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The roles of awareness and encoding effectiveness in repetition blindness

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Abstract

Three experiments examined the necessity of awareness in producing the repetition blindness (RB) effect. This was done by using a novel procedure in which three orthographically similar items appeared in the RSVP stream (e.g., *mine, mile, file*). On these trials participants would often be unaware of the second similar item, so report of the third similar item served as an index of how often RB occurs when participants are unaware of the second similar item. Results give no indication that RB can occur without awareness of the preceding similar item. Additional comparisons revealed that RB late in the RSVP stream was significantly smaller than RB occurring early in the RSVP stream. These results are discussed in terms of current RB theories. It is suggested that awareness often co-occurs with RB because both processes rely on encoding effectiveness. It is also proposed that encoding effectiveness determines the magnitude of RB.

Chapter 1. Introduction

Repetition blindness (RB; coined by Kanwisher, 1987) is described as a deficit in reporting the second occurrence (C2) of two identical items when the second item follows shortly after the first item (C1). Usually C1 and C2 appear with filler items in a rapid serial visual presentation (RSVP) stream where each item is displayed briefly, one after another, in the same location. Although most studies use the RSVP procedure, RB has also been demonstrated in simultaneous displays where all items onset at once and are displayed for a limited amount of time (e.g., 300 ms; Luo & Caramazza, 1996; Morris, Still, & Caldwell-Harris, 2006). The implication from studies using simultaneous displays is that RB should not be characterized as a phenomenon observed only in an artificial lab environment. Instead RB may reflect the natural response of the visual and attentional systems to repeated items (Morris et al., 2006). For instance, this mechanism that produces RB may ensure that one item is not mistakenly perceived as multiple items during everyday visual processing.

Most perceptual theories of RB posit that when a participant encodes C1 something occurs which reduces the probability that a repetition of C1 - C2 - will be identified. For example, according to Luo & Caramazza's (1995; 1996) *type refractoriness hypothesis* when an item is presented visually the abstract representation, also referred to as the type representation, of an item is activated in memory. The magnitude of the type activation is related to how well the item is encoded. Under conditions of good encoding, the type activation will exceed a threshold and enter awareness. Once the type representation of C1 has crossed the threshold, it undergoes a refractory period within which it cannot be reactivated for a finite amount of time. RB occurs because C2 appears while the type is still refractory, making C2 unavailable for identification and, hence, unavailable for report.

Another perceptual theory, the *token individuation hypothesis*, has been the most widely accepted theory of RB over the last 20 years (e.g., Bavelier, Prasada, & Segui, 1994; Kanwisher, 1987; 1991; Park & Kanwisher, 1994). The hypothesis operates under similar assumptions to the two-stage models of attention and object recognition (e.g., Feature-integration theory; Treisman & Gelade, 1980; Two-stage model; Chun & Potter, 1995). Within these theoretical frameworks, items in the environment undergo two stages of processing before they reach consciousness. During stage one, all items in the display, and their features, are processed rapidly in parallel. After stage one, only relevant items or features enter stage two processing. Stage two is selective. It has a limited capacity and only processes one item at a time. When an item completes stage two processing it becomes available to consciousness. Kanwisher's (1987; 1991) token individuation hypothesis is similar in that the abstract representation of an item (type) can be activated in parallel with other items, similar to stage one processing. Tokens are also formed representing the space and time information associated with each individual item (spatiotemporal token; Chun, 1997). Before an item can be remembered, and subsequently reported, the type and spatiotemporal token must be bound together, forming an object token (Chun, 1997). Token individuation is the process by which attention binds the type and spatiotemporal token; much like stage two processing. This means that the token individuation process must also "decide" which types and spatiotemporal tokens should be bound together, so it is responsible for distinguishing between items that have similar types. Within this framework, RB occurs because only one object token is formed even though the type has been activated twice. In other words, the two type representations are not distinguishable.

Awareness and RB

Even though most RB researchers mention concepts such as awareness and consciousness when discussing theories and results, those concepts are usually left undefined. For example, what does it mean to say that type activation reaches the level of awareness or that an item becomes available to consciousness? When RB researchers talk about these concepts they usually equate awareness and consciousness with the ability to correctly report an item. But it seems possible that one can be aware of the fact that a word appeared, but be unable to correctly identify the item. Thus having the ability to detect the presence of an item is not equivalent to correct report of an item. It also seems possible that one can detect a word, but misidentify that word. This would occur when the wrong type is activated. So at least detection and type activation contribute to correct report[1]. Figure 1 illustrates possible outcomes that are associated with different combinations of detection and type activation. As illustrated in Figure 1, the only time C1 will be reported correctly is when participants detect the item and the correct type is activated. It is in this situation that most

	Type Activation (C1)	
	Correct	Incorrect
Detected	C1 reported*	C1 not reported
Undetected	C1 not reported	C1 not reported

Figure 1. Possible outcomes for report of C1. Report depends on detection and type activation. The asterisk indicates what is usually referred to as awareness in the RB literature.

[1] An additional factor is memory. In Sperling's (1960) experiment participants were aware of many items but could only report a small number of them before their memory traces decayed.

RB researchers would say participants have awareness of C1[2]. When C1 is not reported one cannot know if C1 went undetected or if C1 was detected but the wrong type was activated (although the latter could cause the wrong item to be reported). Because RB is usually measured by report of critical items, researchers only know the status of detection *and* type activation when items are reported correctly. In addition, these theories predict that RB occurs only when the participant is aware of C1 and the type has been correctly identified, but the theories have very different reasons for why one would not expect RB in the other conditions.

In the token individuation hypothesis, awareness of an item does not occur until the type and spatiotemporal token for the item have been bound together. This binding is also the key to producing RB. When an object token has been created for the first critical item, the second item is not distinguished from the first – no token individuation process - so participants are unaware of the repeated item. Several explanations have been given for why an object token is not formed for a repeated type. One explanation is that the recognition system may employ a token minimization bias, which would serve to reduce the likelihood that a single item would be perceived as two or more items (Chun, 1997). If this is the case, an object token is formed for the first item, but once the second of the two identical items appears, no object token is formed because the recognition system is set up to err on the side of underestimating the number of identical items. In this framework, RB can only occur when the first item has been detected. If the first of the repeated items is not detected, no object token is formed, so there is no reason *not* to tokenize the second of the repeated items. In addition, RB would not occur when participants detect C1 but misidentify it because then

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[2] To remain consistent with the literature, awareness will be used in the same way in this paper.

C1 and C2 would have different type representations. One situation in which this token minimization bias would be useful is when an observer sees a moving object. Although the observer may blink or saccade, or the item may become occluded, a token minimization bias would allow the observer to correctly see one object (Kanwisher, 1987; Chun, 1997; Chun & Cavanagh, 1997).

The type refractoriness hypothesis also implies that awareness is required to produce RB. In this theory, RB only occurs when C1 is well encoded; that is, the correct type must be sufficiently activated. C1 is consciously perceived when type activation surpasses a fixed threshold; crossing that threshold subsequently causes the type to go into a refractory state. Thus RB for C2 should only occur when C1 has been consciously perceived. Like the token individuation hypothesis, this framework would not predict RB when the wrong type is activated. When this is the case, different types would be activated for C1 and C2 so report of C2 would not be affected by C1's refractory period. But, is awareness of the first critical item really necessary to produce RB? Could RB and awareness simply be correlated, that is, could both arise from a third factor?

There is evidence that more than awareness is involved in RB as characteristics of the critical items influence the magnitude of RB. These characteristics include relative word frequency, lexicality, and item exposure duration (Bavelier, Prasada, & Segui, 1994; Coltheart & Langdon, 2003; and Luo & Caramazza, 1995 respectively). Researchers have been able to examine the effects of individual variables on RB magnitude by looking only at trials where the participant was aware of C1. These conditional analyses are necessary because the variables are often correlated with awareness. For example, as duration of an item increases, the likelihood that one will be aware of the item increases, so the researcher would not know if increased duration or increased awareness produced differences in RB. Results from these types of studies indicate that even if awareness of C1 is necessary to produce RB, awareness is not the only factor contributing to the RB effect. For example, in Bavelier et al's (1994) Experiment 1 the effects of word frequency on RB were examined. When analyzing the results, they only looked at trials in which C1 was reported correctly; so all the trials were aware trials. Frequency effects were significant indicating that word frequency influences the magnitude of RB. Studies like this indicate that theories like the token individuation hypothesis may be underspecified. One way current theories could account for data like that found for word frequency is by assuming that those variables affect the type representation (e.g., high frequency word types are different than low frequency word types) so they may indirectly affect RB.

But another finding presents more of a challenge for the token individuation and type refractoriness hypotheses. Whittlesea and Masson (Experiment 1; 2005) found that RB may depend on what items are used as fillers. While holding the amount of time constant between C1 and C2, Whittlesea and Masson varied what appeared as filler items in the RSVP stream (see Table 1 for examples of trial content and results). In one condition, C1 and C2 were displayed with no fillers, that is, a blank 120 ms interval separated C1 and C2. In the second condition, a symbol string was displayed before and after C1 and after C2. The third condition was the same, except that the word *WHITE* was used as the filler. Finally, in the fourth condition, random words were used as the fillers. In this experiment participants were asked to report whether or not a repeated word appeared in the RSVP stream. Results indicated that the magnitude of RB was affected by the characteristics of the fillers. With no fillers, there was no RB. In the other conditions, as the fillers became less visually distinct from (in that they look more like random words) C1 and, the magnitude of RB increased, so the largest RB effect was found when the fillers were random words (see Table 1 for hit and false alarm rates by condition). These results are interesting because there is no change in the characteristics of the critical items, but there are clear changes in RB. The findings are particularly problematic for the explanation of RB provided by the token minimization bias. There is no *a priori* reason to think that changing the filler items would change the bias to report only one of two similar items.

Table 1.

Results from Whittlesea and Masson's (2005) Experiment 1

Condition	Items in RSVP	Hit	False Alarm
1	_______ C1 _______ C2 _______	.99	.02
2	@#$%& C1 @#$%& C2 @#$%&	.78	.04
3	WHITE C1 WHITE C2 WHITE	.58	.10
4	word 1 C1 word 2 C2 word 3	.10	.01

Note: In condition 4, *word* stands for a random filler word. Hit rates are the probability that participants report a repetition on a repeated trial. False alarms are cases when participants report a repeated item when there was not. Lower hit rates represent larger RB effects.

Morris, Still, & Caldwell-Harris (2006) have taken Whittlesea and Masson's (2005) finding, and other results, as evidence that competition between items produces the RB effect – the *competition hypothesis*. According to this hypothesis, RB occurs because repeated items compete less effectively for access to awareness than nonrepeated items. In an RSVP stream an item competes with whatever stimuli are presented before and after it. When nothing appears immediately before or after a repeated item, there is nothing for it to compete against, so it will reach awareness (no RB like in Whittlesea and Masson's blank condition). When fillers are used repeatedly (like the @#$%& and WHITE conditions), they will not compete much so repeated items will still often reach awareness. Finally, when filler items are random words and critical items are words, the repeated item will be at a competitive disadvantage compared to the items that precede and follow it, so often it will not reach awareness.

The competition hypothesis is much different than the other two theories, in part, because it does not make the assumption that awareness of C1 is necessary to produce RB. Specifically, it asserts that RB arises in part from the same process that produces short-term repetition priming. Findings from the repetition priming literature indicate that some cells that are active during the first presentation of the item fire less with the second presentation of the item (e.g., Miller, Li, & Desimone, 1991), while other cells show an increase in activity upon second presentation of the item (Ringo, 1996). This has been described as neural sharpening (Desimone, 1996). According to the competition hypothesis this neural sharpening results in C2 having a "cleaner" (less noise) and smaller representation (because fewer cells respond). This smaller representation is composed of features that are critical for identifying the item, but it contains fewer features than those active from the first presentation (not all of the features activated the first time are necessary for identification). The second component of this hypothesis proposes that summed neural activity dictates which items reach awareness in that items with higher activity out-compete items with lower activity. This means that a repeated item will be less likely to enter awareness than a nonrepeated item. According to this theoretical framework, RB is not triggered by awareness of C1; RB is evident because a nonrepeated item is more likely to reach awareness than a repeated item. An additional factor, the quality of C1's type representation will influence whether or not RB occurs. When C1 is well encoded, it leads to greater neural sharpening in C2 (less noise and smaller representation). When C1 is poorly encoded its type representation is noisier. This means that a repeated C2 will have a cleaner representation but there is still more noise than if C1 had been well encoded, so the representation is not as small. In this case RB is less likely to occur because C2's representation would compete with nonrepeated items for access to awareness. Within this framework RB for C2 will usually correlate with awareness of C1 because the type representation of C1 will usually be large enough to compete effectively for access to awareness.

The goal of this investigation is to examine RB when participants are not aware of the first of two similar items. If RB is found it would present a challenge for the type refractoriness and token individuation hypotheses. In addition it would provide indirect support for the competition hypothesis as it is the only theory that does not require the involvement of awareness in RB.

