PHONOLOGICAL REPETITION BLINDNESS

by

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ABSTRACT

Repetition Blindness (RB) is the inability to detect or recall a repeated word in rapid serial visual presentation. RB has been interpreted in a type/token model as arising from a failure to initiate a new type-token link from a visual type which is already linked to another distinct token (Kanwisher, 1987).

The role of visual versus phonological (name) similarity in RB was examined. RB was found for single letters, whether printed in the same or different cases, and for single digits, whether represented verbally (nine), as arabic numeral (9), or in the mixture of the two formats. Hence, visual similarity is not necessary to produce RB. RB was obtained between homophonic pairs (won/one), showing that phonological similarity (even in the absence of semantic similarity) is sufficient to produce RB, although visual identity also contributes to RB.

The nature of RB between words was further explored. RB was found to be unaffected by factors known to affect lexical organization such as morphology or frequency. On the other hand, either orthographic or phonological similarity were shown to be necessary and sufficient for RB between words. It was then shown that phonological RB is not restricted to readily verbalized stimuli, such as words, but extends to pictures. RB was found not only between identical pictures. but also between pictures and words, whether semantically related (the picture of a cat and the word 'cat') or not (the picture of a sun and the word 'son'). Hence, phonological similarity alone can produce RB. Furthermore, the amount of RB between visually different items was shown to be dependent on whether the task required similar or different codes to be registered in STM. It was proposed that RB between visually identical items is best understood as a failure to open a new visual token, while phonological RB is a failure to register the phonological code usually used to stabilize an opened token in STM.

This body of work indicated that RB between visually dissimilar items is due to the similarity of the codes that have to be entered in STM. It was further proposed that RB could occur at any step during the establishment of a stable token, arising not only from a failure to create a new token, but also from a failure to construct and stabilize an opened token. This view makes two new assumptions about the nature of tokens by proposing that their establishment is a dynamical, graded process, and that, as memory representations, they can be more or less stable, and so subject to loss.

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INTRODUCTORY COMMENTS

This thesis is composed of three independent, but related, experimental chapters, followed by an overview chapter in which the synthesis of the work done, as well as a discussion of its consequences is elaborated. The first chapter is entirely devoted to the establishment of a "phonological RB" effect. This work was done in collaboration with M. C. Potter (Bavelier & Potter, 1992). The second chapter, while more concerned with the status of RB between words, argues for a distinction between orthographic and phonological RB. This work was done in collaboration with S. Prasada and J. Segui (Bavelier, Prasada, & Segui, 1992). In the third chapter (referred as Bavelier, 1992), a further characterization of the mechanism responsible for phonological RB, and more generally for RB between visually different items is undertaken. Finally, chapter IV reviews the standard RB findings, summarizes the results from this thesis, proposes several changes to the previous theoretical framework, shows how these changes affect the account of RB, and speculates about the role of these changes in understanding other visual phenomena.

CHAPTER I

VISUAL AND PHONOLOGICAL CODES IN RB

I. INTRODUCTION

Recent studies have made clear that our visual system has difficulties in representing separately two instances of the same event, at least when the two events are in close temporal proximity (Kanwisher, 1986, 1987; Mozer, 1989). Such repetition blindness (RB) is substantial when subjects are presented repeated targets over time using rapid serial visual presentation (RSVP) of words or other stimuli, at rates of about 150 ms per item and higher. The size of the RB effect diminishes as the rate of presentation decreases or as the lag between the repeated items increases, during repetition detection or recall tasks (Kanwisher, 1986, 1987). Ordinarily, the first instance (C1) of the repetition is noted but the second instance C2 is not (whether it is C1 or C2 that a subject has recalled is determined by the serial order of recall)[1]. Kanwisher (1986) proposed a two-stage model of visual encoding in which first the visual input activates its corresponding <u>type</u> (a mental representation that is accessed through the encoding process), and then in a second step, a <u>token</u> of the type

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[1]In Kanwisher's initial papers "R1" and "R2" were used, but because R implied "repeated" even for the control (unrepeated) trials, the more neutral "C" (for "critical") is used in Kanwisher (1991) and in this paper.

is created. The token is a specific representation of the event available in episodic memory for recall. In this model, RB is attributed to the inability to individuate a second new token from the same type at a very short lag. So, only the first instance is represented episodically.

The original hypothesis assumed that a condition for RB was the presentation of two visual events that share a common type; two events that have different types should not be subject to RB. However, Kanwisher and Potter (1990) reported difficulties in the processing of similar words such as cape and cap; recall of C2 was impaired by the presence of C1 earlier in the sentence. Bavelier and Segui (1990) reported a similar finding for French words differing by as many as three letters (e.g. sort (fate) and ressort (spring) or baguette (bread) and bague (ring)). Thus, RB appears to occur not only for identically repeated words, but also for pairs of morphologically-unrelated, similarly-spelled words.

The presence of RB between different words that are orthographically similar suggests that RB is not restricted to just one form of type-coding, such as the orthographic lexical entry. The purpose of the present experiments was to examine other relationships between the two items that might be the basis for RB, focusing on cases in which visually distinct stimuli shared the same phonology. In the initial experiments phonological identity and conceptual identity corresponded; in the later experiments, they were dissociated by the use of homophones.

II. EXPERIMENTS

Experiment 1

In Experiment 1 we examined RB between single letters that were the same or different in case. Kanwisher (1987) (see also Marohn & Hochhaus, 1988) found RB between words differing in case, but that may have been because word identity was more salient in those experiments than physical form. Earlier experiments (Adams, 1979; Besner, Coltheart & Davelaar, 1984; Evett & Humphreys, 1981; Friedman, 1980; Morton, 1979; Scarborough, Cortese & Scarborough, 1977) have indicated that letter identity is abstracted from case and font early in processing, so that it is plausible that RB reflects abstract orthographic or letter-level type-identity rather than exact visual identity. In Experiment 1, short RSVP lists of single letters were immediately recalled by subjects. To increase the likelihood that subjects would attend to case differences, subjects were asked to indicate the case of letters they recalled.

Method

Subjects. Twenty-two Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Materials and design. Fourteen practice trials were followed by 96 experimental and 20 filler trials. Each trial consisted of a sequence of six arrays preceded and followed by a row of percentage signs. On the experimental trials, three of the six arrays were single letters, written in uppercase (A) or in lower case (a). The other three arrays each consisted of a single keyboard symbol. Figure 1 shows a sample trial. The position of the two critical letters C1 and C2 was varied, but the first letter never appeared as the first item and the two critical letters were always separated by the third intervening letter. On half the trials a symbol also intervened between the two critical letters. The 20 filler trials consisted of two letters (sometimes repeated) and four symbols.

<u>Figure 1</u>

<u>Examples of trials from Experiments 1, 2 and 3; displays were presented sequentially at the same CRT location</u>

Experiment 1	**Experiment 2**	**Experiment 3**
%%%%%	%%%%%	%%%%%
+	+++	>>>>
=	nine [C1]	won [C1]
a [C1]	{{{{	caught
C	8	+++
A [C2]	nine [C2]	one [C2]
>	<<<<	}}}}
%%%%%	%%%%%	%%%%%

All the letters of the alphabet were used except i, u, v and l. These letters were eliminated because they were difficult to discriminate. Adjustments were made to avoid sequences of letters on a given trial that formed a word, but otherwise random permutations of the 22 letters were used to assign the letter identities.

On half the experimental trials C1 and C2 had the same letter identity (repeated trials) and on half, a different identity (unrepeated trials). Repeatedness was counterbalanced between two versions of the experiment by changing the letter identity of C1. The case of C1 and C2 was varied between items (on 25% of the trials C1 and C2 were both upper case, on 25%, both lower case, on 25% upper-lower, and on 25% lower-upper). Thus on half the trials, case of the critical items was the same, on half different, crossed with the letter-repeatedness factor. Each subject saw 24 experimental trials in each of these 4 conditions, repeated/unrepeated x same/different case. A final between-items variable was the lag between C1 and C2: on half the trials in each of the four main conditions, one letter intervened, and on the other half a letter plus a symbol intervened. In the present experiments RB almost always showed a tendency to be larger at lag 1 than at lag 2. This trend is in accordance with the finding that RB decreases when lag increases (Kanwisher, 1986). Because this effect ordinarily did not interact with other variables, it will not be discussed further in this paper.

