Visual Cognition

Accurate identification but no priming and chance recognition memory for pictures in RSVP sequences

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Accurate identification but no priming and chance recognition memory for pictures in RSVP sequences

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In 1969, Potter and Levy reported that recognition memory of accurately perceived RSVP pictures was extremely low, an effect that they attributed to disruption of memory consolidation. Here we report that the repetition of an RSVP picture (72–126 msec/picture) up to 31 times prior to when it became a target had no effect on identification accuracy. At these rates, forced-choice recognition memory was at chance. Single presentations of the pictures outside of the RSVP sequences readily resulted in substantial priming of their identification within the sequences. We offer a neural interpretation of Potter and Levy's explanation, as well as contemporary two-stage accounts of RSVP memory and attentional phenomena, based on the recent finding (Tovee & Rolls, 1995) that most of the information in inferior temporal cells is conveyed in the first 50msec of firing but the cells continue their activity for an additional 350msec. The additional activity, by our account, is required for memory and it is this activity that may be disrupted by attention to the next image during RSVP presentations. The critical factor for priming, if not memory in general, may be attention to the stimulus for a few hundred milliseconds beyond that required for its identification. Single-trial presentations thus manifest robust memory and priming effects—even when the stimulus cannot be identified—whereas RSVP conditions in which the stimulus can be identified result in poor memory.

Most of us have the subjective feeling that if we can see a picture clearly then we will be able to remember it. Experimental evidence seems to bear this out. After viewing thousands of slides of scenes, each for only a few seconds, recognition memory (against reasonably dissimilar distractors) is typically found to

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be greater than 90% (Nickerson, 1965; Shepard, 1967; Standing, 1973; Standing, Conezio, & Haber, 1970).

Other than employing highly similar distractors, what manipulation could substantially degrade recognition memory for accurately identified pictures? A number of researchers, using a variety of methods, have shown that reducing the effective stimulus duration (or stimulus onset asynchrony, SOA, between one picture and the next) results in substantial decrements in recognition memory performance despite reasonably high identification accuracy at those same durations (Loftus & Ginn, 1984; Loftus & Kallman, 1979; Paivio & Csapo, 1971; Potter, 1976; Potter & Levy, 1969; Shaffer & Shiffrin, 1972). These studies firmly establish that the time to attend to a picture, following that which is sufficient for its identification, is crucial in determining its subsequent accuracy of recognition.

The remarkable dissociation between identification[1] and recognition memory was discovered by M. C. Potter and her associates three decades ago (Potter, 1976; Potter & Levy, 1969). She showed participants a Rapid Serial Visual Presentation (RSVP) sequence of 16 pictures at various exposure durations ranging from 113 to 333msec per picture. Target detection at 113msec, with a verbally specified target, was reasonably high (64%). However, after viewing RSVP sequences at these rates, old–new recognition memory judgements averaged only 11% after correction for guessing. Intraub (1980, 1984) showed that it is possible to obtain higher levels of recognition memory at these brief exposure durations, provided the pictures are separated by lengthy ISIs containing a blank field or a repeated picture mask (which becomes ineffective as a consequence of the repetitions).

Why is recognition for briefly presented, though readily identifiable, pictures so poor? Potter (1976) hypothesized that when pictures are presented at a rapid rate they may be subject to "conceptual masking", from subsequent pictures in the sequence, interrupting "memory consolidation". Presumably, the activity in perceiving and attending to the picture in position N + 1 interferes with the activity from the picture in position N. Indeed, a number of researchers have been able to demonstrate conceptual masking, defined as interruption of conceptual processing of a picture by the onset of a subsequent picture with short SOAs, of object pictures under a variety of experimental conditions (e.g. Intraub, 1984; Loftus & Ginn, 1984; Loftus, Hanna, & Lester, 1988).

In the Discussion we will propose a specific neural account of Potter's suggestion based on the finding (Tovee & Rolls, 1995) that most of the information in inferior temporal cells is conveyed in the first 50msec of firing but the cells continue their activity for an additional 350msec. The additional activity, by our account, is required for memory (consolidation) and it is this activity that is disrupted by attention to the next image during RSVP presentations. Attention to the stimulus, even after it is shown and masked, may thus be critical, not only

for (explicit) recognition memory but for (implicit) priming as well—even when the stimulus cannot be identified (Bar & Biederman, 1998, 1999). By this account, not only should episodic recognition memory be impeded at fast RSVP rates, but perceptual priming from identified pictures should also be impeded.

Here we report three experiments assessing memory for RSVP sequences of pictures of common objects. Most studies of RSVP memory have examined a form of explicit memory, episodic recognition, in which participants judge whether an item was presented in the sequence. Would a (presumably) implicit task, identification of the RSVP images themselves, be primed by repetition of pictures in prior sequences when they were non-targets? Experiment I provided a negative answer to this question and Experiment II established, along with controls in Experiment I, that pictures presented at RSVP rates (72–126msec/ image) are capable of being primed if sufficient time for processing the prime is available after its presentation. Experiment III assessed memory performance as the total time per picture was varied. At the fastest rates, 72–126msec per picture, which matched those in Experiment I (which evidenced no priming), recognition memory was at chance. Lengthening presentation durations resulted in improvement in memory, consistent with previous findings for memory for RSVP sequences (e.g. Potter & Levy, 1969). Because we used a forced-choice technique in which subjects had to choose between a picture in the sequence and a distractor picture, we could make some coarse assessment of the extent to which the improvement in memory at the longer durations was visual or verbal-conceptual.

EXPERIMENT I:
Does a Distractor Picture, Repeatedly Shown in RSVP Sequences, Prime Itself When it Subsequently Becomes a Target?

In this experiment, participants attempted to identify whether a target object, specified by name, was contained in a RSVP sequence of object pictures. Each participant viewed 32 sequences. Before a picture became a target, it could appear as a non-target from zero to 31 times in the prior sequences. It is fairly well established in the implicit memory/priming literature that prior exposure to a briefly presented (e.g. 100msec) picture, when the total time (exposure duration + ISI) is at least a few seconds, facilitates subsequent identification (e.g. Bartram, 1974; Biederman & Cooper, 1992; Jacoby, Baker, & Brooks, 1989). At issue was whether repetition of non-target pictures, under RSVP conditions in which the exposure durations were generally sufficient for well-above chance identification, would result in higher identification accuracy when the picture finally became a target.

Method

Participants.   Twenty students with normal or corrected-to-normal vision participated in this experiment for research experience points for the Cognitive Psychology course at the University of Southern California.

