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Repetition blindness under minimum memory load: Effects of spatial and temporal proximity and the encoding effectiveness of the first item

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Repetition blindness (RB) refers to the reduced performance in reporting a repeated as opposed to a nonrepeated item in rapid serial visual presentation. In Experiment 1, we found RB for two-item stimuli in uncertain locations. The magnitude of RB decreased significantly with increases in interstimulus interval, but not with increases in spatial separation, indicating that RB is determined primarily by temporal factors. In Experiment 2, we found RB when subjects were required to report only the second of two successively presented items. The magnitude of RB increased with the duration of the first item, indicating that RB is determined by the encoding effectiveness of the first item. The results of this study collectively indicate that RB is not a memory or a sensory phenomenon, but rather a perceptual phenomenon occurring at the stage of identity encoding. The findings also undermine the arguments (Kanwisher, 1987) that have been offered in favor of the type–token binding failure hypothesis and indicate instead that type-node refractoriness may be the cause of RB.

In recent years, researchers have become increasingly interested in studying how the visual system works to recognize similar or identical objects. This interest was largely triggered by Kanwisher (1987), who reported a finding called *repetition blindness*, or RB. The effect refers to the failure to detect repetitions of words in rapid serial visual presentation (RSVP). In a typical experiment in Kanwisher's study, subjects were asked to report back words of a sentence which appeared quickly one after another at the same location. It was found that the subjects missed the second occurrence of a repeated word much more frequently than they missed a nonrepeated word.

RB seems to indicate a reduced recognition of the second occurrence of a repeated item. This is in sharp contrast to the finding of *repetition priming* in implicit memory research, which is an enhanced performance for the second occurrence of a repeated item (see, e.g., Feustel, Shiffrin, & Salasoo, 1983; Jacoby & Dallas, 1981; Luo, 1993). The demonstration of RB in RSVP also contrasts with the fast-*same* effect found in the *same–different* judgment studies (e.g., Krueger, 1978, 1983; Proctor, 1981). In *same–different* judgments, subjects are typically faster when two successively presented items are identical than when they are different. However, there is also some similarity between the two sets of studies inasmuch as subjects also make more errors on the *same* than on *different* trials in *same–different* judgments—the false-*different* effect (Krueger, 1978). The study of repetition blindness, repetition priming, and their relationship is important because it can provide important insights into the functional architecture of perception and cognition.

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Alternative Accounts of Repetition Blindness

RB has been shown to occur not only for words but also for letters and pictures (e.g., Bavelier, 1994; Bavelier & Potter, 1992; Kanwisher & Potter, 1990). The effect has also been extended from the temporal domain to the spatial domain. Thus, RB occurs not only for items that are shown sequentially at the same spatial location, but also for items that are shown simultaneously in visual space (see, e.g., Kanwisher, 1991; Luo & Caramazza, in press; Mozer, 1989) and for items that are shown sequentially but displaced spatially (see, e.g., Hochhaus & Marohn, 1991; Kanwisher & Potter, 1989; Luo & Caramazza, in press). The theoretical basis of the effect, however, is still not clear. A number of alternative accounts posit the locus of the effect at different stages of information processing.

To identify the possible loci of the effect, Figure 1 shows a modal model of visual letter recognition, with "ABA" as input, for example. The model is a modification of similar models proposed by Kanwisher (1987, 1991), Kahne-

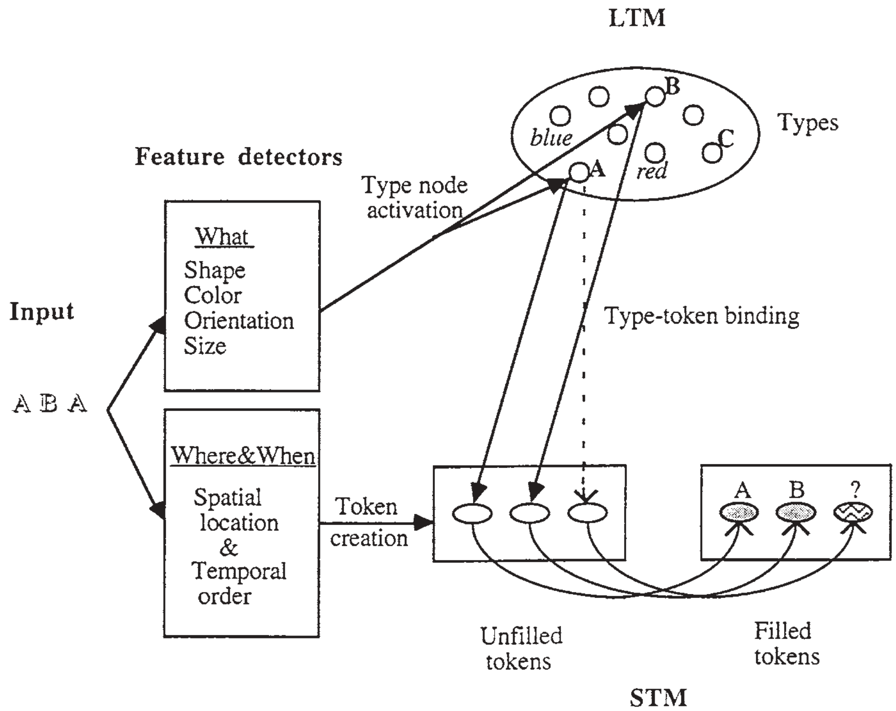

Figure 1. A model of visual object recognition. The model consists of six stages of information processing: feature analysis, type-node activation, token creation, type–token binding, and storage in and retrieval from short-term memory (STM). In this example, the input to the system is ABA, and the dotted arrow indicates that type–token binding may fail if the same type (A) has to be tokenized repeatedly (see, e.g., Kanwisher, 1987).

man and Treisman (1984), Mozer (1989), Sperling (1967), and others.

According to this model, visual object recognition involves the following six stages of information processing: feature analysis, token creation, type-node activation, type-token binding, and information storage in and retrieval from short-term memory (STM).

During feature analysis, an item's sensory and perceptual features, such as shape, color, orientation, and size, are analyzed by corresponding specialized feature detectors; its spatiotemporal characteristics are analyzed by other, separate processing channels (see, e.g., Mishkin, Ungerleider, & Macko, 1983; Ungerleider & Mishkin, 1982). A feature assembling mechanism then leads to the creation of an episodic trace (token) and the activation of a type node in long-term memory (LTM).

The next stage involves binding the activated type to the created token to form an internal representation of the stimulus which contains the information not only about its identity (what) but also about its spatiotemporal characteristics (when and where). This process is called token individuation, or type–token binding.

Finally, this representation needs to be kept in STM so that it can be further processed for output. It is further assumed that the passage of information from a visual display to the sensory organs and the analysis of perceptual features can be parallel and preattentive, whereas the construction of a symbolic representation beyond feature analysis, type–token binding in particular, is sequential and attention demanding in nature (see, e.g., Kanwisher, 1991; Treisman, 1988; Treisman & Gelade, 1980; but see also Duncan & Humphreys, 1989).