Procedure. Each trial began when the subjects pressed the space bar on the computer keyboard. The row of asterisks present at the same location as the subsequent items disappeared and the items appeared one at a time in the same place, for 100 ms per item (see figure 1).

Subjects were instructed to read the letters and ignore the symbols; they were asked to write down after each trial the letters they saw, in the order and in the format (upper versus lowercase) in which they had seen them. They were explicitly told that if they saw a repeated letter they should write the letter twice. They were also told that there could be one, two, or three letters per trial. Fourteen practice trials preceded the experimental and filler trials.

Apparatus. The stimuli were presented on a CRT screen with a rapid fade phosphor, controlled by an IBM-XT. The experiment was carried out in normal room illumination.

Results

For each condition we counted the number of recalls of C1 and C2. The percentage of trials in which both[2] C1 and C2 were recalled, for each of the format categories, is presented in Table 1. Analyses of variance by subjects were carried out, with repeatedness, sameness of case, and the case of C1 as variables.

An overall repetition effect, $F(1, 21) = 82.5$, $p<.0001$, was present, but there was no same-different case effect and no

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[2]Most previous repetition blindness experiments reported the recall of C1 and C2 separately, and we did such analyses also in the four first experiments. To determine in the repeated case whether C1 or C2 had been recalled, if only one was, we relied on the relative serial position in recall of the target and the item presented between C1 and C2. We found similar results for C2 to those obtained when looking at the recall of both C1 and C2. We also found some repetition effects on C1, but there was uncertainty as to whether C1 was missing or had changed serial position. The recall of both C1 and C2 seemed to be a clearer indicator of the RB effect. In the last three experiments using sentences there was rarely any ambiguity about whether C1 or C2 was missing, so the two were analyzed separately.

interaction between repetition and same-different case, $F(1, 21) = 2.3$, $p>.15$. For the minor variable of which case came first there was a significant main effect, $F(1, 21) = 10.7$, $p<.004$, and an interaction with same-different case, $F(1, 21) = 13.4$, $p<.001$, suggesting that upper-case letters were recalled somewhat more accurately than lower-case letters.

A triple interaction between repetition, same-different case and lower-upper case first, $F(1, 21) = 32$, $p<.0001$, suggested that RB was larger when C2 was a lower-case letter than when C2 was an upper-case letter, independent of the case of C1 (see Table 1).

Table 1

Experiment 1: Percentage of trials in which C1 and C2 were both recalled

Repeatedness

		Same Case	
	l/l	u/u	Mean
NR	66.5	69.5	68
R	32	52.5	42.5
NR-R	34.5	17	25.5

		Different Case	
	l/u	u/l	Mean
NR	64.5	71.5	68
R	52	42.5	47
NR-R	12.5	29	21

Note. The case of C1 and C2 is shown in the form l/u, etc..where l=lower case and u=upper case.

Separate analyses of each of the four case combination (C1 and C2 lower case, C1 and C2 upper case, C1 lower and C2 upper case, and C1 upper and C2 lower) showed a significant repetition effect in each condition (all $ps < .0001$).

We also looked at the percentage of times subjects reported C1 or C2 in the wrong case. Altogether there were few case errors: 8% of the recalled items were reported in the wrong case. The percentage of case errors (given that the item had been recalled) was not affected by repetition or whether the item was C1 or C2.

Discussion

The main finding consisted of a significant negative effect of repetition that was unaffected by difference in case. The size of the RB effect, expressed as the percentage of C1 and C2 recalls in the nonrepeated condition minus the percentage in the repeated condition, was comparable for same (25.5%) and different (21%) formats.

This confirms the previously reported indifference to case of RB for words (Kanwisher, 1986). The finding is consistent with evidence that letter identification happens at an abstract level dissociated from case (Friedman, 1980; Rayner, McConkie & Zola, 1980).

The comparable size of the RB effect for same and different case letters shows that RB can be independent of specific visual properties, but does not rule out the hypothesis that RB could be due to the sharing of abstract, highly overlearned visual features. Our ability to read handwritten text is highly dependent on our capacity to encode visually-different targets into the same letter or word category. This abstraction from configural information (case format as well as font or handwriting styles) appears to occur during early stages of visual encoding and is certainly a learned skill. Letter case changes are part of the same representational system, and many upper and lower case letters share at least some visual features. Experiment 2 was designed to test whether RB would be found across different formats, when the corresponding systems are more distinct.

Experiment 2

In Experiment 2, the format change involved single digits written either in verbal (nine) or arabic (9) format. Although the spoken names of the two digit formats and their mathematical meanings are identical, the representational systems are distinct both visually and in usage. While we can read words with a mixture of cases (e.g., capitalized words, or even THis word), mixtures of digit formats are unacceptable. Further, each format system for digits is ordinarily restricted to certain contexts. Calculations, for example, are invariably represented with arabic numerals. The question in Experiment 2 was the same as in Experiment 1: would there be RB for different-format digits, and if so, would it be as strong as for same-format digits?

Method

The method was the same as that of Experiment 1 unless otherwise specified. Subjects viewed sequential trials that included three single digits mixed with three irrelevant arrays of symbols. Their task was to write down the numbers in the format in which each had been presented.

Subjects. Twenty-eight subjects who did not participate in the previous experiment participated in Experiment 2.

Materials and design. One-digit numbers were used (between 1 and 9), in place of the 22 letters used in Experiment 1. The symbol arrays consisted of rows of 3, 4 or 5 identical keyboard symbols. Figure 1 shows a sample trial. The design, procedure and apparatus were otherwise identical to that of Experiment 1. In particular, there were two versions of the experiment, counterbalancing repeatedness; the other variables (same/different format, lag) were counterbalanced between items and remained constant in the two versions.

Results

The percentage of recalls of both C1 and C2, for each of the format categories, is shown in Table 2. Analyses of variance by subjects were carried out on the number of trials in which both C1 and C2 were recalled.

Overall effects of repeatedness, $F(1, 27) = 122.9$, $p<.0001$, and of same-different format, $F(1, 27) = 24.1$, $p<.0001$, were observed. There was, however, a significant interaction between repeatedness and same-different format, $F(1, 27) = 19.3$, $p<.0001$, with a greater repetition effect when the format was the same. In separate analyses of same and different format conditions, we observed a significant repetition effect in both conditions (p's <.0001).

An arabic-verbal first effect was also present in the main analysis, $F(1, 27) = 19.3$, $p<.0001$, showing overall better recall of C1 and C2 when C1 was a verbal number rather than an arabic one. No other interactions were significant.

We also looked at the percentage of times subjects reported C1 or C2 in the wrong format. Altogether there were few format errors: 4.5% of the recalled items were reported in the wrong format. The percentage of format errors (given that the item was recalled) was not affected by repetition or whether the item was C1 or C2.

Table 2

Experiment 2: Percentage of trials in which C1 and C2 were both recalled

Repeatedness

	Same Format		
	v/v	a/a	Mean
NR	84.5	77	80.5
R	56	47.5	52
NR-R	28.5	34.5	28.5

	Different Format		
	v/a	a/v	Mean
NR	84	80	82
R	74	64.5	69
NR-R	10	15.5	13

Note. The format of C1 and C2 is shown in the form a/v, etc..where a=arabic format and v= verbal format.

