set of parameter values. The log-likelihood was summed across all trials and converted to a negative value to be used by a function minimisation algorithm (BFGS), as implemented in R: A language and environment for statistical computing (R Development Core Team, 2008). Different starting values of the parameters to be estimated were used for the minimisation routine in order to maximise the chance of finding the global minimum for the negative log likelihood for each model (equal to maximising the log-likelihood; see Table B1).

Table B1
Maximum Likelihood Estimates of the Parameters

	Experiment 1	Experiment 2	Experiment 3 (objects)	Experiment 3 (words)
μ	1.36	0.59	1.45	0.84
β	7.48	7.48	7.48	7.48
σ_f	$= \sqrt{1/2}$	$= \sqrt{1/2}$	$= \sqrt{1/2}$	$= \sqrt{1/2}$
σ_r	$= \sqrt{1/2}$	$= \sqrt{1/2}$	$= \sqrt{1/2}$	$= \sqrt{1/2}$
σ_p	1.17	1.17	1.17	1.17
b	5.94	5.94	5.94	5.94
s	0.31	0.31	0.31	0.31
C_{ON}	0.75	0.30	0.61	0.33

Table B2
Recognition and Priming Measures and Their Expected Values

Measure	Expected value
P(hit | attended)	$1 - \Phi(C_{\mathrm{ON}} - \mu)$
P(hit | ignored)	$1 - \Phi(C_{\mathrm{ON}} - \mu/\beta)$
P(false alarm)	$1 - \Phi(C_{\mathrm{ON}})$
d' (attended)	μ
d' (ignored)	μ/β
E[ID | new]	b
E[ID | attended]	$b - s\mu$
E[ID | ignored]	$b - s\mu/\beta$
Priming effect (attended)	$s\mu$
Priming effect (ignored)	$s\mu/\beta$

Note. ID = fragmentation identification level.

Expected Values

Although, in previous articles, we have derived the single-system model results via simulation, it is possible to determine many of the expected model results analytically, as detailed in Table B2. These expected values are shown in Figures 1 and 2 of the main text.

Received November 30, 2009
Accepted September 14, 2010 ■