RB could occur at any stage of information processing outlined above. Table 1 shows several possible loci of the RB effect in three groups: early, or sensory (feature analysis); middle, or perceptual (type activation, token creation, and type–token binding); and late, or memory (storage and retrieval). In the following, we consider each of the major alternatives in detail.

Sensory locus. RB could occur at the stage of feature analysis. There are some well-documented sensory mechanisms, such as fatigue of feature detectors (see, e.g., Banks & Kane, 1972), lateral masking (e.g., Wolford & Hollingsworth, 1974), and feature-specific inhibition (Bjork & Murray, 1977), that conceivably could be much stronger when feature analysis must deal with a lot of the same things in a very brief period of time.

Table 1
Alternative Accounts of Repetition Blindness

Sensory	Perceptual	Memory
Fatigue of feature detectors	Type-node refractoriness	Storage failure
Lateral masking	Token creation failure	Retrieval failure
Feature-specific inhibition	Type–token binding failure	

Specifically, when items are presented sequentially and at the same location, the possible fatigue of feature detectors may result in a failure to respond to the same set of features, thus causing RB. When items are presented simultaneously or sequentially but displaced spatially, lateral masking may very well be stronger among identical items than among items that have different features, thus causing RB. Bjork and Murray (1977) have also proposed that there exists feature-specific inhibition among visual input channels that lead to the same feature detectors. 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 inhibition is maximal when two stimuli are identical, the identical items are predicted to be identified less well than the items that have different features, thus causing RB.

Perceptual locus. RB may also occur at the stages beyond feature analysis. The possible perceptual accounts of RB include type refractoriness at the stage of type-node activation (e.g., Luo & Caramazza, in press), token creation failure at the stage of setting up episodic tokens, and type–token binding failure at the stage of token individuation (Kanwisher, 1987; Kanwisher & Potter, 1989).

Specifically, RB may occur if the type node has a refractory period during which its ability to be reactivated is reduced. In that case, a type activation failure will occur if two identical items are processed too closely in time. This hypothesis has been called recognition refractoriness (Kanwisher, 1987; Park & Kanwisher, 1994), self-inhibition (Hochhaus & Marohn, 1991; MacKay, 1987), and type refractoriness (Luo & Caramazza, in press).

RB may also occur if there is a failure in setting up episodic tokens. Token creation, however, is less likely to be a locus of RB, because subjects are usually able to report the presence of an item even when they are wrong about its identity, indicating that subjects have no difficulty setting up tokens. The token with a question mark in Figure 1 shows this fact. Token creation failure will not be considered further.

Kanwisher (1987, 1991) attributed RB to type–token binding failure by assuming that the same type node, after being linked to some token, cannot be linked to other tokens in a brief period of time. This hypothesis is called token individuation failure or type–token binding failure. The dotted arrow in Figure 1 indicates this possibility.

Memory locus. Alternatively, RB may also occur if there is a failure at the stage of memory storage or retrieval. Because RB was originally demonstrated by using rapid serial visual presentation of multiple items, memory storage and retrieval is surely a complicating factor in such a complex situation. Because of memory capacity limitation, a failure in memory storage can occur because two representations (memory codes) may be confused in STM if they are sufficiently similar to each other (see, e.g., Bavelier, 1994). A failure in memory retrieval may also occur because of output interference or guessing bias (e.g., Fagot & Pashler, 1995; Greene, 1991). There may be other explanations of RB (see Park & Kanwisher, 1994), but in this article we will focus on the major alternative theories outlined above.

The Present Study

The main purpose of the present study was to evaluate the major alternative accounts of RB. Because it is difficult to find evidence that supports one particular account exclusively, our strategy was to rule out various possible loci and thus narrow down the possible alternatives. We first tried to determine whether RB is a memory phenomenon or not. If the memory locus could be ruled out, we could then consider whether it occurs at the sensory or perceptual stages of processing. If the sensory locus could be ruled out, along with the memory locus, we could then try to seek evidence pinpointing the exact perceptual locus of RB.

Ruling out the memory locus. The memory account argues that RB occurs at the stage of memory storage or retrieval. One way to test this hypothesis is to investigate whether RB occurs when memory load is at or near minimum, and thus a memory locus may be ruled out. In Experiment 1, we tested whether RB would occur for stimuli consisting of only two items. In Experiment 2, we further investigated whether RB would occur when subjects only needed to report the second of two successively presented items.

Sensory versus perceptual locus. If RB were not to be a memory phenomenon, we would then need to determine whether it occurs at the sensory or perceptual stages of processing. One way of tackling this issue is to investigate whether spatial factors affect RB. If the fatigue of feature detectors were the cause of RB, displacing two identical items spatially and increasing the spatial distance between them should reduce the possibility that the same set of feature detectors is used to analyze them and thus reduce RB. Similarly, if lateral masking were the cause of RB, increasing the spatial distance between two identical stimuli should reduce the masking effect and thus reduce RB.

In short, if RB were due to fatigue of feature detectors or lateral masking, the magnitude of RB would be expected to be influenced by the spatial proximity of stimuli. In Experiment 1, we varied the spatial distance between the first (C1) and the second occurrence (C2) of a repeated item and investigated whether it would have any effect on RB. We will also discuss related evidence regarding the feature-specific inhibition account of the RB effect.

Pinpointing the precise perceptual locus. If the sensory and memory loci are ruled out by the evidence of Experiment 1, that leaves only perception as a viable locus. In Experiment 2, we focused on and tried to distinguish between two possible mechanisms at the perceptual locus. Thus, the final question in the present study concerned whether type refractoriness or type–token binding failure is a better account, if RB is a perceptual phenomenon. In Experiment 2, we varied the duration of C1 and investigated whether RB for C2 is a function of the encoding effectiveness of C1 when C1 is not required to be reported by subjects.

According to the type refractoriness hypothesis, the perception of C2 is impaired only when C1 is well processed. The type refractoriness hypothesis thus predicts that the magnitude of RB for C2 is an increasing function of the encoding effectiveness of C1, independent of whether C1 must be individuated as a separate token or not. Because the type–token binding failure hypothesis, in contrast, predicts RB to occur only when C1 and C2 must both be individuated as a separate token, RB should not occur when only C2 needs to be reported. The results of Experiment 2, therefore, can potentially provide important evidence for pinpointing the precise perceptual locus of the RB effect.

EXPERIMENT 1

The purpose of Experiment 1 was to investigate whether RB occurs when stimuli consist of only two items whose spatial locations are uncertain and whether RB is affected by the spatial distance and the interstimulus interval (ISI) between two repeated items. Because RB is believed to occur only when two identical items are processed within a narrow time window (e.g., Kanwisher, 1987; Luo & Caramazza, in press), it is important to test whether RB decreases with ISI and determine how big the window is before RB disappears. The results of this experiment are also important for distinguishing between the sensory, perceptual, and memory accounts of RB. The memory locus could be ruled out if RB is found with memory load being near a minimum and the sensory locus could be ruled out if RB does not depend on spatial distance.