Evidence for the role of awareness in RB

Other researchers have attempted to show that awareness is necessary to produce RB by looking at conditional analyses or by using an attentional blink paradigm. The results from these studies are difficult to interpret (for reasons that will be explained later), but they are noteworthy because they have at least examined the issue.

Insight as to whether or not awareness of C1 is required to produce RB for C2 might be found in two studies in which the duration of C1 was manipulated. While investigating whether or not RB arises because participants have to distinguish between C1 and C2, Luo and Caramazza (1995, Experiment 2) manipulated duration of C1 but only asked participants to report C2. C1 was displayed for 25, 50, 100, or 200 ms while C2 was displayed for 50 ms, both items were letters; repeated items were identical letters. Results show that RB for C2 increased as duration of C1 increased indicating that encoding effectiveness of C1 has a significant effect on the magnitude of RB. These results are in line with Luo and Caramazza's predictions. They argued that encoding effectiveness of C1 was the critical factor in producing RB and that RB did not depend on distinguishing between C1 and C2. Specifically, they predicted that if C1 is shown too briefly it will not be processed sufficiently so no RB would occur, but if the duration of C1 is increased, C1 would be effectively encoded thus allowing RB to occur. While this appears to be evidence that RB only occurs when participants are aware of C1, Luo and Caramazza did not have a measure of C1 awareness since participants did not report C1. To make the claim that awareness is necessary for RB from these results, one would have to assume that participants were not aware of C1 when it was displayed for a short duration.

To investigate how repetition of a letter affects participants' ability to recognize repeated letters, Kuwana (2004) presented two masked letters (C1 and C2), side by side, with one appearing 100 ms after the other. C1 was displayed for 10, 30, 50 or 200 ms, while C2 was always displayed for 40 ms. When the duration of C1 was short (10 ms), participants failed to report C1 but they reported a repeated C2 more accurately than a nonrepeated C2 demonstrating repetition priming. In contrast, when duration of C1 was longer (50 and 100 ms), participants accurately reported C1 and when C2 was a repeated item it was reported with lower probability than a nonrepeated C2 demonstrating repetition blindness. In Kuwana's 30 ms condition, a conditional analysis revealed that when C1 was reported, a repeated C2 was missed more often than a nonrepeated C2 demonstrating RB. When C1 was not correct, there was no evidence of RB for C2. Kuwana used this as evidence to suggest that C1 must be processed sufficiently so it can be correctly identified and that identification of C1 is what leads to RB. This indicates that awareness of C1 may be the critical factor in producing RB, but these results must be interpreted with caution because they are post hoc and identical items were used for C1 and C2.

Conclusions derived from conditional analyses are necessarily post hoc. That is, experimenters do not control the outcome on a trial-by-trial basis; instead they must take the participants' results and separate them by condition. For example, Kuwana could not assign awareness or unawareness to specific trials, instead, after the experiment, he separated the trials into aware and unaware (of C1) and compared report of C2 for those trials. The difficulty with conditional analyses is that the researcher cannot know the actual differences between an aware and unaware trial. For example, participants may not report C1 for three reasons 1) the correct type was activated, but the item was not detected, 2) the wrong type was activated and the item was not detected, or 3) the wrong type was activated, but the item was detected so the participant gave an incorrect response (For a visual depiction refer back to Figure 1). Only one of these situations would be expected to possibly produce any RB – when the correct type is activated, but the item is not detected.

The fact that identical items were used for C1 and C2 adds to the concerns about using conditional analyses. When items are shown very briefly participants have difficulty reporting the correct identity *and* correct position. It is likely that when processing is difficult (as in Kuwana's 30 ms condition) participants can get the identity of one of the items, but may not know if it was the first or second item, so that item may be reported in the wrong position. The concern about this type of misreport is that although these errors would be obvious in the nonrepeated condition because one can see that the item reported as C1 was really C2, the errors would not be obvious in the repeated condition because C1 and C2 are identical. There may be cases when the participant missed C1 and was aware of C2, but reported C2 as the first item. This would look like RB for C2 when C1 is reported. Of course, the opposite result is possible as well – C1 is identified and C2 is missed, but C1 is inadvertently reported as C2. This would look like there is no RB when C1 is missed. Both types of order errors produce results that would lead to the same conclusion – there is no RB for C2 when C1 is missed. The implication is that if RB for C2 from a missed C1 is small, a significant number of order errors could mask this RB.

In general the results from Kuwana (2004) and Luo and Caramazza (1995) suggest that the duration of C1 affects the magnitude of RB[3] and that awareness of C1 may be necessary to produce RB, but there are two reasons to further investigate the role of awareness in RB. First, both experiments used identical items for repeated stimuli so the directionality of RB cannot be determined. This is important to consider because backward RB – C2 is identified but C1 is missed – has been observed in a few experiments (Neill, Neely, Hutchison, Kahan, & VerWys, 2002). A second reason for further investigation is that awareness and duration most likely co-varied in these experiments so their individual influences on RB cannot be determined.

Determining the direction of RB

Luo and Caramazza (1995), and Kuwana (2004) used identical critical items making the results more difficult to interpret. In experiments that use identical items, a basic measure

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[3] When duration of C1 is too short RB is reduced (e.g., Luo & Caramazza, 1996; Kuwana, 2004), but increasing the duration of C1 over 150 ms typically has little effect on RB (e.g., Park & Kanwisher, 1994, Experiment 2).

of RB is obtained by finding the proportion of repeated trials where C1 and C2 were both reported correctly (the both score) and subtracting that from the proportion of nonrepeated trials where C1 and C2 were both reported correctly. If the difference is positive, RB has occurred; if the difference is negative, a repetition advantage is present. Although RB was originally defined as a deficit in reporting C2, it is difficult to know which item the participant is reporting if C1 and C2 are identical. When researchers have to rely on the both score (joint report of C1 and C2), they cannot know with certainty which item is missed, so strong claims about the directionality of RB cannot be made.

Because most perceptual theories of RB rely on the assumption of a sequential progression of RB – C1 is activated causing C2 to be missed – it is essential to demonstrate that participants are in fact reporting C1 and not C2 when RB occurs. Johnston, Hochhaus, and Ruthruff (2002) conducted 2 experiments in which participants were required to press a button as soon as they detected targets (repeated or nonrepeated items) in an RSVP stream. They found that participants missed repeated targets in an RSVP stream more often than nonrepeated targets, thus participants demonstrated RB. Additionally, Johnston et al. used participant reaction times to determine which targets participants had most likely detected. Using this method, they were able to demonstrate that when a participant only detected one of two identical targets, they usually detected C1. This is evidence that C2 is most often missed in RB, thus it seems that something involved in the processing of C1 causes RB for C2. Even with this evidence, one cannot be certain that participants in the Luo and Caramazza (1995) and the Kuwana (2004) experiments were actually missing C2 when they experienced RB. To alleviate this problem, researchers must make C1 and C2 distinguishable from one another.

One common way to differentiate between critical items is to use orthographic neighbors – items that share all letters except one in the same positions (e.g., *horse, house*). Although orthographic neighbors had been used in RB experiments, Chialant and Caramazza (1997) suggested that RB for neighbors was not the same as RB for identical items because they follow a different time course - RB for identical items produced the most RB at lag one (one item between C1 and C2) then decreased while orthographic RB produced the most RB at lag two (two items between C1 and C2) before decreasing (Chialant & Caramazza, 1997). In a series of four experiments, Harris and Morris attempted to replicate those findings, but instead found that RB for identical and orthographically similar items follow the same time course, with both producing the most RB at lag one and decreasing with each subsequent lag. The reason for the difference in results perhaps lies in a stimulus confound in Chialant and Caramazza's Experiment 1. Occasionally the nonrepeated, control words used for C1 shared the first letter (in some cases up to three consecutive letters) with C1, so RB would be expected to occur in those control trials. This confound was only present in the orthographically similar condition at the shortest lag and would lead to what appears to be less RB for orthographically similar words than for identical words.

Even though RB appears to be the same phenomenon whether items are identical or not; RB is reduced when C1 and C2 are less similar. For example, in a series of experiments conducted by Harris and Morris (2000), RB was found more often when C1 and C2 shared the first three letters (35% of potential RB trials) than when C1 and C2 shared only the first letter (12% of potential RB trials). Harris (2001) specifically investigated whether RB was limited to words that share consecutive letters or if it also occurs for words that share nonconsecutive letters. She found significant RB for words that share as few as three nonadjacent, internal letters (e.g., *pigment, diamond*). These studies have been taken as evidence that RB for words can occur at a sublexical level. This is important because the ability to use non identical items to investigate RB allows researchers to determine which critical item a participant is reporting and can therefore be used to test current RB theories (including the role of awareness) in more detail.

Duration and awareness confound

The other concern about the Luo and Caramazza (1995) and Kuwana (2004) experiments was the possible confound between duration and awareness – awareness of C1 likely increased as duration of C1 increased. When investigating the role of awareness in a process is it important to unconfound duration and awareness as they have been shown to produce dissociable effects in other studies. For example, in the semantic priming literature there is an interesting dichotomy; sometimes semantic relatedness leads to priming, while other times it leads to interference. Facilitation typically occurs when awareness of the prime is limited, while interference effects typically arise when participants are aware of the prime. Wentura and Frings (2005) noted that duration was confounded with awareness in these studies: When prime awareness was limited because the prime was briefly displayed, priming occurred; but when participants were aware of the prime because the prime was displayed longer, interference occurred. In an attempt to tease apart the individual influences of duration and awareness, Wentura and Frings used a procedure in which they were able to display the prime for a longer duration by rapidly alternating the prime and a mask, but despite the long duration, participants were often unaware of the prime. In a series of four experiments interference was found for low dominance exemplars – *apple* is a high dominance exemplar while *mango* is a low dominance exemplar in the fruit category - using the repeated prime procedure with category names serving as the prime. Interestingly, these interference effects were only consistently found when participant awareness was low and prime duration was long – a combination of conditions that is rarely tested, but produced theoretically important results.

Eliminating the awareness and duration confound

One way to discover the necessity of awareness in RB without the duration confound, would be to use an established procedure that results in an item being missed (C1) even when it is shown for a relatively long duration (e.g., 100 ms). Then the missed item would be followed by an orthographic neighbor (C2). If a repeated[4] C2 is missed when C1 goes unidentified, it would show that RB is dependent on something other than awareness of C1. One way to investigate this is to use the same methodology as Wentura and Frings (2005). Unfortunately, they used a random letter mask to reduce awareness of C1 but because RB can occur at a sublexical level, it is not clear how those masks would affect RB.

Another option would be to use an attentional blink paradigm in which two targets and multiple distractors are displayed rapidly in RSVP. The attentional blink (AB; coined by Raymond, Shapiro, & Arnell, 1992) is demonstrated by the fact that successful encoding of the first target hinders report of the second target if it occurs within a brief window of time (approximately 200-500 ms after the first target). This deficit in reporting the second target is usually attributed to an attentional bottleneck[5] - processing a target takes more time than the actual duration of the target, occupying resources that are needed to process the subsequent

[4] The term 'repeated' will be used loosely to mean an orthographically similar item in the remainder of the manuscript. When identical repetitions are discussed, they will be clearly described as identical items.

[5] Although recently it has been suggested that a difficulty in disengaging attention from the first target is what causes the AB for the second target (DiLollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Chua, 2005).

target (Chun & Potter, 1995). While the first target is being processed, the second target is missed. In the AB paradigm, both targets have the same duration, but the second one is missed. If an orthographic neighbor of target two could be presented as a third target in the RSVP stream, one could investigate whether RB occurs for an orthographic neighbor of a missed item (see Table 2, AB and RB study, for an example). In this type of design, RB would be measured by the difference in report of a nonrepeated third target compared to an orthographically similar third target. Shapiro, Driver, Ward, and Sorensen (1997) used a similar method to discover if items missed during the AB have had their type representations activated. In Experiment 1 of their study, three targets were presented among number distractors in RSVP. Target one was always a white number, while targets 2 and 3 were letters that either had the same identity or not (e.g., *E, e* or *E, n* respectively; see Table 2).

Table 2.

Example of critical items used in two AB experiments containing RB trials.

	Shapiro et al. Exp. 1			AB and RB study		
Condition	T1	T2	T3	T1	T2	T3
Repeated	1	E	e	room	cane	cake
Nonrepeated	1	E	n	room	drum	cake

Note: *T* represents target. In the Shapiro et al. experiment T1 was white, T2 and T3 were black.

Trials where targets 2 and 3 were identical are potentially informative for the present investigation. When target 2 was reported, participants demonstrated RB for target 3, but when target 2 was missed, target 3 was reported more often than a nonrepeated target 3.

These results suggest that identification of target 2 produced RB for target 3 while missing target 2 led to repetition priming of target 3. Shapiro et al. (1997) used a strict criterion – report was only considered correct if the identity and letter case were correct, but even using this criterion, one cannot be certain which target the participant reported as participants often have difficulty accurately reporting the order and case of letters in AB tasks (e.g., Chun, 1997).