Stimuli.   The stimulus set consisted of 92 simple line drawings of common objects, each with a readily available basic-level name. Eighty were used as actual test items and twelve were used as "buffers" (described later). The images were created with Cricket Draw/Adobe Illustrator 5.0 and shown on a high-resolution (1024 × 768) monitor controlled by a Macintosh Quadra. The line width was two pixels and the images were of a size that the most distant points would be on the perimeter of an imaginary circle that subtended a visual angle of approximately 5°.

Design.   There were four RSVP sequences. Each sequence consisted of 32 objects. The first six and last six objects were "buffer" objects and were never tested. The buffer objects were the same in all sequences. Each sequence consisted of 20 unique objects selected from the original set of 80 objects. Each sequence was repeated 32 times for a total of 128 trials. Half the presentations of each sequence were in one order and half in the reverse order so that the average serial position of each picture was identical (16). Half the trials were positive (target present) and half negative (target absent). On the target-absent trials, a target name other than those belonging to the 20 items in the sequence was chosen. On average, each non-target picture was repeated 15.5 times (range of 0 to 31) before it became a target. All subjects were exposed to the same set of sequences in the same order. This was an inadvertent and undesirable aspect of the design, as it would have been clearly better to counterbalance the order of administration of the sequences over subjects. An additional condition with 32 subjects was run at the 72msec exposure duration with full counterbalancing and it yielded virtually identical data.

The duration of the individual images in each RSVP sequence was either 72 or 126msec per picture. Ten participants were run at one duration, the other ten at the other.

Procedure.   Prior to viewing each RSVP sequence, participants were provided with an object name. The participants were instructed to indicate verbally if the target was present in the sequence or not. The experimenter recorded the response manually.

Results

The overall results are shown in Table 1. Identification accuracy, measured as percentage correct on both positive and negative trials, was well above chance

TABLE 1
Average hit and false alarm rates and *d'*s for
identification performance

Exposure Duration	Hit Rate (%)	False Alarm (%)	d'
72 msec	70	16	1.53
126 msec	82	11	2.15

at both exposure durations but increased from 77% at 72msec to 86% at
126msec, $t(18) = 3.48$, $p < .005$. Table 1 shows the *d'* values calculated from
the hit and false alarm rates at the two exposure durations. At 126msec, the *d'*
was 2.15, while at 72msec the *d'* was only 1.53, indicating that identification
performance was indeed better at the longer exposure duration.

Figure 1 shows the effects on identification accuracy of repeating a picture
an average of 15.5 times before it became a target. There was absolutely no
increase in accuracy, $t(18) < 1.00$. Clearly, there is no gain in identification of
non-target pictures presented repeatedly before they became targets.

We analysed the effect of trials to determine whether the lack of an effect of
repetition priming was due to a systematic decrement in performance over the
course of the experiment, e.g. due to fatigue, which might have counteracted a
positive priming effect. Figure 2 shows the effect of trial block in the RSVP
task. Within each of the four blocks, subjects viewed 32 RSVP sequences. An

FIG. 1.   Mean object identification accuray (Target Present) as a function of the number of times that
an object appeared in RSVP sequences as a non-target before it became a target. "First" designates those
trials when the object was the target the first time it was shown. 15.5 is the value of the mean number of
presentations of an object (range 1 to 31) before it became a target. Error bars are the standard errors of
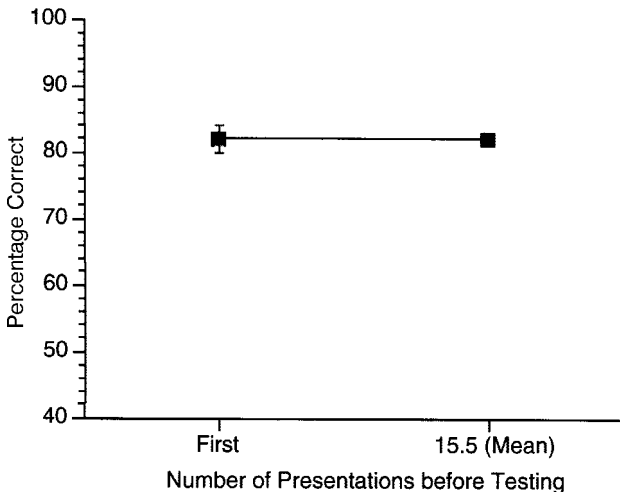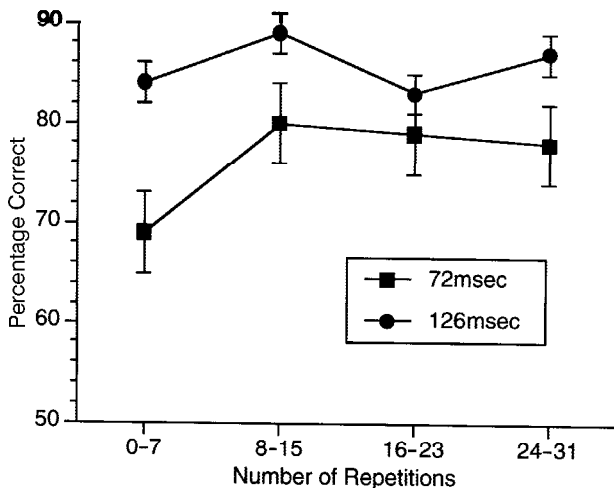the mean for 20 subjects.

FIG. 2.   Mean object identification accuracy (Target Present) as a function of the number of times that an object appeared in RSVP sequences as a non-target before it became a target and the exposure duration per picture. Error bars show the standard errors of the difference scores of each subject's mean score and his or her mean score for that condition. Between-subjects variability is thus removed from these measures of error.

ANOVA revealed a significant main effect of both Exposure Duration, $F(1, 18) = 8.68$, $p < .05$, and Practice Block, $F(3, 54) = 9.51$ $p < .001$, primarily attributable to the increase in accuracy from the first to the second block at 72msec. The interaction between these variables fell short of significance, $F(3, 54) = 2.04$, $p = .11$. There was thus no evidence that a priming effect from repetition of non-targets was obscured by a general decline in performance over the course of the experiment.