Using the traditional RSVP paradigm, Park and Kanwisher (1994) have shown that memory load has little effect on RB and that RB also occurs when subjects are asked to report only C1 and C2 while they ignore other symbols in the stimulus. To further reduce memory load, we used stimuli consisting of only two items and tested whether RB occurs when memory load is near a minimum.

Using the non-RSVP paradigm, Hochhaus and Marohn (1991, Experiment 4) have studied the effect of spatial distance between C1 and C2 on RB. They fixed the location of C2 and varied the C1–C2 distance, which was 0º, 0.56º, 1.12º, or 1.68º of visual angle. They found a significant decrease in RB magnitude from 0º to 0.56º, but further increases in spatial separation had little effect on RB. The finding suggested that the perceptual fusion of two identical stimuli when they are very close to each other might contribute to the observed RB effect, but it cannot explain why RB also occurred when two items were quite far apart. Because in that study subjects were only required to respond to C2, the subjects might have attempted to ignore C1. In Experiment 1, we varied the spatial distance between C1 and C2 and investigated its effect on RB when the two items' spatial locations were uncertain and when subjects had to respond to both C1 and C2.

The effect of ISI on RB has been studied by Park and Kanwisher (1994, Experiment 3), using traditional RSVP. They asked subjects to report four letters that were embedded in a string of symbols. Each item was shown for 117 msec, and the ISI between C1 and C2 was varied from 117 to 583 msec in increments of 117 msec. They found that RB was a decreasing function of ISI and that whether a blank interval or to-be-ignored symbols appeared during the ISI made little difference. Hochhaus and Marohn (1991, Experiment 1) also investigated the effect of ISI on RB but found that RB was an inverted U-shaped function of ISI. They used a priming paradigm in which subjects were first shown a word prime for 250 or 500 msec and then a word target that appeared below the prime after an ISI of 0, 250, 500, or 1,750 msec. RB was found only when ISI was 250 msec.

The finding of no RB when ISI was 0 is difficult to interpret for current theories of RB. Because Park and Kanwisher (1994) did not use very short ISIs, the results from the two studies cannot be compared directly. There are also procedural differences between the two studies. First, in Hochhaus and Marohn's (1991) study, subjects were shown only two items and they were not required to respond to C1, whereas in Park and Kanwisher's study, noncritical items preceded C1 and followed C2, and subjects were required to report all items. Second, C1 and C2 were spatially separated from each other in the former but were shown at the same location in the latter study. Finally, because Hochhaus and Marohn did not vary ISI in small steps, it is not clear what would happen when ISI is between 0 and 250 msec. Further investigation is needed to clarify these issues.

In summary, in Experiment 1 we examined the memory accounts of RB by testing whether RB occurs when memory load is near minimum (the two items to be named were located on a circle). We also examined the sensory accounts of RB by testing whether the magnitude of RB is affected by spatial proximity between two identical items (spatial distance apart on the circle). Finally, we examined whether RB occurs only when the two identical items are to be processed within a narrow time window by testing whether RB diminishes with increases in ISI.

Method

Subjects. Eighteen undergraduates from an introductory psychology course at Dartmouth College served as subjects for extra course credit. All subjects had normal or corrected-to-normal vision.

Apparatus and Materials. The experiment was run on an Apple Macintosh microcomputer (Centris 610). Subjects sat at a distance of about 50 cm in front of the computer screen. The laboratory was dimly lit to minimize screen reflections.

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 two letters. A repeated trial consisted of two identical letters, whereas a nonrepeated trial consisted of two distinct ones. Letters were sampled randomly in each condition and separately for each subject.

Each letter was printed in uppercase Geneva typeface in 12-point size, which was about 2.5 mm wide and 3 mm high (0.29º × 0.34º of visual angle). All characters were black on a white background. The two letters on each trial were presented in a small circle centered on the computer screen. They might appear at any two of the eight locations in the visual display (at 1:30, 3, 4:30, 6, 7:30; 9, 10:30, and 12 o'clock, respectively) that formed an imaginary circle with a radius of approximately 10 mm.

There were four possible spatial distances between the two letters. They were 5, 11, 15, or 17 mm, which corresponded to 0.57º, 1.26º, 1.72º, or 1.95º of visual angle, respectively. More specifically, the edge-to-edge distance between two adjacent letters in the imaginary circle was about 5 mm (0.57º), and the distance between two opposite elements was 17 mm (1.95º). Thus, the maximum total extent across two elements was 22 mm (2.5+17+2.5). Because the diameter of the outer visible circle was 30 mm, all elements were 4 mm away from the circle. The four spatial distances were used equally frequently and the exact locations for the two letters were sampled randomly.

Design and Procedure. A within-subjects design was used. There were three independent variables in this experiment. The first was repetition status (repeated vs. nonrepeated). The second variable was ISI between the two successively presented letters. Each letter was shown for 50 msec, and the ISI was 0, 50, or 100 msec. Thus stimulus onset asynchrony (SOA) was 50, 100, or 150 msec. The third variable was the spatial distance between the two letters in a stimulus. In the present study, items were presented at different spatial locations so that very small values of ISI could be employed without causing stimulus summation or masking.

At the beginning of the experiment, subjects were shown written instructions on the computer screen. They were told that their task was to identify two letters that would be presented briefly and successively. 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 sec, a circle with a radius of 15 mm that remained throughout the trial, and a fixation cross (2×2 mm) that followed after 0.5 sec and appeared at the center of the circle for 1 sec. The stimulus sequence started as soon as the fixation cross disappeared. The poststimulus mask was composed of 8 dollar signs which immediately followed the stimulus sequence and lasted for 100 msec. After stimulus presentation, the subjects were asked to type the letters they had seen on the computer keyboard. They were also told that on half of the trials, the two letters were identical, and that in that case they should report both of them. The subjects were not required to report the items in their presentation order. Figure 2A shows an example of successive stimulus presentation in Experiment 1.

The experiment was run in three blocks, one for each ISI (0, 50, and 100 msec). The order of ISIs was counterbalanced across subjects. There were 80 stimulus trials in each block. Half of them (40) were repeated trials, and the other half were nonrepeated ones. All stimulus trials within a block were intermixed, and the order of their presentation was randomized separately for each subject. There were 240 experimental trials. An additional set of 16 trials—8 repeated and 8 nonrepeated trials—was generated and used for practice. The ISI was 50 msec during practice. In the practice session, subjects received feedback about their responses: the correct answer was shown for 2 sec in a small window near the bottom of the computer screen. This was intended to ensure that subjects had a clear understanding of the task. Feedback was not given in the experimental session. The data from the practice session were not included in the analyses. The subjects initiated each trial by pressing a key.

