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Temporal and Spatial Repetition Blindness: Effects of Presentation Mode and Repetition Lag on the Perception of Repeated Items

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In this study, participants were asked to identify briefly presented 5-letter (Experiments 1–3) or 2-letter (Experiment 4) strings. Identical items in a repeated trial were identified worse than their counterparts in a nonrepeated trial, indicating repetition blindness (RB; N. G. Kanwisher, 1987). In Experiment 1, RB occurred regardless of whether items were presented successively or simultaneously. In Experiments 2–4, RB occurred regardless of whether 2 simultaneously presented items were spatially close or far apart. The magnitude of RB, however, varied with presentation mode and repetition lag: RB was smaller in simultaneous than successive presentation, and RB increased and then decreased with the number of items separating 2 identical ones. These results provide important constraints in the interpretation of RB. A model that attributes RB to the refractoriness of perceptual recognition units is proposed.

One of the most important functions of the visual recognition system is to detect differences as well as similarities among objects in the visual field. Although most of the time the recognition system is confronted by a variety of visually distinct objects, not infrequently it must also deal with visually similar or identical objects. The issue of detecting repetitions arises on at least two occasions. The first is when the same object appears twice at different moments in time. The second is when two similar or identical objects appear concurrently at different locations in space. The present study is concerned with how the recognition of an item is influenced by the presence of an identical item that appears closely in time or simultaneously in space.

In a seminal article, Kanwisher (1987) reported a finding she called *repetition blindness* (RB). This effect refers to the failure to detect repetitions of words in rapid serial visual presentation (RSVP). In a typical experiment, participants are asked to report back words of a sentence that quickly appear one after another at the same location. If the sentence contains a repeated word, the second occurrence of the repeated word is less likely to be reported than is a control word. RB has also been shown to occur for letters and pictures, between words and their corresponding pictures, and between words in two different languages (e.g., Bavelier, 1994; Bavelier & Potter, 1992; Kanwisher & Potter, 1990b; MacKay & Miller, 1994).

This difficulty in recognizing a repeated item may provide important insights into how the recognition system is organized. For example, Kanwisher and her coworkers (Kanwisher, 1987; Kanwisher & Potter, 1990a, 1990b; Park & Kanwisher, 1994) interpreted RB as supporting the distinction between types (categories) and tokens (instances) in mental representation. According to the type–token model, two basic processes are involved in visual object recognition. The first is that a type node must be activated to signal that a token of that type is or was present. This process is called *type activation.* The second is that the activated type must be linked to the appropriate token that corresponds to the item that appeared at a particular spatial location, in a particular temporal order, or both. This process is called *token individuation* or *type–token binding.*

According to Kanwisher (1987), RB results from the dissociation between the type activation process and the type–token binding process. She has argued that even though the second occurrence of a repeated item is not reported in RB, both occurrences of the repeated item are in fact recognized as a type. The reason for the failure to report the second occurrence of the repeated item is due to a failure to individuate the recognized type as a second episodic token. Kanwisher (1987; see also Park & Kanwisher, 1994) has also listed and dismissed a number of alternative accounts of RB such as recognition failure, recognition refractoriness, encoding failure, selective loss of repeated items in memory, output interference, and response bias.

Although the type–token binding theory seems to provide an adequate explanation for the general phenomenon of RB, this theory has recently been challenged. For example, Fagot and Pashler (1995; see also Whittlesea & Podrouzek, 1993) questioned the nature of RB and asked whether the effect is simply a memory rather than a perceptual phenomenon. They compared RB to a seemingly similar memory

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effect, the Ranschburg effect (Crowder, 1968), which is found in immediate-recall tasks with relatively slow item-presentation rates, and argued that the two effects are probably the same. In support of their account, Fagot and Pashler found no RB when using a task that did not require full report of items in a display. On the basis of this and other related findings, they concluded that RB is not a perceptual phenomenon and attributed RB primarily to a mixture of guessing bias and output interference. We return to this issue of perception versus memory later in this article.

Even if RB were a perceptual phenomenon, alternative explanations to the type–token binding hypothesis are possible. One such explanation is provided by the *type (recognition) refractoriness hypothesis.* This hypothesis attributes RB to reduced responsiveness of the type node, during a refractory period, to the second stimulation shortly after the first one. This theory was dismissed by Kanwisher (1987) on the basis of the results of her Experiment 3. In that experiment, participants were asked to identify only the last item in a sequence of words. It was found that the target item was identified better rather than worse when an identical word had appeared previously in the same list. Thus, depending on the type of task the participant is required to perform, the repetition of an item can have either a positive (repetition priming) or a negative (RB) effect. Kanwisher argued that whether one gets RB or repetition priming in a particular task is determined by whether both of the repeated items must be individuated as separate tokens: In the case where both items must be individuated for recall, RB should occur; in the case where only the second item need be individuated, repetition priming should occur.

Kanwisher's (1987) proposal has the virtue of offering a unitary account for RB and priming in different tasks. However, the supposed differences between the two types of tasks have not been clearly replicated. For example, Kanwisher and Potter (1990b, Experiment 6) failed to obtain priming and in fact obtained RB in an almost identical experiment. Park and Kanwisher (1994) have recently noted that very similar experiments designed to obtain priming instead of RB have not produced converging results and that the reason for this is unknown. This pattern of results undermines Kanwisher's argument against the type refractoriness hypothesis. In a recent study, Luo and Caramazza (1995) also failed to find repetition priming; instead, they found RB when participants were asked to report only the second of two successively presented items. Thus, the evidence against the type refractoriness hypothesis is not decisive. A principal purpose of the present study was to seek evidence in favor of the type refractoriness hypothesis. In the course of this effort, we explored whether spatial factors affect RB and whether RB varies as a function of stimulus presentation mode and repetition lag.

The classic RB phenomenon is concerned with the ability to identify identical items that appear closely in time at the same location. One interesting question is whether RB also occurs for identical items that appear concurrently in space. Previous work has indicated that this is indeed the case. For example, using words and pronounceable nonwords that contained repeated letters, Kanwisher (1991) demonstrated RB in both sequential (temporal) and simultaneous (spatial) presentation. She also reported RB for letters and color patches that appeared simultaneously in space. Earlier research has also documented participants' difficulty in perceiving repeated objects appearing concurrently in a visual display, although using different paradigms. For example, Mozer (1989) showed that when participants were asked to estimate the numerosity of a multielement display, reports were lower for displays containing repeated letters than for displays containing distinct letters. Earlier still, Bjork and Murray (1977; see also Santee & Egeth, 1980, 1982), using the poststimulus-cuing and the forced-choice response paradigm, demonstrated a similar repeated-letter inferiority effect. They asked participants to identify a target letter (e.g., *B*) that was flanked by a noise letter. The noise letter was the same as the target letter, a nontarget letter (e.g., *K*), or another target letter (e.g., *R*). A poststimulus cue indicated which letter the participants were supposed to report. Bjork and Murray found that the report of *B* from the *BB* pair was less accurate than that from the *BK* or *BR* pairs.

The main purpose of Experiment 1 in the present study was to further explore whether and how RB is affected by presentation mode. Although the demonstration of RB in the space domain indicates that it is not simply the temporal successiveness of stimulus inputs that is the factor mediating RB, it is not clear what the common factor underlying RB in both conditions is. In this study, we attempted to identify the common factor underlying the two presentation modes by analyzing the functional similarity between RSVP and brief simultaneous visual presentation (BSVP) conditions.

The difference between successive and simultaneous presentations may be more apparent than real. On the one hand, because perception lags behind stimulation and the visual response to a brief stimulus lasts much longer than the stimulus that caused it, the responses of the visual recognition system to two successive stimuli may overlap in time. On the other hand, because the system has limited processing capacity, it may not be able to respond at exactly the same time to multiple simultaneously presented items and may, therefore, sequentially process these items. The two opposing factors end up making successive and simultaneous presentations functionally much more similar to each other than is implied by their names.

We suspected that in both RSVP and BSVP, a necessary condition to produce RB is that the recognition processes of two identical items partially overlap in time, in the sense that the first stimulation has an aftereffect on the state of the recognition unit, such that when the second stimulation occurs, the unit has not completely recovered from the first stimulation. If this were the case, then RB might be the result of the dynamics of the partially overlapping activation of a single recognition unit by two temporally or spatially distinct inputs. On this view, the crucial variable might very well be the temporal separation in the encoding processes for recognition of the stimuli and not the actual time separating the physical presentation of two stimuli (as long as they are sufficiently close together to lead to processing overlap). In other words, the term *encoding* or *coding* is not used here to refer to the initial registration of information coming from a stimulus or the analysis of its simple features. Rather, encoding is used to refer to the stage at which all information from various feature detectors or feature maps about the stimulus is integrated into a symbolic and abstract representation by activating a corresponding type node in long-term memory (e.g., Treisman, 1988; Treisman & Gelade, 1980) so that it can be reported if necessary. Accordingly, we assumed that, although the registration of information from a visual display occurs in parallel, the recognition of multiple elements in the display occurs sequentially. We use the expression *coding onset asynchrony* (COA) to describe the (theoretical) difference in onset between the encoding of two critical items, in contrast to *stimulus onset asynchrony* (SOA), which describes the difference in onset between the physical presentation of two critical items.

Because COA refers to internal perceptual processes, it cannot be measured directly, but it can be manipulated indirectly (and can be inferred from performance). In the case of RSVP, the internal COA between two successively presented items can be assumed to increase with the physical SOA between them.[1] But what is the COA in a BSVP condition? Because in this presentation condition the items in a stimulus display are presented simultaneously, the COA between any two elements in the display is unknown. However, given the assumption that two tokens of a same type can be recognized only sequentially, the COA between two simultaneously presented items should be some nonzero value. Furthermore, if a participant were to be instructed to report the items in the display in a particular order, then processing order might correspond to the imposed order of recall. If this were the case, then repetition lag (i.e., the number of intervening items separating two identical ones in report order) would determine the COA between two critical items in BSVP.

Earlier studies have indicated that RB in RSVP seems to diminish with increases of SOA between two repeated items (Park & Kanwisher, 1994; see also Kanwisher, 1987). In BSVP, the temporal lag between items is eliminated, but as argued above, the serial nature of encoding processes may introduce a COA that is comparable to SOA in the RSVP condition. The question that follows is whether RB in BSVP, if it occurs, also varies with repetition lag. If the proposed role of COA is real and the partial overlap in encoding of two identical items is an important determinant of RB, then we would expect RB to vary as a function of repetition lag in RSVP as well as BSVP.