Even if one were to use Shapiro et al.'s (1997) design with nonidentical words (e.g., orthographic neighbors) for the repeated items, there are other concerns. Because the present investigation depends on participants having limited awareness of the first critical item (target 2), one would want to make sure participants miss target 2 on most trials. In Shapiro et al.'s Experiment 1, target 2 was reported 67% of the time when target 1 was reported, so it appears as if the attentional blink was actually rather small for target 2. Therefore, an alternative method might provide more trials of interest.

Fortunately, there is another way to manipulate awareness while holding duration constant: A paradigm that produces RB could be used. Participants are not aware of an item that is missed due to RB. If an additional orthographic neighbor follows an item that is missed due to RB, report of that third critical item can be examined to find out whether or not awareness is necessary to produce RB. For example, if the words *dark*, *bark*, and *barn* are shown in RSVP, participants will usually report *dark* but will often be "blind" to the word *bark*. Examining report of *barn* in this situation could reveal whether or not awareness of *bark* is required to produce RB for *barn*. Discovering if awareness of C1 is necessary to produce RB would help pinpoint the mechanisms involved in RB.

Experimental Design

Because the current investigation depends on having some certainty about which items are reported, orthographic neighbors were used instead of identical items in the following experiments. Typical RB experiments compare report of critical items in a nonrepeated condition where no items are orthographically similar (e.g., *dark*, *goat*; see the nonrepeated example in Table 3) to a repeated condition (e.g., *dark*, *bark*; see the early RB example in Table 3) in which two items are orthographically similar[6]. RB is demonstrated by the finding that critical items in the repeated condition - *dark* and *bark* - are reported less often than critical items in the nonrepeated condition - *dark* and *goat*. This can be measured by the both score or by comparing the proportion of report for the second nonrepeated critical item compared to report for the second repeated critical item. From the example mentioned before, RB would be apparent because *bark* in the repeated condition would have a lower probability of report than *goat* in the nonrepeated condition.

In order to manipulate awareness without it being confounded with duration, an RB procedure was used where three critical items appear in the RSVP stream (e.g., *dark*, *bark*, *barn*). On trials in which participants experience RB for C2 they do not have awareness of C2. By placing an additional critical item after C2, the necessity of awareness in RB can be investigated. If RB for C3 only occurs when C2 is identified, awareness must be necessary; conversely, if any RB occurs for C3 when C2 is not identified, awareness is not necessary to produce RB. This new type of condition with three critical items will be referred to as the three critical condition (see Table 3 - three critical - for an example).

[6] RB has also been found for phonologically similar words but the effect is smaller than that produced by orthographic similarity (Bavelier & Potter, 1992).

Table 3

Example of the conditions used to investigate the role of awareness in RB

	Sets of yoked critical items					
Condition	C1	C2	C3	C1	C2	C3
Nonrepeated	dark	goat	file	mine	spot	barn
Early RB	dark	bark	file	mine	mile	barn
Three Critical	dark	bark	barn	mine	mile	file
Long distance RB	dark	goat	barn	mine	spot	file

Even with this new condition, one cannot simply compare report of a repeated C3 when there are three critical items to report of C3 in a nonrepeated condition because there is evidence that when an item is missed due to RB, report of other items in the display sometimes increases. For example, Luo & Caramazza (1996) investigated RB in simultaneous displays and instructed participants to report items from left to right in the display. They found that when a repeated critical item was missed, a benefit for report of the following noncritical item was found. A similar result was found by Morris et al. (2006) in which the benefit occurred in a nonadjacent item. This increased report for nonrepeated items in RB trials, will be referred to as the RB benefit. The RB benefit for report of C3 would be calculated by the following formula:

RB benefit for C3 = early RB report of C3 - nonrepeated report of C3

This RB benefit would be expected in the typical RB condition that contains two critical items (e.g., early RB in Table 3), and in the new condition with three critical items, but clearly not in the nonrepeated condition. If one were to compare the nonrepeated and three critical conditions, report of C3 in the three critical condition could be inflated by the RB benefit for C3. This is a problem because RB is evident only when repeated items are reported less often in the repeated (ie., three critical condition) than in a nonrepeated condition. If report of the repeated item is inflated by the RB benefit, RB could not be detected because report of the repeated item could be equal to or higher than report of the corresponding item in the nonrepeated condition. Because of this possibility, it is more appropriate to compare report of C3 in the three critical items condition to report of C3 in the early RB condition with two critical items as they both should have the same RB benefit and they should differ only in report of C3.

Another factor to consider is that in order to have three critical items in one RSVP stream, there is a chance that the first item could cause RB for the third item. When C1 is an orthographic neighbor of C2, but not of C3, C1 and C3 will still share several letters. For example, if the critical items *dark*, *bark*, and *barn* are presented, *dark* and *barn* still share two letters and could result in RB at the level of letter clusters (Harris & Morris, 2000). Because the intention is essentially to investigate RB for C3 when participants are unaware of C2, the RB that occurs because C1 and C3 are similar is a nuisance factor that needs to be accounted for as it could make it appear as if a missed C2 is producing RB for C3 when actually C3 is missed just because it shares some letters with C1. The possibility for this type of "long distance RB" between C1 and C3 necessitates an additional control condition where C1 and C3 are the same as those used in the three critical item condition but C2 is a nonrepeated item (see long distance RB in Table 3 for an example). This condition will give an indication of the amount of long distance RB that occurs in the three critical items condition and is calculated by the following formula:

Amount of long distance RB = nonrepeated report of C3 – long distance report of C3

Considering the possible existence of this long distance RB, it is apparent that simply comparing report of C3 in the early RB condition to report of C3 in the three critical items condition is inappropriate because there may be some long distance RB occurring in the three critical items condition that is not accounted for by the early RB condition. Because of this, one cannot know if the reduced report of C3 in the three critical condition compared to the typical RB condition comes from long distance RB or the RB of interest (RB for C3 when C2 is missed). To remedy this issue, additive logic could be used to account for the nuisance RB by, first, assuming that the amount of long distance RB is the same in the three critical condition as in the long distance control condition. Then the amount of RB obtained for C3 in the long distance control condition is added to the total report of C3 in the three critical item condition. The following formula demonstrates how this adjusted C3 value for the three critical condition is calculated:

Adjusted C3 value = three critical report of C3 + Amount of long distance RB

This adjusted value accounts for any long distance RB that may be present in the three critical condition. Because of this, the adjusted C3 score could be appropriately compared to report of C3 in the early RB condition to investigate the primary question of whether or not awareness is necessary to produce RB. The only difference between the adjusted C3 value and C3 in the early RB condition would be RB for C3 that caused by C2. In this design, the RB of interest would be detected if the adjusted value of C3 in the three critical condition is lower than report of C3 in the early RB condition:

Adjusted C3 value < early RB report of C3

Chapter 2. Experiment 1

This experiment examined whether or not RB occurs for C3 when C2 is missed due to RB in the three critical condition (e.g., for critical items *dark*, *bark*, *barn*; is there RB for *barn* when *bark* is missed?). Results have the potential to determine whether or not conscious awareness is necessary to produce RB. To appropriately investigate this matter, four conditions were created.

1) Nonrepeated – No item shares more than one letter with the others and no items share the same first letter so that RB does not occur within these trials.
2) Early RB – This is a typical RB trial in which C1 and C2 are orthographic neighbors. The filler items and C3 do not share more than one letter with any other item.
3) Three Critical – C1 is an orthographic neighbor of C2 and C2 is an orthographic neighbor of C3. Care was taken to ensure that C1 and C3 were not orthographic neighbors in order to reduce potential long distance RB.
4) Long Distance RB – C1 and C3 share letters but are not orthographic neighbors and C2 is a nonrepeated item.

Examples of these conditions are given Table 3. The nonrepeated condition is used as a baseline to determine the amount of RB obtained in the early RB and long distance conditions. The amount of RB found for C3 in the long distance condition is added to the report of C3 in the three critical condition. This adjusted value for C3 can then be compared to report of C3 in the early RB condition to determine the necessity of awareness in producing RB.

Method

Participants

Twenty-eight Iowa State University students (15 females) participated in Experiment 1 in exchange for course credit. The institutional review board approved this experiment and all others reported. All participants gave their informed consent before participating and were monolingual English speakers. Participant age ranged from 18-25 ($M = 19.6$).

Materials

All experiments were conducted on a Macintosh computer with a Mitsubishi Diamond 73 monitor with a 40 cm screen. Presentation was controlled by PsyScope experimental software (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants were seated approximately 60 cm from the monitor and all items were presented in black 48 point Arial font.

Words for the experiment were obtained from the MRC psycholinguistic database (Wilson, 1988). All items in experimental trials were monosyllabic nouns with word frequency ranging between 7 and 100 per million (Kuĉera & Francis, 1967). Each trial consisted of three critical words in serial positions one, three, and five and two filler words in serial positions two and four. Because RB was being investigated, filler and nonrepeated items could not share more than one letter with other items in the trial and could not share the same first letter[7]. Four conditions were created to investigate RB. The three critical condition was created first. C2 was an orthographic neighbor of C1 and C3, but C3 was not a neighbor of C1. In addition, C1 was higher frequency than C2 and C2 was higher frequency than C3. This was done to maximize the RB obtained in the experiment as a high frequency C1 and

[7] Filler and nonrepeated items can share one internal letter with one another and critical items without producing RB (Harris & Morris, 2001), but if they share the first letter RB may occur (Harris & Morris, 2000).

low frequency C2 has been shown to produce more RB than a C1 and C2 that are both low frequency (Bavelier, Prasada, & Segui, 1994; Experiment 1). Phonological similarity was not controlled for in these stimuli. All items are listed in Appendix B.

A within item design was used to control for stimulus variability. A yoking procedure was also used allowing multiple versions of the experiment to be made for counterbalancing without inadvertently using the same items more than once in the same version. In the yoking procedure two critical sets are paired together to produce each of the conditions, for example, an item in position one in critical set A would be switched with an item in position one from critical set B. Examples of all conditions and how they are yoked are shown in Table 3. Using the yoking procedure, the early RB condition was created by choosing a pair of three critical trials and switching C3, so the early RB trial contained an orthographically similar C1 and C2 and contained a nonrepeated C3. To illustrate, the critical sets *dark*, *bark*, *barn* and *mine*, *mile*, *file* from the three critical condition are yoked so the early RB conditions created from these would be *dark*, *bark*, <u>*file*</u> and *mine*, *mile*, <u>*barn*</u>. The long distance RB condition was created by replacing C2 in the three critical condition with a nonrepeated word, therefore each trial consisted of a C1 and C3 that had 2-3 overlapping letters and a nonrepeated C2 (e.g. *dark*, *bark*, *barn* and *mine*, *mile*, *file* becomes *dark*, <u>*goat*</u>, *barn* and *mine*, <u>*spot*</u>, *file*). The nonrepeated condition was created by taking the yoked long distance RB condition and substituting C3 with the nonrepeated C3 used in the early RB condition (e.g. *dark*, *goat*, *barn* and *mine*, *spot*, *file* becomes *dark*, *goat*, <u>*file*</u> and *mine, spot,* <u>*barn*</u>).

Forty filler trials (non experimental, nonrepeated trials) were included to make the occurrence of orthographically similar items less common thereby discouraging guessing. Four versions of the experiment were created so items only appeared once for each participant. Each version contained 80 critical trials, 20 from each of the four conditions, and the 40 filler trials. The order of items was randomly assigned with the restriction that trials from one condition could not occur more than three times in a row. Fifteen additional nonrepeated trials were constructed for the practice block with word frequencies ranging from 101 to 150 per million (Kuĉera & Francis, 1967).

Procedure

Each experimental trial began with a fixation cross in the middle of the screen for 700 ms. The fixation was followed by five words displayed rapidly, one after another at fixation with each item displayed for 125 ms. A mask consisting of a string of five ampersands appeared after the fifth word for 125 ms. A question mark immediately followed the mask and served as a prompt for participants to report the words from the RSVP stream.

Before the experiment, participants were given instructions and completed a block of practice trials. Participants were told that five items would appear in RSVP followed by a question mark. When the question mark appeared, they were to report as many words from the list as possible. They were also instructed to read the words carefully because some would be similar to one another. The practice block consisted of 15 trials with duration decreased incrementally to give participants the opportunity to become accustomed to the RSVP procedure and to ensure that they understood the instructions before the experimental trials began. Words presented in the first five trials were displayed for 180 ms, words in trials 6-10 were displayed for 150 ms, while the final five trials were displayed for 125 ms each.

During the practice and experiment the experimenter recorded the participant's response by circling correct responses and recording erroneous responses on a scoresheet and by recording the participant's report of C1, C2, and/or C3 on a keyboard number pad. If the participant failed to report any of the critical items, that was also recorded via the number pad. After recording the participant response, the experimenter pressed "ENTER" to initiate the next trial. At the conclusion of the experiment, participants were fully debriefed and had the opportunity to ask questions about the experiment.