Data analysis. Because in the present experiment a bias toward or against guessing repeated items when subjects were uncertain about the identity of C2 would cause an under- or overestimation of RB, we need to consider whether there was any bias in subjects' responses and to correct for it if necessary. One way to determine the nature of a report bias is to examine how frequently subjects reported two identical items in the nonrepeated condition.

Table 2 shows error rates for identifying two successively presented items on nonrepeated trials. Three indexes were used: (1) the percentage of C1 being incorrect, (2) the percentage of C2 being incorrect, and (3) the percentage of C1 and C2 being identical given that C2 was incorrect, which would give us an estimate of how likely it was that subjects had guessed C2 as being identical to C1 when they were not sure of the identity of C2. Because very few nonrepeated trials were reported as two instances of C2, it is safe to condition our analysis on an error in C2, and in fact that is the only practical option, given the paucity of C2–C2 reports.

Because in the present study we used 16 letters, the probability that subjects would have guessed a repeated item should be around 1/16 (6.7%) if there was no bias in guessing. Table 2 shows that subjects reported identical items when C2 was wrong 2.8/16.7 (16.8%), 7.9/26.0 (30.4%), and 7.6/28.6 (26.6%) for the three ISIs, respectively. This indicates that subjects were more likely to guess C2 as the same as C1 when they were not sure about the identity of C2. Although this bias toward reporting repeated items was estimated from the nonrepeated trials, there is no reason to believe that subjects did not have the same bias on the repeated trials. Because uncorrected data would only have underestimated the magnitude of RB given subjects' bias toward guessing repeated items, we decided to present uncorrected data.

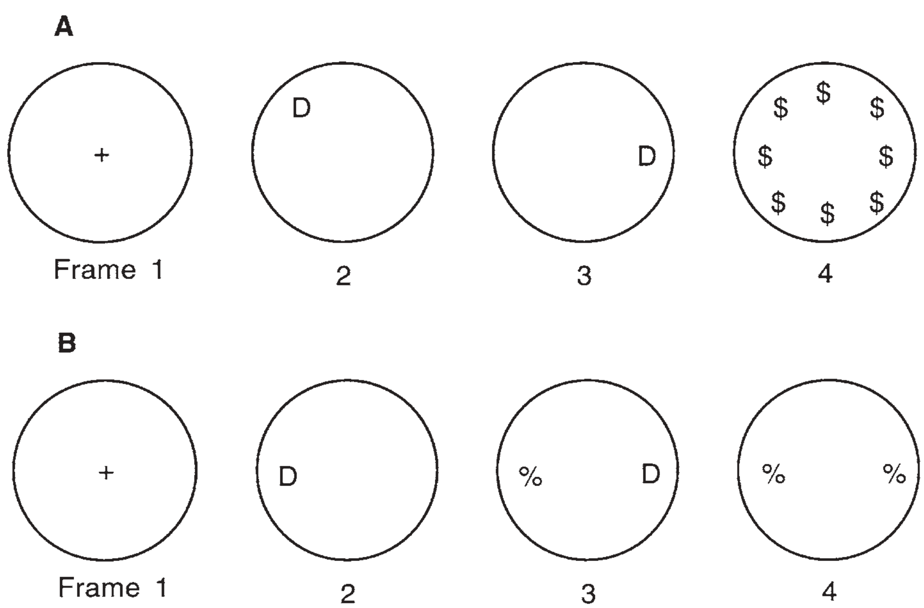

Figure 2. Examples of successive presentation of two items. (A) Two letters were shown sequentially at two of eight possible locations in Experiment 1. (B) Two letters were shown sequentially at the two horizontal locations of the display in Experiment 2.

Table 2
Error Rates of Identifying Two Successively Presented Items on Nonrepeated Trials in Experiment 1

Spatial Distance	ISI 0 C1	ISI 0 C2	ISI 0 C1=C2	ISI 50 C1	ISI 50 C2	ISI 50 C1=C2	ISI 100 C1	ISI 100 C2	ISI 100 C1=C2
0.57º	6.1	15.6	2.8	5.0	19.4	6.1	3.9	24.4	5.6
1.26º	2.8	16.7	2.8	2.8	26.7	8.3	0.0	28.3	10.0
1.72º	2.8	17.2	3.9	0.6	34.4	10.6	1.1	33.9	10.6
1.95º	4.4	17.2	1.7	2.8	23.3	6.7	2.2	27.8	4.4
Average	4.0	16.7	2.8	2.8	26.0	7.9	1.8	28.6	7.6

Note—ISI, interstimulus interval, measured in milliseconds. Three indexes were used (in percentage forms): (1) C1 was incorrect, (2) C2 was incorrect, and (3) C1 and C2 were identical given that C2 was incorrect.

Results and Discussion

Table 3 shows the percentage of trials in which subjects correctly reported both items as a function of repetition status (repeated vs. nonrepeated), ISI (0 vs. 50 vs. 100 msec), and spatial distance (.57º, 1.26º, 1.72º, and 1.95º). RB was measured by the difference in identification performance between the repeated and nonrepeated conditions (repeated − nonrepeated).

There was a significant effect of repetition status [repeated vs. nonrepeated; $F(1,17) = 17.32$, $MS_e = .153$, $p < .001$]. Subjects did significantly worse in identifying two letters when they were identical than when they were different, showing RB for pairs of items in uncertain locations. The effect of spatial separation, however, was not significant [$F(3,51) = 1.14$, $MS_e = .030$, $p = .34$]. There was also no interaction between the spatial distance and the repetition status ($F < 1$), although RB was numerically slightly greater when the spatial distance between C1 and C2 was 0.57º than when they were farther apart. The effect of ISI approached significance [$F(2,34) = 2.45$, $MS_e = .062$, $p = .10$]. Importantly, there was a significant interaction between ISI and the repetition status [$F(2,34) = 4.65$, $MS_e = .033$, $p < .02$], indicating that ISI was an important determinant of the magnitude of RB. A further analysis (*t* test) confirmed that RB was greater when ISI was 0 or 50 msec than when it was 100 msec ($p < .01$). No other interactions reached significance.

The fact that RB occurs even when there are only two items in the display indicates that memory load is not the principal factor in producing RB. Our analysis also indicates that the response bias, if anything, is toward the report of repeated items and therefore was an underestimation of the real magnitude of RB. The findings suggest that RB is not a memory phenomenon.

The finding of no significant effect of spatial separation on the magnitude of RB is consistent with Hochhaus and Marohn's (1991) results. They also found no significant effect of spatial separation when the distance was greater than 0.56º. Because we did not present two items at the same location, we do not know whether RB would be greater when they were presented at the same location than when they were spatially displaced. That may very well be the case. But the fact that RB did not decrease when the distance was increased from 0.57º to 1.95º indicates that spatial factors do not play a major role in modulating RB. It is worth noting that in *same–different* judgments, Chignell and Krueger (1984) also found no significant effect of spatial separation on the fast-*same* effect or the false-*different* effect.