Discussion

As in Experiment 1, a strong RB effect was found even when the critical stimuli were presented in different visual formats. However, in Experiment 2 the size of the RB effect was greater when the format was the same (28%) than when it was different (13%). Concerning our main question, the presence of substantial RB between different-format digits cannot easily be explained on the basis of the sharing of abstract learned perceptual features by the verbal and arabic forms of a given number. Evidently, visual similarity (however abstract) is not a necessary condition for RB. The reduction in the size of the RB effect for different-format numbers is consistent with the hypothesized existence of two separate pathways to encode verbal and arabic numbers (McCloskey, Sokol & Goodman, 1986). In contrast, upper and lower case letters are unlikely to be processed by different pathways.

The presence of RB between different-format numbers suggest that the RB phenomenon might be located at a higher level of processing than that of visual types and tokens. There are two dimensions on which '9' and 'nine' are identical: conceptual and phonological. The conceptual hypothesis would posit that RB between '9' and 'nine' occurs because they share a common conceptual type. This could correspond to the internal representation of numbers proposed by McCloskey and Caramazza (1987), which relies on a complex semantic and syntactic system. However, no RB was found between noun synonyms such as 'rug' and 'carpet' (Kanwisher &

Potter, 1990), casting doubt on the conceptual explanation of RB between '9' and 'nine'.

The phonological hypothesis would claim that RB between '9' and 'nine' occurs because they share a common phonological representation. However, Kanwisher and Potter (1990) found little RB (Experiment 4A) or no RB (Experiment 4B) between heterographic homophones, such as 'eight' and 'ate', when embedded in sentences. The small numbers of sentences and subjects they used, as well as the conflicting results they obtained between their two experiments, left the role of phonology uncertain. Moreover, a phonological representation might be expected to play a larger role in short-term recall of an unstructured list (as in Experiments 1 and 2), than in recall of a meaningful sentence. In Experiment 3, homophones were presented in lists to investigate those questions.

Experiment 3

In Experiment 3, subjects viewed trials consisting of three words mixed with three irrelevant arrays of symbols. Their task was to report all the words. The set of words used consisted of pairs of homophones which differed in spelling.

Method

The method was the same as that of Experiment 2 unless otherwise specified.

Subjects. Twelve subjects from the MIT pool participated in Experiment 3. None of them had participated in the previous experiments.

Materials and design. The design was like that of Experiment 2 except that nine pairs of heterographic homophones were used, in place of the nine numbers. The homophones were: ate/eight, one/won, know/no, you/ewe, days/daze, hymn/him, right/write, cot/caught, seas/seize. The symbol arrays consisted of rows of 3, 4 or 5 identical symbols. Figure 1 shows a sample trial. Fourteen practice trials were followed by 96 experimental and 20 filler trials. Each trial consisted of a sequence of six arrays preceded and followed by a row of percentage signs. On the experimental trials three of the six arrays were words from the homophone set, the other three arrays each consisted of a row of symbols. The 20 filler trials consisted of two words from the homophone set (sometimes repeated) and four arrays of symbols.

The design and procedure of this experiment was otherwise identical to that of Experiment 2. Repeatedness was counterbalanced between the two versions of the experiment by replacing C1 with another word in the homophone set. The other main variable, counterbalanced between items, was whether C1 and C2 were repeated as the same word (e.g., won/won), or as homonyms (e.g., one/won). Note that this second variable (same versus different format) was meaningless for nonrepeated trials. (For letter case or for arabic versus verbal number, in contrast, C1 and C2 on the nonrepeated trials could have either the same or a different format). The other between items variable was, as before, lag.

Results

The percentage of trials in which both C1 and C2 were recalled, for the identical and different spelling conditions, is given in Table 3. Analyses of variance by subjects were carried out on the number of trials in which both C1 and C2 were recalled.

Table 3

Experiment 3: Percentage of trials in which C1 and C2 were both recalled

	Identical (ate/ate)	Homophones (eight/ate)
Repeatedness		
NR	80	82
R	44	65
NR-R	36	17

An overall repetition effect, $F(1, 11) = 34.2$, $p<.0001$, and an identical-different spelling effect, $F(1, 11) = 29.0$, $p<.0001$, were present; there was a significant interaction between repeatedness and identical-different spelling, $F(1, 6) = 25$, $p<.0001$, indicating that the repetition effect is larger when targets are identical (won/won) than when targets are different words that are homophones (one/won), (the nonrepeated control conditions are equivalent, as they should be; format was a dummy variable for nonrepeated trials). Separate anovas for the identical and different-spelling conditions showed a significant repetition effect in both cases, p's <.005.

Discussion

As expected, RB was substantial between identical words. The striking result was the clear RB effect found between differently-spelled homophones (e.g. 'ate' and 'eight'), contrary to the sentence experiment of Kanwisher and Potter (1990, Experiment 4B). The size of the RB effect was, however, much larger (36% versus 17%) in the identical than in the different spelling condition. This pattern of results is similar to that of Experiment 2 with numbers.

One question is whether the reduction in RB is proportional to the orthographic difference. If so, there should be more RB between homophonic pairs that share a larger number of letters (days/daze) than between those that are clearly not orthographically related (eight/ate). We carried out a post hoc item analysis, comparing three pairs with a large letter overlap (days/daze, him/hymn, seas/seize) and three pairs with no same-position letter overlap (ate/eight, ewe/you, one/won). This analysis showed no interaction between repetition and overlap ($F(1,11)= 1.14$, $p>0.3$). However, the initial design of the experiment was not set up to control for this variable. Since it has been shown that RB is found between non-identical but orthographically similar words (Bavelier & Segui, 1990; Kanwisher & Potter, 1990), a more thorough investigation of the role of orthographic overlap in the RB effect between differently-spelled homophones was undertaken in Experiment 4.

Experiment 4

This experiment was designed to test whether the orthographic overlap between the homophone pairs could be responsible for the RB found between differently-spelled homophones in Experiment 3. For this purpose, we compared these differently-spelled homophones with nonhomophonic control pairs matched for orthographic overlap.

Method

The method was the same as that of Experiment 2 unless otherwise specified.

Subjects. Twenty-four subjects from the same pool participated in Experiment 4.

Materials and design. The same nine pairs of heterographic homophones of Experiment 3 were used; for each pair, we constructed a control pair such that the pattern of orthographic overlap between the control items was identical to that between the homophones. That is, the mapping between letters in the homophone pairs was matched by an identical mapping in the control, non-homonym pairs. For example, the control for one/won was get/age. The following 9 sets of two pairs of words were used: one/won - get/age; ate/eight - bed/drive; know/no - work/or; you/ewe - bog/has; days/daze - tofu/toys; hymn/him - menu/man; right/write - above/label; cot/caught - art/accept; seas/seize - dead/dense. An effort was made to match the frequency of each homophone and its corresponding control.

There were three main variables, within subjects: repeatedness (r/n), identical-different spelling (i/d) and homophone or control pair (h/c). Repeatedness and identical-different spelling were counterbalanced within items and subjects; homophones and control pairs were between items. Each homophone or control pair appeared equally often in each order (e.g. ewe/you versus you/ewe) across the different conditions. Similarly, half the trials in each condition were at lag 1 (one word between C1 and C2) and half at lag 2 (one word plus a row of symbols between C1 and C2). Altogether there were 144 trials. Figure 2 shows a sample trial of each type (homophone or control) in the repeated condition. The procedure of this experiment was otherwise identical to that of Experiment 2.

Figure 2

Examples of trials from Experiment 4

	Homophone trials		**Control trials**	
	identical:	**different:**	**identical:**	**different:**
	%%%%%	**%%%%%**	**%%%%%**	**%%%%%**
	===	**===**	**>>>>>**	**>>>>>**
[C1]	**one**	**won**	**get**	**age**
	{{{{{	{{{{{	**+++**	**+++**
	days	**days**	**label**	**label**
[C2]	**one**	**one**	**get**	**get**
	****	****	**<<<<**	**<<<<**
	%%%%%	**%%%%%**	**%%%%%**	**%%%%%**

Results

The percentage of recall of both C1 and C2 for the homophones and the orthographic control conditions is given in Table 4. Analyses of variance by subjects were carried out on the number of trials in which both C1 and C2 were recalled, for the different conditions.