In short, the present study is concerned with the effects of presentation mode and repetition lag on RB. In Experiment 1, we investigated whether and how RB is affected by successive and simultaneous presentation. In Experiments 2 and 3, we investigated whether RB for simultaneously presented items varies as a function of repetition lag. Because in the latter experiments spatial distance and repetition lag were completely confounded, the purpose of Experiment 4 was to unconfound these factors. We used the results of these studies to articulate a specific type refractoriness hypothesis of RB.

Experiment 1

The main purpose of Experiment 1 was to demonstrate RB in a paradigm that is adaptable to both RSVP and BSVP and to test whether we could replicate Kanwisher's (1991) findings of temporal and spatial RB by using unrelated letter strings. To do so, traditional RSVP was modified by presenting items at different spatial locations that formed an imaginary circle in a small visual display.

Method

Participants. Participants were 36 undergraduates from an introductory psychology course at Dartmouth College. The first group of 21 participants was tested in the modified RSVP condition. The second group of 15 participants was tested in the BSVP condition. They received extra course credits for participating in the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus. The experiment was carried out on an Apple Macintosh microcomputer (Centris 610). Each letter was printed in uppercase Geneva typeface in 12-point type size, which was about 2.5 mm wide × 3 mm high (0.29° × 0.34° of visual angle). On each trial, five letters and three dollar signs ($) were presented at eight different locations, which formed an imaginary circle with a radius of approximately 10 mm. The spacing between two adjacent items was approximately 5 mm (0.57°). All characters were black on a white background. Participants sat at a distance of about 50 cm from the computer screen. The laboratory was dimly lit to minimize screen reflections.

Materials and design. Sixteen capital letters (*A, B, C, D, E, H, K, L, N, P, R, S, T, U, X,* and *Z*) were used to generate stimuli. Each stimulus consisted of a sequence of five unrelated letters that resulted in an unpronounceable letter string. Letters were sampled randomly and appeared an approximately equal number of times in each position and condition.

There were two independent variables in this experiment: Presentation mode (RSVP vs. BSVP) was manipulated between subjects, and repetition status (repeated vs. nonrepeated) was manipulated within subjects. A repeated trial consisted of two identical and three distinct letters, whereas a nonrepeated trial consisted of five distinct letters. Two sets of repeated trials and one set of nonrepeated trials were constructed. In the first set of repeated trials, repetition occurred in the second and fourth positions (e.g., *RDKDH*), whereas in the second set, repetition occurred in the third and fifth positions (e.g., *SLBRB*). The two repeated items in the repeated trials and their counterparts in the nonrepeated trials were called *critical items,* labeled C1 and C2 for the first and the second item, respectively. There were 32 trials in each of the two repeated sets and 64 trials in the nonrepeated set, resulting in a

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[1] The assumption that COA is a monotonic function of SOA may be too strong. Thus, consider the case in which two stimuli are presented at very short SOAs (e.g., <100 ms) and the later presented stimulus is more frequent than the earlier presented one. In such a case, the second item may actually be identified earlier than the first one, violating the assumption that COA is a monotonic function of SOA. However, given that the focus in this study was on the recognition of identical items, the aforementioned scenario probably does not occur very often. Nonetheless, the observation of backward RB in this study (see footnote 2; see also Bavelier, 1994) may, in part, reflect the extent to which the second item was actually identified earlier than the first one.

total of 128 experimental trials. The three sets of stimulus trials were intermixed, and the order of their presentation was randomized separately for each participant. An additional set of 16 trials (8 repeated and 8 nonrepeated) was constructed for practice.

Procedure. At the beginning of the experiment, participants were shown written instructions on the computer screen. The participants in the RSVP condition were told that their task was to identify letters that were presented briefly and sequentially. The participants in the BSVP condition were told that their task was to identify letters that were presented briefly and simultaneously.

Each trial consisted of a prestimulus sequence, a stimulus sequence, and a poststimulus mask. The prestimulus sequence included a "GET READY" signal lasting for 2 s, a circle with a radius of 15 mm that remained visible throughout the trial, and a fixation cross that followed after 0.5 s and appeared in the center of the circle for 1 s. Each stimulus consisted of five letters and three dollar signs. The letters and the dollar signs appeared sequentially in the RSVP condition and concurrently in the BSVP condition at eight consecutive locations within the circle (at the following clock positions: 1:30, 3:00, 4:30, 6:00, 7:30, 9:00, 10:30, and 12:00, respectively). The poststimulus mask was composed of eight dollar signs that immediately followed the stimulus sequence and covered the eight locations of the visual display for 100 ms. The participants' task was to report the letters they saw.

Figure 1A shows an example of the stimulus sequence in the RSVP condition. On each trial, five letters were shown clockwise one after another and they were preceded and followed by 1–3 dollar signs, so that participants could not predict precisely when the first letter would appear. The stimulus sequence (five letters and three dollar signs) could start at any of the eight locations. Each item was shown for 100 ms, and there was no interstimulus interval. After a poststimulus mask, participants were asked to type on the computer keyboard the letters they had seen in the order of their appearance. They were also told that on half of the trials there would be two identical letters in the stimulus, and in that case, they should report both of them according to their order of presentation.

Figure 1B shows an example of the stimulus sequence in the BSVP condition. On each trial, five letters appeared simultaneously and occupied the five upper locations, along with three dollar signs occupying the three lower locations of the display. The exposure time of the stimulus display was determined individually for each participant on the basis of his or her performance in the practice session, so that neither ceiling nor floor effects would occur. The average exposure time was 300 ms, ranging from 200 ms to 400 ms. After a poststimulus mask, participants were asked to type the letters they had seen, in the left-to-right order (clockwise). They were also instructed that there might be two identical letters in the display and that they should report both of them according to their relative positions in the display.

Sixteen practice trials preceded 128 experimental trials. In the practice session, participants received feedback about their response from the computer, which showed the correct answer for 2 s in a small window near the bottom of the computer screen. This was intended to ensure that participants had a clear understanding of the task. Feedback was not provided during the experimental session. The data from the practice session were not analyzed. Participants initiated each trial by pressing a key.

Scoring. Although participants were instructed to report identified letters in their order of appearance in RSVP and clockwise in BSVP, an identified letter was scored as correct regardless of

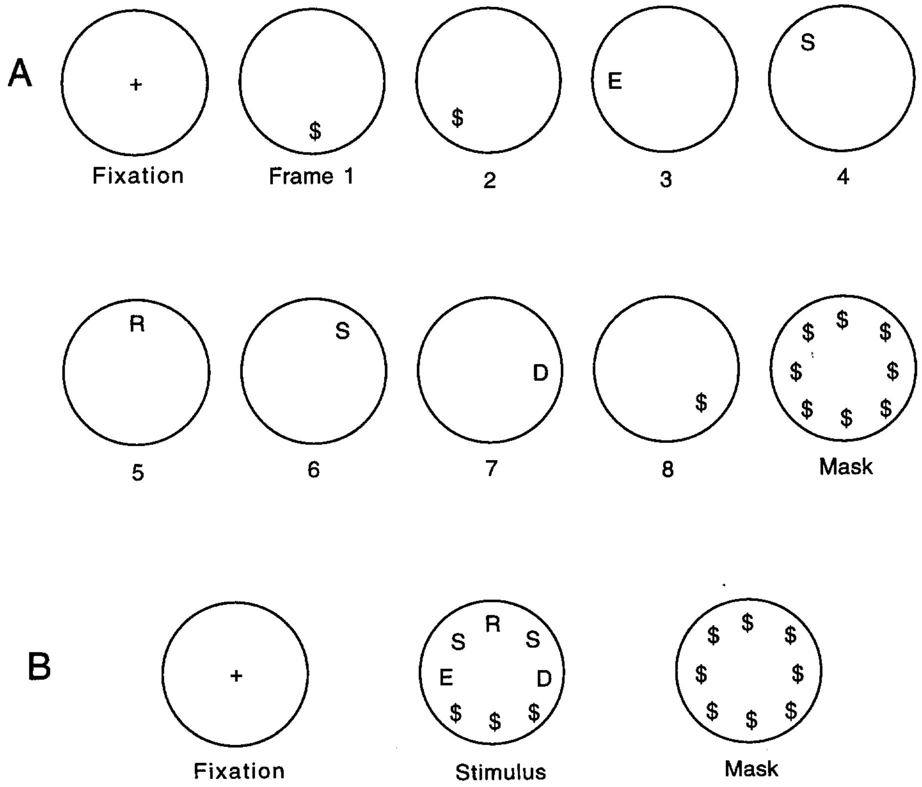

Figure 1. A shows an example of a stimulus sequence in rapid serial visual presentation and B shows an example of a stimulus sequence in brief simultaneous visual presentation in Experiment 1.

whether its serial order was correct. However, when a participant reported only one of two identical letters in the repeated condition, the following four criteria were used in turn until the response could be scored as unambiguously as possible.

First, if the item was reported in the position of C1, then C1 was scored as correct (e.g., reporting *NSLD* or *NSLHD* in response to stimulus *NSLSD*); if the item was reported in the position of C2, or if C1 was seemingly missing (e.g., reporting *LSBKN* or *LBKN* in response to stimulus *LKBKE*), then C2 was scored as correct. About 7 out of 10 responses (in which only one of two identical items was reported) were of this type, and a unique solution could be obtained by applying the first criterion. Otherwise, the second criterion was applied. This criterion was based on the relative order among reported items. For example, if a participant reported *XLRDN* in response to the stimulus *XRDRN*, the position of the repeated letter in the response would not be sufficient to tell which *R* the participant was reporting. In these cases, we relied on the relative order between items to infer which of the two *R*s was being reported. In the present example, the *R* was scored as correct in the second position because omitting the *R* in the fourth position (becoming *XRDN*) made the resulting (relative) letter order more similar to the response (*XLRDN*) than did omitting the *R* in the second position (becoming *XDRN*). About 2 out of 10 responses were of this type. If order information offered no unique solution, then a third criterion was used: If the item was reported nearer the position of C1 than C2, C1 was scored as correct; if it was reported nearer the position of C2 than C1, C2 was scored as correct. If this criterion also failed to give a solution (e.g., if the item happened to be reported in the middle range between C1 and C2), then a final biased criterion was used, and C1 was counted as correct. This final criterion was used in less than 1 out of 20 cases. Because there were very few such cases, this biased criterion should not have appreciably changed the overall picture.