The lack of an effect of repetition in the priming of non-target pictures might have been due to a ceiling effect. To assess this possibility, we analysed the data, for positive trials only, separately for the best eight and worst eight objects in blocks of eight repetitions (averaged over both exposure durations). Figure 3 shows that performance for the worst objects remained considerably worse, mean 60.5%, than the best objects, mean 90.25%, across all repetition blocks. There was thus considerable opportunity for the worst objects to improve with repetition but this did not happen. In fact, there was a drop off in accuracy in the last block for these items from 63% in the third block to 56% in the fourth block. A 2 (Difficulty) × 4 (Repetition Blocks) ANOVA revealed a main effect of the Difficulty variable, $F(1, 14) = 24.00$, $p < .001$, but the negative effect of repetition fell short of significance, $F(3, 42) = 2.48$, $p = .07$. The near significant F-ratio was primarily due to the fall off and the extremely high power of this test. The fall off for the worst items produced a significant Difficulty × Repetition
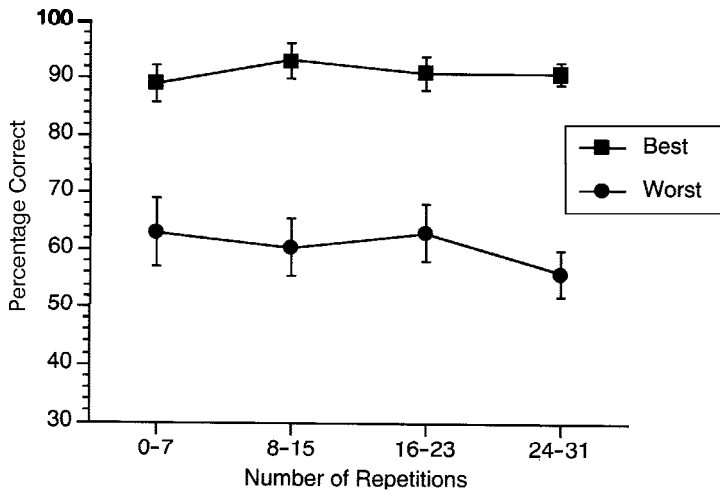
FIG. 3.   Mean object identification accuracy (Target Present) as a function of the number of times that an object was presented in RSVP sequences as a non-target before it became a target, plotted separately for the best eight and worst eight (out of 32 pictures). Error bars show the standard errors of the difference scores around each subject's mean score and his or her mean score for that condition. Between-subjects variability is thus removed from these measures of error.

interaction, $F(3, 42) = 4.05, p < .05$, but this was in a direction opposite to what would be expected from a ceiling effect.

Table 2 shows the hit rates, false alarms and d' values, calculated for the best eight ($d' = 4.1$) and worst eight ($d' = 1.08$) objects, for each block of eight repetitions, averaged over both exposure durations. No systematic effect of repetition was apparent in this breakdown. The high variability for the d's for the best objects was primarily attributable to the absence of false alarms on two of the blocks. Slight increases in the false alarm rate resulted in large drops in d'.

TABLE 2
Average hit rates, false alarms, and d's for the best and worst eight objects in blocks of eight repetitions (at both exposure durations)

| | Best | | | | Worst | | |
Number of Repetitions	Hit Rate	False Alarm	d'		Hit Rate	False Alarm	d'
0–7	89.0	10.5	2.48		63.0	16.0	1.33
8–15	93.0	0.0	6.49		60.0	26.0	0.91
16–23	91.0	4.0	3.10		63.0	16.0	1.33
24–31	91.0	0.0	6.35		56.0	27.0	0.77

Could the lack of an effect of repetition be a function of the lack of counter-balancing? The group of 32 subjects who performed with counterbalanced blocks at the 72msec exposure duration yielded data that were virtually identical to those of the 72msec group. The overall identification rate was 77%, identical to that of the original group. There was also no effect of the number of repetitions of a distractor before it became a target: For the repetition numbers of 0–7, 8–15, 16–23, and 24–31, the overall accuracy rates were 76%, 76%, 79%, and 77%, respectively. If anything, the 11% increase from Test Block 1 (0–7 repetitions) to Test Block 2 (8–15 repetitions) in Figure 1, was now completely absent.

Perhaps the identification of pictures presented in an RSVP sequence cannot be primed? Potter (1976), however, showed that, under similar conditions, a long pre-exposure (for 5sec) of the target picture before the onset of the RSVP sequence conferred, on average, a 11% increase in identification accuracy over verbally pre-specified targets.

To assess whether brief exposure of a picture could prime identification in our task, we conducted an additional experiment in which six subjects were pre-exposed to the target picture prior to viewing a particular RSVP sequence. Three subjects were run at 72msec and the other three at 126msec. Prior to each RSVP sequence, the target was shown for 72 or 126msec, matched to the duration of the RSVP sequences for that subject, followed by a 3sec blank interval. The RSVP sequence was then shown for identification of the target, which would be present on half the trials. We used the same 64 "yes" trials from Experiment I. However the best 32 trials from Experiment I were now "no" responses and the worst 32 trials were "yes" responses to provide an opportunity for the pre-exposures to have an effect.

For pre-exposed picture targets the hit rate was 71%, a 10.5% gain compared to the 60.5% hit rate for the same targets when viewed as distractors without a blank interval and pre-specified verbally. An independent t-test performed on the difference scores (each subject's mean score in the pre-exposed target condition [at 72 or 126msec]—the mean score [at 72 or 126msec] in the verbally pre-specified target condition) was highly significant, $t(5) = 4.92$, $p < .005$. The experiment, even with only six subjects, was sufficiently sensitive to detect a 5.6% increase in hit rates at $\alpha = 0.05$. The RSVP identification task is thus capable of manifesting priming for the target pictures.

Discussion

In RSVP sequences an object representation can be sufficiently activated to allow identification without leaving any residual effect of this activation on subsequent identification performance. The identification performance levels in Experiment I are consistent with those of previous investigators in indicating that well-above chance accuracy can be achieved in the identification of

pictures in RSVP sequences at brief exposure durations, here at 72msec. By 126msec, identification accuracy is almost perfect for more than half of the pictures. Despite the high level of identification performance indicating that the pictures were usually perceived,[2] there was no "priming" as a consequence of repetition of the pictures as non-targets. This result is surprising in that, prima facie, prior research on implicit priming would predict substantial gain in identification accuracy with repetition (e.g. Bartram, 1974; Biederman & Cooper, 1992; Jacoby et al., 1989).