Table 4

Experiment 4: Percentage of trials in which C1 and C2 were both recalled

Repeatedness

	Homophones	
	Identical (won/won)	Different spelling (one/won)
NR	80.5	82.5
R	52	66
NR-R	28.5	16.5

	Orthographic controls	
	Identical (get/get)	Different spelling (age/get)
NR	83	85
R	44.5	80
NR -R	38.5	5

An overall repetition effect, $F(1, 23) = 90.5$, $p<.0001$, and an identical-different spelling effect, $F(1, 23)= 63.4$, $p<.0001$, were present. These two factors interacted, $F(1, 23) = 64.5$, $p<.0001$, indicating that when targets are identical the size of the repetition effect is larger than when targets are differently spelled. The identical-different spelling factor (i/d) also interacted with the type (h/c) of the targets, $\underline{F}(1, 23) = 15.5$, $\underline{p}<.001$; a significant triple interaction between the factors identical-different, repeatedness and homophone-control, $\underline{F}(1, 23) = 14.1$, $\underline{p}<.001$, showed that the size of RB effect in the identical and different conditions was significantly different for the homophone than for the control condition. We ran separate analyses of the identical and different trials.

For the identical condition, there was an overall repetition effect, $\underline{F}(1, 23) = 106.87$, $\underline{p}<.0001$, no homophone-control effect, but a significant interaction between repetition and homophone-control, $\underline{F}(1, 23) = 5.9$, $\underline{p}<.023$, indicating a somewhat larger repetition effect for the non-homophone control words than for the homophones, even though in both cases C1 and C2 were identical. In a further breakdown, both homophones and controls had highly significant repetition effects, $\underline{p}$'s <.0001.

For the different-spelling condition (one-won and age-get), we found an overall repetition effect, $\underline{F}(1, 23) = 27.3$, $\underline{p}<.0001$, an overall homophone-control effect, $\underline{F}(1, 23) = 13.2$, $\underline{p}<.001$, and a significant interaction between repetition and homophone-control, $\underline{F}(1, 23)= 6.0$, $\underline{p}<.022$, indicating a larger repetition effect for the homophones than for the orthographic control stimuli. Separate analyses for the homophones and the orthographic controls showed a highly significant repetition effect for differently spelled homophones (won/one), $\underline{F}(1, 23) = 19.1$, $\underline{p}<.0001$, but a much weaker repetition effect for the orthographic controls (age/get), $\underline{F}(1, 23) = 5.05$, $\underline{p}<.035$.

Discussion

The results confirmed the findings of Experiment 3, showing a RB effect for both identical (won/won) and different-spelling (one/won) homophones. As before, the size of the RB effect was larger (28% versus 16%) in the identical than in the different spelling condition. The control trials in the identical-spelling condition confirmed the standard RB results. However, the main finding of Experiment 4 is that orthographic overlap is not responsible for the sizeable RB effect between homophones: non-homophone control pairs with the same pattern of letter overlap showed only a small RB effect (85 versus 80% correct).

In Experiments 1 and 2 we established that visual similarity between C1 and C2 was not necessary for RB; items that were only conceptually and phonologically equivalent (e.g., '9' and 'nine') were subject to RB. In Experiments 3 and 4 we showed that phonologically equivalent words that were not conceptually related could produce RB, and that partial orthographic overlap could not account for this result. Taken together, these results strongly suggest that phonology per se plays a role in RB.

This stands in opposition to the findings reported by Kanwisher and Potter (1990) for pairs of homophones embedded in sentences. These authors found no RB effect between differently spelled homophonic pairs given that the orthographic overlap between them was minimal. In an earlier experiment, however, they had found some indications of RB between homophones. These contradictory results were found with very similar targets to those used in the present experiments; the main difference was the context in which those targets were presented. The experiments reported here used a new method with recall of three-word lists, where the words were intermixed with irrelevant rows of symbols; furthermore, the critical targets appeared repeatedly in the course of the experiment; finally, the rate of presentation was 100 ms/item, whereas in Kanwisher and Potter's experiment the rate was 117 ms/item. All these factors might have increased reliance on short-term codes such as a phonological code, although that the fact that subjects wrote down their responses should have encouraged the retention of a visual representation as well. Unlike sentence recall, however, there was no incentive for the subjects to rely on a conceptual representation of these unrelated items. If any of these factors were responsible for the phonologically based RB evident in Experiments 3 and 4 (and possibly accounting for the different-format RB found in Experiments 1 and 2), then such an RB effect should diminish or disappear if the critical pairs are presented in sentences, at a rate of 117 ms per item. In Experiment 5, different-format numbers were included in sentences, and in Experiment 6, different-spelling homophones were presented in sentences.

Experiment 5

Method

Subjects. Twenty-four subjects of the same pool participated in this experiment, none of whom had participated in Experiment 2 (the previous numbers experiment).

Materials and design. Thirty-two sentences containing a repeated number between 1 and 9 were written. For each sentence, a non-repeated version was produced by replacing C1 by another number between 1 and 9. C1 and C2 were always separated by one to three words and C2 was never the last word in the sentence. The sentences were written so that removal of C2 left an ungrammatical or highly anomalous sentence. When possible, the entities to which the two numbers referred were different (e.g., 'four o'clock' and 'four cars').

The two variables of interest, repeatedness and same-different format, were both counterbalanced over the eight versions of the experiment, together with the format of C1. An example of a sentence in each of its eight version is given in Figure 3. The 32 sentences and their controls are given in Appendix A.

Figure 3

Experiment 5: The four repeated versions of one sentence counterbalancing format (the unrepeated control word is shown in parentheses)

A collision of four (nine) cars at four o'clock was reported to the police.
A collision of 4 (9) cars at four o'clock was reported to the police.
A collision of four (nine) cars at 4 o'clock was reported to the police.
A collision of 4 (9) cars at 4 o'clock was reported to the police.

Each version of the experiment contained 70 sentences: 32 experimental sentences, 28 fillers without numbers, and 10 ungrammatical sentences (intended to discourage guessing). The experimental list was preceded by 10 practice sentences.

Procedure. Each trial began when the subject hit the space bar on the computer keyboard. The row of asterisks then disappeared and was replaced by the sentence appearing one word at a time in the same place, for 117 ms per word. Each word was centered on the screen. Except for the initial capitalized letter of the first word, all words were in lower case. The last word of the sentence was displayed with a period on its right.

Subjects were instructed to read the sentence as carefully as possible and to recall it aloud as soon as it ended. Subjects were warned that some sentences would be strange or ungrammatical, but they were to report the words just as they saw them, and particularly not to put in words they had not seen in order to reconstruct a correct sentence. Subjects were not asked to report the format of numbers.

Apparatus. The same apparatus as in Experiment 1 was used.

Results and Discussion

The percentage of recall of C1 and C2 respectively (according to their position of recall within the sentence) was scored. The percentages are reported in Table 5 separately for the same and different format conditions.

Table 5

Experiment 5: Percentage of recall of C1 and C2

	Same Format (9/9)		Different Format (nine/9)	
	C1	C2	C1	C2
Repeatedness				
NR	88	73	90	76
R	88.5	47	90	49
NR-R	0.5	26	0	27

Overall recall accuracy for the sentences was high. Recall of C1 averaged 89%, which was representative of recall of the other words of the sentences (other than C2). As expected on the basis of previous work, there was marked RB for C2 in the recall of same-format numbers. The primary focus of this experiment was on the recall of C2 in the different-format condition (9 and nine). In this condition the size of the RB effect (27%) was comparable to that of same-format numbers (26%).