Results

Probability of identifying each item. The probability of identifying each letter in RSVP and BSVP as a function of repetition status (repeated vs. nonrepeated) and serial position (1 through 5) is shown in Table 1. Inspection of Table 1 shows that the overall pattern of performance was strikingly similar in the two presentation conditions. In both the RSVP and BSVP conditions, participants were impaired in reporting repeated items relative to nonrepeated ones.

As can be seen in Table 1, C2 was identified worse in the repeated condition than in the nonrepeated condition, indicating classic RB. This effect was significant in the RSVP condition, $t(40) = 12.37$, $p < .001$, for the fourth letter in the first set and $t(40) = 11.17$, $p < .001$, for the fifth letter in the second set, and in the BSVP condition, $t(28) = 5.01$, $p < .001$, for the fourth letter in the first set and $t(28) = 2.82$, $p < .02$, for the fifth letter in the second set. Surprisingly, there was also a small effect of repetition for C1. The backward RB was significant in the RSVP condition, $t(40) = 8.98$, $p < .001$, for the second letter in the first set and $t(40) = 3.28$, $p < .01$, for the third letter in the second set, and was marginally significant in the BSVP condition, $t(28) = 2.66$, $p < .02$, for the second letter in the first set and $t(28) = 1.55$, $p < .14$, for the third letter in the second set.

Table 1
Probability of Identifying Each Item as a Function of Presentation Mode, Repetition Status, and Serial Position in a Five-Letter String in Experiment 1

	Serial position				
Repetition status	1	2	3	4	5
Rapid serial visual presentation					
Repeated at 2 and 4	.90	.65	.83	.41	.75
Repeated at 3 and 5	.94	.81	.70	.81	.38
Nonrepeated	.93	.80	.76	.73	.67
Brief simultaneous visual presentation					
Repeated at 2 and 4	.95	.86	.88	.49	.73
Repeated at 3 and 5	.95	.93	.77	.73	.51
Nonrepeated	.96	.92	.81	.70	.64

A potential problem with the aforementioned data (and thus the effect of backward RB) concerns the possibility of migration errors when only one of two repeated items was reported by a participant. If the participant identified the first occurrence of a repeated item but reported it in the position of the second occurrence, an underestimation of identification performance for the first occurrence would occur. This is not merely a theoretical possibility but an empirically justified one because letter migration errors are common in RSVP (e.g., Reeves & Sperling, 1986) as well as BSVP (e.g., Mozer, 1983). To avoid the difficulties introduced by the effects of item migration, Kanwisher (1987, 1991) used a different way of determining the magnitude of RB. This procedure relies on the analysis of participants' probability of reporting two critical items together as a function of repetition status (repeated vs. nonrepeated). We present the results based on this analysis later in this article.

Another striking result emerged from Table 1. It appears that nonrepeated letters that preceded or followed C2 in the repeated condition were identified better than their counterparts in the nonrepeated condition. In RSVP, when C2 occurred in the fourth position, the letters in the third and fifth positions were identified better than their counterparts in the nonrepeated condition: 83% vs. 76%, $t(40) = 3.81$, $p < .001$, for the third position and 75% vs. 67%, $t(40) = 2.83$, $p < .01$, for the fifth position; when C2 occurred in the fifth position, the letter in the fourth position was identified better than its counterpart in the nonrepeated condition: 81% vs. 73%, $t(40) = 4.45$, $p < .001$. Similarly, in BSVP, when C2 occurred in the fourth position, the letters in the third and fifth positions were identified better than their counterparts in the nonrepeated condition: 88% vs. 81%, $t(28) = 3.70$, $p < .002$, and 73% vs. 64%, $t(28) = 2.42$, $p < .03$, respectively; when C2 occurred in the fifth position, the letter in the fourth position was also identified slightly better than its counterpart in the nonrepeated condition, but the effect did not reach significance. Note that this enhanced performance for nonrepeated items in the repeated condition seemed to occur only for the nonrepeated items that immediately preceded and those that followed the second occurrence of a repeated item.

Probability of identifying both critical items. Following Kanwisher (1987), we also analyzed the proportion of trials in which participants correctly reported both critical items (C1 and C2) as a function of repetition status in order to further evaluate whether RB occurred in the RSVP and BSVP conditions. In the repeated trials, repeated items occurred either in the second and fourth positions or in the third and fifth positions. Preliminary analysis showed that the pattern of results was almost identical in the two cases. For simplicity, Table 2 shows the results after collapsing across the data from the two sets of repeated trials.

In Table 2, we assessed RB by analyzing the difference in performance between the repeated (R) and nonrepeated (NR) conditions, namely R − NR.[2] Three main results emerged from Table 2. First, participants were much more likely to miss at least one of the two critical items when they were identical than when they were different, indicating classic RB. Second, RB occurred both when items were presented successively and when items were presented simultaneously, showing both temporal and spatial RB. Third, RB seemed to be smaller in the simultaneous presentation condition than in the successive presentation condition.

An analysis of variance (ANOVA) of the data confirmed these observations. First, there was a significant effect of presentation mode (RSVP vs. BSVP), $F(1, 34) = 7.03$, $MSE = .046$, $p < .01$. Second, there was a significant effect of repetition status (repeated vs. nonrepeated), $F(1, 34) = 132.66$, $MSE = .012$, $p < .001$, indicating RB. A further analysis (*t* test) showed that this was true in both presentation modes (both *p*s < .01). Finally, there was a significant interaction between presentation mode and repetition status, $F(1, 34) = 9.04$, $MSE = .012$, $p < .01$, indicating that the magnitude of RB was smaller when items were presented simultaneously than when items were presented successively. A further analysis (*t* test) confirmed that RB in the BSVP condition was significantly smaller than that in the RSVP condition ($p < .01$).

Discussion

This experiment showed that (a) repeated items were identified worse than their counterparts in the nonrepeated condition regardless of whether they were presented successively or simultaneously, indicating both temporal and spatial RB; (b) RB was smaller in simultaneous presentation than in successive presentation; and (c) in both presentation modes, nonrepeated items that immediately preceded or followed C2 in the repeated condition were identified better than their counterparts in the nonrepeated condition.

Table 2
Magnitude of Repetition Blindness as a Function of Presentation Mode in Experiment 1

Presentation mode	Repeated (R)	Nonrepeated (NR)	Repetition blindness (R − NR)
RSVP	15.3	52.6	−37.3
BSVP	36.6	58.4	−21.8

Note. The data are based on the percentage of reporting two critical items together. RSVP = rapid serial visual presentation; BSVP = brief simultaneous visual presentation.

The first two results confirmed the findings by Kanwisher (1991), who, using words and pronounceable nonwords, demonstrated RB for both sequentially and simultaneously presented items and also obtained reduced RB with simultaneous presentation. These findings indicate that it is not the temporal proximity of stimulus inputs per se that is the necessary condition for RB to occur. What, then, might be the factor mediating RB in both RSVP and BSVP? As argued in the introduction, the difference between the successive and simultaneous presentations may be more apparent than real. On the one hand, the processing of two successive stimuli may overlap in time. On the other hand, two simultaneously presented stimuli may be processed sequentially to some degree. There is, therefore, a common link between the successive and simultaneous presentation conditions: In both cases, the encoding processes of two identical items may partially overlap in time. This raises the possibility that the necessary condition for RB to occur is the temporal proximity of encoding processes for repeated items. On this view, RB would occur whenever the COA between repeated items is sufficiently small so that their encoding processes overlap. Note that by overlap we mean that the effects of C1 on the recognition unit have not completely dissipated (i.e., the unit has not returned to its resting state) by the time C2 begins to have its effects on the recognition unit. On this view, the BSVP condition should be as likely as the RSVP condition to lead to RB.

How, then, can we account for the fact that the magnitude of RB is smaller in the BSVP condition than in the RSVP condition? One possibility suggested by Kanwisher (1991) is that the simultaneous presentation is probably the only presentation format in which C1 and C2 cannot be interpreted as coming from two different views of the same object. This may very well be the case, but it is not clear how this fact may be used to explain both the presence and the magnitude of the RB effect in the BSVP condition. A second possibility proposed by Kanwisher is the possible change in the level of encoding from isolated letters in

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[2] Another way of calculating RB would be to compare the magnitude of the difference in the repeated versus nonrepeated conditions for C2 and C1, respectively. This estimate of RB requires that C2 suffer from repetition more than C1 before it can be claimed that RB has occurred, that is, $(C2_{NR} - C2_{R}) > (C1_{NR} - C1_{R})$. Although this measure of RB is intuitively appealing, it could not be used in this study because the serial position data were not absolutely valid because of the fact that (a) when only one item was reported in the repeated condition, there was no way of definitely determining whether it was C1 or C2; (b) migration errors in perception might have led to an underestimation of C1 performance and accordingly an overestimation of C2 performance; and (c) in the following experiments, we used a biased scoring procedure when repetition lag was 0 (if participants responded *ABD* to stimulus *ABBD*, the first *B* was scored as correct), and thus C1 in the Lag 0 condition was overestimated relative to C1 in the other lag conditions where order information could be used to infer whether C1 or C2 was reported.

RSVP to a whole stimulus in BSVP. The basis for this proposal is that the former (RSVP) but not the latter (BSVP) condition encourages encoding the stimulus letter by letter instead of treating the letter strings as a potential word. Setting aside the fact that it is not obvious how this change in encoding levels would account for the observed differences, this explanation cannot be extended to account for the results from the present study because we used only unrelated letters and, therefore, the level of encoding is always necessarily at the letter level. A related possibility is that the finding could reflect the fact that in the BSVP condition attention is divided among stimuli that are presented simultaneously, whereas in the RSVP condition attention can be focused sequentially over each letter in the stimulus.[3] Here, the emphasis is not on the difference in stimulus characteristics or the encoding unit (letter vs. word) but on the relative allocation of processing resources to different parts of a stimulus. However, it is not obvious how this difference in attention between RSVP and BSVP should lead to the observed difference in RB magnitude. A final possibility is that the observed difference in RB between RSVP and BSVP may be related to the difference in the degree of temporal overlap (or COA) in processing C1 and C2. Because of the nature of presentation, it can be argued that the degree of processing overlap between C1 and C2 is likely to be greater in BSVP than in RSVP. This will lead to a relatively smaller COA in BSVP than in RSVP. However, it remains to be explained why RB is smaller when COA is smaller. We come back to this issue in the General Discussion section.