With these same pictures, there is ample evidence of visual priming effects on object identification (as assessed by naming tasks) at the same, or even briefer, exposure durations (e.g. Biederman & Cooper, 1992). However, the priming effects in these prior studies were obtained in single-trial presentation conditions in which approximately four to five seconds elapsed between the presentation of one picture, followed by a mask, and presentation of the next. The picture pre-exposure study in the present investigation provides some linkage between the two forms of priming in that a brief exposure to the target picture with a post-stimulus interval of several seconds facilitated its subsequent identification in a RSVP sequence. It is possible that the facilitation observed with the pre-exposures in the present experiment was a consequence of the subject being able to actively maintain the pre-exposed target image in memory, while performing the task, as there was only one target image pre-exposed for each RSVP sequence. This explanation, however, begs the question as to why accurate perception of the images in the RSVP sequences of Experiment I did not result in priming once the name of the target was presented.

Nonetheless, Experiment II was designed to address this potential limitation of the present pre-exposure experiment by pre-exposing half the targets before any of the RSVP sequences were run, so it would be unlikely that active maintenance between pre-exposure and test would be a factor.

EXPERIMENT II:
Can Identification of RSVP Pictures be Primed by Massed Pre-exposures?[3]

Experiment I established that, at exposure durations of 72 and 126msec, fairly accurate identification of pictures in RSVP sequences is possible without any facilitation of the non-targets on their subsequent identification when they became targets. We also demonstrated that pre-exposure of the target image, if followed with a long ISI, prior to its possible presentation in a RSVP sequence facilitated its subsequent identification. This result was taken as evidence that the RSVP identification task is capable of manifesting priming for the target pictures. However, in that demonstration, only the target image was pre-exposed so it would have been possible to actively maintain that image during the subsequent RSVP sequence.

The present experiment was designed to assess whether pre-exposure of target pictures would facilitate their subsequent identification under conditions that more closely approximated the high uncertainty for priming (or the lack thereof) from one RSVP sequence to a later one. That is, when viewing the RSVP sequences in Experiment I, subjects did not know which of the non-targets would be a target in the next sequence. In this experiment, half of the target pictures were pre-exposed in the study phase. Would these images be more accurately identified in the RSVP sequences than those that were not pre-exposed?

Method

Sixteen students participated in this experiment. The stimuli, design, and procedure were identical to those used in the 72-msec presentation conditions of Experiment I with the following modifications. Prior to the start of the experimental trials, half (32) of the target images, 8 from each RSVP sequence, were exposed for 5sec each. (In retrospect, it would have been better to have a pre-exposure condition in which each of the pre-exposed targets were shown for only 72msec, followed by a mask, but with a few seconds interval prior to pre-exposure of the subsequent target.) In the pre-exposure stage, 8 subjects viewed half of the 64 experimental images; the other 8 subjects viewed the other 32 experimental images.

Results and Discussion

The results are shown in Figure 4. Overall, pre-exposed target pictures were identified more accurately (79%) than non-pre-exposed target pictures (61%). A 4 (Blocks) × 2 (Pre-exposure/No Pre-exposure) ANOVA revealed a significant main effect of the Pre-exposure variable, $F(1, 15) = 19.74$, $p < .005$. The Blocks main effect was marginally significant, $F(3, 45) = 3.22$, $p = .03$, but this was in a direction opposite to what would be expected from facilitation with repetitions, with increasing numbers of exposures resulting in less facilitation. These results suggest that the RSVP identification task is indeed capable of manifesting picture priming under conditions that would discourage active maintenance of any single pre-exposed image. The results also replicate the results of Experiment I in showing no improvement in identification accuracy of a picture as a function of its repeated prior exposure as a non-target. Critical for obtaining a priming effect would appear to be the time following that which is minimally necessary for identifying the stimulus.
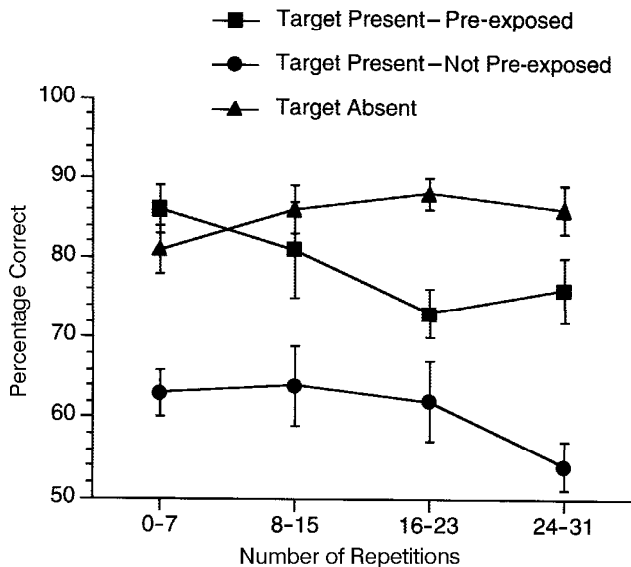
FIG. 4.   Mean object identification accuracy (Target Present) as a function of the number of times that an object was presented in RSVP sequences as a non-target before it became a target, with Pre-exposed (squares) and Non-pre-exposed (circles) trials shown separately as a function of the number of repetitions. Also plotted are the scores for the Target Absent (No) trials (triangles). Error bars show the standard errors of the difference scores of each subject's mean score and his or her mean score for that condition. Between-subjects variability is thus removed from these measures of error.

EXPERIMENT III:
Recognition Memory for the RSVP Pictures

Experiments I and II established that, at exposure durations of 72 and 126msec, pictures in RSVP sequences can be identified without facilitation of their subsequent identification. Experiment II established that picture identification performance in the RSVP task is capable of being primed. The current experiment was designed to assess explicit memory for the pictures in these RSVP sequences with a two-alternative forced-choice test consisting of a picture that was in the sequence and a distractor that was not. In addition to the two exposure durations studied in Experiment I, longer exposure durations of up to 700msec per picture were studied.

With the 2AFC test, we used three kinds of distractor to assess, roughly, the nature of the representation that might be mediating memory in this task, as illustrated in Figure 5. This assessment is termed "rough" in that limitations in the number of same name, different exemplar pairs prevented us from fully balancing stimuli with conditions.