An analysis of variance, by subjects, was conducted separately for recall of C1 and of C2. There were no significant effects for C1. There was a main effect of repeatedness for C2, $\underline{F}(1, 23) = 45.2$, $\underline{p}<.0001$, no effect of same-different format, and no interaction between repeatedness and same-different format (both $\underline{F}$'s < 1.0) . A significant main effect of the arabic-verbal format of C2, $\underline{F}(1, 23) = 14.9$, $\underline{p}<.001$, suggested that C2 is less readily recalled when it is presented in arabic form (as was found in Experiment 2); there was no higher interaction with this variable.

This set of results confirms a strong RB effect between numbers on the recall of C2, but not C1, reproducing the standard RB phenomenon. Moreover, the RB effect was just as large between two different formats as within the same format, suggesting that when attention is directed to processing meaning rather than format subjects do not (or perhaps cannot) focus on the format of presentation as a way of avoiding RB. The level of representation at which C1 and C2 are indistinguishable (despite a clear difference in format) could either be the level of numerical concept or the level of phonological representation. If it is the former, there should be no RB between homophones under the same conditions. But if the representation producing RB with this material is phonological, then RB would be expected for homophones in sentences, contrary to what Kanwisher and Potter (1990) found. Experiment 6 tested RB between homophones embedded in sentences.

Experiment 6

Method

Subjects. Eighteen subjects from the same pool as the previous experiments participated in this experiment, none of whom had participated in Experiments 3, 4, or 5.

Materials and design. Twenty pairs of heterographic homophones were divided into two sets of 10. One set included only pairs that were orthographically distinct, to reduce the likelihood of visual confusion between them. For this set (cot/caught, won/one, eight/ate, weight/wait, seas/seize, I/eye, you/ewe, write/right, daze/days, know/no), sentences were written in which each of the two words in a pair appeared. Two sentences were written for each pair, varying the order of the two homophones: e.g. 'The dog jumped from the cot and caught the ball.' and 'The child was caught under the cot in her room.' None of these sentences used identical words.

The other set of 10 homophones (meet/meat, bear/bare, pair/pear, sun/son, week/weak, tale/tail, sail/sale, clothes/close, board/bored, ants/aunts) were used in sentences that included two occurrences of the same word. Hence, one sentence was written for each of the words of a given pair; for example, 'Each time I meet you here I meet some classmates on the way.' and 'I like meat but this meat smells awful.'. Thus, although all the critical words in the experiment were homophones, the identical versus different spelling conditions were between items.

For each sentence a non-repeated version was produced by replacing C1 by another word, often a synonym, leaving the semantics and the syntax of the sentence almost unchanged. C1 and C2 were always separated by one to three words and C2 was never the last word in the sentence. The sentences were written so that removal of C2 left an ungrammatical or highly anomalous sentence. The 40 sentences and the nonrepeated C1 words are given in Appendix B.

Each version of the experiment contained 40 experimental sentences, 20 filler sentences without homophones, and 15 ungrammatical sentences. The experimental list was preceded by 10 practice sentences.

Procedure. The same procedure as in Experiment 5 was used.

Apparatus. The same apparatus as in Experiment 1 was used.

Results

The percentage of recall of C1 and C2 was scored (when only one was recalled, scoring was based on recall order with respect to other words in the sentence). The percentages are reported in Table 6, separately for the identical and different-spelling conditions.

Table 6

Experiment 6: Percentage of recall of C1 and C2

	Identical (meet/meet)		Different (ate/eight)	
	C1	C2	C1	C2
Repeatedness				
NR	96	80	94	89.5
R	94	53	93	64
NR-R	2	27	1	25.5

Overall recall accuracy for the sentences was high. Recall of C1 averaged 93%, which was representative of the other words of the sentences (other than C2). As expected on the basis of previous work, there was marked RB for C2 in the identical condition. The primary focus of this experiment was on the recall of C2 in the different-spelling condition. As with numbers in Experiment 5, the RB effect was substantial (25%) and was comparable with that of the identical condition (27%).

Analyses of variance by subjects and by items were conducted separately for C1 and for C2. There were no significant effects for C1. There was a main effect of repeatedness for C2, $F1$ (by subjects) (1, 17) = 39.1, $p<.0001$, and $F2$ (by items)(1, 38) = 51, $p<.0001$, and a significant effect of the identical-different spelling factor for subjects, $F1(1, 17) = 15.5$, $p<.001$, but only marginally for items, $F2(1, 38) = 3.2$, $p<.08$. There were no interactions (both F's <1.0).

Discussion

As in Experiments 3 and 4, the results clearly show a strong RB effect between the differently spelled instances of a homophonic pair (won/one). Surprisingly, RB was as strong between two different instances of a homophonic pair (e.g., won/one) as between identical instances (e.g., meet/meet). In Experiment 3 and 4, in contrast, RB was significantly weaker for nonidentical pairs. (In Experiment 7, as will be seen, RB was also weaker for nonidentical pairs.)

The results of Experiment 6 conflict once again with those of Kanwisher and Potter (1990, experiments 4A and 4B), who found no RB for homophones in sentences. However, a closer inspection of their results suggests that there was some RB for homophones not only in their experiment 4A (a 23% RB effect on C2), but also perhaps in 4B (a 13% RB effect on C1 and a 2% effect on C2). Other differences that might account for the diverging results between the experiments include, for Kanwisher and Potter's study, a smaller number of items and subjects and the presence of homographs that had distinct pronunciations and meaning as well as homonyms with distinct meanings but identical orthography and pronunciation. It was also the case that in their Experiment 4B subjects had atypical difficulty recalling homophones, both C1 and C2.

Altogether, it seems that phonology plays an important role in the RB effect, even in sentences. Phonological codes are thought to be involved in reading in at least two ways: during word recognition and in working memory. Hence, the phonological effect we observed in RB could occur during the recognition of the word, but prior to registration in short-term memory (STM) or could be a consequence of confusion in STM, manifested at the time of recall.

The latter explanation would account for the repetition effect between homophones (or numbers) in terms of phonological similarity once the items have been stored in verbal STM. There is a large literature showing that a list of similar-sounding items is difficult to memorize and recall. Conrad (1964) reported more errors in the immediate recall of visually presented sequences of consonants when those consonants were phonologically similar (such as B, G, V, P, T) than when dissimilar (such as W, H, K, R, S). Baddeley (1966) confirmed this effect with lists of acoustically similar words (e.g. man, mad, map, mat, max) compared with control lists (e.g. pen, rig, bar ,cow, pit). The mean recall score for the acoustically similar sequences was significantly lower than for the control sequences.

Murray (1968) showed that the differential difficulty of acoustically similar versus control lists was reduced or eliminated when subjects were asked to repeat a given word (like 'the'), during the visual presentation of the items. Irrelevant concurrent articulation appears to suppress the component of STM that sustains and permits rehearsal of a phonological representation of words. The memory span is reduced and at the same time phonological similarity effects are largely eliminated (cf. Baddeley, 1986, for a review). On the other hand, recent work suggests that articulatory suppression does not interfere with the phonological code derived from printed English and used for lexical access (Besner, Davies & Daniels, 1981; Besner & Davelaar, 1982; Besner, 1987a, 1987b; Van Orden , Pennington & Stone, 1990). Hence articulatory suppression seems to be able to differentiate between a late, post-access, phonological effect due to rehearsal in STM and an earlier phonological effect associated with lexical access.

Experiment 7

In Experiment 7 we tested the hypothesis that RB for homophones is a consequence of phonological confusion in short-term memory by comparing two reading conditions: silent or with concurrent articulation. Experiment 7 was similar to Experiment 6 except that on half the trials subjects articulated a syllable while the RSVP sequence was presented. Thus, we tested the effect of concurrent articulation on the RB effect for identical homophones (meet/meet) versus differently-spelled homophones (cot/caught). It is important to note that articulating does not interfere with the recall of RSVP sentences that do not have repeated words (Potter, 1984). When sentences were presented at a rate of 100 ms/word, Potter found no difference in the percentage of omitted words during the recall of sentences, whether subjects were articulating or were silent.