Another result that needs to be explained is the fact that nonrepeated items in the repeated condition were identified better than their counterparts in the nonrepeated condition. At first glance, this result might be taken as prima facie evidence for the view that RB is a memory as opposed to a perceptual phenomenon (e.g., Fagot & Pashler, 1995). Thus, one might argue that the better performance for nonrepeated items in the repeated condition makes sense if a repeated item were deleted from the memory buffer, reducing competition for scarce memory storage, retrieval resources, or both. However, it is not clear how the memory account of RB can explain the specific patterns of results obtained in this experiment. According to the *storage failure hypothesis,* both occurrences of a repeated item are identified and stored in the memory buffer, but somehow one of the two is later deleted. If this were the case, it would reduce the memory load, leading to better performance for the remaining items. But, why is it that only the items that immediately precede or follow C2 seem to benefit from the reduction in memory load? To explain this result, stronger assumptions than simply the claim of reduced memory load are necessary. Even more serious difficulties are encountered by the *memory retrieval failure hypothesis.* According to this explanation of RB, all items in a stimulus trial are processed and stored in memory, and RB occurs because of output bias against repeated items. If this were the case, then it is not clear why there should be any benefit at all for the nonrepeated items in the repeated condition relative to their counterparts in the nonrepeated condition. That is, because the memory loads in the repeated and nonrepeated conditions are the same, there is no reason to expect better performance for the nonrepeated items in either condition. Thus, it is not clear how the memory retrieval failure hypothesis can account for the superior performance in reporting nonrepeated items in the repeated condition.

Finally, we would like to suggest that a perceptual account may be able to provide a satisfactory explanation for the enhanced performance on nonrepeated items in the repeated condition. It can be argued that if the visual recognition system is "blind" to the second occurrence of a repeated item, then there should be less interference in processing the items that immediately precede and follow the repeated one. The local nature of the reduction in processing interference also explains why only the items around the repeated C2 are identified better. On this view, when RB occurs, the repeated item does not get into the memory buffer at all, and the better performance for the nonrepeated items around C2 is a consequence of C2 not being recognized. In short, the finding that the nonrepeated items in the repeated condition were identified better than their counterparts in the nonrepeated condition is not at all problematic for perceptual accounts of RB and may, in fact, be problematic for some memory accounts of the phenomenon.

Experiment 2

In Experiment 1, we obtained RB both for items in RSVP and for those in BSVP. We speculated that the reason that RB occurred regardless of whether items were presented successively or simultaneously was because the encoding processes of the repeated items partially overlapped in the two conditions. We referred to the lag between the encoding processes of two identical items in the successive and simultaneous presentation conditions as COA.

If COA is an important determinant of RB as we proposed, we should be able to observe a change in the magnitude of RB by manipulating factors affecting COA. Park and Kanwisher (1994) found that RB in RSVP diminished with temporal lag between two identical items (either a blank or some not-to-be-reported symbols between C1 and C2). This result can be interpreted as indicating that RB is a decreasing function of COA. The question we wanted to ask is whether spatial RB also varies as a function of repetition lag, where repetition lag is quantitatively defined as the number of distinct items separating repeated elements in report order. If the proposed role of COA is real, the answer should be positive.

Therefore, the purpose of Experiment 2 was to test whether spatial RB varied with COA. We used two repetition lags: 0 and 1. When lag was 0, two identical items appeared side by side without intervening items. When lag was 1, one item intervened between two identical ones, as in Experiment 1.

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[3] We thank Kim Shapiro for bringing this possibility to our attention.

Method

Participants. Twenty undergraduates from the same pool as that described in Experiment 1 participated for extra course credits.

Materials and design. The same 16 capital letters as those used in Experiment 1 were used to construct 5-letter stimuli. There were two independent variables in the experiment: repetition status (repeated vs. nonrepeated) and repetition lag (0 vs. 1). There were thus two sets of repeated trials. When the lag was 0, repetition occurred either in the second and third positions or in the third and fourth positions (e.g., *RDDKH, EZTTN*). When the lag was 1, repetition occurred in the second and fourth positions or in the third and fifth positions (e.g., *RDKDH, SLBRB*), as in Experiment 1.

There were 32 trials in each of the two repetition lag conditions and 32 trials in the nonrepeated condition, resulting in a total of 96 experimental trials. We used a within-subjects design in this experiment. All sets of stimulus trials were intermixed. Their order of presentation was randomized separately for each participant. An additional set of 12 trials was constructed for practice.

Procedure. The procedure was exactly the same as the one for simultaneously presented items in Experiment 1. The exposure time of the stimulus displays was determined individually for each participant on the basis of his or her performance in the practice session. The average exposure time was 323 ms, ranging from 200 ms to 400 ms. Participants were again instructed to report identified items in the left-to-right order (clockwise).

Results and Discussion

To determine whether RB varied with repetition lag, we analyzed participants' probability of reporting two critical items together as a function of repetition status (repeated vs. nonrepeated) and repetition lag (0 vs. 1). The results are shown in Table 3. The independent probability of identifying each item as a function of serial position was also analyzed. These data are shown in Appendix A. Because they did not show different patterns of results, only the probability of correctly identifying both critical items is discussed here.

When repetition lag was 0, repeated items occurred either in the second and third positions or in the third and fourth positions. Similarly, when repetition lag was 1, repeated items occurred either in the second and fourth positions or in the third and fifth positions. Preliminary analysis showed that in both cases the pattern of results was almost identical for the two sets of repeated trials. The data were therefore pooled together. Table 3 shows the results after collapsing across the two sets of repeated trials for each repetition lag.

There are two main results of interest in Table 3. First, RB occurred both when two identical items appeared side by side (lag = 0) and when they were separated by one intervening element (lag = 1). Second, the effect was smaller in the Lag 0 condition than in the Lag 1 condition. A within-subjects ANOVA confirmed this observation. The analysis showed a significant effect of repetition lag, $F(1, 19) = 51.95$, $MSE = .012$, $p < .001$, and a significant effect of repetition status, $F(1, 19) = 37.29$, $MSE = .015$, $p < .001$. Finally, the ANOVA showed a significant interaction between repetition lag and repetition status, $F(1, 19) = 23.35$, $MSE = .005$, $p < .001$, indicating that the magnitude of RB was smaller when repetition lag was 0 than when it was 1. A further analysis (*t* test) confirmed that RB was smaller in the Lag 0 condition than in the Lag 1 condition ($p < .01$), although it was significant in both conditions (both $ps < .01$).

The finding of reduced RB with immediate repetition (lag = 0) is surprising. First, if RB were a monotonically decreasing function of COA, we would have expected to observe greater RB in the Lag 0 condition than in the Lag 1 condition. Second, the finding seems to be inconsistent with the earlier report that RB in RSVP decreased monotonically with SOA (Kanwisher, 1987; Park & Kanwisher, 1994). In RSVP, because of possible stimulus summation when two identical items follow one another too closely in time, the effects of immediate repetition on RB have not been examined carefully. However, in BSVP, this question can be easily addressed because repetition lag can be varied to include a 0 lag condition. If the finding of reduced RB with very small repetition lags were to prove to be a reliable one, it would constitute a significant challenge to current theories of RB and provide important constraints in the development of alternative accounts of the phenomenon.

Table 3
Magnitude of Spatial Repetition Blindness as a Function of Repetition Lag in Experiments 2 and 3

Repetition lag	Repeated (R)	Nonrepeated (NR)	Repetition blindness (R − NR)
	Experiment 2		
Lag = 0	60.8	69.8	−9.0
Lag = 1	35.3	60.2	−24.9
	Experiment 3		
Lag = 0	45.3	61.0	−15.7
Lag = 1	24.2	50.1	−25.9
Lag = 2	33.3	56.2	−22.9
Lag = 3	41.1	54.6	−13.5

Note. The data are based on the percentage of reporting two critical items together.

Experiment 3

Experiment 3 had two purposes. The first was to replicate the finding that RB is smaller at very short lags than at slightly longer lags. The second purpose was to further investigate the repetition lag effect by varying lag over a wider range of values and to examine how RB varied over this wider range.

Method

Participants. Eighteen undergraduates from the same pool as that described in Experiment 1 participated for extra course credits.

Materials and design. The same 16 capital letters as those used in Experiment 1 were used to construct 5-letter stimuli. As in Experiment 2, there were two independent variables: repetition status and repetition lag. For the repeated trials, repetition lag was varied from 0 to 3. When the lag was 0, repetition occurred either in the second and third positions or in the third and fourth positions (e.g., *RDDKH, EZTTN*). When the lag was 1, repetition occurred either in the second and fourth positions or in the third and fifth positions (e.g., *RDKDH, SLBRB*). When repetition lag was 2, repetition occurred in the first and fourth positions and in the second and fifth positions (e.g., *TKETS, EPHLP*). When repetition lag was 3, repetition occurred in the first and fifth positions (e.g., *NLECN*). All 16 letters had approximately the same probability of appearing in each of the nonrepeated and repeated positions.

There were 20 trials in each of the four repetition lag conditions and 80 trials in the nonrepeated condition, resulting in a total of 160 experimental trials. A within-subjects design was used. All sets of stimulus trials were intermixed. Their order of presentation was randomized separately for each participant. An additional 16 trials were constructed for practice.

Procedure. The procedure was exactly the same as that in Experiment 2. The exposure time of the stimulus displays was 200 ms for all participants. Participants were again instructed to report identified items in the left-to-right order (clockwise).

Results and Discussion

To determine whether RB varied with repetition lag, we analyzed participants' probability of reporting two critical items together as a function of repetition status and repetition lag. Table 3 shows participants' percent correct performance for each repetition lag. The independent probability of identifying each item as a function of serial position was also analyzed and is shown in Appendix A. As in Experiment 2, our analyses focused on the probability of reporting C1 and C2 together. A within-subjects ANOVA of the data showed three main results. First, there was a significant effect of repetition lag, $F(3, 51) = 14.43$, $MSE = .011$, $p < .001$. Second, there was a significant effect of repetition status, $F(1, 17) = 85.07$, $MSE = .016$, $p < .001$. More important, there was a significant interaction between repetition lag and repetition status, $F(3, 51) = 4.50$, $MSE = .007$, $p < .01$, indicating that the magnitude of RB varied as a function of repetition lag.