The finding that RB decreased with increases in ISI in this experiment is consistent with Park and Kanwisher's (1994) results, although they did not use very short ISIs (< 117 msec). The present results contrast with Hochhaus and Marohn's (1991) finding of no RB when ISI was 0. It is unclear why Hochhaus and Marohn found no RB when ISI was 0. A number of procedural differences may be responsible for the discrepancy. As noted earlier, in Hochhaus and Marohn's study subjects needed only to respond to C2 and they presented C1 for a long duration (250 or 500 msec) with fixed location for C2.

To summarize, Experiment 1 extended the finding of RB to two-item stimuli whose spatial locations were uncertain. The spatial distance between C1 and C2 did not have

Table 3
Percentage of Trials in Which Subjects Correctly Identified Both of Two Successively Presented Items as a Function of Repetition Status, Interstimulus Interval (ISI, in Milliseconds), and Spatial Separation in Experiment 1

ISI	0.57º R	0.57º NR	0.57º R–NR	1.26º R	1.26º NR	1.26º R–NR	1.72º R	1.72º NR	1.72º R–NR	1.95º R	1.95º NR	1.95º R–NR
0	52.8	78.3	−25.5	61.7	81.1	−19.4	62.8	79.4	−16.6	60.6	79.4	−18.8
50	53.3	76.1	−22.8	55.0	72.2	−17.2	50.6	67.2	−16.6	57.2	75.0	−17.8
100	57.2	71.7	−14.5	56.1	66.7	−10.6	61.1	66.1	− 5.0	67.8	70.6	− 2.8

Note—R, repeated; NR, nonrepeated. The magnitude of repetition blindness was measured by repeated − nonrepeated (R–NR).

a significant effect on the magnitude of RB. In contrast, the magnitude of RB decreased substantially with increases in ISI between C1 and C2. The results of this experiment indicate that RB is determined primarily by temporal rather than spatial factors, and that RB occurs only when C1 and C2 are to be processed within a narrow time window. Although it is difficult to estimate the exact size of this window, it appears to be around 100–150 msec. Because memory load is near minimum in the present study, it is very unlikely that RB can be attributed to memory storage or retrieval failure. Because spatial factors had little effect on RB, fatigue of feature detectors or lateral masking at the earliest stages of visual processing cannot entirely explain the RB effect.

The feature-specific inhibition model (Bjork & Murray, 1977) is also an unlikely candidate because RB has been found to occur when C1 and C2 are separated by several distractor items with long ISIs (Kanwisher, 1987; Park & Kanwisher, 1994). The model has also been questioned on the basis of other findings, such as the mixed-category, repeated-stimulus inferiority effect (see, e.g., Egeth & Santee, 1981; Proctor & Fober, 1988) obtained when two stimuli are not physically identical. For example, Egeth and Santee showed that RB (which they call the repeated-letter inferiority effect) occurred even when the two letters were visually dissimilar and shared only the same name (e.g., Aa). The finding strongly argues against any accounts localizing the deficit at the feature extraction stage. Therefore the findings of Experiment 1 add to accumulating evidence indicating that RB is a perceptual phenomenon that occurs at the stage of identity encoding and is determined by temporal factors.

EXPERIMENT 2

In Experiment 2, we sought further evidence against the memory account of RB by investigating whether this effect would occur when subjects were asked to identify only the second of two successively presented items. In this experiment, we also evaluated two major perceptual accounts of RB: the type refractoriness hypothesis and the type–token binding failure hypothesis. According to the type refractoriness hypothesis, RB results from a deficit at the stage of type activation due to refractoriness of type nodes; according to the type–token binding failure hypothesis, RB is due to token individuation failure at the stage of type–token binding.

Kanwisher (1987, Experiment 3) considered and rejected the type refractoriness hypothesis on the basis of her finding that when subjects were asked to report only the last word in an RSVP sequence, repetition priming rather than repetition blindness occurred. She took this finding as evidence for double type activation but failed type–token binding for the repeated item when both C1 and C2 must be reported. It was argued that if the type node had a refractory period, RB should also occur when subjects were asked to report C2 only.

The demonstration of repetition priming versus repetition blindness as a function of response requirements provided evidence for the possible dissociation between the type activation process and the type–token binding process. However, the priming effect has not been reliably replicated. For example, Kanwisher and Potter (1990, Experiment 6) found RB rather than priming when a very similar procedure was used. This pattern of results undercuts the motivation for Kanwisher's (1987) proposal that RB is due to type-binding failure rather than type-node refractoriness.

One possible explanation for the discrepancy is that whether one gets repetition priming or repetition blindness is dependent on the encoding effectiveness of C1, independently of whether C1 must be individuated as a separate token or not. When subjects are required to report only C2, they may very well attempt to ignore C1 and other items in the list. The degree to which they can suppress the processing of C1 may depend on the length of the list, among other experimental factors. If it were the case that repetition priming for C2 occurred when C1 was processed only subliminally (and its corresponding type node was not activated supraliminally), whereas repetition blindness occurred when C1 actually activated its corresponding type node, then the finding of repetition priming in Kanwisher's original study might have nothing to do with the dissociation between the type activation and the type–token binding processes. It would suggest instead that the nature of the repetition effect is dependent on how well C1 is processed—namely, on the encoding effectiveness of C1.

The demonstration of a reversal in the effects of repetition by Humphreys, Besner, and Quinlan (1988) using non-RSVP seems to support this speculation. They found that repetition blindness reversed to repetition priming when C1 was shown very briefly (e.g., 40 msec) and masked. In addition, several other studies have found RB when C1 was presented for a relatively long duration and subjects were only required to respond to C2, which either appeared at the same location as C1 (e.g., Forster & Davis, 1984) or was displaced spatially (e.g., Hochhaus & Marohn, 1991). The findings seem to be inconsistent with the type–token binding failure hypothesis, which predicts RB to occur only when C1 and C2 are both to be individuated as separate tokens. On the other hand, the demonstration of RB when subjects need to report only C2 is consistent with the type refractoriness hypothesis, which predicts RB to occur independently of whether C1 is to be tokenized or not, given that it is processed.

The purpose of Experiment 2 was to investigate further whether RB also occurs when subjects are asked to report only the second of two sequentially presented and spatially displaced items (with C2 in an uncertain location) and whether RB for C2 is determined by the encoding effectiveness of C1, which was varied in its presentation duration.

Our expectation is that the nature of the repetition effect (priming vs. blindness) may be determined by the encoding effectiveness of C1: When C1 is processed well, RB for C2 will occur; when C1 is poorly processed, RB for C2 will not occur and instead priming may occur, if C1 and C2 are processed in a narrow time window. Because masked repetition priming (e.g., Humphreys et al., 1988) has been demonstrated when stimulus duration is about 40–60 msec, whereas RB has usually been demonstrated when the duration is around 100 msec, we decided to vary the duration of C1 over a wide range (25, 50, 100, and 200 msec) to test whether the repetition effect is a function of the encoding effectiveness of C1.