Method

Subjects. Twenty-four subjects from the same pool as the previous experiments participated in this experiment, none of whom had participated in the previous experiments.

Materials and design. The materials were the same as those used in Experiment 6. The list of sentences was separated into two blocks. In each block, there were 10 sentences with differently-spelled homophones (e.g. cot/caught); and 10 with identically-spelled homophones (e.g. meet/meet). For each block, in a given version, 5 sentences of each type were repeated and 5 were nonrepeated (C1 was replaced by another word). Repeatedness was counterbalanced between versions of the materials. Subjects viewed the sentences silently in one block, and repeated the syllable dadada... about four times per second in the other block. The order of the blocks and the order of the two conditions were counterbalanced.

Procedure. The procedure was like that of Experiment 6, except that in one block the subjects were instructed to begin saying dadada... before they pressed the space bar to begin the trial, stopping only when the sentence ended. Five practice trials preceded each block.

Apparatus. The same apparatus as in Experiment 1 was used.

Results

The percentages of recall of C1 and C2 was scored (when only one was recalled, scoring was based on recall order with respect to other words in the sentence). The percentages are reported in Table 7 separately for identical and different-spelling trials for the silent and articulation conditions.

Table 7

Experiment 7: Percentage of recall of C1 and C2

Repeatedness	Identical (meet/meet)		Different (ate/eight)	
	C1	C2	C1	C2
	Silent			
NR	92	86	94	80
R	91	52	92	67
NR-R	1	34	2	13

	Identical (meet/meet)		Different (ate/eight)	
	C1	C2	C1	C2
	Articulation			
NR	85	80	93	79
R	93	51	87	67
NR-R	-8	29	6	12

Overall accuracy in recall of the sentences was high. Recall of C1 was comparable in the silent and articulation conditions and averaged 91%, which was representative of recall of the other words of the sentences (other than C2). With identically-spelled homophones (meet/meet) there was marked RB in both the silent condition (34%) and the articulation condition (29%). In the different-spelling condition, the RB effect was lower but was equal in the silent condition (13%) and in the suppression condition (12%).

Analyses of variance by subjects and by items were conducted separately for C1 and for C2. None of the effects were significant for C1 except the interaction of the identical-different spelling condition with repeatedness, in the subject analysis, $F1(1, 23) = 9.11$, $p<.006$, but not in the item analysis, $F2(1, 38) = 1.2$, $p>.21$ (this interaction does not seem to have a meaningful interpretation). There was a main effect of repeatedness for C2, $F1(1, 23) = 72.2$, $p<.0001$, $F2(1, 38) = 50.3$, $p<.0001$, and a significant interaction of the identical-different spelling factor with repeatedness, $F1(1, 23) = 11.2$, $p<.003$, and $F2(1, 38) = 8.9$, $p<.005$. RB was more marked for identically spelled homophones than for heterographic homophones such as ate/eight. No other significant effects were obtained; in particular, there was no significant effect of silence versus articulation, and no interaction between this factor and any of the others (both F's < 1.0). Whether the subjects articulated in the first block of the experiment or in the second block was not significant either (both F's < 1.0).

The significant interaction between identical-different spelling and repeatedness led us to run separate anovas for identical and differently-spelled homophones. In the identical condition, there was no effect for C1 and a main effect of repeatedness, $F1(1, 23) = 50.6$, $p<.0001$, $F2(1, 38) = 60.1$, $p<.0001$, for C2. No other interactions were present. In the different-spelling condition, there was a small effect of repeatedness for C1, $F1(1, 23) = 4.84$; $p<.038$, but $F2(1, 38) = 1.0$, $p < .4$, and a large effect for C2, $F1(1,23)= 17.3$, $p<.0001$, $F2(1,38)= 7.3$, $p<.015$. No other interactions were present. In both the identical and different spelling conditions, no interaction of repeatedness with articulation approached significance.

Discussion

The results of Experiment 7 confirm that phonological similarity plays a role in RB. Contrary to the findings of Experiment 6, however, the size of the RB effect was significantly smaller for differently-spelled homophones than for identically-spelled homophones. (Since the materials were the same in both experiments, this difference seems difficult to explain; it was found even in the first block of trials for the silent condition.)

The focus of this experiment was on the effect of articulation on the RB effect. Articulation had no effect on RB, either in the identical spelling condition or in the different-spelling condition. Because irrelevant articulation has been shown to disrupt phonological rehearsing in STM, this result indicates that the phonological RB effect observed with differently-spelled homophones is unlikely to be due to a late phonological confusion during rehearsal in short-term memory. This point is discussed further below.

III. General Discussion

The present studies indicate that RB cannot be accounted for entirely by visual resemblance between the targets and show that acoustic, phonological or articulatory identity can play an equally important role. (Although it is not clear exactly what the representation in question is, we follow common practice in terming it "phonological".) These findings raise the question of the stage of processing at which a phonological representation becomes involved. We propose that phonological RB is not due to phonological confusion after items have been encoded in STM , but results from the failure to establish a phonological representation of the second target in STM. RB reflects an inability to select for a second time a phonological representation that has recently been used for registration of information in STM. More generally, we propose that RB is not dependent on the complete type-identity of C1 or C2, but on the attributes of the type that are selected for initial registration in STM.

To review our findings briefly, Experiments 1 and 2 indicated that RB can be found between items that share few if any configural properties, such as a letter in lower or upper case or a given number in its verbal (nine) or arabic (9) representation. So, visual similarity is not a necessary condition for the RB effect. In Experiments 1 and 2 conceptual equivalence might have accounted for RB between items in distinct formats. However, Experiment 3 established the presence of RB between homophonic pairs (won/one) which share phonology but not meaning. This result could not be explained solely by the sharing of some common letters by the homophones (Experiment 4). Hence it appeared clear that phonological identity of the targets contributed to the repetition effect in these experiments. It was noted, however, that in all instances except letter case RB was reduced when the visual format was different.

Experiments 5 and 6 investigated this result in RSVP sentences, where word or number meaning was expected to be more important than in lists. In Experiment 5 the RB effect was as strong for identical-format (nine/nine or 9/9) as for different-format numbers (9/nine or nine/9). This result could have been due to an increased reliance either on meaning commonality or on phonology when processing sentences. In Experiment 6 a similar result was found for identical and differently-spelled heterographic homophones (eye/I) in sentences, indicating that phonological identity, not meaning, was critical. Although the RB effect was equally large for identical and differently-spelled homophones in Experiment 6, in Experiment 7 identical words produced a substantially larger RB effect than heterographic homophones (as in Experiments 3 and 4).

This set of experiments clearly establishes that phonology plays a role in RB. We consider two stages of processing at which phonological RB might occur. The first possibility is that the phonological code used to hold and rehearse information in STM is responsible for the RB effect found between homophones. The short term memory account would explain the effect by arguing that both occurrences of the targets have been stored in STM, but due to phonological confusion between the two targets only one is recalled.

Because RB is hypothesized to come after memory encoding, we call this the late phonological hypothesis.

It seems unlikely that RB between different-format items (numbers or homophones) was due to a phonological effect of this kind, because in the list experiments only three items were to be remembered. Furthermore, in the present experiments item recall rather than order recall was measured. The phonological similarity effect in short-term memory is typically reflected in the difficulty of recalling item order, not the items themselves. In most of the experiments reporting a phonological similarity effect (e.g; Conrad, 1964; Baddeley, 1966) correct recall was scored as the number of items reported in their correct order, not the total number of correct items recalled regardless of order, which would be the relevant score to compare with RB. Watkins, Watkins, and Crowder, (1974) compared free and serial recall of written words having either high or low phonological similarity. Serial recall procedures gave a phonological similarity effect, where similarity impaired recall. However, under free-recall conditions similarity actually improved recall. While these studies clearly show that written stimuli are encoded phonologically in STM, they fail to explain RB because phonological similarity does not impair item recall and may even help it.