Results and Discussion

In each of the experiments planned comparisons were conducted to test *a priori* hypotheses. Subject and item analyses were conducted and are reported in that respective order; all means for critical items from the subject analyses are reported in Table A1 of Appendix A and the amount of RB found in each condition and experiment from the subject analyses is reported in Table A2 of Appendix A.

Early RB condition

Results from the early RB condition are examined first. RB was present in this condition as evident by several measures: Report of C2 was significantly lower in the early RB condition ($M = .10$) than in the nonrepeated condition ($M = .47$), $t_1(27) = 14.67$; $t_2(79) = 10.77$, both $ps < .001$; and joint report of C1 and C2 (the both score) was significantly lower in the early RB ($M = .09$) condition than in the nonrepeated condition ($M = .45$), $t_1(27) = -14.03$; $t_2(79) = -10.66$, both $ps < .001$. Because the magnitude of this RB may be compared to RB in other conditions with different nonrepeated baselines, the repetition blindness index (RBI) was also used. The RBI, introduced by Park and Kanwisher (1994), considers and controls for different baselines in its calculation while allowing researchers to examine the magnitude of RB. RBI equals the repeated both score divided by the sum of the nonrepeated and repeated both scores. When RBI equals 0 that represents the maximum amount of RB, a score of 1 represents repetition priming, and a score of .5 indicates the absence of RB. In the early RB condition the RBI was .15. This was tested in a one-sample *t* test against the value .5, $t_1(27) = -16.47$, $p < .001$; $t_2(73) = -14.94$, $p < .001$. Additional *t* tests revealed that report of C3 was higher in the early RB condition than the nonrepeated condition (although only marginally significant in the item analysis), $t_1(27) = -2.99$, $p = .006$; $t_2(79) = -1.90$, $p = .061$, showing the "RB benefit" for other items presented in the same display as an item that is missed due to RB.

Long distance RB condition

RB was also observed in the long distance RB condition. Report of C3 was significantly lower in the long distance RB condition ($M = .35$) than in the nonrepeated condition ($M = .43$), $t_1(27) = 3.5$, $p = .002$; $t_2(79) = 2.25$, $p = .027$; joint report of C1 and C3 (both score) was significantly lower in the long distance RB condition ($M = .32$) than the nonrepeated condition ($M = .39$), $t_1(27) = -3.02$, $p = .005$; $t_2(79) = -2.21$, $p = .03$; and the RBI ($M = .45$) was significantly lower than .5, $t_1(27) = -3.38$, $p = .002$; $t_2(79) = -2.46$, $p = .016$. This evidence demonstrates that RB for C3 can be caused by C1 even though the items only share a few letters supporting Harris and Morris' (2000) claim that RB can occur at the level of letter clusters.

Three critical condition

Using the additive logic suggested earlier, one would predict that the value of C3 in the three critical condition would be the same as C3 in the early RB condition after the long distance RB is considered if there is no additional RB from C2 to C3. When report of C3 in the three critical condition is adjusted by adding to it the amount of RB from the long distance RB condition (refer to the Adjusted C3 formula; $M = .54$), it is not significantly different than report of C3 in the early RB condition (M = .49), $t_1(27) = -1.70$, $p = .10$; $t_2(79)$ = .-814, $p = .418$, suggesting that no additional RB is present. Although the difference between the adjusted C3 and the early RB C3 was not significant, the fact that report of C3 is numerically higher for the adjusted three critical condition is puzzling. There is no reason to believe that repetition priming would occur for C3 in the three critical condition because C2 and C3 are not identical, but there may be something else occurring only in the three critical condition which works to inflate report of C2 and C3 compared to the other conditions.

One reason to entertain this concern is that the amount of RB found in the Early RB condition is larger than that in the three critical condition. Significant RB was found for C2 in the three critical condition (M = .16; $t_1(27) = 9.77$; $t_2(79) = 8.48$, both ps < .001), indicating RB, but the difference between report of C2 in the early RB condition (M = 10) and in the three critical condition was marginally significant in the subject analysis and significant in the item analysis, $t_1(27) = 2.00$, $p = .055$; $t_2(79) = 3.07$, $p = .003$. This difference suggests that the amount of the RB obtained in the early RB condition (37%) was greater than that in the three critical condition (31%). Why might this be the case? The three critical and early RB conditions have exactly the same words except C3, so there seems to be no reason for the difference in report of C2 between these conditions.

A possible explanation for the difference is simply that a word may be misread as a similar word. For this series of RB experiments the issue to consider is whether or not the probability of misreading is the same between the early RB and three critical conditions and whether or not misreading would be as likely to lead to inadvertent correct responses in the two conditions. It seems that the probability of misreading C2 in either condition is the same, but misreading of C2 is more likely to lead to a correct response in the three critical condition than in the early RB condition. In the three critical condition C2 and C3 are neighbors (e.g., *bark* and *barn*), but in the early RB condition C2 and C3 are dissimilar (e.g., *bark* and *file*); the misreading asymmetry occurs because the word *bark* is more likely to be misread as *barn* than *file*. Although there is no way to predict how often misreading occurs in these experiments, it is reasonable to assume that misreading is more likely to lead to a correct response in the three critical condition and could have slightly inflated the report of C2 and C3 compared to the early RB condition. This may explain the difference in RB for C2 between the two conditions and raises the possibility that misreading masks the RB for C3 in the three critical condition.

Chapter 3. Experiment 2

Results from Experiment 1 suggest that RB may depend on awareness because there is no additional RB for C3 from C2, but this may be the case because misreading in the three critical condition masks RB for C3. In addition, it is important to consider that the potential RB late in the RSVP stream may be smaller than the potential RB occurring early in an RSVP stream. If this is the case, RB from C2 to C3 might be present, but too small to detect. There are several potential contributing factors that may lead to reduced RB late in an RSVP stream, one of which is the serial position effect.

In the memory literature the well known serial position effect is demonstrated by the fact that initial items in a list are remembered more accurately than items occurring later in the list (primacy effect), except for the final items in the list which are also reported with high accuracy (recency effect). A similar serial position curve occurs when participants immediately report items presented in RSVP with the exception that the last item does not benefit as much from recency if it is followed by a mask. These serial position effects have interesting implications for RSVP streams; simply because C2 appears in the middle of the RSVP stream, it should be reported with lower probability than the other critical items. As can be seen in Table A1 of Appendix A, report of C2 was only 47% in the nonrepeated condition. In the three critical condition C2 was reported 16% of the time. If RB for C3 depends on awareness of C2, there are few instances in the three critical condition that would produce RB for C3.

Another concern is that RB from C2 to C3 might be present, but is too small to detect in report of C3 or is masked by inflated report of C2 and C3 due to misreading – recall that misreading may preferentially inflate report of C2 and C3 in the three critical condition.

Unfortunately, the three critical condition was the only condition investigating RB for orthographic neighbors late in the RSVP stream and results from this condition do not provide conclusive evidence about the ability of C2 to produce RB for C3 independent of an orthographically similar C1.

According to the token individuation hypothesis, it should not matter where critical items occur in the list, RB should occur with the same probability. For example, RB for C2 should be more likely to occur when C1 is reported, but that probability should not depend on the serial position in which those items occur as long as the SOA between them is the same. Park and Kanwisher (1994, Experiment 5) found just that. Even when the positions of C1 and C2 varied within the RSVP stream, there was no difference in RBI when SOA was held constant.

In contrast, the type refractoriness hypothesis (Luo & Caramazza, 1995; 1996) provides a possible explanation for why RB might be reduced when the first critical item is presented in the middle of the RSVP stream. This theory proposes that RB only occurs when the first critical item is sufficiently encoded. When C1 is presented too briefly or participants are not required to attend to it, C1 may not be encoded effectively and will not produce RB; instead the repeated item may be reported with a higher probability than a nonrepeated item - repetition priming. A similar prediction is made by the competition hypothesis. Although duration is the only factor that has been investigated regarding its influence on encoding effectiveness, it is likely that many other factors influence encoding effectiveness.

Two things that may affect encoding effectiveness in RSVP streams are serial position effects and masking. Position effects could occur because items appearing in the middle of the RSVP stream are not reported as often as items from the beginning of the

RSVP stream. Masking could affect encoding effectiveness because an RSVP procedure is used. In RSVP items are presented sequentially at fixation. Because of this, each item is masked by the items that come before and after it (Keysers & Perrett, 2002) and it is likely that masked items are not encoded as effectively as unmasked items. In the experiments reported in this paper, no mask comes before C1, but C2 is premasked because a filler comes before it. Because encoding effectiveness may be influenced by serial position effects and masking within the RSVP stream, C1 and C2 may not be encoded to the same extent, with C1 being encoded more successfully and thus producing more RB than C2. This could lead to relatively less RB when critical items appear later in the RSVP stream. Because this is a possibility, Experiment 2 was designed to demonstrate whether or not RB could be obtained late in the RSVP stream. To test this, the late RB condition was created in which two critical items appeared in positions 3 and 5 of the RSVP stream.

The second issue stemming from Experiment 1 is whether or not there really is only one difference between the three critical and early RB condition. On the surface it seems that the only difference is C3, but clearly there is another difference because the amount of RB for C2 is larger in the early RB condition than in the three critical condition. It is proposed that the difference between these conditions may stem from the fact that misreading in the three critical condition is more likely to result in a correct response than misreading in the early RB condition. If this is the case, the additive logic proposed to "neutralize" the long distance RB in the three critical condition (adjusted C3 score) does not account for every difference between the early RB and three critical conditions. This is a problem because additive logic strictly assumes that everything is identical except the variable of interest.

One approach to Experiment 2 is to attempt to eliminate long distance RB. This would remove one variable from the equation so report of C3 in the three critical condition could simply be compared to report of C3 in the early RB condition. One way to eliminate the long distance RB would be by increasing the time between C1 and C3 as several studies have indicated that the magnitude of RB decreases as SOA increases (e.g., Park & Kanwisher, 1994, Experiment 3). To increase the SOA without reducing participant performance on critical items in Experiment 2, filler symbol strings were inserted into the RSVP stream. Because participants would not be required to report the symbol strings, SOA would be lengthened without increasing memory load from Experiment 1. Figure 2 illustrates the difference in SOA between critical items in Experiments 1 and 2.

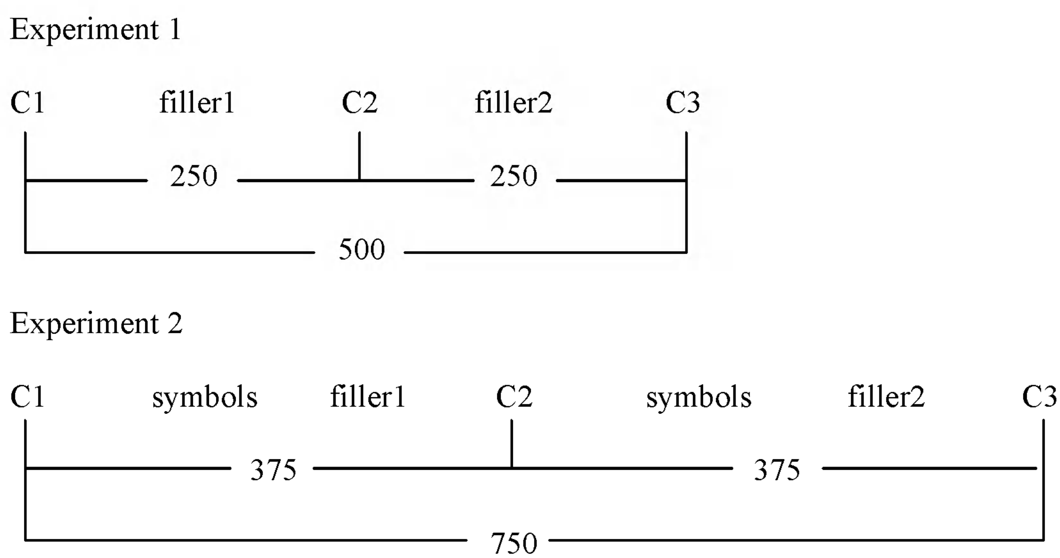

Figure 2. Time (in milliseconds) between the onset of critical items in Experiments 1 and 2

Method

Participants

Forty Iowa State students (21 female) participated in exchange for course credit. Three participants were bilingual; two spoke English from birth and one started speaking English before the age of five, the remaining participants were monolingual English speakers. Participant age ranged from 18-50 (*M* = 22).

Materials

The apparatus and word stimuli were the same as Experiment 1. Because a new condition, Late RB, was introduced in Experiment 2, new trials for that condition were constructed. The Late RB condition investigates RB when the two critical items occur in positions three and five of the RSVP stream. These conditions were produced by substituting one C1 for the other (e.g., *dark*, *bark*, *barn* and *mine, mile, file* becomes <u>*mine*</u>*, bark, barn* and <u>*dark*</u>*, mile*, *file*) in the three critical conditions of the yoked pairs. Two yoked pairs from Experiment 1 were incompatible with this new condition and had to be yoked to different trials. Some filler items also had to be replaced because of this re-yoking. All critical items are listed in Appendix C. With the additional condition, five versions of the experiment were created with 16 experimental trials from each condition. This resulted in a total of 80 experimental trials and 40 filler trials, as in Experiment 1.