Because in Experiment 1 spatial proximity and location uncertainty were shown to have little effect on RB, in Experiment 2 we reduced spatial uncertainty of stimuli by presenting C1 and C2 only at the two horizontal locations of the visual display. Presumably this also made it easier for subjects to attend to the stimuli and to figure out which was the C2 that they should report. However, we did not want to eliminate the positional uncertainty completely, because we wanted subjects to attend to both C1 and C2 initially. Therefore, the relative positions of C1 and C2 at the two horizontal locations were made unpredictable in Experiment 2.

Method

Subjects. Twenty-two undergraduates from the same pool as that in Experiment 1 served as subjects. The material was the same as in Experiment 1.

Design and Procedure. There were several differences between Experiments 1 and 2. The first was that the two letters (C1 and C2) were presented only at the two horizontal locations of the display (3 and 9 o'clock), as shown in Figure 2B. On each trial, C2 had an equal probability of being on the left or on the right. The second was that duration of C1 was varied. The third was that subjects were required to report only the second item (C2). Another minor difference was that, after their presentations, C1 and C2 were both masked by a "%" sign. We used the percent sign instead of the dollar sign as masks in Experiment 2 because some of the subjects in Experiment 1 reported that the "$" was sometimes confused with the letter S.

There were three independent variables: (1) repetition status (repeated vs. nonrepeated), (2) duration of C1 (25, 50, 100, or 200 msec), and (3) ISI (0 vs. 50 vs. 100 msec). As in Experiment 1, C2 was shown for 50 msec. A within-subjects design was used. There were 360 experimental trials, preceded by 16 practice trials. All trials were intermixed, and the order of their presentation was randomized separately for each subject. The procedure was the same as in Experiment 1, except for the differences described above.

Results and Discussion

The percentage of trials in which subjects correctly identified the second item as a function of repetition status, duration of C1, and ISI between C1 and C2 is shown in Table 4.

The effect of repetition status (repeated vs. nonrepeated) was significant [$F(1,21) = 10.49$, $MS_e = .249$, $p < .01$]. In general, C2 was identified worse when C1 and C2 were identical than when they were different, indicating RB. The correct identification of C2 decreased with increases in the duration of C1, whose effect also was significant [$F(3,63) = 10.40$, $MS_e = .015$, $p < .001$]. Importantly, there was a significant interaction between the duration of C1 and the repetition status [$F(3,63) = 15.40$, $MS_e = .022$, $p < .001$]. The correct identification of C2 decreased with increases in the duration of C1 only when C1 and C2 were identical, indicating that RB for C2 increased as the encoding effectiveness of C1 increased.

The effect of ISI was also significant [$F(2,42) = 46.48$, $MS_e = .021$, $p < .001$], showing that the correct identification of C2 decreased with increases in ISI between C1 and C2. The interaction between ISI and the repetition status also reached significance [$F(2,42) = 3.64$, $MS_e = .014$, $p < .05$]. In both repeated and nonrepeated conditions, the percentage of identifying C2 decreased as the ISI between C1 and C2 increased, but the decrease was more drastic in the repeated than in the nonrepeated condition. No other interactions reached significance ($F < 1$).

The most important results from Experiment 2 are that RB occurs even when subjects are required to report only the second item and that the magnitude of RB is determined by the encoding effectiveness of C1. The demonstration of RB when subjects need to report only the second of two successively presented items further indicates that memory load is not an important factor in producing RB. The fact that RB rather than repetition priming occurs when only the second item needs to be reported is also consistent with the type refractoriness hypothesis.

Apparently, when subjects are asked to report only the second item, the determinant of RB for the second item is how well the first item is processed. As speculated earlier, subjects may attempt to suppress the processing of C1 when they are required to report C2 only. However, they may not succeed in suppressing the processing of C1, because one item follows another closely in time and selective processing cannot be reliably achieved all the time. The degree to which the processing of C1 is successfully suppressed depends on its duration and ISI between C1 and C2. When ISI is short, the processing of C1 is more likely to be terminated or interrupted by the processing of C2 because C2 is the item subjects are supposed to identify.

It is worth noting that Park and Kanwisher (1994, Experiment 2) also investigated the effect of duration of C1

Table 4
Percentage of Trials in Which Subjects Correctly Identified the Second C2 of Two Successively Presented Items as a Function of Repetition Status, Interstimulus Interval (ISI, in Milliseconds), and Duration of the First Item (C1) in Experiment 2

	Duration of C1 (msec)											
	25			50			100			200		
ISI	R	NR	R–NR	R	NR	R–NR	R	NR	R–NR	R	NR	R–NR
0	86.1	79.7	+6.4	75.0	83.0	− 8.0	63.0	80.6	−17.6	63.9	86.0	−22.1
50	67.6	72.9	−5.3	59.7	73.3	−13.6	55.7	72.7	−17.0	55.5	79.1	−23.6
100	65.8	67.9	−2.1	54.9	71.8	−16.9	47.3	73.0	−25.8	48.5	71.5	−23.0

Note—R, repeated; NR, nonrepeated. The magnitude of repetition blindness was measured by repeated − nonrepeated (R–NR).

on RB. They found no effect of C1 duration on RB magnitude. Their results, however, do not contradict ours, because the duration of C1 was varied from 117 to 233 msec only. In our study, increases of duration from 100 to 200 msec also had little effect.

It is not clear why Kanwisher (1987, Experiment 3) found repetition priming whereas Kanwisher and Potter (1990b, Experiment 6) found RB when subjects were asked to report the last item in a rapid sequence of items. We speculate that the inconsistency might have arisen from slight differences in subjects' strategies—in whether they had attempted to ignore items preceding the last one. Subjects may be able to suppress the processing of those items if they choose to do so. Because RB for C2 depends on whether C1 is recognized or not, the difference in their strategies may explain why RB occurs in one study but not in another.

Why, then, did repetition priming occur at all? We think that it may have the same underlying mechanism as does masked repetition priming. A number of researchers (e.g., Forster & Davis, 1984; Humphreys et al., 1988; Humphreys, Evett, Quinlan, & Besner, 1987) have investigated 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. They found that if the first item was presented very briefly (about 40–60 msec) and masked so that subjects were not able to identify it, the probability of correctly identifying the second item was higher when the two items were the same than when they were different. The effect can be interpreted as summation or as facilitation at the stage of item recognition. It is probably such an effect that Kanwisher (1987) found in her Experiment 3. The small priming effect when the duration of C1 was 25 msec and the ISI was 0 msec in our Experiment 2 (Table 4), though not statistically significant, seems to indicate such an effect.

Although the finding of RB when only C2 needs to be reported is consistent with the type refractoriness hypothesis, one might argue that it is also consistent with the type–token binding failure hypothesis. For example, it can be argued that because of location uncertainty, both C1 and C2 must be attended initially in our Experiment 2, which could lead to an automatic tokenization of C1 and thus RB for C2. We will return to this argument in the following section.