In one condition (Different Name, Different Shape), the distractor was of a basic-level object class that was not present in the RSVP sequence. In a second condition (Same Name, Similar Shape), the distractor had the same basic-level

Assume that the following two pictures were shown.
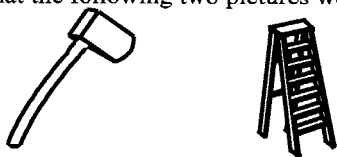
Forced choice recognition memory was tested in three ways:
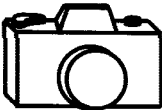
Distractor Type	Original	Distractor	Original	Distractor
Same Name Similar Shape				
Different Name Different Shape				
Different Name Different Shape Mirror Reversed Target				

FIG. 5.   Examples of the different distractor types used in the forced-choice recognition memory test. The images on the left, in each panel, were the targets shown in the study sequence, except in the bottom row where the target was mirror reversed. The distractors on the right, in each panel, could be the same name but a similar shape (top row), or a different name and a different shape (middle and bottom rows). In the actual experiment, the original was on the left and half the trials and on the right on the other half. In the Same Name, Similar Shape condition, most of the distractors differed in a non-accidental proepty of a single part, as with the two types of axe shown in the upper-left panel.

name as the target picture, but was, generally, of a highly similar shape to the target, differing only in a single, non-accidental property of a single part, as illustrated with the axes in Figure 5, although some differed in more than one characteristic, as with the ladders. Equivalent performance on the Different Name and Same Name (Similar Shape) conditions would suggest that all the memory was visual, none verbal or basic-level conceptual, insofar as the

opportunity to employ different basic-level classes (and names) did not improve performance. An advantage of the condition with distractors of a different name and category than the target would suggest that at least some of the memory was non-visual. (Because the same name distractors were often highly similar in shape to the targets, perceptual factors are likely underestimated in this investigation.) The third distractor condition (Different Name, Mirror-reversed Target) also had items that were not in the RSVP sequence but on these trials the target item was mirror reversed from how it appeared in the RSVP sequence. If the binding of mirror reversed orientation to a particular shape requires additional time beyond that required for storage of the shape itself, presumably through interactions between the dorsal and ventral streams (Biederman & Cooper, 1992), at short stimulus durations mirror reversal of the target might not be expected to result in a large cost in recognition if orientation and shape were not bound.

Method

Participants.   Forty students with normal or corrected-to-normal vision were run in this experiment. They participated for research experience points for the Cognitive Psychology course at the University of Southern California.

Stimuli.   The pictures were the 92 images that were used in Experiments I and II along with 119 others, drawn in a similar manner to produce a set of 211 pictures. These were composed of 58 pairs with the same name but (slightly-to-moderately) different-shaped exemplars (e.g. a round-face clock and a square-face clock) and 95 single exemplars from different basic-level classes. Approximately half of these images were left-oriented and half were right-oriented.

Procedure.   Each participant viewed an RSVP sequence of 92 (80 test + 12 buffers) pictures. They were instructed to view the sequence but were not given instructions to memorize the pictures nor were they told that a recognition test would follow. Under these conditions, participants become riveted to the sequences but do not engage in any rehearsal operations. A few seconds after the RSVP sequence, a two-alternative forced-choice recognition memory test was administered for all the items in the sequence save for the 12 buffers. Each test trial started with the side-by-side presentation of two pictures, one with a shape that had been in the RSVP sequence and a distractor. The participant was to respond by pressing one of two keys (one on the left side and the other on the right side) corresponding to the picture that he or she judged to have been in the sequence. The trials were participant-paced (the maximum allowed response time was set at 6sec). A message saying "press any key for the next trial" prompted the participant to present the next recognition pair. Error rates and response latencies were recorded for each participant.

Design.   There were four sequences with 80 experimental pictures (not counting the buffers). The experimental pictures were composed of one member of the 58 pairs of images that had a same name, similar shaped mate, and 22 single pictures. For the paired pictures, half the test trials had the mate as a distractor; the other half had a picture from a new class (and name) that did not appear in the RSVP sequence. For the single pictures, the distractors on all the trials were from a new class (and name) that had not appeared in the RSVP sequence. However, half of these single pictures were presented in mirror-reversed orientation from their orientation on the RSVP sequence. (All the paired objects were tested in their original orientation.) These conditions are illustrated in Figure 5. The correct choice (i.e. the original picture) was on the left for half the trials and on the right for the other half of the trials.

Eight participants, at each of five exposure durations, were required to balance testing of each of the paired pictures with its mate and a new item as distractors over the four sequences. The differences among these balancing conditions were negligible so the data were combined for the presentation of the results. Participants were run at one of five exposure durations: 72, 126, 196, 462, or 700msec. In addition, another group of eight subjects was run with a 20-item experimental sequence (also with six buffers at either end) at 126msec.

Results

At the 72 and 126msec exposure durations performance was at chance (Figure 6). As exposure duration was increased there was a small but consistent improvement so that, at 700msec, performance was at 60% correct, only modestly above the 50% chance level. Recognition performance on the 20-item sequence was 58%, only moderately, though non-significantly, better than the 52% for the 80-item sequence at that rate, $t(7) < 1.00$ for this between-subjects test. This slight advantage could not be readily attributed to retroactive interference from later presentation items or proactive interference from earlier test items for the longer list in that performance on the first 20 presentation items and first 20 test items were equal to the performance levels for all 80 items as discussed later. (Little differences were expected from these analyses because the overall recognition rate was near chance.) The relatively poor recognition memory performance, even with the shorter sequences (see also Potter, 1976, & Intraub, 1980, 1981), should be contrasted with the high recognition memory performance, 90%+, for thousands of pictures when each picture is viewed for several seconds (e.g. Shepard, 1967).

To investigate the effect of distractor type, the data for the two briefest exposure durations (72 and 126msec) were combined and are shown in the upper panel of Figure 7a. The data for the three longer durations were combined and
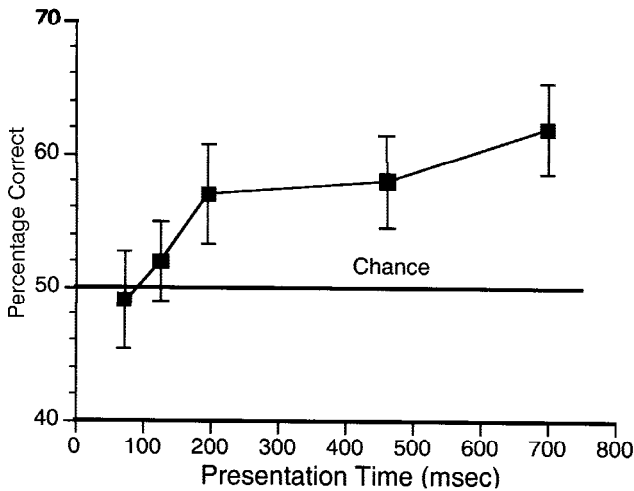
FIG. 6.   Mean forced-choice recognition memory accuracy for RSVP sequences of 80 objects as a function of exposure duration. Eight different subjects were run at each of the five exposure durations. Error bars show the standard errors for the eight subjects at that exposure duration.

are shown in the lower panel of Figure 7b. At the two shorter presentation durations, performance was at chance so it is not surprising that there was no difference in the accuracy of recognition memory among the different Distractor Types, $F(2, 30) < 1.00$, n.s.