Procedure

All procedures were the same as Experiment 1 except that filler symbol strings were inserted into the RSVP stream to increase the SOA between critical items. Symbol strings ($$$$$ and @@@@ respectively) appeared immediately after C1 and C2 and were displayed for 125 ms. The difference between the trial structures of Experiment 1 and Experiment 2 is illustrated in Figure 2.

Results and Discussion

Early RB condition

The early RB condition was investigated first. RB was evident in that report of C2 (M = .29) was significantly lower than in the nonrepeated condition (M = .61), $t_1(39) = 14.25$; $t_2(79) = 9.82$, both ps < .001; joint report of C1 and C2 was significantly lower in the early RB condition (M = .27) than the nonrepeated condition (M = .58), $t_1(39) = 15.00$, $p < .001$; $t_2(79) = -9.96$, $p < .001$; and the RBI (M = .28) was significantly lower than .5, $t_1(39) = 10.94$, $p < .001$; $t_2(78) = -9.93$, $p < .001$. In this experiment, there was no RB benefit for report of C3 in the early RB condition ($t_1(39) = -1.67$, $p = .103$, $t_2(79) = -1.36$, $p = .178$).

Long distance RB condition

Even though the SOA between C1 and C3 was 750 ms, RB was still present in the long distance RB condition. Report of C3 was significantly lower in the long distance condition (M = .55) than in the nonrepeated condition (M = .61), $t_1(39) = 2.52$, $p = .016$, $t_2(79) = 1.96$, $p = .054$; joint report of C1 and C3 was significantly lower in the long distance RB condition (M = .50) than the nonrepeated condition (M = .57), $t_1(39) = -2.38$, $p = .022$; $t_2(79) = -2.08$, $p = .041$; and the RBI (M = .46) was significantly less than .5, $t_1(39) = -2.71$, $p = .010$; $t_2(79) = -2.03$, $p = .046$. In addition, an RB benefit for report of C2 was found in the long distance condition (M = .70), $t_1(39) = -3.29$, $p = .002$; $t_2(79) = -2.67$, $p = .009$.

Late RB condition

A new condition, the late RB condition was included in this experiment to investigate RB occurring later in the RSVP stream. In this condition, C3 (M = .55) was reported less frequently than C3 in the nonrepeated condition (M = .61). This difference approached significance, $t_1(39) = 1.83$, $p = .074$, $t_2(79) = 1.64$, $p = .106$. There are some reasons to think that even though RB measured by report of C3 was not significant there was RB in the late RB condition. Using two other measures of RB, the both score and the RBI, it is apparent that RB was present in the late RB condition: Joint report of C2 and C3 was significantly lower in the late RB condition (M = .31) than in the nonrepeated condition (M = .39), $t_1(39) = 2.74$, $p = .009$; $t_2(79) = 2.52$, $p = .014$; and the RBI was significantly lower in the subject analysis (M = .44), but was nonsignificant in the item analysis (M = .46), $t_1(39) = -2.72$, $p = .010$; $t_2(78) = -1.53$, $p = .13$.

Three critical condition

To investigate the role of awareness in RB, an adjusted C3 value from the three critical condition is compared to report of C3 in the early RB condition. When the adjusted C3 value (M = .64) was compared to the early RB condition (M = .65) there was no detectable difference ($t_1(39) = .23$, $p = .731$; $t_2(79) = .273$, $p =.786$), suggesting that no additional RB occurred for C3 from a similar C2. As mentioned earlier, the adjusted C3 value may underestimate RB for C3 due to misreading. In the three critical condition, significant RB for C2 was found. Report of C2 (M = .36) was lower than that in the nonrepeated condition (M = .61), $t_1(39) = 8.60$; $t_2(79) = 6.71$, both ps < .001. As in Experiment 1, a greater reduction in report of C2 was seen in the early RB condition than the three critical condition, $t_1(39) = 2.43$, $p = .02$; $t_2(79) = 2.13$, $p = .036$, indicating larger magnitude RB in the early RB condition.

Magnitude of RB

An interesting finding from this experiment is that although RB for orthographic neighbors was found in several conditions, the magnitude was not equal. According to the token individuation hypothesis there is no reason to expect RB in the early RB condition to be different than RB in the late RB condition. Because baseline performance for joint report of C1 and C2 is different than joint report of C2 and C3 an appropriate comparison would use the RBI. Analyses indicate that the magnitude of RB was significantly smaller in the late RB condition (RBI = .44) than RB in the early RB condition (RBI = .28), $t_1(39) = -5.26$; $t_2(79) = -4.94$, both ps < .001.

Chapter 4. Experiment 3

The late RB condition introduced in Experiment 2 demonstrated that RB can occur when critical items appear later in the RSVP stream, but the amount of RB is significantly less than RB for critical items occurring early in the RSVP stream. There are a few possible explanations for this smaller magnitude RB. One possibility is that simply because C2 is reported less often than C1, there are fewer opportunities for RB to occur. According to the token individuation and type refractoriness hypotheses, awareness of C2 is necessary to produce RB for a similar C3. When report of C2 is low, there are few cases in which C2 can produce RB for C3 so it could *appear* as if there is less RB. For example, if report of C3 is 10% in the late RB condition and 20% in the nonrepeated condition, one might say RB is occurring on 10% of the trials. Now consider if report of C2 is 20% in the early RB condition and 40% in the nonrepeated condition – 20% RB appears to be larger than 10% RB. When the RBI is calculated for these same conditions they are the same, .33, indicating that there is no difference between the two conditions. Two measures of RB, report of a single critical item and the both score, are affected by this problem but the RBI is not because it accounts for differences in baselines. Because the RBIs for the early RB and late RB condition were significantly different, it is unlikely that the difference in the magnitude of RB is only driven by low report of C2. Another possibility is that C2 is not encoded as effectively as C1 resulting in less RB in the late RB condition compared to the early RB condition (Luo & Caramazza, 1995). This encoding effectiveness could be influenced by serial position and masking as discussed earlier.

In addition to the aforementioned factors, word frequency may influence encoding effectiveness. It is well known that frequency has dramatic effects on word recognition and recall. Of specific interest is the finding that high frequency words are identified at shorter durations than low frequency words (Howes & Solomon, 1951). If an item is difficult to identify, like a low frequency word or a word that is briefly displayed, it may not be encoded effectively. Recall that in both experiments C1 was higher frequency than C2, which was higher frequency than C3. It is possible that differences in frequency between C1 and C2 resulted in different amounts of RB in Experiment 2. Bavelier et al. (1994) found that a high frequency C1 produced significantly more RB for C2 than a low frequency C1. In their experiment a high frequency C1 was very high frequency, with mean frequency of approximately 1,400 per million in Experiment 1, while a low frequency C1 was very low, with mean frequency of approximately 7 per million. Although the difference in RB (9%) between the frequencies was rather small, RB produced by a high frequency C1 (28%) was greater than RB produced a low frequency C1 (17%).

To investigate whether frequency differences in the early and late critical items could have produced the difference in RB magnitude for Experiment 2, the mean frequencies for C1, C2, and C3 were calculated: they were 51, 27, and 12 per million respectively. Because C1 was not nearly as high frequency as C1 in Bavelier et al. experiments, it is unlikely that the 23% (as measured by the difference in both scores) difference in RB between the early and late RB conditions in Experiment 2 was caused by the difference in frequency for the respective (C1 or C2) first critical items.

Whether the different magnitudes of RB resulted from encoding effectiveness or not, Experiment 2 demonstrates that it is at least possible for C2 to produce RB for C3 in the three critical condition. Unfortunately, the modified trial procedure used for Experiment 2 failed to eliminate long distance RB; therefore it did not reduce the number of factors contributing to report of C3. The same problem from Experiment 1 remains: What if the RB for C3 is being masked by misreading? This could be the case especially, if C2 only produces a small amount of RB. For example, in Experiment 2, the adjusted value of C3 in the three critical condition was .64 and mean report of C3 in the early RB condition was .65 suggesting that no RB was present. But, if misreading occurs more often in the three critical condition than in the early RB condition the RB of interest could be masked.

Considering this possibility, three options remain for investigating the necessity of awareness in RB: 1) attempt to eliminate the long distance RB, 2) adjust for the misreading asymmetry in the early RB and three critical conditions, or 3) increase the potential for RB late in the RSVP stream. For the first option there is no obvious manipulation that would eliminate long distance RB. Clearly, adding more filler symbol strings would not necessarily eliminate long distance RB; as was demonstrated, RB was only reduced by 1% although the SOA between C1 and C3 was increased by 250 ms from Experiment 1 to Experiment 2. As for the second option, there is no way of knowing how often misreading really occurs. The third option does allow some obvious manipulations, but would not necessarily eliminate long distance RB or misreading.

As Experiment 2 demonstrates, report of C2 is very low in comparison to report of C1 and the corresponding RB produced by C2 is smaller than RB produced by C1. One way to equate Early and Late RB would be by increasing report of C2. This could be done by increasing the duration of C2 which should improve report of C2 and its encoding effectiveness. Support for this hypothesis comes from Park and Kanwisher (1994, Experiment 2) who demonstrated that increasing the duration of the first critical item successfully increases report of that item without reducing the magnitude of RB. By improving the encoding effectiveness of C2, the potential for RB late in the RSVP stream may increase (although RB for a repeated C2 might decrease). Because the main concern from the first two experiments is that any RB for C3 occurring when the participant does not report C2 is being masked, it is possible that by making the RB of interest larger, it could be detected even when long distance RB and misreading are present. From Experiment 2 it is apparent that the amount of RB late in the RSVP stream is very small; only 6% when looking at the difference in report of C3 in the late RB and nonrepeated conditions. If the potential RB from a missed C2 could be increased by 10 or 15%, it could be detected even when it is partially obscured by misreading.

An important consideration for Experiment 3 is that although the duration manipulation is intended to improve encoding effectiveness of C2, it is crucial to avoid eliminating RB for C2. To address this concern, a pilot study was conducted in order to find a reasonable duration manipulation. Results from that pilot revealed that adding 50 ms to C2 completely eliminated RB for that item, while increasing the duration by 15 ms had no effect. An intermediate duration, 25 ms, was selected for Experiment 3.

Method

Participants

Forty Iowa State students (24 female) participated in exchange for course credit. Two participants were bilingual; one spoke English from birth and one started speaking English before the age of five; the remaining participants were monolingual English speakers. Participant age ranged from 18-26 ($M = 20$).

Materials and Procedure

The apparatus and word stimuli were the same as Experiment 2. Critical items were also the same as those used in Experiment 2 (Appendix C). All procedures were the same as Experiment 2 except that the second critical item in each trial was displayed for 150 ms instead of 125 ms, as in Experiments 1 and 2.

Results and Discussion

Early RB condition

In the early RB condition RB was evident in that report of C2 ($M = .26$) was significantly lower than in the nonrepeated condition ($M = .62$), $t_1(39) = 11.48$; $t_2(79) = 10.23$, both ps $< .001$; joint report of C1 and C2 was significantly lower in the early RB condition ($M = .23$) than the nonrepeated condition ($M = .58$), $t_1(39) = 10.71$; $t_2(79) = 10.42$, both ps $< .001$; and the RBI ($M = .28$) was significantly lower than .5, $t_1(39) = -9.50$; $t_2(79) = -9.72$, both ps $< .001$. As in Experiment 2, there was no RB benefit for report of C3 ($t_1(39) = -1.39$, $p = .171$; $t_2(79) = -1.18$, $p = .241$).

Long distance RB condition

The SOA between C1 and C3 was increased to approximately 775 ms as a result of increasing the duration of C2. Apparently this SOA was sufficient to reduce long distance RB: simple report of C3 in the long distance RB condition ($M = .45$) was not significantly different than report of C3 in the nonrepeated condition ($M = .49$), $t_1(39) = 1.49$, $p = .143$; $t_2(79) = 1.33$, $p = .188$; the both score was not significantly different than the nonrepeated condition, $t_1(39) = 1.57$, $p = .125$; $t_2(79) = 1.54$, $p = .129$); and the RBI ($M = .46$) was not significantly different than .5 ($t_1(39) = 1.78$, $p = .08$; $t_2(79) = -1.35$, $p = .182$. No RB benefit was found for report of C2 in this condition, $t_1(39) = 1.01$, $p = .317$; $t_2(79) = .733$, $p = .466$.

Late RB condition

The magnitude of late RB was more consistent in this experiment compared to Experiment 2 as it was significant in each of the measures of RB. C3 ($M = .40$) was reported less often than C3 in the nonrepeated condition ($M = .49$), $t_1(39) = 3.94$; $t_2(79) = 3.28$, both ps < .003; joint report of C2 and C3 ($M = .21$) was significantly lower in the late RB condition than in the nonrepeated condition ($M = .32$), $t_1(39) = 4.64$; $t_2(79) = 4.14$, both ps < .001; the RBI in this condition was significantly lower than .5 ($M = .41$), $t_1(36) = -2.30$, $p = .027$; $t_2(78) = -4.16$, $p < .001$.