Further analyses (*t* tests) of the magnitude of RB among the four repetition lag conditions showed that the effect in the Lag 0 condition was smaller than that in the Lag 1 condition, $t(34) = 2.56$, $p < .02$, and that the Lag 3 condition was smaller than that in the Lag 2, $t(34) = 2.84$, $p < .01$, and Lag 1, $t(34) = 3.73$, $p < .01$,[4] conditions, indicating that RB first increased and then decreased with repetition lag. The results for Lag 0 and Lag 1 replicate those obtained in Experiment 2, which showed that RB was smaller at very short lags than at longer lags. However, the finding that RB decreased when lag was increased from 1 to 2 or 3 items confirms earlier reports (Kanwisher, 1987; Park & Kanwisher, 1994) that RB in RSVP diminishes with the number of intervening items (beyond immediate repetition). Taken together, Experiments 2 and 3 show that RB in BSVP is an inverted U-shaped function of repetition lag.

Experiment 4

A potential problem in Experiments 2 and 3 is that repetition lag between repeated items was confounded with spatial distance between them: Short lag was associated with small spatial separation, whereas long lag was associated with large spatial separation. Thus, it is possible that the observed relationship between repetition lag and the magnitude of RB may be due in part to differences in spatial separation of C1 and C2. Accordingly, the purpose of Experiment 4 was to determine whether RB was affected by the spatial separation between C1 and C2. If not, we can be more confident that it is repetition lag rather than spatial distance that is the factor modulating RB.

Method

Participants. Sixteen undergraduates from an introductory psychology course at Dartmouth College participated for extra course credits.

Materials and design. The same 16 capital letters as those used in Experiment 1 were used to generate 2-letter stimuli. Letters were sampled randomly in each condition and separately for each participant. A within-subjects design was used. There were two independent variables in this experiment. The first was repetition status (repeated vs. nonrepeated). A repeated-stimulus trial consisted of 2 identical letters, whereas a nonrepeated trial consisted of 2 distinct letters. The second variable was the spatial distance between the 2 letters in a stimulus. The 2 letters appeared at any two of the eight locations in the visual display described in Experiment 1. The spatial distance between 2 letters was measured by the number of spaces separating them: 0, 1, 2, or 3. When the distance was 0, the 2 letters were adjacent to each other along the circumference of the circle in the visual display. When the distance was 3, the 2 letters were at the two ends of the circle's diameter. The four spatial distances corresponded to a separation of 0.57°, 1.26°, 1.72°, and 1.95° of visual angle, respectively.

Procedure. At the beginning of the experiment, participants were shown written instructions on the computer screen. They were told that their task was to identify two letters that were presented briefly and simultaneously. The stimulus consisted of two letters and six dollar signs. They appeared as soon as the fixation cross was off and lasted for 67 ms. The presentation time was determined on the basis of a pilot study designed to avoid ceiling effects. The poststimulus mask was composed of eight dollar signs that immediately followed the stimulus and lasted for 100 ms. After stimulus presentation, participants were asked to type on the computer keyboard the letters they had seen. They were also told that on half of the trials the two letters would be identical, and in that case they should report both of them.

There were 160 stimulus trials. Half of them were repeated trials, and the other half were nonrepeated trials. All stimulus trials were intermixed, and the order of their presentation was randomized separately for each participant. An additional set of 16 trials (8 repeated and 8 nonrepeated) was generated and used for practice.

Results and Discussion

Table 4 shows the percentage of trials in which participants correctly reported both items as a function of repeti-

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[4] The significance level for these three *t* values was $p < .05$ after we made error corrections for multiple *t* tests.

Table 4
Percentage of Correctly Reporting Both of Two Presented Items as a Function of Repetition Status and Spatial Distance in Experiment 4

Spatial distance	Repeated (R)	Nonrepeated (NR)	Repetition blindness (R − NR)
0	54.4	67.8	−13.4
1	55.3	70.6	−15.3
2	54.4	74.1	−19.7
3	59.7	74.1	−14.4

tion status (repeated vs. nonrepeated) and spatial distance (0 through 3). A within-subjects ANOVA on the data showed a significant effect of repetition status, $F(1, 15) = 20.04$, $MSE = .039$, $p < .001$, indicating spatial RB for two-letter stimuli. The effect of spatial distance was not significant, $F(3, 45) = 1.71$, $MSE = .011$, $p = .18$. There was no indication of interaction between the two variables, $F < 1$, indicating that the spatial distance between two items had no influence on the magnitude of RB.

The fact that RB did not vary with the spatial distance between C1 and C2 indicates that the observed relationship between repetition lag and RB magnitude in Experiments 2 and 3 was not due to a difference in spatial distance associated with repetition lag. The finding also indicates that RB is modulated primarily by temporal rather than spatial factors, which is consistent with the notion of COA. Finally, the fact that spatial RB occurred even when there were only two items to be recognized by participants suggests that RB is a perceptual rather than a memory phenomenon.

General Discussion

This study investigated the effects of presentation mode and repetition lag on RB. Two results are of particular interest. One is that RB was obtained in both RSVP and BSVP conditions (Experiment 1), replicating Kanwisher's (1991) earlier report. The second and more important result is that the magnitude of spatial RB varied with repetition lag (Experiments 2 and 3): RB first increased and then decreased with the number of distinct items separating two identical ones, indicating that it is an inverted U-shaped function of repetition lag. We also showed that this relationship is not due to differences in spatial separation between C1 and C2 because RB does not vary with spatial distance (Experiment 4).

The fact that RB is an inverted U-shaped function of repetition lag severely limits the range of plausible interpretations of the phenomenon. However, so far, this result has been obtained only in the BSVP condition. The question arises whether RB in RSVP is also an inverted U-shaped function of repetition lag. We proposed that the common element relating the occurrence of RB in successive (RSVP) and simultaneous (BSVP) presentation is COA—the temporal lag in processing two repeated items. Because RB in BSVP is an inverted U-shaped function of repetition lag, it invites the inference that the magnitude of RB is an inverted U-shaped function of COA. If, as proposed here, COA were the common factor modulating RB in both RSVP and BSVP, then we would expect RB in RSVP to also be an inverted U-shaped function of repetition lag. As already noted, Park and Kanwisher (1994) manipulated SOA and found that RB was a decreasing function of SOA. However, since they used only long SOAs (>200 ms), probably because of possible masking or summation effects at very short SOAs, it is possible that their results simply reflect the later, increasing part of the inverted U-shaped function. In contrast, Hochhaus and Marohn (1991) varied SOAs and found that RB was an inverted U-shaped function of SOA, although they used a priming paradigm in which only two items were presented. Clearly, a definitive answer requires further investigation. However, the current results are not incompatible with the possibility that RB in RSVP could also be an inverted U-shaped function of SOA and thus of COA.

In the following sections, we first consider whether RB should be characterized as a perceptual or a memory phenomenon. We argue that the current results are better explained as an on-line perceptual phenomenon occurring at the stage of stimulus encoding rather than an off-line memory phenomenon occurring at the stage of memory storage or retrieval. Second, we consider whether a particular perceptual account (the type refractoriness hypothesis) can provide an adequate account of RB. Finally, we explore whether the type refractoriness hypothesis can explain other repetition effects found in visual perception.

Is RB a Memory Phenomenon?

The RB phenomenon was originally explained in terms of a perceptual processing deficit—the type–token model proposed by Kanwisher (1987). However, Fagot and Pashler (1995; see also Whittlesea & Podrouzek, 1993) recently proposed a memory account of RB. They suggested that both RB and the Ranschburg effect reported in the memory literature are caused by a mixture of guessing bias and output interference from memory.

Although the paradigm used in the present study imposed relatively strong demands on memory processes, this does not mean that the RB effects we have reported necessarily have to have a memory locus. Indeed, a memory storage or retrieval failure explanation faces nontrivial difficulties in explaining the full range of RB effects. There are two facts that are particularly problematic for the memory account: (a) the finding that RB is an inverted U-shaped function of repetition lag and (b) the fact that RB also occurs in conditions where memory requirements are at a minimum.

A major difficulty for the memory account is the finding that RB in BSVP is an inverted U-shaped function of repetition lag. As noted, Fagot and Pashler (1995) argued for a similar underlying mechanism for RB and the