Figure 7a shows that at the longer exposure durations (192, 462, and 700msec), recognition memory exceeded chance for all distractor conditions. Comparison of memory performance in the three conditions indicated a modest but significant effect of Distractor Type, $F(2, 46) = 3.97$, $p < .05$. Approximately, half the increase in accuracy could be attributed to visual information and half to conceptual (or name) information in that the same name, similar shaped condition was between chance and the performance of the different name, different shape condition. A visual effect is suggested to the extent that recognition memory performance is above chance in the same name, similar shape condition. The employment of conceptual (or name) information is suggested to the extent that there was an advantage for recognition memory performance in the different name, different shape distractor conditions over the same name, similar shape condition. These suggestions as to the information specified by the representation must be made tentatively as the pairwise differences were not significant (by Least Significant Difference tests). Reversing the target picture did not result in a decrement in performance: Accuracy for mirror-reversed targets was slightly (though non-significantly) higher than targets in their original orientations.
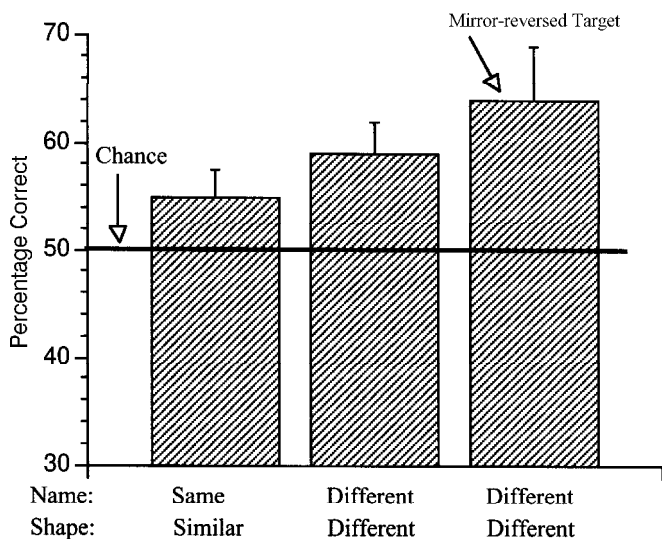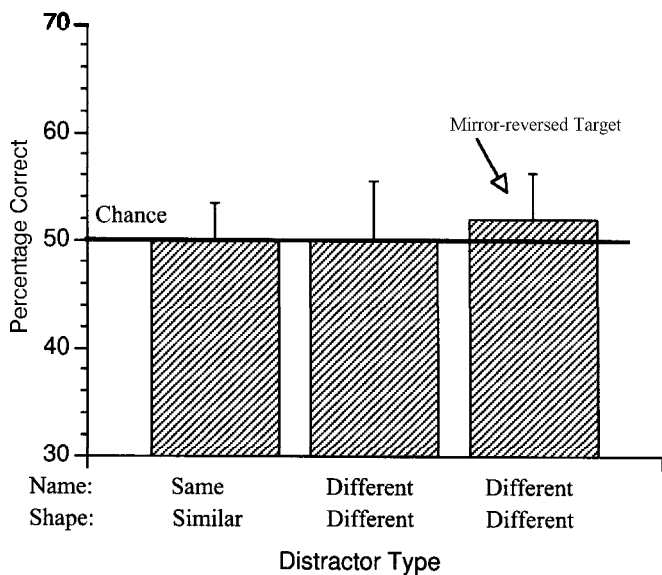
FIG. 7. Mean forced-choice recognition memory accuracy for 80 objects presented in RSVP sequences as a function of exposure durations of (a) 72 and 126msec and (b) 196, 462, and 700msec and distractory type (Same Name–Similar Shape; Different Name–Different Shape; Reversed Target–Different Name–Different Shape). Eight different subjects were run at each of the five exposure durations. Error bars show the standard errors of the difference scores between each subject's mean score and his or her mean score for that condition. Between-subjects variability is thus removed from these measures of error.

Discussion

Recognition memory was at chance at the two fastest rates of presentation (72 and 126msec/item). Only modest improvements in memory resulted from increasing the exposure duration to 700msec/item. These results are thus quali- tatively consistent with earlier studies of recognition memory for RSVP pic- tures in showing poor memory at fast rates (Intraub, 1980; Loftus & Ginn, 1984; Loftus & Kallman, 1979; Potter, 1976). However, these other studies did show above-chance recognition at 100msec/picture rates, comparable to the faster rates here. Three factors may have contributed to the chance-level perfor- mance in our experiment. One, as noted earlier, was that our 92 picture sequences were considerably longer than those used in other studies. When we used shorter sequences of 32 pictures, poor (58%) but above-chance perfor- mance was evident. In addition, many of the prior studies used photographs, which are probably more likely to include some that attract interest. If these are preferentially attended, then they will result in an improvement in their recog- nition. If the other pictures will be recognized at chance levels anyway, the dis- tribution of attention to some pictures can be made without apparent cost.

At slower rates (196, 462, and 700msec), there was some indication that part of explicit memory is visual in nature and part conceptual, in that recognition was more accurate when the distractors were of a different name than those in the sequence. Explicit memory on this task, at the slower rates of presentation, was unaffected by mirror reversal of target objects. Intraub (1980), also using RSVP presentations, found similar results in that old–new judgements were unaffected by mirror-reversal of targets. Biederman and Cooper (1991) observed that, whereas priming was unaffected by mirror reversal, old–new recognition memory was reduced by mirror reversal. Stankiewicz, Hummel, and Cooper (1998) reported that whether priming was invariant over reflection depended on the subject's attention: Unattended objects were not invariant.

GENERAL DISCUSSION

The major new empirical result in this investigation was that repetition of non- targets in the RSVP sequences up to 31 times prior to when they became targets did not facilitate their identification in the RSVP sequences. It was not the case that RSVP picture identification cannot be primed: Priming was readily evi- denced if enough time was available for attending to the picture, without the necessity for immediately attending to another picture. The critical time for producing both identification priming and improved recognition memory would appear to be several hundred milliseconds beyond that which is required for the picture's identification.