Three critical condition

Similar to the previous experiments, the adjusted value of C3 ($M = .51$) was compared to report of C3 in the early RB condition ($M = .53$). No difference was detected between these conditions, $t_1(39) = .46$, $p = .649$; $t_2(79) = .736$, $p = .464$. Unlike Experiments 1 and 2, RB for C2 ($M = .29$) in this condition was not significantly different than RB for C2 in the early RB condition ($M = .26$), $t_1(39) = 1.55$, $p = .128$; $t_2(79) = .951$, $p = .345$. This result may suggest that whatever (e.g., misreading) produced differences in the conditions in Experiment 2 did not have a significant effect in Experiment 3.

Magnitude of RB

As in Experiment 2 early and late RB were compared. Analysis of the RBI indicates that the magnitude of late RB (RBI = .41) was significantly smaller than the magnitude of early RB (RBI = .28), $t_1(37) = -3.09$; $t_2(79) = -2.70$, $p = .009$ both $ps < .01$. In addition, conditional RBIs (early RB - RBI when C1 is correct; late RB - RBI when C2 is correct) were calculated for the early and late RB conditions. This analysis was conducted to see if early and late RB were still different when awareness of the first critical item was equated. It revealed that late RB (RBI = .39) was still smaller than early RB (RBI = .29), $t(37) = -2.60$, $p = .014$.

Manipulation Check

The goal of Experiment 3 was to increase encoding effectiveness of C2 which would increase late RB. This was intended to increase RB for C3 in the three critical condition so it could be detected even in the presence of other mitigating factors. The simplest evidence for increased encoding of C2 would be found if report of C2 in Experiment 3 was higher than in Experiment 2. This was not the case: mean report of C2 was essentially the same in both experiments (see Figure 3). This does not mean the duration manipulation had no effect. Planned comparisons between Experiments 2 and 3 revealed that participants in Experiment 3 had lower overall performance; they reported an average of 2.8 items per trial, while participants from Experiment 2 reported an average of 3.1 items per trial, $t(78) = -2.73$, $p = .008$. Additional comparisons examine report of each item in the RSVP stream from Experiments 2 and 3 in the nonrepeated condition. Comparing the nonrepeated condition is most appropriate because it would reflect differences caused by the duration manipulation without being contaminated by differences in the magnitude of RB. Planned comparisons showed that report of filler 1, $t(78) = -2.05$, $p = .043$; filler 2, $t(78) = -2.41$, $p = .018$; and C3 $t(78) = -2.73$, $p = .008$, were significantly lower in Experiment 3 than Experiment 2, while no difference was found in report of C1 or C2 (both ps > .3). The comparisons between experiments show that even though report of C2 did not increase in Experiment 3, C2 still may have benefited from the duration manipulation as participant performance in Experiment 3 was lower than that of Experiment 2.

The second, related goal of the duration manipulation was to increase late RB. Although late RB was not increased by 10 or 15% in comparison to Experiment 2, late RB was larger and more consistent in Experiment 3, as the effect was significant in every measure of RB (recall that in Experiment 2 RB was only marginally significant for report of C3 in the subject and item analyses, and the effect was nonsignificant in the RBI item analysis).

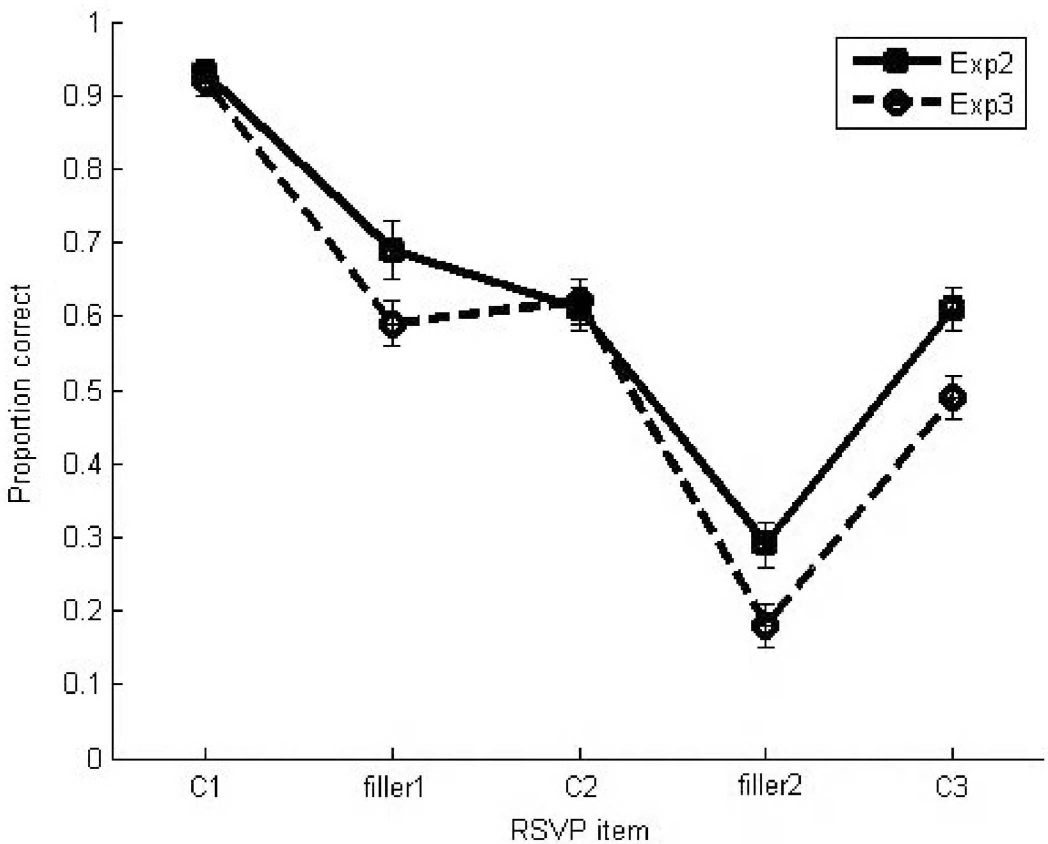

Figure 3. Mean report of each item in the Nonrepeated condition from Experiments 2 and 3. Note that report of C2 is nearly identical between the experiments even though participant performance was significantly worse in Experiment 3.

Chapter 5. General Discussion

These experiments investigated whether or not awareness is a critical component for producing repetition blindness by looking for RB when the critical item that should produce RB has been missed (e.g., when C2 is missed in the three critical condition). By placing three orthographic neighbors within one trial (e.g., *mine*, *mile, file*) - with the assumption that the first critical item would result in RB for the second critical – the opportunity was provided to find this effect. Comparing report of C3 in the new three critical condition (where participants are often unaware of C2 and C2 is a neighbor of C3) to report of C3 in a control condition (early RB; where C2 is missed, but C3 is not an orthographic neighbor) one can determine if RB can be caused by an item that does not reach awareness. This comparison could demonstrate whether or not awareness is necessary to produce RB.

Why might awareness be related to RB?

Nearly all theories of repetition blindness assume that awareness of the first item is needed to produce RB for the following similar item. This requirement has intuitive appeal especially when approached from the token minimization bias viewpoint which suggests that the visual system is hard wired to produce the minimum number of spatiotemporal tokens needed to represent a given number of items. Thus, in this framework, when one item appears twice, only one spatiotemporal token is formed resulting in only one object token. This assumption makes sense because there are many instances in life where an identical item is seen multiple times, when really there is only one object. For example, if one sees a bird that flies behind a tree and reappears on the other side, one would assume that the bird is the same bird and not just a similar bird that happened to leave from behind the tree as the first bird arrived. But, as mentioned previously, this approach has difficulty accounting for the finding that the type of fillers used in the experiment can affect the magnitude of RB.

Even though RB has not been found in the absence of awareness in previous studies, it is possible that the process that leads to RB merely co-occurs with awareness. Two theories suggest that encoding effectiveness is tied to RB and awareness. Within the type refractoriness hypothesis, RB can only occur when C1 reaches the threshold to awareness, which subsequently causes the type to go into a refractory period. When C1 is poorly encoded, the type will never reach that threshold so it could never produce RB for C2. In this theoretical framework encoding effectiveness leads to awareness and a refractory period which leads to RB. Similarly, according to the competition hypothesis RB typically does not occur when C1 is poorly encoded because the presentation of C1 will not result in a substantial reduction in the summed neural activation of C2. Because there is relatively little reduction in activity, the repeated item competes as well for access to awareness as an unrepeated item. In both of these theoretical frameworks, RB may only be found when C1 is sufficiently encoded and since sufficient encoding often leads to awareness of that item, RB appears when participants are aware of C1. Although both theories posit a role for encoding effectiveness, those roles are quite different. Within the type refractoriness framework sufficient encoding effectiveness causes the type to cross the threshold to awareness and go into a refractory state. Thus by this theory the effects of encoding effectiveness and awareness on RB are not independent. In contrast, the competition hypothesis posits that encoding effectiveness affects type activation so it may bias the competition for awareness, but it contributes to the RB effect independently of awareness.

Recapitulation of results

Results from the current experiments help clarify the roles of awareness and encoding effectiveness in RB. In Experiments 1 and 2, no significant difference was found between the adjusted report of C3 in the three critical condition and report of C3 in the early RB condition. This could be used as evidence that awareness is required to produce RB, but two findings caution against this conclusion. First, the amount of RB found for C2 in the three critical condition was significantly less than the RB found for C2 in the early RB condition. No *a priori* prediction was made concerning this because there was no reason to expect a difference as both conditions use the same words for C1 and C2 (e.g., *mine mile file* and *mine mile barn*). More importantly, whatever caused this difference in report of C2 has the potential to mask any RB occurring for C3. Recall that misreading C2 or C3 as a similar item is more likely to result in an erroneous correct response in the three critical condition than in the early RB condition. If enough misreading results in correct answers, the subsequent pattern of data could effectively mask any RB for C3.

A second finding was that RB in the late RB condition was significantly smaller than RB in the early RB condition. The token individuation hypothesis cannot account for this difference in RB magnitudes. Luo and Caramazza's (1995; 1996) idea of encoding effectiveness could explain these results by assuming that items presented later in the RSVP stream are encoded less effectively. The difficulty introduced by this low magnitude late RB is that it makes it hard to know if RB is present but masked, or if RB is not present. If RB is difficult to obtain for C3 it is unlikely that RB for C3 could be found when participants are unaware of C2.

In an attempt to compensate for poor encoding effectiveness later in the RSVP stream, the duration of C2 was increased to 150 ms in Experiment 3 while duration of the other items was kept the same as in the previous experiments. The manipulation did not produce a clear effect as report of C2 did not increase. Although this was the case, there is reason to believe that encoding effectiveness was improved. Participant performance in Experiment 3 was significantly worse than that of participants in Experiment 2, but report of C2 was equivalent. This suggests that encoding effectiveness was increased in Experiment 3. Other evidence indicates that the duration manipulation increased encoding effectiveness of C2. For instance, more late RB was found in Experiment 3 than in Experiment 2 even though report of C2 was the same; this shows that the better encoded C2 from Experiment 3 produced more RB than C2 in Experiment 2. This adds support to the claim that factors outside of awareness have a significant effect on RB.

While the duration manipulation did not lead to an increase in report of C2, it appears to have eliminated a nuisance factor thereby making the results more interpretable than those of the previous experiments. As before, in Experiment 3 there was no detectable difference between the adjusted report of C3 in the three critical condition and report of C3 in the early RB condition suggesting that no additional RB occurred when participants were unaware of C2. This finding is more interpretable than those from Experiment 2 for two main reasons. First, no difference was found between RB for C2 in the three critical and early RB conditions suggesting that if misreading was present it did not significantly influence report of C2 in the three critical condition. This result is essential for the additive logic used to calculate the adjusted C3 score. Second, although the duration manipulation did not produce a large increase in late RB, it did make the effect more consistent as it was significant in every measure of RB. Importantly, the combination of increased reliability of late RB and the absence of factors that potentially masked RB for C3 in Experiments 1 and 2, means that even a small RB effect for C3 when C2 is missed should be detectable. No difference was detected. From these experiments there is no indication that one can get RB for an orthographically similar C3 when C2 is not available for report.

Another intriguing finding from the current experiments was that long distance RB persisted for at least 750 ms. No other study has detected RB at this SOA. This finding is potentially problematic for the token individuation hypothesis and type refractoriness hypothesis because RB simply is not predicted to last that long. The finding is more problematic for the type refractoriness hypothesis as the refractory period that produces RB is not supposed to last that long. In contrast, if one assumes that increased encoding effectiveness can increase the magnitude of RB, it becomes plausible to assume that RB will not always persist for the same amount of time. The competition hypothesis could account for the discrepant SOA findings by assuming that encoding affects the magnitude and duration of the RB effect. This theoretical framework specifically would predict that C1 in the current experiments would produce RB at a longer SOA than C2 because C2 is not encoded as well as C1.