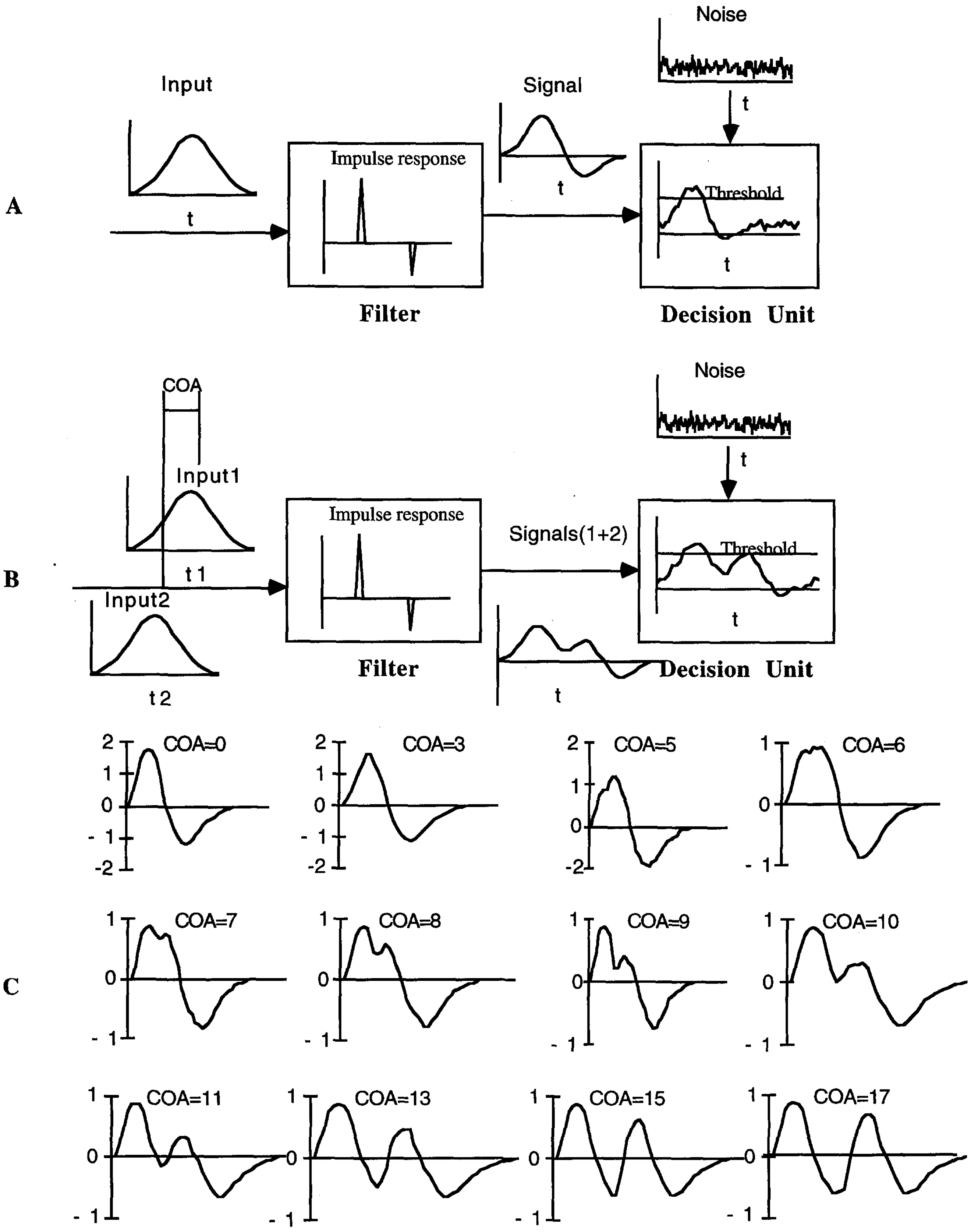
Ranschburg effect. Because Crowder (1968) also found a similar inverted U-shaped relationship between repetition lag and the Ranschburg effect, one might think that this indicates that the effect demonstrated in the present study and the Ranschburg effect have a common basis. However, the two functions are only superficially similar: Close inspection reveals that the effects of repetition lag on RB and the Ranschburg effect are radically different. In the present experiments, RB was obtained when repetition lag was 0, although its magnitude was reduced relative to Lag 1. In contrast, in Crowder's memory study, the effect of repetition was facilitatory when lag was 0 or 1. This discrepancy undermines the argument that RB and the Ranschburg effect have a common basis. The facilitatory effect of repetition when lag was 0 or 1 in Crowder's study may be accounted for by arguing that chunking occurred in processing the repeated items when they closely followed each other in time. However, the chunking mechanism cannot be used to explain why RB was reduced when repetition lag was 0 in the present study. This is because if the repeated item were not lost before entering the memory buffer, the chunking process would have made RB completely disappear, as in Crowder's experiment. One might argue that if chunking did not get applied 100% of the time, then there would be a cost of repetition, but a reduced one. This argument is based on the seemingly plausible assumption that participants must notice a repetition before chunking can be applied and that in the very rapid presentation format we used to get RB, immediate repetitions are less likely to be noticed than they are in slow serial (Ranschburg) presentation. But this argument begs the question. If participants have no problem in perceptually processing the items (at least as compared with nonrepeated items), as the memory account assumes, the exact opposite argument could be made: It should be very easy to notice immediate repetition when two identical items are side by side. Therefore, the memory account should predict repetition facilitation in the Lag 0 and Lag 1 conditions, as has been reported for the Ranschburg effect. The fact that RB, rather than priming, occurred in our experiments indicates that the phenomenon we are dealing with is most likely different than the (memory) Ranschburg effect.

The other major difficulty for memory accounts of RB concerns evidence from task conditions where memory requirements are at or near the minimum. The logic of the memory account of RB is that memory storage and retrieval processes and strategies might work against repeated items when the system is near or beyond its limit of capacity. One problem for this view is that RB has also been demonstrated under the minimum or near minimum memory load conditions (e.g., Hochhaus & Johnston, in press; Hochhaus & Marohn, 1991; Humphreys, Besner, & Quinlan, 1988), including our Experiment 4. In Hochhaus and Marohn's study, for example, RB occurred when participants needed to identify only the second of two sequentially and spatially displaced items. In a recent study, Luo and Caramazza (1995) also showed RB for two sequentially presented items in both full and partial report (reporting only the second of two successively and briefly presented items). Similarly, Ward, Duncan, and Shapiro (1992; see also Shapiro & Raymond, 1994) demonstrated RB when participants ignored noncritical items in an RSVP sequence. Finally, Park and Kanwisher (1994) showed that RB did not increase significantly with memory load, whether the extra items were added before C1 or after C2. Taken together, these findings indicate that RB cannot be entirely explained in terms of deficits in memory storage or retrieval. However, we wish to stress that the mere fact that a simple memory explanation cannot fully account for the core features of RB does not mean that memory processes may not, in fact, contribute to the complex pattern of RB phenomena.

Type Refractoriness Account of Repetition Blindness

Even if RB were really a perceptual deficit, currently the best articulated perceptual account of this phenomenon—the type–token binding failure model (Kanwisher, 1987)—also encounters difficulty in accounting for some of the data from the present and other studies. First, it is not clear how the model can account for the nonmonotonic relationship between repetition lag and RB that we reported in the present study. Because the type–token binding failure model emphasizes the dissociation between the type activation process and the token individuation process, the model in its current form does not provide a mechanism for interpreting the observed time course of the RB phenomenon. Another difficulty for the type–token binding failure model is that the evidence Kanwisher presented for the dissociation between type activation and type–token binding is not decisive. Her original finding that repetition priming occurred only when C2 had to be reported cannot be reliably replicated (e.g., Kanwisher & Potter, 1990b). Luo and Caramazza (1995) also failed to replicate the original priming result and instead obtained significant RB when participants were required to report only the second of two successively presented items. This pattern of results undermines Kanwisher's argument against the type refractoriness hypothesis. The original motivation for proposing the type–token dissociation is thus weakened.

Because the aforementioned findings collectively raise difficulties for the type–token binding failure model as well as the memory account, we were encouraged to explore whether some variant of the type refractoriness hypothesis might not provide a better explanation of the RB phenomenon. The account we propose here is based on the concepts of COA and refractory period. *Refractory period* refers to a brief period of time in which a recognition system's sensitivity, immediately after responding to a stimulus, is reduced and then recovers to its resting level. The idea that a system might have a refractory period is not new. For example, the concept of refractoriness is an important one in neurobiology: Neurons have a refractory period in which their excitability is temporarily reduced after firing. In the present case, the assumption is that a type node in long-term memory becomes temporarily insensitive immediately after having fired in response to appropriate stimulation. The


A
Input
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Impulse response
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B
COA
Input1
t1
Input2
t2
Impulse response
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Signals(1+2)
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Noise
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Threshold
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Decision Unit
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COA=0
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model presented here, schematically shown in Figure 2, is a specific worked-out version of the type refractoriness hypothesis. Bavelier and Jordan (1992) proposed a somewhat similar model, although based on the idea of threshold resetting after a unit fires.

The proposed system can be thought of as a mechanism for activating a type node in long-term memory. The type node has two components: (a) a linear filter that has a rising and falling impulse response and (b) a decision unit that takes the output of the filter as its input and fires if it satisfies some decision criteria. (To make the system work, just surpassing some fixed threshold is not enough. To avoid responding to noise too often, other criteria are needed. See Appendix B for details.) Note that the output function from the filter is the convolution of the original input Gaussian function with the filter's impulse response. The particular forms of input to the filter and the impulse function we have used here were chosen simply for convenience so that we could get an output signal of the desired shape (i.e., that of having a refractory period). The activation function in the decision unit, then, is a combination of this output function and a noise function added to the decision unit.

Figure 2A schematically shows this process. The input to the filter is an activation function of a target stimulus, which we suppose is a Gaussian function. The response of the filter to this stimulation has two phases: a positive peak and a negative valley. Note that the type node does not instantly return from the firing state to its resting state. After giving a spike response, the type node's activation level reverses to a below baseline level before it fully recovers. The period of time in which the type node's activation level decreases and falls below the baseline level and then recovers to its resting state is the so-called refractory period.

Figure 2B schematically shows what happens when the type node is stimulated repeatedly. Because of the existence of the refractory period, the type node's responses to two identical stimuli may overlap when they are processed closely in time. If the filter receives a second input before it returns to its resting state, its response to this second input will be affected. There are two possible outcomes, depending on the lag between the encoding of the two stimuli, namely, COA. If COA is sufficiently small and the second input comes before the activation of the first one reaches its peak, two activation functions may be summated into a single one. If the onset of the second input falls in the refractory period, a reduced response to the second input can be expected.

Figure 2C shows the filter's responses to two stimulations as a function of their COA. It can be seen that when COA is very small, there is only one peak response. As COA increases, a second peak emerges. Importantly, the strength of this second peak first decreases and then increases with COA, showing that RB is an inverted U-shaped function of repetition lag. A simulation of the model is shown in Appendix B.

The model can account for the principal results in the present study. First, the fact that RB was obtained with both successive and simultaneous presentations is explained by the assumption that despite the differences in the mode of presentation, the processing of the repeated items partially overlap in both tasks. Accordingly, the relevant variable in determining RB is not SOA but COA. Thus, both temporal and spatial RB can be explained as resulting from a reduced sensitivity of the type node to the second stimulation after it had just responded to the first occurrence of the repeated item.

The proposed model can also account for the principal result in Experiments 2 and 3, where we found that RB first increased and then decreased with repetition lag. By hypothesis, the sensitivity of a type node decreases and then returns to its resting level as a result of responding to the first stimulation. Consequently, the probability that the second stimulation would cause the type node to fire again first decreases and then increases to its normal level. As shown in Figure 2, because the difference between the first peak and the second peak increases and then decreases, RB is expected to be an inverted U-shaped function of COA. Because repetition lag is the major determinant of COA in these experiments, RB is thus predicted to be an inverted U-shaped function of repetition lag.