GENERAL DISCUSSION

In Experiments 1 and 2, we examined several alternative accounts of RB and explored temporal and spatial factors affecting RB. There are two main findings from the present study. First, the present study extended the phenomenon of RB to two-item stimuli whose spatial locations were uncertain (Experiment 1). In Experiment 1, the magnitude of RB decreased significantly with increases in ISI but not with increases in the spatial separation of C1 and C2, indicating that RB is determined primarily by temporal factors.

Second, the present study showed that RB also occurred when subjects were required to report only the second of two successively presented items (Experiment 2). The magnitude of RB increased with increases in the duration of C1, indicating that RB is determined by the encoding effectiveness of C1.

One interesting aspect of the data is that identification performance (especially for nonrepeated items in Experiment 1, and for all items in Experiment 2) seemed to be a decreasing function of ISI within the range we have manipulated. In Experiment 1, error rates for C2 increased with increases in ISI whereas error rates for C1 decreased somewhat (Table 2). Consistent with this, accuracy for identifying both C1 and C2 declined with increases in ISI (Table 3). This relationship between identification performance and ISI was even more salient in Experiment 2 (Table 4). These results are very similar to a phenomenon in RSVP that has been called *attentional blink*, which occurs when ISI is less than about 400 msec, with maximum effect at around 200 msec (see, e.g., Duncan, Ward, & Shapiro, 1994; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994). The finding refers to a deficit in detecting the second target after the successful identification of the first. The results of the present study indicate that attentional blink is a quite general phenomenon.

One discrepancy between Experiments 1 and 2 concerns the effect of ISI on RB. In Experiment 1, we found that RB decreased with increases in ISI. In Experiment 2, however, RB increased slightly with increases in ISI. The reason for this discrepancy is not obvious. Apparently, when subjects are required to report C2 only, they will try to ignore C1. However, C1 has to be attended initially because of the spatial uncertainty of C1 and C2. The extent to which C1 can be processed successfully might depend on ISI: C1 might be processed poorly when the ISI is short and relatively better when the ISI is long. Because RB is an increasing function of C1 identification, this leads to increased RB with increases in ISI. If this were the case, this effect would offset the normal effect of ISI on RB which is to decrease the magnitude of RB with increases of ISI. In short, the effects of ISI on RB in the reporting-C2-only condition may be different from those in the reporting both-C1-and-C2 condition.

A related issue concerns our recent finding (Luo & Caramazza, in press) that the magnitude of RB is an inverted U-shaped function of repetition lag—the number of items intervening between C1 and C2 in report order. Although the results are obtained when all items have been presented simultaneously, we have argued that they are in fact processed sequentially and that RB is determined by the encoding lag between C1 and C2. If this hypothesis were correct, we might expect that when items are actually presented sequentially, ISI should have a similar effect on RB as repetition lag does. Because Experiment 1 showed that RB is a decreasing function of ISI, the results seem to be inconsistent with our proposal.

A possible explanation for this discrepancy may be found in the baseline conditions for sequential as opposed to simultaneous presentations. Because RB is measured by the performance difference between repeated and nonrepeated conditions, the magnitude of RB as a function of ISI is determined in part by performance in the baseline (nonrepeated) condition. If attentional blink were to differentially affect performance in the baseline condition for the two modes of stimulus presentation, we might get different magnitude functions for RB in the two cases.

Let us examine the results in Table 3 more carefully. If we average the data across different spatial distances, the average probabilities of identifying both items correctly as a function of ISI are 0.60, 0.54, and 0.61 in the repeated condition and 0.80, 0.73, 0.69 in the nonrepeated condition. If the performance difference between the repeated and nonrepeated condition were used to estimate RB, it would be a decreasing function of ISI. Note, however, that performance in the nonrepeated condition was also a decreasing function of ISI. To take this attentional blink effect into account, we might want to use only the relative performance in the repeated condition as an indicator of RB as a function of ISI. When we consider only the performance in the repeated condition, an inverted U-shaped function emerges. Therefore, it remains possible that RB in sequential presentation is also an inverted U-shaped function of processing lag between C1 and C2. However, it is clear that further investigation is needed for this issue to be resolved.

In the following we further consider the implications of the findings from the present study and summarize related evidence for each of the current principal proposals concerning the RB effect.

Can RB Be a Memory Phenomenon?

As noted earlier, some researchers (e.g., Fagot & Pashler, 1995) have recently questioned the nature of RB and asked whether it is not simply a phenomenon of memory rather than perception. They compared RB with the Ranschburg effect, a memory deficit in recalling a repeated item, and argued that they are basically the same.

The Ranschburg effect reported in the memory literature (e.g., Crowder & Melton, 1965; Jahnke, 1969) is indeed strikingly similar to the RB effect reported in the visual perception literature. The reason that researchers consider the Ranschburg effect to be a memory phenomenon is probably that stimulus presentation rate is quite slow (about two items per second), and, therefore, it is not likely that subjects did not *see* the repeated item during stimulus presentation.

In contrast, the stimulus presentation rate in the RSVP paradigm used to demonstrate RB is much faster (over six items per second). It is likely that subjects may simply not be able to recognize a repeated item under such fast presentation conditions. However, because relatively long lists of items (typically 5 to 10) were used, memory storage and retrieval are surely a factor affecting performance in both cases. This leaves open the possibility that RB may actually be a manifestation of the Ranschburg effect in RSVP, resulting from retrieval bias, output interference, or guessing strategy (see, e.g., Crowder, 1968; Fagot & Pashler, 1995; Greene, 1991).

The basic assumption of the memory account of RB is that the memory system may have a bias against repeated items in storage and/or retrieval when it is near or beyond its capacity. Thus if it can be shown that memory load has no effect on RB, or if RB occurs even when memory load is near or at a minimum, we can argue that RB is probably not a memory phenomenon. Park and Kanwisher (1994; see also Bavelier & Potter, 1992) have recently made a similar argument. In two experiments addressing this issue (Experiments 4 and 5), they presented subjects with a string of letters, along with to-be-ignored symbols, and varied memory load. They found very little effect of memory load on RB. Importantly, RB occurred even when there were no other items to be reported except C1 and C2. The finding of RB in the near-minimum memory load condition strongly suggests that RB is not a memory phenomenon.

The demonstration of RB for two-item stimuli (without to-be-ignored symbols) in our Experiment 1 provides further evidence against the memory account of RB. Furthermore, Humphreys et al. (1988) and Hochhaus and Marohn (1991) have reported that RB occurred when subjects were asked to report only C2 in non-RSVP conditions. The fact that RB occurred even when subjects were required to report only the second of two sequentially presented items in our Experiment 2 further adds to the evidence indicating that RB occurs even when the memory load is at minimum. These findings strongly suggest that RB is a deficit occurring at a stage before memory storage or retrieval.