Taken together, the results from these experiments replicate previous results showing a dissociation between the high levels of identification accuracy of a

target in an RSVP sequence of approximately 100msec per item and extremely low recognition memory rates for such pictures (Loftus & Ginn, 1984; Loftus & Kallman, 1979; Paivio & Csapo, 1971; Potter, 1976; Potter & Levy, 1969; Shaffer & Shiffrin, 1972). Although 100msec is sufficient for accurate image classification in an RSVP sequence, at least several hundred additional milli- seconds exposure duration is required for recognition memory to match such performance levels, irrespective of whether the pictures are coloured photo- graphs of natural scenes (e.g. Intraub, 1980; Potter, 1976) or line drawings of single objects (this investigation; Paivio & Csapo, 1971).

That these additional milliseconds are critical was argued by Potter in her initial (1976) account of RSVP recognition in which she proposed that at high rates of presentation subsequent objects in the RSVP sequence interfere with a memory consolidation process. To handle the phenomena of the attentional blink (e.g. Shapiro, Raymond, & Arnell, 1994)—the lowered accuracy in reporting a second target, T2, presented approximately 200msec after an initial target, T1[4]—she (Chun & Potter, 1995; Potter, 1993) elaborated on a two-stage account (as had others) in which the first stage is a high capacity process by which items are detected on the basis of physical features or category member- ship. However, the representations formed in this process cannot be directly reported and rapidly decay. A second, capacity-limited process is required for transferring (or transforming) the representations into a form that can be reported and remembered. Essentially, the second stage can only operate on one stimulus at a time (or incur a cost in attempting to operate on multiple stim- uli), although the category membership of succeeding items may be detected by the first processes. Two-stage models have a long history in psychology. In addition to Chun and Potter (1995), see Vogel, Luck, and Shapiro (1998) for a review (and slightly different account) within the context of RSVP processing.

Attention and consciousness

That a first stage of stimulus processing may activate category membership and other familiar semantic information without being available for report is amply documented in a number of recent studies showing that attentionally blinked stimuli nonetheless produce semantic (or associative) priming (Maki, Frigen, & Paulson, 1997; Shapiro, Driver, Ward, & Sorensen, 1997). Are these incon- sistent with the absence of visual priming in the present study? We think not. As noted, these studies assessed semantic priming whereas we assessed visual priming. The evidence is that semantic priming of an unreported stimulus is short lived, on the order of a few hundred milliseconds (Greenwald, Draine, & Abrams, 1996; Maki et al., 1997; Shapiro et al., 1997; Vogel, et al., 1998). The Vogel et al. (1998) experiment, prima facie, might be construed as demonstrat- ing longer-term semantic priming from RSVP stimuli. These investigators showed that a word (T2) presented in the blink interval (a few hundred

milliseconds after T1) elicited differential evoked potentials depending on whether it matched a prime word presented prior to the sequence. For example, given the prime "doctor", and the requirement to judge the semantic relatedness of T2, a larger N400 evoked potential, diagnostic of an associative mismatch, was elicited to "rope" compared to "nurse", despite lowered accuracy in explicitly judging T2.[5] However, the prime word was clearly studied so it would have enjoyed the benefits of the post-perceptual activity. The evoked potential activity could have reflected short-lived semantic activation of the T2 word and its non-match. That information about the non-match is available early is evidenced by Thorpe, Fize, and Marlot's (1996) report of a frontal negativity that starts at 150msec after stimulus onset for single non-match trials in which subjects have to judge (Go/No-Go) whether a 20msec presentation of a complex scene contains an animal. The Go reaction times in the Thorpe et al. (1996) experiment were approximately 400msec.

Visual priming, in contrast, persists over months (Cave, 1997). For unreported visual stimuli (line drawings similar to those used in the present investigation), Bar and Biederman (1998, 1999) have recently shown that pictures that were not identified—or guessed above chance—nonetheless produced strong name priming when they were shown 10min and 20 trials later. All the priming in these investigations was visual; there was no facilitation of same name, different shaped objects. Like supraliminal priming (e.g. Bartram, 1974), subjects in the Bar and Biederman experiments had several seconds to think about the brief, effectively masked exposure before the next picture was shown.

We now speculate on a neural account for these effects and then consider our results in the context of other behavioural results in visual priming and RSVP recognition.

Speculation: A neural activation account of RSVP phenomena

The two-stage accounts have been phrased in terms of functional information processing accounts, e.g. "transfer of information", "short-term conceptual memory", but it is not clear how to conceptualize these processes in terms of the neural activity that forms the substrate by which these functions are implemented. We here offer some thoughts on a neural instantiation of two-stage search models inspired by recent single-unit recording results, in particular, those of Tovee and Rolls (1995). These investigators have shown that most of the information in a population code of face cells in the inferotemporal cortex (IT) of the macaque can be derived from the first 50msec of firing, but the cells continue to fire for at least 350msec longer. We will term this activity post-perceptual.[6] A similar phenomenon characterizes the tuning of IT cells selective to objects or object features (e.g. Logothetis & Sheinberg, 1996; Tanaka, 1996).

Although these data are from monkeys, monkeys show data quite comparable to those of humans in making rapid categorizations (food/non-food or animal/non-animal) of briefly presented familiar and unfamiliar natural images (Fabre-Thorpe, Richard, & Thorpe, 1998a,b). Most striking is the strong correspondence between the temporal values, 50msec for the initial phase and approximately 350msec for the post-perceptual phase, and the behavioural time requirements for perceptual identification and memory, respectively.

There is a high metabolic cost in firing a spike so there is likely some functionality as to why the firing persists. Indeed, repetition of stimuli typically results in *less* net firing of macaque IT cells (Miller, Li, & Desimone, 1991) and less fMRI activity in humans (Wagner, Desmond, Demb, Glover, & Gabrieli, 1997), presumably because competitive interactions in a self-organizing network reduce the number of cells required to represent a particular stimulus.[7] The survivors inhibit other cells that were initially excited by the stimulus, freeing them up to code other patterns. We assume that this activity can be initiated by a stimulus that is presented for a single millisecond, insofar as variation in stimulus duration below 50-100msec does not affect identifiability as long as the mask is presented 100msec SOA (Sperling, 1959). Whereas the first 50-100msec of the activity may be disrupted by a mask—as evidenced by the effectiveness of masking at SOAs of up to 100msec—the subsequent activity may be affected by attentional selection (which could include attention to the mask itself).

We speculate that the initial stage of tuned firing forms the substrate for the first stage in the two-stage models and that both the initial stage and the post-perceptual activity form the second. (The memory activity would thus be "pipelined" from the very onset of tuned responding. However, the data suggest that more than 50–100msec of this activity is required to obtain a memory effect.) RSVP presentations may manifest poor memory because the pattern of post-perceptual firing of IT cells is disrupted by attention to the subsequent picture (as discussed later). The 50–100msec of initial activation may be sufficient for object identification/classification but the interference with the subsequent activity may severely retard the development of a more permanent representation of that image and even utilization/awareness of the stimulus itself.