Finally, there is the matter of why in our Experiment 1 (see also Kanwisher, 1991) RB was greater in RSVP than in BSVP. A possible explanation for this result may be found in the hypothesized temporal differences in encoding between the two experimental conditions. We have suggested that processing overlap between C1 and C2 may be relatively smaller in successive presentation than in simultaneous presentation; that is, we hypothesized that the COA at Lag 1 in the BSVP condition would be smaller than the COA for the corresponding RSVP condition. Because we hypothesized that at very short COAs the magnitude of

Figure 2. A type refractoriness account of repetition blindness. A shows the dynamics of the type node after a single stimulation. B shows the dynamics of the type node when it is stimulated repeatedly and one stimulation follows another closely in time. Repetition blindness occurs because after firing, the type node needs to recover from a refractory period during which its sensitivity is lower than the baseline. Note that t_1 and t_2 denote the time at which the stimulus is encoded (rather than the time at which it is presented), and coding onset asynchrony (COA) = $t_2 - t_1$. The superposition of two inputs' activation functions results in reduced net activation for the second occurrence of a repeated item, resulting in repetition blindness. C shows the response of the filter to two stimulations as a function of COA (arbitrary unit). When COA is very small, there is only one peak response. As COA increases, the second peak emerges. However, the strength of the second peak first decreases and then increases with COA; an inverted U-shaped function is obtained.

RB is smaller than at relatively longer COAs, it follows that RB should be larger in RSVP conditions than in BSVP conditions.[5]

Other Repetition Effects in Visual Perception

Several investigators have demonstrated other repetition effects that may or may not have connections to the repetition effects discussed above. One difficulty in determining whether these repetition effects have a common basis is that they usually have been demonstrated in studies that have used different experimental paradigms. Despite this difficulty, in this section we explore whether these repetition effects reflect a common functional property of the visual system.

Repeated-letter inferiority effect. As noted previously, Bjork and Murray (1977; see also Egeth & Santee, 1981; Santee & Egeth, 1980, 1982) reported a repeated-letter inferiority effect for two simultaneously presented letters. In their study, participants were briefly shown two letters and asked to report the one indicated by a poststimulus cue. The target letter was identified worse when the unreported noise letter was the same as the target letter than when it was a different letter.

Bjork and Murray (1977) interpreted the repeated-letter inferiority effect as indicating feature-specific inhibition among visual input channels. This conception was an extension of Estes's (1972, 1974) interactive channels model. The basic idea is that the excitation of a particular input channel caused by a specific feature in a stimulus results in both feature-specific inhibition of other channels processing the same feature and a more generalized inhibition of all input channels. Because the feature-specific inhibition is maximal when two stimuli are identical, the pair *BB* was predicted to be identified worse than the pairs *BK* and *BR.*

It has been argued that positional uncertainty for the target letter is important in producing the repeated-letter inferiority effect or similar effects (e.g., Keren & Boer, 1985; Mozer, 1989). In support of this notion, Keren and Boer found that repetition inhibition occurred when a poststimulus cue was given, whereas repetition facilitation or redundancy gain (e.g., B. A. Eriksen & C. W. Eriksen, 1974; C. W. Eriksen & B. A. Eriksen, 1979; C. W. Eriksen & Schultz, 1979) occurred when a prestimulus cue was given. However, there was an important variable that covaried with the manipulation of positional uncertainty in Keren and Boer's study. Thus, participants were required to process both the target and noise letters in the poststimulus cuing condition, but they were required to process only the target letter in the prestimulus cuing condition. As a consequence, the noise letter had to be attended in one case but could be ignored in the other. Kanwisher (1991) made a similar observation, although she used the token individuation terminology.

It can thus be argued that repetition inhibition occurs whenever two identical items have to be attended and processed together in a narrow time window. On this view, the repeated-letter inferiority effect and RB may have a common basis. Specifically, it could be argued that both the repeated-letter inferiority and the RB effects result from a deficit not at the feature detector level, as proposed by Bjork and Murray (1977), but at the level where letter identity is encoded. Support for the latter hypothesis also comes from Egeth and Santee (1981), who demonstrated that the repeated-letter inferiority effect can be obtained for letters of different cases (e.g., *A* and *a*). This result is in accord with the claim that the performance deficit for repeated letters reflects effects at the level of letter identity encoding rather than feature detection.

Finally, just like RB, the repeated-letter inferiority effect can also be explained by the type refractory model. Given that each type node has a refractory period, a target letter has an equal chance of being identified worse in the repeated condition than in the nonrepeated condition. If the postcued target letter happens to be processed first (first to activate its corresponding type), the target letter will be identified equally well in the repeated and nonrepeated conditions. However, if the noise letter, rather than the postcued target letter, happens to be processed first, the target letter will be identified less well because of type refractoriness. Here, the basic assumption is that COA between the two items cannot be zero (no parallel recognition at the identity level).

Masked repetition-priming effect. Using a priming paradigm, several investigators (e.g., Forster & Davis, 1984; Humphreys et al., 1988; Humphreys, Evett, Quinlan, & Besner, 1987) examined the effect of a briefly presented prime on the perception of a target item that followed immediately. The prime and the target could be the same or different. It has been found that if the first item was presented very briefly (about 40–60 ms) and masked, so that participants were not able to identify it, participants' probability of identifying the immediately following item was higher when the two items were the same than when they were different. This effect is called *masked repetition priming.*

In the type refractoriness model, masked repetition priming can be explained as activation summation. When the exposure time of the first occurrence of repeated items is very brief and followed immediately by the second occurrence, the small activation from the first occurrence does not reach threshold and thus would be summated with the activation of the second occurrence of the repeated item. Summation of activation from the two occurrences of the

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[5] Because RB is an inverted U-shaped function of repetition lag, an interaction between presentation mode and the magnitude of RB may be obtained when repetition lag is varied in a wide range. For example, if we assume that the hypothesized difference in COA between RSVP and BSVP conditions remains across different repetition lags, greater RB may be obtained in BSVP than in RSVP when repetition lag is big and falls in the range of the rising part of the function. Further investigation is needed to test this prediction. However, the aforementioned argument indicates that the smaller RB in BSVP than in RSVP for Lag 1 in Experiment 1 is potentially consistent with the more general finding that RB is an inverted U-shaped function of repetition lag, or COA.

same item results in enhanced perceptibility for the second occurrence.

Summary

In the present study, we were concerned with how and why the recognition of an item is influenced by the presence of an identical item close in time, space, or both—the phenomenon of RB. Temporal RB refers to the reduced performance in reporting a repeated item relative to a nonrepeated item in RSVP (Kanwisher, 1987). In Experiment 1, we varied presentation mode and demonstrated a parallel spatial RB effect in BSVP. RB thus occurs in both temporal and spatial domains, confirming earlier reports (e.g., Kanwisher, 1991; Mozer, 1989). In Experiments 2–4, spatial RB was shown to be an inverted U-shaped function of repetition lag—the number of items intervening between two identical ones in report order—rather than spatial separation per se. We argued that spatial lag becomes temporal lag in processing and that both temporal and spatial RB should be construed as a processing deficit modulated by COA—temporal lag in encoding two identical items—as opposed to SOA.

We further examined the theoretical implications of these findings and concluded that RB is better characterized as an on-line perceptual phenomenon rather than as a memory storage or retrieval phenomenon. We formalized a particular perceptual account—the type refractoriness hypothesis—and argued that RB and other repetition deficits reflect an intrinsic property of the activation function of type nodes in long-term memory, namely, the fact that after a type node reaches threshold it becomes temporarily hypoactive during a refractory period. This assumption allowed us to explain not only the existence of RB but also the time course of the effect.

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Appendix A

Serial Position Data for Experiments 2 and 3

Tables A1 and A2 show the independent probability of identifying each item as a function of serial position and repetition status in Experiments 2 and 3, respectively. Note that when repetition lag was 0 and participants reported only one repeated item, no intervening item could be used to infer whether the reported item was C1 or C2. In this case, if the item was reported either at or before the position of C1, C1 was scored as correct; if the item was reported either at or after the position of C2, C2 was scored as correct.

In general, the results replicate those in Experiment 1. An additional result is that when lag was 0, both the item that immediately followed C2 in the repeated condition and the one after were identified better than their counterparts in the nonrepeated condition. Is this consistent with the notion that RB is a memory phenomenon? The answer is probably no. First, note that RB in the Lag 0 condition was generally smaller than that in the Lag 1 condition, whereas the memory benefit in the Lag 0 condition was greater than that in the Lag 1 condition. The greater memory benefit, coupled with less RB, is not consistent with the memory explanation. This contrasting result suggests that even when RB does not occur, less burden is imposed on the memory buffer when lag is 0. One easy account for this is to assume that chunking occurred in processing C1 and C2. However, given that chunking occurs in processing, the memory account should then predict no RB. Our claim here is that when RB occurs, C2 does not get into the memory buffer at all, and when RB does not occur, C1 and C2 are chunked. In both cases, processing resources are saved, and thus the remaining items benefit.

Table A1
Probability of Identifying Each Item as a Function of Serial Position and Repetition Status (Repetition Lag) in a Five-Letter String in Experiment 2

	Serial position				
Repetition status	1	2	3	4	5
Repeated at 2 and 3	.96	.94	.76	.78	.72
Repeated at 3 and 4	.95	.94	.85	.58	.78
Repeated at 2 and 4	.94	.89	.89	.50	.65
Repeated at 3 and 5	.93	.92	.79	.71	.44
Nonrepeated	.96	.94	.84	.68	.57

Table A2
Probability of Identifying Each Item as a Function of Serial Position and Repetition Status (Repetition Lag) in a Five-Letter String in Experiment 3

	Serial position				
Repetition status	1	2	3	4	5
Repeated at 2 and 3	.97	.89	.61	.72	.68
Repeated at 3 and 4	.98	.96	.77	.46	.61
Repeated at 2 and 4	.98	.92	.79	.33	.65
Repeated at 3 and 5	.96	.94	.62	.58	.41
Repeated at 1 and 4	.93	.94	.84	.46	.69
Repeated at 2 and 5	.98	.85	.75	.71	.35
Repeated at 1 and 5	.96	.93	.77	.65	.45
Nonrepeated	.97	.94	.77	.61	.57

Appendix B

Simulation of the Model

To further illustrate how the model can be applied to predict the relationship between repetition lag and the magnitude of RB, we provide the results of a simulation of the model. The simulation work started with the selection of a Gaussian function as initial input and an impulse response function for the filter so that the output from the filter had the same shape as that shown in Figure 2A.