The late phonological account also seems to be seriously weakened by the results of Experiments 5 and 6. First, the use of sentences with several different words (with different phonological patterns) between the two targets seems to make the hypothesis of phonological confusion in STM less likely. Second, RSVP sentences in themselves give enough contextual cues to enable a rapid semantic coding of each word as it is identified (Potter, 1984), which should immunize the sound-alike words from a "late" phonological problem. The results of Experiment 7 also suggest that the RB effect observed is not happening at the level of phonological rehearsal in STM. In Experiment 7, articulatory suppression did not interact with the RB effect, whether the targets were identical words or differently-spelled heterographic homophones. This finding suggests that the phonological RB effect happens before the establishment of a memory trace in STM rather than afterward.

The early phonological hypothesis proposes that the phonological effect we observed is localized in an early stage of processing. There is considerable evidence in the literature that phonological information about a written word becomes available almost immediately (Perfetti, Bell & Delanay, 1988; Van Orden, 1987; Van Orden et al., 1990). Although most such studies are concerned with the question of whether access to the lexicon (and hence to meaning) is "direct" (based on visual information) or "phonologically mediated", all these studies agree that encoding of the orthographic input leads directly to retrieval of a phonological or articulatory code, whether retrieval or computation of the phonology precedes identification of the word, follows it, or runs in parallel with lexical access. Indeed, in experiments using brief, masked presentation of visual strings, perceivers may ordinarily encode information phonologically (Hawkins, Reicher, Rogers & Peterson, 1976). Large effects of stimulus word phonology have also been found in reading experiments using a lexical decision task (Coltheart et al., 1977; Rubenstein et al, 1971) and a categorization task (Van Orden, 1987). All those results show that the visual presentation of an orthographic string leads to the rapid activation of its corresponding phonological representation.

This early phonological level of encoding, we propose, is the locus of the RB effect found with homophones or numbers in different formats. Our claim is that in the present experiments subjects usually relied on this early phonological code for initial registration of the information in STM. The RB mechanism has been characterized as an inability to individuate a second new token from a type that has just been token individuated (Kanwisher, 1986, 1987). Accordingly, we propose that a second, phonologically identical code is not available for registration in STM for some interval of time after the same phonological code has been selected. However, if the initial registration based on the phonological code is successful, then other attributes (e.g., semantic or visual) will also be attached to this new token established in STM.

To fully understand the role of phonology in RB, some questions remain to be answered. The influence of particular tasks on the phonological effect needs to be clarified. Using short lists we found a stronger RB effect when targets shared both phonology and orthography than when they only shared phonology, but the orthographic contribution disappeared (except in Experiment 7) when using sentences. It may be that with short lists visual as well as phonological codes were used in tokenizing items, whereas with sentences only phonological information was used. Phonology may have been less important in lists than in sentences because written recall was required for lists, but spoken recall for sentences. Moreover, in written recall subjects were always instructed to use the format they had seen. Thus, the information used to initially register an item in STM may be under some degree of subject control.

Another question is whether phonologically based RB would be found in tasks that do not require recall. Kanwisher (1986) first demonstrated RB by studying the ability of subjects to detect a repeated word in a RSVP list; the task did not require recall, although of course it required memory for the sequence. In another task not requiring recall she showed that subjects are more likely to falsely rate RSVP sentences as ungrammatical when they contain repeated words than when they do not. Using a recognition probe technique Bavelier and Segui (1990) were also able to demonstrate the presence of RB. Whether phonological RB would be observed in such tasks is not known.

It will also be important to know whether the phonological effect generalizes to phonologically similar but not identical stimuli. If RB does not occur between phonologically similar items it will suggest that the phonological representation involved is lexical rather than sublexical. The fact that semantic differences do not prevent RB for phonologically identical targets and that semantic similarity alone does not produce RB (e.g., synonyms, Kanwisher & Potter, 1990) points to the phonological representation of a word as the trigger for RB. This does not necessarily imply that the sublexical phonological representation of the word (Seidenberg & McClelland, 1989; Van Orden et al., 1990) is the relevant one, because even if activated lexically the phonological information could be used independently of the semantic information.

Even if, as we have just seen, questions remain with respect to the nature of phonological RB, the fact that phonological identity alone can produce RB challenges the leading interpretation of this phenomenon. RB has been interpreted as an instance of the type-token problem that reflects a general limitation on visual information processing, and thus would not be expected between events that shared few or no visual (even abstract visual) properties (Kanwisher, 1987, in press; Kanwisher & Potter, 1989, 1990). We suggest, to the contrary, that RB is not invariably dependent on common visual properties of the two targets, but on common attributes of the type that are used for initial registration of the events in STM. RB will arise whenever the codes used in initial registration of C1 and C2 in short term memory are too similar, regardless of the actual stimuli the subject saw. If this initial code is subject to RB, then the other attributes of the type (e.g., semantic) are apparently not registered.

This initial code which is subject to RB is often phonological, consistent with a wide range of evidence for the importance of phonology in STM for written material. Perfetti and McCutchen (1982) suggest that an immediate effect of phonological encoding ("speech recoding") in reading is "reference securing", in which the notion conveyed by a word is held in active memory by a combination of semantic and phonological (name) codes. Moreover, it has also been established that if the phonological code proves to be dysfunctional for the task required, subjects may switch to nonphonological codes (possibly semantic or visual) to succeed in the task (Hawkins et al, 1976; Spoehr, 1978; Scarborough, 1972; see Carr & Pollatsek, 1985, for a review). Accordingly, the present studies suggest that stimuli were implicitly named when recognized, providing a phonological basis for RB. Experiments that have been taken to show that RB happens at the level of single visual features, such as color (Kanwisher, in press), may conceivably be explained by naming. However, as the results of our list experiments indicate, visual format can also be used for initial registration in STM, if subjects are required to focus on it or if it is more efficient for the task required. Moreover, as the high accuracy of format recall in the list experiments suggests, if the code selected for initial registration has been successfully established in STM, then other information linked to that code is also represented in the token established in STM. But if the code selected for initial registration has been subject to RB, then the other codes (e.g., visual or semantic) are unable to overcome RB.

Depending on the task, the initial code selected for registering information in STM may be predominantly visual or predominantly phonological. Under these assumptions, RB should depend not so much on the stimuli presented as on the way the task encourages or forces the subjects to encode those stimuli for later recall. In this view RB can still be seen as a type-token problem, in the sense of a distinction between identifying a stimulus (type activation that can even be unconscious) and registering the stimulus in STM, enabling later conscious recall of the item.

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V. APPENDICES

Appendix A
Materials used in Experiment 5

I put aside two (six) eggs and two peaches for the cake.
Jeremy painted one (three) chair(s) and one desk over the weekend.
A collision of four (nine) cars at four o'clock was reported to the police.
Gary lost five (eight) dollars in five seconds playing poker.
I can only see three (five) plants in three different pots.
My father planted eight (four) trees eight months ago in the garden.
We had to answer seven (nine) questions in seven minutes on the test.
Maggie has already fried nine (seven) eggs and nine sausages for the breakfast.
Tony added six (four) units after dropping six last term.
At the zoo there are one (two) adult rhino(s) and one baby.
That experiment will require seven (eight) subjects coming seven times each.
Jacob woke up at two (three) and had two big mugs of coffe before he left.
The temperature dropped off nine (seven) degrees in nine hours.
A carpet that is four (two) yards long and four feet wide will fit here perfectly.
This T-shirt costs five (six) dollars less five percent.
In this expedition there were eight (five) camels and eight donkeys for carrying baggage.
The Smiths bought four (one) kitten four months ago after their wedding.
We had to learn two (four) poems and write two papers to get credit.
Peter will serve the three (six) cakes on three plates.
They put handcuffs on seven (two) men and seven young boys.
I added the nine (three) beers to the nine bottles of ale on the table.
I discovered I was missing six (five) plates and six cups after I moved.
We discovered three (five) bird nests under three of the windows of the house.
There are one (two) computer(s) and one printer in this room.
The cash-box contained only seven (four) bills and seven sale slips.
This lamp will not fit in an eight (nine) by eight foot box.
William lost four (seven) keys and four wallets in less than a year.
This recipe called for the juice of three (nine) lemons mixed with three cups of sugar.
Dad came back with six (one) pineapple(s) and six mangoes from the market.
I have two (one) hour to finish two problem sets.
They sold this bowl at an advertised price of nine (six) dollars and nine cents.
Their income increases five (eight) percent every five years.