The attentional effects could be manifested as suppression of the post-perceptual activity to unselected stimuli.[8] With single unit recording techniques in primates, it may be possible to observe directly whether suppression of post-perceptual activity occurs to unselected stimuli in RSVP sequences. It also may be possible to determine whether the suppression of the P2 and P3 components of the evoked potential during the attentional blink observed by Vogel et al. (1998) correspond to the post-perceptual activity. An alternative possibility, more difficult to assess neurally, is that the post-perceptual activity itself is unaffected by attention to a subsequent stimulus but is, somehow, not preferentially selected by other stages.

Attention can be a critical factor in modulating RSVP memory interference (Shapiro et al., 1994). There is little doubt that in a relatively fast RSVP sequence that normally would manifest little or no recognition memory, an observer can selectively attend to a particular picture and subsequently recognize that picture correctly. However, this would be achieved at a cost both to detection, as evidenced by the attentional blink, and to recognition memory of other pictures (if recognition performance for those pictures was above chance). If our account is correct, a testable prediction is that attention to an item should result in sustained post-perceptual activity tuned to it, despite the presence of succeeding items.

Behavioural consequences of disruption of post-stimulus neural activity

It is likely that all memory functions would suffer from suppression of the post-perceptual activity. We will here limit our consideration to three memory/processing functions associated with picture recognition and priming insofar as they may have testable consequences for the behaviour affected by RSVP presentations, particularly if the functions have different time requirements (and hence might be differentially affected by variations in RSVP rates).

(1) The post-perceptual activity may be required for consolidation, to use Potter's term, in a local network presumably within the ventral pathway that mediates shape priming (Biederman & Cooper, 1992; Ungerleider & Mishkin, 1982).

(2) Whereas familiar associations may be directly activated from the perceptual activity, the post-perceptual activity (or more of it) may be required for conjoining separable aspects of the stimulus or their activation into a representation that might be reportable. Our analysis here would be consistent with that offered Chun and Potter (1995), Duncan and Humphreys (1989), Lawrence (1971), Sperling, Budiansky, Spivak, and Johnson (1971), and Vogel et al. (1998), in detailing the time course of the first and second stages. In addition, given that unfamiliar concepts tend to be complex (i.e., have separable aspects), more post-perceptual activity may be required for the larger number of units representing a complex concept so that a link binding them might be activated, e.g. a link binding "capital letters" to "chair". The illusory conjunctions of objects in scenes presented in RSVP sequences (Intraub, 1989), are not unexpected from this perspective. If one of the atomic components is taken as a cue, e.g. capital letters, then the time required to process that cue and direct attention to the words in an RSVP sequence will often result in a later word being reported, as Lawrence observed. However, the initial perceptual activity itself may be sufficient to activate a representation of "chair" and its well-learned associations.

(3) The post-perceptual activity may be required for binding the separable attributes of the stimulus as well as its episodic context, possibly by way of an IT → hippocampus feedback loop as posited by Tovee and Rolls (1995). Temporal lobe interactions with cortical structures that might be involved in providing a reportable representation, such as the pre-frontal cortex, might also benefit from additional post-stimulus activity so that feedback links could match the initial pattern of activity. The post-perceptual activity may also be required for binding an object's shape to information specified in the dorsal pathway, such as the object's position, size, and orientation, posited by Biederman and Cooper (1992). (See also Ellis & Allport, 1986.) That mirror reversal of the targets had no deleterious effect on explicit recognition memory in Experiment III is consistent with the failure to bind mirror orientation and shape. With post-stimulus durations of several seconds, Biederman and Cooper (1991) and Cooper, Biederman, and Hummel (1992) demonstrated interference on old–new judgements from mirror reversal as well as good explicit memory for object orientation for these types of picture.

SUMMARY AND CONCLUSIONS

Line drawings of objects shown at the 72–126msec/picture under RSVP conditions, although moderately well identifiable, nonetheless produce chance forced-choice recognition memory. Repeated presentation of non-target pictures resulted in no benefit (priming) when these pictures eventually become targets. Although 50–100msec may be sufficient for classification of a stimulus, both priming and recognition memory may require that the subject attend to the stimulus for a few hundred milliseconds beyond this minimal duration. We offer a neural interpretation of these effects. The first 50msec of firing of IT cells is sufficient for a population code that can distinguish visual stimuli. However, the cells fire for an additional 350msec. We speculate that the additional neural firing reflects post-stimulus attentional activity required for recognition memory and priming and that, under RSVP conditions, attention to the next stimulus suppresses this activity.

NOTES

[1] We use the term identification to refer to the classification of a picture into its basic-level class as when a target, e.g. "elephant", specified by name, is detected in a sequence of pictures of objects. Recognition is here used to refer to the episodic judgement as to whether a given picture was in a previously shown sequence of pictures.

[2] In addition to the high identification accuracy, the strong subjective impression in viewing the sequences was that the objects were understood as they are presented. A target need not be specified when viewing the sequences for this impression of comprehension to occur.

[3] We thank Molly C. Potter for suggesting this experiment.

[4] T1 and T2 need not be presented in succession. Perhaps the more dramatic form of the attentional blink is simply the time required to respond to a cue, as in Lawrence's (1971) study in which he observed that when asked to report the capitalized word in an RSVP list of lower case distractor words, subjects often reported a word after the target.

[5] Unfortunately, these authors did not conditionalize the magnitude of the N400 on the accuracy of the T2 judgement.

[6] The onset of tuned responding of these cells occurs slightly longer than 100msec after stimulus presentation. Nothing is affected in our discussion if the neural firing under examination has a constant lag after the onset of the stimulus.

[7] It is possible that the reduced firing to a repeated stimulus is why masks lose their effectiveness as they are repeated (Intraub, 1981). Although the net activity is diminished, a large number of cells ultimately become tuned to a familiar stimulus repeated over many months (Logothetis, Pauls, & Poggio, 1995; Logithetis & Sheinberg, 1996; Miyashita, 1993; Tanaka, 1996). These may be coding different episodic traces (Biederman, Gerhardstein, Cooper, & Nelson, 1997).

[8] Insofar as attentional modulation has been observed in V4 (Moran & Desimone, 1985), there might well be attentional modulation in the initial 50–100msec as well.

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