Let $G(t)$ denote the input function and $I(t)$ denote the filter's impulse response. Then the output from the filter, $H(t)$, is the convolution of $G(t)$ with $I(t)$, namely,

$$H(t) = G(t) * I(t) = \int_{-\infty}^{\infty} G(v)I(t - v)dv.$$

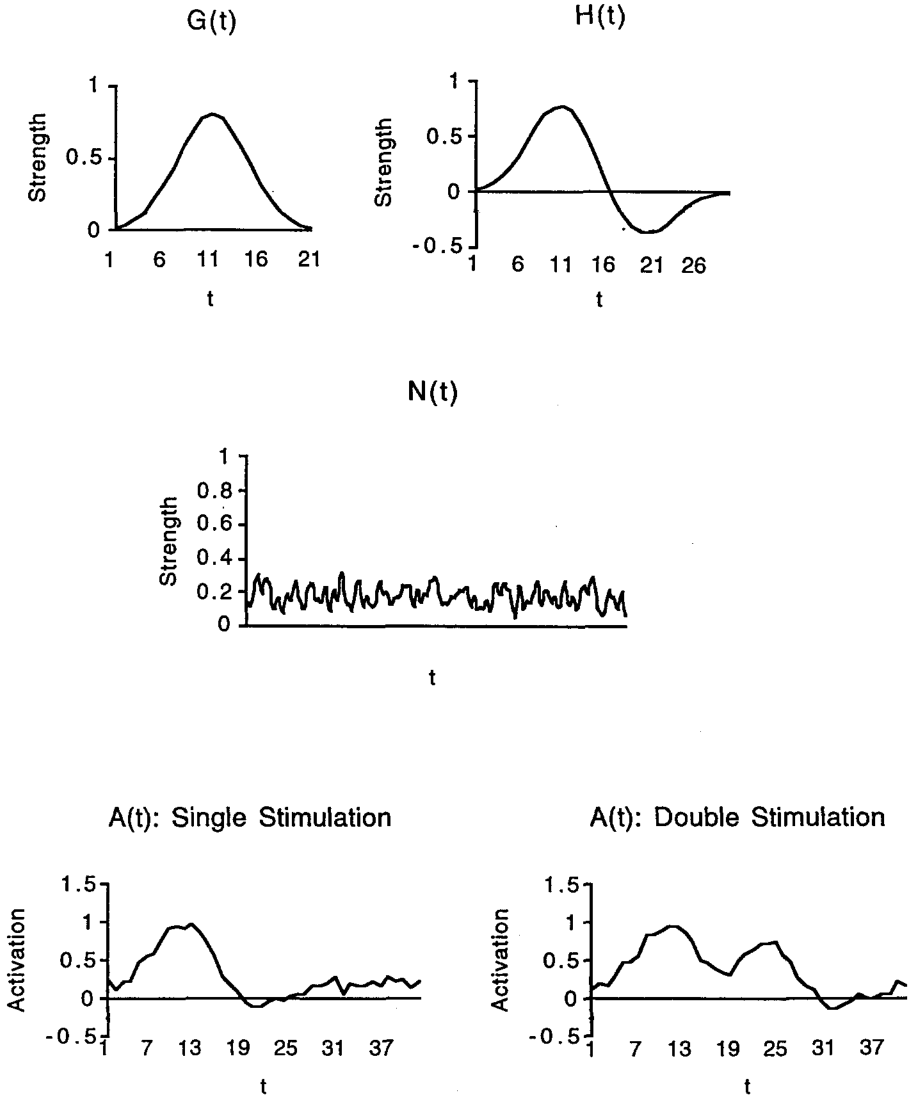

Figure B1. Examples of initial input function, $G(t)$; output from the filter, $H(t)$; random noise, $N(t)$; and activation function in the decision unit, $A(t)$, after single stimulation and double stimulation.

To simplify the case, we used a Gaussian function with mean $\mu = 0$ and variance $\sigma = 0.5$ as input and the following function as the ideal impulse response of the filter[B1]:

$$I(t) = \begin{cases} 1 \text{ if } t = -0.5, \\ -\beta \text{ if } t = 0.5, \\ 0 \text{ otherwise,} \end{cases}$$

where $0 < \beta \leq 1$. Note that β represents the falling part of the impulse response and thus determines the extent to which the activation function dips below the baseline. Figure B1 shows a concrete example of $G(t)$ and $H(t)$ with $\beta = 0.5$.

Next, we need to find a noise generator, $N(t)$. We used the following purely numerical procedure to obtain a noise waveform (Bracewell, 1978, pp. 333–334). First, we used a computer program to generate a series of random digits between 0 and 9. Then, we convolved these random digits with the sequence of binomial coefficients {1 5 10 10 5 1} and put a smooth curve through the points. The derived sequence had a mean of 144, and a further transformation was necessary to make it suitable for the present purposes. The final noise waveform was obtained after dividing each number by 800. A sample of the noise waveform is shown in Figure B1. The activation function in the decision unit, $A(t)$, is the combination of the signal, $H(t)$, and the random noise, $N(t)$. Examples of the activation function following single or double stimulation are also shown in Figure B1.

The decision algorithm of the model is as follows: The unit fires if and only if (a) the activation level, $A(t_i)$, is above some fixed

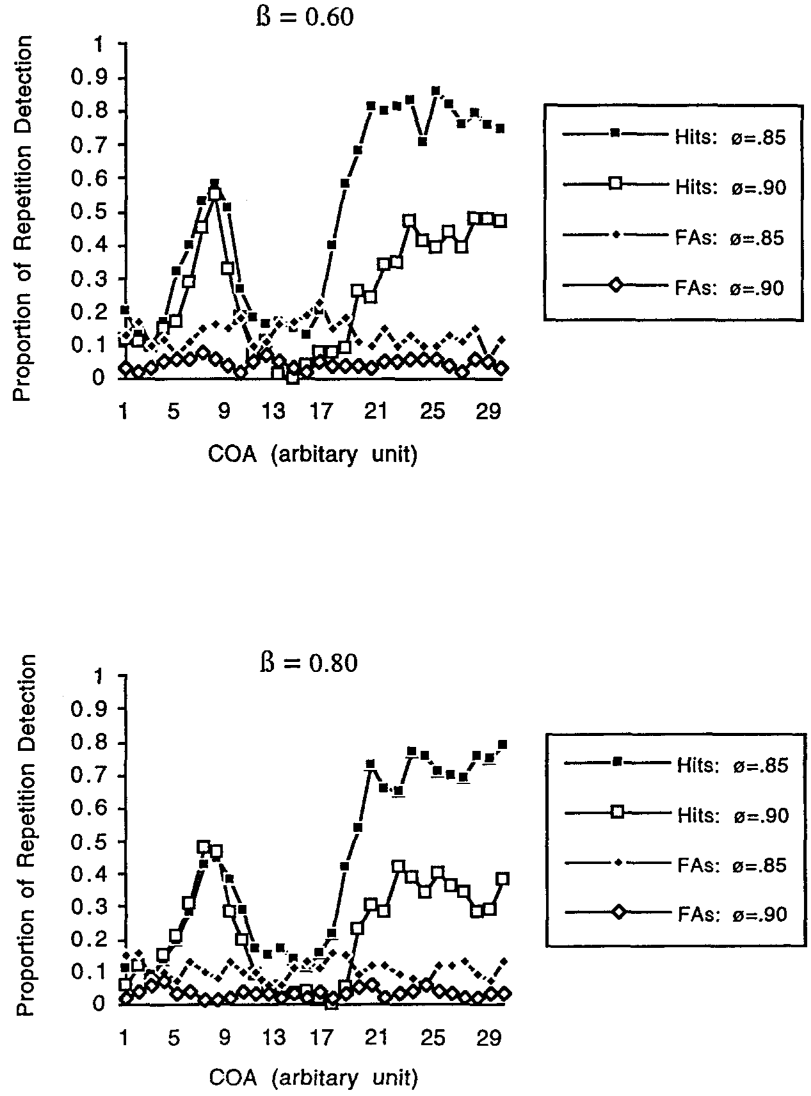

Figure B2. Performance (hits and false alarms [FAs]) in detecting repetitions as a function of coding onset asynchrony (COA). The data are based on 100 simulated trials. β = filter parameter; ϕ = threshold.

[B1] We also tried other input functions and more complicated impulse response functions. They did not lead to different outcomes as long as the resulting output function retained the shape shown in Figure 2A.

threshold, ϕ, and $A(t_{i+1}) < A(t_i)$ and (b) the activation falls down in at least two of the next three time steps (from t_{i+1} to t_{i+3}) but remains above the threshold in at least one of the three time steps. The first condition ensures that the unit detects each spike in the waveform. The second condition reduces the possibility that the unit is responding to a spike activated by the noise rather than by the signal.[B2] If the unit fires only once in some reasonably long time interval, it signifies a single stimulation; if the unit fires twice in this time interval, then it signals double stimulation—stimulus repetitions. Note that the noise here has two components: internal noise in the system and activation received from a nontarget item. Because internal noise alone is not very likely to be able to excite the type node, false alarms result primarily from the activation of the type node by a distractor item that presumably shares some features with the target item.

Figure B2 shows the model's performance in detecting repetitions (hits and false alarms) as a function of COA. Two parameters—the magnitude of threshold ϕ and the depth of dip β—were varied. Note that greater β results in greater RB, especially when ϕ is high. As can be seen, performance in detecting repetitions is initially very poor (because of stimulus summations), and it is a U-shaped function of COA thereafter (because of the unit's refractory period). The finding that RB is an inverted U-shaped function of repetition lag can be predicted if we assume that Lag 0 corresponds to a COA somewhere around the time the first stimulation has reached its peak. This is reasonable given the assumption that there is no parallel recognition and thus COA must be bigger than the time interval that a stimulation takes to reach its peak. In addition, we believe that masked repetition priming (e.g., Humphreys et al., 1987) can be explained by stimulus summation at very short COAs.

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[B2] Of course, this condition can be changed to increase or decrease the unit's hit or false-alarm rates.