What contributes to encoding effectiveness?

Because encoding effectiveness may be the key to understanding RB, it is important to consider what factors affect encoding effectiveness and type activation. Several possibilities have been mentioned in this report: duration, word frequency, and position in the RSVP stream. It is already well established that duration influences encoding effectiveness. Items with short durations are not identified as often as items with longer durations and, to a certain extent, items with longer durations produce more RB than items with very short durations (Luo & Caramazza, 1995). Although only duration has been investigated specifically as a factor affecting encoding effectiveness, many factors may influence encoding effectiveness. For example, word frequency has been shown to affect the magnitude of RB (although Bavelier et al., 1994, did not discuss the results in terms of encoding effectiveness).

Another factor that may affect encoding effectiveness is position in the RSVP stream. When items occur early in the RSVP stream (e.g., C1 produced large RB effects for C2) they produce more RB than items that occur later in the RSVP stream (e.g., C2 produced small RB effects for C3). This is the case even when the comparison is restricted to aware trials (aware of C1 in the early RB condition and aware of C2 in the late RB condition). The token individuation hypothesis would not predict this difference in RB. This finding has not been reported in other RB papers, but this is not surprising. RB studies usually depend on full report of the RSVP stream, if the stream is too long, performance is too low to find reliable effects; it is difficult to manipulate RSVP position. One possible explanation for the finding that late RB is smaller than early RB in the current experiments is related to masking. As mentioned previously, in RSVP C2 is both forward and backward masked, while C1 is only backward masked: additional masking for C2 may cause it to be encoded less effectively, thus C2 would produce less RB than C1. The competition hypothesis would predict changes in the magnitude of RB from different amounts of masking. According to this hypothesis forward masking affects encoding and identification of an item. If C1 is not forward masked, it will be encoded more effectively than C2 this would mean that C1 has a greater potential to produce RB than C2.

Similarly, encoding effectiveness may explain the presence of long distance RB in the current experiments. If one assumes that encoding effectiveness impacts RB, any increase in encoding effectiveness has the potential to increase the RB effect. The fact that long distance RB occurred even when C1 and C3 only shared 2-3 letters and were separated by more than 700 ms in Experiments 1 and 2 may indicate that a better encoded C1 results in relatively long lasting RB.

Even though the evidence for differences in early and late RB must be interpreted with caution (because C1 and C2 frequency were not the same), evidence from several experiments now points to the conclusion that something more than awareness is involved in RB. That something could be encoding effectiveness. It may be that encoding effectiveness modulates the magnitude of RB independent from awareness. Evidence for this comes from results where the influence of various factors is still evident when conditional analyses are conducted (Conditional RBI in Experiment 3; Bavelier et al., 1994, Experiment 1). These findings suggest that even when awareness is controlled for, encoding effectiveness has an effect on RB over-and-above the contribution of awareness.

In conclusion, although awareness usually co-occurs with RB, it is premature to say that awareness is necessary to produce RB because the mechanism that leads to RB may also lead to awareness, so RB and awareness may simply be highly correlated. In contrast, the evidence is clear that something more than awareness contributes to the RB effect. From these findings RB may be more appropriately described as relying on encoding effectiveness than simply on awareness.

Appendix A. Tables – Measures of performance and RB

Table A1.

Proportion of report of critical items in Experiments 1, 2 and 3.

	Experiment 1			Experiment 2			Experiment 3		
Condition	C1	C2	C3	C1	C2	C3	C1	C2	C3
Nonrepeated	.94	.47	.43	.93	.61	.61	.92	.62	.49
Early RB	.95	.10	.49	.94	.29	.65	.94	.26	.53
Three Critical	.94	.16	.47	.96	.36	.58	.93	.29	.47
Long Distance	.93	.49	.35	.92	.70	.55	.92	.59	.45
Late RB				.93	.66	.55	.93	.65	.40

Note. Standard error varied between .010 and .036 for all means reported. Empty cells indicate conditions not present in the experiment.

Table A2.

Three measures of repetition blindness by condition in Experiments 1, 2, and 3.

	Experiment 1			Experiment 2			Experiment 3		
RB	CI[a]	Both[b]	RBI[c]	CI	Both	RBI	CI	Both	RBI
Early	.37	.36	.15	.32	.31	.28	.36	.35	.27
Long distance	.08	.07	.45	.06	.06	.46	.04	.04	.46
Late				.06	.08	.44	.09	.11	.41

Note. Empty cells indicate conditions not present in the experiment. For the CI and Both measures larger positive differences reflect more RB. For the RBI measure, zero represents maximum RB while .5 represents the absence of RB.

a. CI stands for the difference between the critical item of interest in the nonrepeated condition and the critical item of interest in a repeated condition. Early CI = Nonrepeated C2 – Early RB C2; Long distance CI = Nonrepeated C3 - Long distance RB C3; Late CI = Nonrepeated C3 – Late RB C3.

b. Both stands for the difference in both scores between a nonrepeated and repeated condition. Early Both = Nonrepeated C1 and C2 – Early RB C1 and C2; Long distance Both = Nonrepeated C1 and C3 – Long distance RB C1 and C3; Late Both = Nonrepeated C2 and C3 – Late RB C2 and C3.

c. RBI = repeated both score / (nonrepeated both score + repeated both score)

Appendix B. Stimuli used in Experiment 1

Three critical condition				Early RB condition				Long distance condition				Nonrepeated condition				Fillers	
	C1	C2	C3		C1	C2	yC3		C1	C2	C3		C1	C2	yC3	f1	f2
1	bond	bone	cone	1	bond	bone	vent	1	bond	wear	cone	1	bond	wear	vent	tour	stag
2	text	tent	vent	2	text	tent	cone	2	text	pair	vent	2	text	pair	cone	odds	sigh
3	ford	fork	pork	3	ford	fork	dash	3	ford	yarn	pork	3	ford	yarn	dash	song	cure
4	cast	cash	dash	4	cast	cash	pork	4	cast	roll	dash	4	cast	roll	pork	tomb	bunk
5	rain	rail	hail	5	rain	rail	hood	5	rain	drug	hail	5	rain	drug	hood	gown	plot
6	mold	mood	hood	6	mold	mood	hail	6	mold	trig	hood	6	mold	trig	hail	draw	calf
7	gate	mate	mare	7	gate	mate	bail	7	gate	root	mare	7	gate	root	bail	stud	plus
8	bowl	boil	bail	8	bowl	boil	mare	8	bowl	junk	bail	8	bowl	junk	mare	hurt	rose
9	page	pace	pack	9	page	pace	bust	9	page	lord	pack	9	page	lord	bust	mine	wait
10	rush	bush	bust	10	rush	bush	pack	10	rush	gift	bust	10	rush	gift	pack	cole	tree
11	pill	dill	doll	11	pill	dill	cage	11	pill	shaw	doll	11	pill	shaw	cage	twin	jeep
12	tape	cape	cage	12	tape	cape	doll	12	tape	fold	cage	12	tape	fold	doll	drum	kiss
13	lamp	damp	dame	13	lamp	damp	kick	13	lamp	zinc	dame	13	lamp	zinc	kick	pass	star
14	neck	nick	kick	14	neck	nick	dame	14	neck	cool	kick	14	neck	cool	dame	smug	fish
15	tale	tile	tide	15	tale	tile	dusk	15	tale	flux	tide	15	tale	flux	dusk	coin	arch
16	risk	disk	dusk	16	risk	disk	tide	16	risk	herb	dusk	16	risk	herb	tide	lift	bang
17	sell	seal	zeal	17	sell	seal	hint	17	sell	knot	zeal	17	sell	knot	hint	drag	june
18	aunt	hunt	hint	18	aunt	hunt	zeal	18	aunt	milk	hint	18	aunt	milk	zeal	gene	load
19	plug	slug	slum	19	plug	slug	duck	19	plug	team	slum	19	plug	team	duck	moon	heir
20	desk	deck	duck	20	desk	deck	slum	20	desk	male	duck	20	desk	male	slum	wash	roar
21	ring	wing	wink	21	ring	wing	hoot	21	ring	soak	wink	21	ring	soak	hoot	jump	glue
22	boat	boot	hoot	22	boat	boot	wink	22	boat	spur	hoot	22	boat	spur	wink	edge	camp
23	deer	deed	heed	23	deer	deed	foil	23	deer	coat	heed	23	deer	coat	foil	tone	sign
24	tool	fool	foil	24	tool	fool	heed	24	tool	mess	foil	24	tool	mess	heed	hide	gain
25	sale	sole	sore	25	sale	sole	pipe	25	sale	link	sore	25	sale	link	pipe	writ	gang
26	pale	pile	pipe	26	pale	pile	sore	26	pale	horn	pipe	26	pale	horn	sore	boom	gait
27	dome	dose	hose	27	dome	dose	mask	27	dome	flow	hose	27	dome	flow	mask	snap	tune
28	park	mark	mask	28	park	mark	hose	28	park	folk	mask	28	park	folk	hose	vote	buzz
29	colt	bolt	bout	29	colt	bolt	lump	29	colt	wage	bout	29	colt	wage	lump	span	hymn
30	lime	limp	lump	30	lime	limp	bout	30	lime	slab	lump	30	lime	slab	bout	fare	nest
31	film	file	mile	31	film	file	burr	31	film	gear	mile	31	film	gear	burr	wood	soft

Note: C indicates critical items; f indicates filler items; y indicates that the item comes from the yoked trial.

Appendix B. Stimuli used in Experiment 1 (continued)

Three critical condition				Early RB condition				Long distance condition				Nonrepeated condition				Fillers	
	C1	C2	C3		C1	C2	yC3		C1	C2	C3		C1	C2	yC3	f1	f2
32	barn	burn	burr	32	barn	burn	mile	32	barn	push	burr	32	barn	push	mile	ease	goal
33	suit	spit	spat	33	suit	spit	reef	33	suit	lens	spat	33	suit	lens	reef	term	joke
34	beer	beef	reef	34	beer	beef	spat	34	beer	lock	reef	34	beer	lock	spat	walk	chip
35	till	toll	poll	35	till	toll	seam	35	till	bank	poll	35	till	bank	seam	rage	inch
36	beat	beam	seam	36	beat	beam	poll	36	beat	whip	seam	36	beat	whip	poll	cell	dawn
37	hole	pole	pose	37	hole	pole	raid	37	hole	harm	pose	37	hole	harm	raid	chin	gaze
38	mail	maid	raid	38	mail	maid	pose	38	mail	babe	raid	38	mail	babe	pose	huff	lung
39	luck	buck	bulk	39	luck	buck	fame	39	luck	self	bulk	39	luck	self	fame	peak	wool
40	hate	fate	fame	40	hate	fate	bulk	40	hate	lore	fame	40	hate	lore	bulk	king	soap
41	trip	trap	tray	41	trip	trap	bass	41	trip	newt	tray	41	trip	newt	bass	skin	join
42	loss	boss	bass	42	loss	boss	tray	42	loss	gram	bass	42	loss	gram	tray	dirt	pope
43	fist	mist	mint	43	fist	mist	sack	43	fist	veil	mint	43	fist	veil	sack	rear	cook
44	rock	rack	sack	44	rock	rack	mint	44	rock	wave	sack	44	rock	wave	mint	lamb	grin
45	soil	soul	soup	45	soil	soul	leap	45	soil	chef	soup	45	soil	chef	leap	dean	norm
46	heat	heap	leap	46	heat	heap	soup	46	heat	mice	leap	46	heat	mice	soup	post	calm
47	foot	fort	port	47	foot	fort	cane	47	foot	butt	port	47	foot	butt	cane	site	mode
48	lake	lane	cane	48	lake	lane	port	48	lake	moss	cane	48	lake	moss	port	prop	bath
49	warm	wart	tart	49	warm	wart	fake	49	warm	jail	tart	49	warm	jail	fake	bore	nose
50	save	sake	fake	50	save	sake	tart	50	save	prey	fake	50	save	prey	tart	crop	dust
51	task	tank	yank	51	task	tank	hull	51	task	grab	yank	51	task	grab	hull	seed	pond
52	bell	bull	hull	52	bell	bull	yank	52	bell	swim	hull	52	bell	swim	yank	noon	jazz
53	wake	cake	cave	53	wake	cake	silk	53	wake	bent	cave	53	wake	bent	silk	myth	fair
54	pink	sink	silk	54	pink	sink	cave	54	pink	lure	silk	54	pink	lure	cave	haze	flag
55	fell	fill	mill	55	fell	fill	rope	55	fell	zone	mill	55	fell	zone	rope	dive	grip
56	core	cope	rope	56	core	cope	mill	56	core	flat	rope	56	core	flat	mill	base	host
57	wine	pine	pint	57	wine	pine	meal	57	wine	bulb	pint	57	wine	bulb	meal	curb	dish
58	seat	meat	meal	58	seat	meat	pint	58	seat	dice	meal	58	seat	dice	pint	loop	gray
59	ship	shop	shoe	59	ship	shop	leaf	59	ship	glow	shoe	59	ship	glow	leaf	fund	trot
60	loan	lean	leaf	60	loan	lean	shoe	60	loan	gold	leaf	60	loan	gold	shoe	wind	duke
61	shift	shirt	skirt	61	shift	shirt	grove	61	shift	block	skirt	61	shift	block	grove	cream	wound
62	grade	grave	grove	62	grade	grave	skirt	62	grade	porch	grove	62	grade	porch	skirt	lease	clerk

Note: C indicates critical items; f indicates filler items; y indicates that the item comes from the yoked trial.