Can RB Occur at the Earliest (Sensory) Stages of Processing?

If RB were not a memory phenomenon, it could have a sensory or a perceptual locus. The first sensory account attributes RB to the possible fatigue of feature detectors when two identical stimuli have to be detected within a narrow time window. The second possibility is lateral masking that attributes RB to a greater masking between identical items than between distinct ones. If fatigue of feature detectors or lateral masking were the cause of RB, increasing the spatial distance between two repeated items should reduce RB, because increased distance should reduce lateral masking and the possibility that the same set of feature detectors is used to detect the two stimuli. Since spatial distance was found to have no significant effect, Experiment 1 provided evidence against these two sensory accounts of RB.

The feature-specific inhibition hypothesis attributes RB to greater inhibition among the visual input channels processing the same features than among the input channels processing different features (Bjork & Murray, 1977). There are two pieces of evidence against such an explanation. First, RB has been shown to occur when two repeated items are separated by several intervening items, temporally, spatially, or both (e.g., Kanwisher, 1987; Luo & Caramazza, in press). Second, Egeth and Santee (1981) have shown that the repetition effect occurs even when the two letters are visually dissimilar and only shared the same name (e.g., Aa). This finding indicates that RB cannot be entirely explained in terms of inhibition between visual features at the stage of feature extraction. Rather, RB is a perceptual phenomenon that occurs at the stages of identity encoding.

Type Refractoriness Versus Type–Token Binding Failure

Even if RB were a perceptual phenomenon, alternative accounts would be possible. Next we will consider two major competing perceptual accounts of RB: the type–token binding failure hypothesis and the type refractoriness hypothesis.

According to the type–token binding failure hypothesis, as formulated by Kanwisher (1987, 1991), RB occurs because the same type cannot be linked to two separate tokens, and not because the same type cannot be activated repeatedly. Kanwisher (1987) dismissed the type refractoriness hypothesis in favor of the type–token binding failure hypothesis. However, the evidence she presented against the type refractoriness hypothesis was based primarily on the results of one experiment. In that experiment, subjects were asked to report only the last item in word lists that varied in length. If RB were due to the type-node refractory period, RB should also occur in this report-only-C2 condition. Because Kanwisher (1987, Experiment 3) found that the word was identified better rather than worse when an identical word had appeared previously in the same list, she argued that the type refractoriness hypothesis must be false. Kanwisher interpreted repetition priming obtained in this experiment as indicating that both the first and second occurrences of repeated items were recognized as a type but only C2 was individuated as a token.

However, in another very similar experiment, Kanwisher and Potter (1990, Experiment 6) found RB rather than repetition priming. As noted by Kanwisher (Park & Kanwisher, 1994), the results of her original experiment have not been reliably replicated. The failure to replicate repetition priming undermines Kanwisher's argument that RB is due to the type–token binding failure rather than refractoriness of type nodes. On the other hand, other researchers have also demonstrated RB when similar, though not identical, procedures have been used. As noted earlier, Hochhaus and Marohn (1991) found RB when subjects were asked to respond only to a target in the priming paradigm. Humphreys et al. (1988) also found RB when subjects were shown two items that appeared at the same location and C1 was not masked. The demonstrations of RB in these studies are all consistent with the type refractoriness hypothesis, which predicts RB to occur independently of whether C1 was to be reported or not (provided it was processed). In Experiment 2, we too demonstrated RB when subjects were asked to report C2 only. The fact that RB is determined by the encoding effectiveness of C1 is also consistent with the type refractoriness hypothesis.

Does repetition priming observed in some conditions undermine the type refractoriness hypothesis? We think the answer is "no." As argued previously, the determinant of RB as opposed to repetition priming is whether or not the first occurrence (C1) has activated its corresponding type node supraliminally: When C1 is processed incompletely (subliminally), it primes the processing of C2; when C1 is processed completely, it inhibits the processing of C2 (owing to type refractoriness). The repetition priming effect in Kanwisher's study may thus be interpreted as one manifestation of the masked repetition priming reported by Forster and Davis (1984) and Humphreys et al. (1987), which occurs because of an increased activation or facilitation of a type node.

One might argue that the results of our Experiment 2 are also consistent with the type–token binding failure hypothesis. For example, it can be argued that RB occurred in our Experiment 2 because subjects simply could not prevent themselves from individuating C1. Two factors in our Experiment 2 could have made it possible for that to happen. The first is that the location uncertainty of C1 and C2 made it necessary for subjects to attend to C1 initially. The second is that an abrupt onset of C1 may have automatically captured their attention (see, e.g., Yantis, 1993). If it were the case that when C1 was attended, it would often get individuated, then it can be claimed that in our Experiment 2 there was an automatic tokenization of C1 and thus RB for C2, even though subjects were supposed to individuate C2 only.

One difficulty with this argument is that we then have to explain why the subjects in Kanwisher's (1987) Experiment 3 could avoid individuating C1 and also why the subjects in Kanwisher and Potter's (1990) Experiment 6 could not. If the type–token binding failure theory were successful in claiming that C1 was not attended in Kanwisher's (1987) Experiment 3 but was attended in Kanwisher and Potter's (1990) Experiment 6 and in our Experiment 2, then the present results would not really be inconsistent with the type–token individuation failure hypothesis. The bottom line, however, is that when the evidence supporting the dissociation between type activation and token individuation is uncertain, the argument against the type refractoriness hypothesis is seriously weakened. In a nutshell, the type refractoriness hypothesis may still be a viable account of the RB effect.

We have recently developed and formalized one version of the type refractoriness hypothesis (Luo & Caramazza, in press) which seems to be able to account for the major findings in the field. The proposed system has two components: a linear filter, which has a rising and falling impulse response, and a decision unit, which takes the output of the filter as its input and fires if the activation surpasses some fixed threshold. The system can be taken as a mechanism for activating a type node in long-term memory. Type refractoriness is embodied in the behavior of the linear filter. And RB occurs when a second stimulation arrives while the state of the type node has not recovered from the below-baseline level to the resting level. The simulation showed that it can account for major findings concerning the RB effect.

The Noisy-Operator Theory

Finally, we consider another possible alternative account of RB: the noisy-operator theory. This theory was developed by Krueger (1978, 1983) to account for the fast-*same* effect and the false-*different* effect in *same–different* judgments. According to the noisy-operator theory, noise in perceptual processing turns objective matches into perceived mismatches more frequently than vice versa. In the present study, backward masking could have added to the noise level. If this was the case, the RB effect found in the present study could be accounted for by arguing that the task of identifying the two letters was disrupted to a greater extent by noise when the two letters were objectively identical yet had to be given different names because of a perceived mismatch, than when they were objectively different and thus had to be given different names no matter how different they look. One potential problem with this account is that it remains to be seen whether it can be extended to account for the RB effect found in the traditional RSVP paradigm, in which stimulus identity rather than match–mismatch is the focus of the task.

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