Appendix B. Stimuli used in Experiment 1 (continued)

Three critical condition				Early RB condition				Long distance condition				Nonrepeated condition				Fillers	
	C1	C2	C3		C1	C2	yC3		C1	C2	C3		C1	C2	yC3	f1	f2
63	score	swore	sword	63	score	swore	creed	63	score	brush	sword	63	score	brush	creed	pants	fight
64	greek	creek	creed	64	greek	creek	sword	64	greek	proof	creed	64	greek	proof	sword	thank	laugh
65	shoot	shout	scout	65	shoot	shout	dread	65	shoot	plain	scout	65	shoot	plain	dread	guide	brace
66	break	bread	dread	66	break	bread	scout	66	break	craft	dread	66	break	craft	scout	flash	print
67	shape	shade	spade	67	shape	shade	dough	67	shape	bluff	spade	67	shape	bluff	dough	route	crack
68	touch	tough	dough	68	touch	tough	spade	68	touch	check	dough	68	touch	check	spade	pride	faint
69	roast	boast	beast	69	roast	boast	trunk	69	roast	knock	beast	69	roast	knock	trunk	juice	speed
70	drink	drunk	trunk	70	drink	drunk	beast	70	drink	ghost	trunk	70	drink	ghost	beast	screw	climb
71	sheet	sheer	cheer	71	sheet	sheer	hound	71	sheet	gloom	cheer	71	sheet	gloom	hound	trail	quick
72	mount	mound	hound	72	mount	mound	cheer	72	mount	slave	hound	72	mount	slave	cheer	tract	brief
73	truck	track	trace	73	truck	track	brass	73	truck	nerve	trace	73	truck	nerve	brass	surge	chill
74	glass	grass	brass	74	glass	grass	trace	74	glass	crowd	brass	74	glass	crowd	trace	watch	quote
75	snake	stake	stare	75	snake	stake	hunch	75	snake	bride	stare	75	snake	bride	hunch	cloud	throw
76	bench	bunch	hunch	76	bench	bunch	stare	76	bench	trick	hunch	76	bench	trick	stare	claim	dream
77	guess	guest	quest	77	guess	guest	chore	77	guess	slide	quest	77	guess	slide	chore	theme	knife
78	store	shore	chore	78	store	shore	quest	78	store	gauge	chore	78	store	gauge	quest	judge	yield
79	coach	couch	cough	79	coach	couch	steer	79	coach	brain	cough	79	coach	brain	steer	nurse	drill
80	sleep	steep	steer	80	sleep	steep	cough	80	sleep	guild	steer	80	sleep	guild	cough	ranch	pearl

Note: C indicates critical items; f indicates filler items; y indicates that the item comes from the yoked trial.

Appendix C. Critical items used in Experiments 2 and 3

	Thee critical condition			Early RB condition			Long distance condition			Late RB condition			Nonrepeated condition		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
1	bond	bone	cone	bond	bone	vent	bond	tour	cone	text	bone	cone	bond	tour	vent
2	text	tent	vent	text	tent	cone	text	pair	vent	bond	tent	vent	text	pair	cone
3	ford	fork	pork	ford	fork	dash	ford	cure	pork	cast	fork	pork	ford	cure	dash
4	cast	cash	dash	cast	cash	pork	cast	roll	dash	ford	cash	dash	cast	roll	pork
5	rain	rail	hail	rain	rail	hood	rain	drug	hail	mold	rail	hail	rain	drug	hood
6	mold	mood	hood	mold	mood	hail	mold	draw	hood	rain	mood	hood	mold	draw	hail
7	gate	mate	mare	gate	mate	bail	gate	root	mare	bowl	mate	mare	gate	root	bail
8	bowl	boil	bail	bowl	boil	mare	bowl	junk	bail	gate	boil	bail	bowl	junk	mare
9	page	pace	pack	page	pace	bust	page	lord	pack	rush	pace	pack	page	lord	bust
10	rush	bush	bust	rush	bush	pack	rush	gift	bust	page	bush	bust	rush	gift	pack
11	pill	dill	doll	pill	dill	cage	pill	twin	doll	tape	dill	doll	pill	twin	cage
12	tape	cape	cage	tape	cape	doll	tape	fold	cage	pill	cape	cage	tape	fold	doll
13	lamp	damp	dame	lamp	damp	kick	lamp	zinc	dame	neck	damp	dame	lamp	zinc	kick
14	neck	nick	kick	neck	nick	dame	neck	cool	kick	lamp	nick	kick	neck	cool	dame
15	tale	tile	tide	tale	tile	dusk	tale	flux	tide	risk	tile	tide	tale	flux	dusk
16	risk	disk	dusk	risk	disk	tide	risk	herb	dusk	tale	disk	dusk	risk	herb	tide
17	sell	seal	zeal	sell	seal	hint	sell	knot	zeal	aunt	seal	zeal	sell	knot	hint
18	aunt	hunt	hint	aunt	hunt	zeal	aunt	milk	hint	sell	hunt	hint	aunt	milk	zeal
19	plug	slug	slum	plug	slug	duck	plug	team	slum	desk	slug	slum	plug	team	duck
20	desk	deck	duck	desk	deck	slum	desk	male	duck	plug	deck	duck	desk	male	slum
21	ring	wing	wink	ring	wing	hoot	ring	soak	wink	boat	wing	wink	ring	soak	hoot
22	boat	boot	hoot	boat	boot	wink	boat	spur	hoot	ring	boot	hoot	boat	spur	wink
23	deer	deed	heed	deer	deed	foil	deer	tone	heed	tool	deed	heed	deer	tone	foil
24	tool	fool	foil	tool	fool	heed	tool	mess	foil	deer	fool	foil	tool	mess	heed
26	pale	pile	pipe	pale	pile	hose	pale	boom	pipe	dome	pile	pipe	pale	boom	hose
27	dome	dose	hose	dome	dose	pipe	dome	flow	hose	pale	dose	hose	dome	flow	pipe
28	park	mark	mask	park	mark	sore	park	folk	mask	sale	mark	mask	park	folk	sore
25	sale	sole	sore	sale	sole	mask	sale	link	sore	park	sole	sore	sale	link	mask
29	colt	bolt	bout	colt	bolt	lump	colt	wage	bout	lime	bolt	bout	colt	wage	lump
30	lime	limp	lump	lime	limp	bout	lime	slab	lump	colt	limp	lump	lime	slab	bout
31	film	file	mile	film	file	burr	film	gear	mile	barn	file	mile	film	gear	burr

Note: C indicates critical items.

Appendix C. Critical items used in Experiments 2 and 3 (continued)

	Thee critical condition			Early RB condition			Long distance condition			Late RB condition			Nonrepeated condition		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
32	barn	burn	burr	barn	burn	mile	barn	push	burr	film	burn	burr	barn	push	mile
33	suit	spit	spat	suit	spit	reef	suit	lens	spat	beer	spit	spat	suit	lens	reef
34	beer	beef	reef	beer	beef	spat	beer	lock	reef	suit	beef	reef	beer	lock	spat
35	till	toll	poll	till	toll	seam	till	bank	poll	beat	toll	poll	till	bank	seam
36	beat	beam	seam	beat	beam	poll	beat	whip	seam	till	beam	seam	beat	whip	poll
37	hole	pole	pose	hole	pole	raid	hole	harm	pose	mail	pole	pose	hole	harm	raid
38	mail	maid	raid	mail	maid	pose	mail	babe	raid	hole	maid	raid	mail	babe	pose
39	luck	buck	bulk	luck	buck	fame	luck	self	bulk	hate	buck	bulk	luck	self	fame
40	hate	fate	fame	hate	fate	bulk	hate	lore	fame	luck	fate	fame	hate	lore	bulk
41	trip	trap	tray	trip	trap	bass	trip	newt	tray	loss	trap	tray	trip	newt	bass
42	loss	boss	bass	loss	boss	tray	loss	gram	bass	trip	boss	bass	loss	gram	tray
43	fist	mist	mint	fist	mist	sack	fist	veil	mint	rock	mist	mint	fist	veil	sack
44	rock	rack	sack	rock	rack	mint	rock	wave	sack	fist	rack	sack	rock	wave	mint
45	soil	soul	soup	soil	soul	leap	soil	chef	soup	heat	soul	soup	soil	chef	leap
46	heat	heap	leap	heat	heap	soup	heat	mice	leap	soil	heap	leap	heat	mice	soup
47	foot	fort	port	foot	fort	cane	foot	butt	port	lake	fort	port	foot	butt	cane
48	lake	lane	cane	lake	lane	port	lake	moss	cane	foot	lane	cane	lake	moss	port
49	warm	wart	tart	warm	wart	fake	warm	jail	tart	save	wart	tart	warm	jail	fake
50	save	sake	fake	save	sake	tart	save	prey	fake	warm	sake	fake	save	prey	tart
51	task	tank	yank	task	tank	hull	task	grab	yank	bell	tank	yank	task	grab	hull
52	bell	bull	hull	bell	bull	yank	bell	swim	hull	task	bull	hull	bell	swim	yank
53	wake	cake	cave	wake	cake	silk	wake	bent	cave	pink	cake	cave	wake	bent	silk
54	pink	sink	silk	pink	sink	cave	pink	lure	silk	wake	sink	silk	pink	lure	cave
55	fell	fill	mill	fell	fill	rope	fell	zone	mill	core	fill	mill	fell	zone	rope
56	core	cope	rope	core	cope	mill	core	flat	rope	fell	cope	rope	core	flat	mill
57	wine	pine	pint	wine	pine	meal	wine	bulb	pint	seat	pine	pint	wine	bulb	meal
58	seat	meat	meal	seat	meat	pint	seat	dice	meal	wine	meat	meal	seat	dice	pint
59	ship	shop	shoe	ship	shop	leaf	ship	glow	shoe	loan	shop	shoe	ship	glow	leaf
60	loan	lean	leaf	loan	lean	shoe	loan	gold	leaf	ship	lean	leaf	loan	gold	shoe
61	shift	shirt	skirt	shift	shirt	grove	shift	block	skirt	grade	shirt	skirt	shift	block	grove
62	grade	grave	grove	grade	grave	skirt	grade	porch	grove	shift	grave	grove	grade	porch	skirt

Note: C indicates critical items.

Appendix C. Critical items used in Experiments 2 and 3 (continued)

	Thee critical condition			Early RB condition			Long distance condition			Late RB condition			Nonrepeated condition		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
63	score	swore	sword	score	swore	creed	score	brush	sword	greek	swore	sword	score	brush	creed
64	greek	creek	creed	greek	creek	sword	greek	proof	creed	score	creek	creed	greek	proof	sword
65	shoot	shout	scout	shoot	shout	dread	shoot	plain	scout	break	shout	scout	shoot	plain	dread
66	break	bread	dread	break	bread	scout	break	craft	dread	shoot	bread	dread	break	craft	scout
67	shape	shade	spade	shape	shade	dough	shape	bluff	spade	touch	shade	spade	shape	bluff	dough
68	touch	tough	dough	touch	tough	spade	touch	check	dough	shape	tough	dough	touch	check	spade
69	roast	boast	beast	roast	boast	trunk	roast	knock	beast	drink	boast	beast	roast	knock	trunk
70	drink	drunk	trunk	drink	drunk	beast	drink	ghost	trunk	roast	drunk	trunk	drink	ghost	beast
71	sheet	sheer	cheer	sheet	sheer	hound	sheet	gloom	cheer	mount	sheer	cheer	sheet	gloom	hound
72	mount	mound	hound	mount	mound	cheer	mount	slave	hound	sheet	mound	hound	mount	slave	cheer
73	truck	track	trace	truck	track	brass	truck	nerve	trace	glass	track	trace	truck	nerve	brass
74	glass	grass	brass	glass	grass	trace	glass	crowd	brass	truck	grass	brass	glass	crowd	trace
75	snake	stake	stare	snake	stake	hunch	snake	bride	stare	bench	stake	stare	snake	bride	hunch
76	bench	bunch	hunch	bench	bunch	stare	bench	trick	hunch	snake	bunch	hunch	bench	trick	stare
77	guess	guest	quest	guess	guest	chore	guess	slide	quest	store	guest	quest	guess	slide	chore
78	store	shore	chore	store	shore	quest	store	gauge	chore	guess	shore	chore	store	gauge	quest
79	coach	couch	cough	coach	couch	steer	coach	brain	cough	sleep	couch	cough	coach	brain	steer
80	sleep	steep	steer	sleep	steep	cough	sleep	guild	steer	coach	steep	steer	sleep	guild	cough

Note: C indicates critical items.

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