Appendix B
Materials used in Experiment 6

Identical word condition

Of my many aunts (relatives) two old aunts are living in Europe.
My father thought we got rid of the ants (insects) but there were ants all over the kitchen.
Ron learned to sail (navigate) so he could sail on our boat.
The store's sale (bargains) included a sale on sofas.
John wanted to have a (some) pear (fruit) but the pear turned out to be rotten.
Maggie prefers that pair (those boots) to my pair of shoes.
We lay in the sun (garden) until the sun disappeared behind the clouds.
Dan is not my son (nephew) but the son of a friend.
This cat had such a furry tail (body) that the tail of my kitten looked skinny.
Jan made an hilarious tale (story) from the tale she heard yesterday.
I like meat (steak) but this meat smells awful.
Each time I meet (take) you here we meet some classmates on the way.
The floor was bare (dirty) and the walls bare of any pictures.
They had an old bear (tiger) and a bear from the Rockies on the show.
The whole place will close (shut down) the day they close the bar.
I do need some new clothes (outfits) but the clothes I saw were awful.
Bob was bored with (tired of) her and bored in general with life.
Don was leaning on the board (wall) when the board fell down.
This week (Both today) and next week he will miss class.
William is to weak (kind) not to be weak with his children.

Different word condition

This is the one (craft) that won the race last year.
Last time Lucy won (played) and got one free ticket for the show.
Last night Bob ate (dropped) the eight cookies in the box.
For eight (ten) days we ate their strange food and felt sick.
The dog jumped from the cot (bed) and caught the ball.
The child was caught (found) under the cot in her room.
The pirates roamed over the seven seas (oceans) to seize any ships they found.
The navy decided to seize (invade) the seas that surround the enemy country.
The farmer will show you (us) the white ewe he bought last week.
The little ewe (calf) comes to you to get food.
You have to write (find) the right answer as soon as possible.
Journalists have no right (reason) to write such obnoxious article.
Pat spent many days (hours) in a daze after her accident.
John was in a daze for several days before taking his midterm.

As soon as I (we) touch your eye you must close it.
If you open your eye (mouth) once again I won't play.
There is no (one) theatre that I know of in this area.
The people I know (met) at work have no children but lots of cats.
John has to wait (stand) to get his weight taken by the nurse.
My doctor asked me to record my weight (diet) daily and wait for his call.

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CHAPTER II

RB BETWEEN WORDS

I. INTRODUCTION

Repetition Blindness (RB) is characterized by the inability of subjects to identify the second occurrence of a repeated item during rapid serial visual presentation (RSVP). This effect is particularly striking when it occurs in sentences that have a repeated word in them; subjects generally omit the second occurrence of the repeated word when recalling the sentence, even if the omission leads them to produce an ungrammatical or semantically anomalous sentence (Kanwisher, 1987). Hence, the prior presentation of a given word (C1) impairs subjects' ability to identify the second occurrence of the word (C2). It has been proposed that RB is due to key processes responsible for the stabilization of a perceptual representation or type into an episodic representation or token. More specifically, Kanwisher (1986, 1987) has proposed a model of visual information processing to account for RB between words that distinguishes two kinds of information: type information about word identity, and token information about visual episodes. According to the model, for a word to be consciously identified, its activated type has to be linked with a token node in episodic memory; this is called token individuation. RB occurs because once a type-token link has been established, a new link to a second token from the same type cannot be created for a given period of time.

Within this framework, a better understanding of the RB phenomenon between words requires the determination of the information that defines a type. Previous research has shown that RB occurs between instances of a word appearing in different cases (Bavelier & Potter, 1992; Kanwisher, 1987; Marohn & Hochhaus, 1988), indicating that a word-type is not defined by configural information. The finding of RB between homographs (e.g., to wind/the wind) (Kanwisher & Potter, 1990) suggests that orthographic information is important in defining a type. Exact identity of orthographic information is not required, however, because RB has also been found between pairs of words differing by one letter (e.g. cap/cape). These data pointed to the importance of orthographic similarity in RB, and led Kanwisher and Potter (1989) to propose that RB between words is happening at the level of orthographic representations.

However, the recent finding of RB between different format digits (e.g., 9/nine) and heterographic homophones (e.g. ate/eight) (Bavelier & Potter, 1992) indicates that RB cannot only be understood as happening at the level of orthographic representations. Rather, the involvement of phonological information in RB suggests that RB between words may be dependent on some of the specific characteristic of lexical access. The role of orthographic and phonological codes in RB is appealingly consistent with the well-established role of orthographic and phonological information in lexical access. One of the first studies to show that word recognition is affected by orthographic and phonological similarity was conducted by Meyer, Schvaneveldt, and Ruddy (1974). In their experiment, target words that had been primed by phonologically and orthographically similar words (e.g., *bribe*/*tribe*) led to faster lexical decision responses than unprimed targets, suggesting that word access is sensitive to phonological and orthographic similarity. Since then, orthographic priming has been established with tasks such as tachistoscopic identification (Evett & Humphreys, 1981), lexical decision (Forster, Davis, Schoknecht, & Carter, 1987) and naming (Forster & Davis, 1991). The results of these and other studies strongly suggest that the identification of a target word is affected by its orthographic neighborhood. Similarly, phonological information about a written word has been shown to be available almost immediately and to affect lexical identification (Coltheart, Davelaar, Jonasson, & Davelaar, 1979; Hillinger, 1980; Van Orden, Johnston & Halle, 1988; Van Orden, Pennington, & Stone, 1990; Perfetti & Bell, 1991; Lukatela & Turvey, 1991). Hence, RB involves at least two kinds of representations (orthographic and phonological) that are known to constrain word recognition processes early on.

The goal of the present paper is to investigate at what point during word recognition RB occurs. There are two main levels within the word recognition system at which RB might occur: a level specific to word processing, that we will call the lexical level; and a more general purpose level concerned with the analysis of more elementary properties of words that we will call, the pre-lexical level. The *lexical hypothesis* (Kanwisher & Potter, 1989) is that RB between words is dependent on the levels of representations that are specifically involved in lexical access, such as morphemic representations or lexical representations. The pre-lexical hypothesis (Kanwisher & Potter, 1990) would argue that RB arises from the levels initially involved in the analysis of visually presented orthographic patterns, such as abstract letters or letter clusters representations.

The first part of the paper tests the lexical hypothesis (Experiments 1, 2 and 3). These results will lead us to conclude that while no lexical factors influence RB, orthographic or phonological similarity is necessary for its manifestation. In the second part of the paper, we will pursue the further investigation of how orthographic and phonological information come to play a role in RB (Experiments 4 and 5).

II. ROLE OF LEXICAL FACTORS IN RB

A lexical explanation of RB was initially proposed by Kanwisher and Potter (1989, 1990). They suggested that RB between words arises from the level of lexical orthographic representation, or in other words from the visual word lexicon. Their claim was based on the observation that RB can only happen between items belonging to the same level of representation. No RB was found between pairs of anagrams like early and layer (Kanwisher & Potter, 1990) suggesting that RB observed at the word level cannot be explained at the letter level. Similarly, no RB was found at the letter level when the targets were words. For example, no letter RB was found between the first word fault and the second word heart. Subjects never recalled the word hear, as would be expected if RB could happen between individual letters of different words. From these data, Kanwisher and Potter (1989) proposed that for words the RB type is best interpreted as a pre-existing lexical representation. However, Kanwisher and Potter (1990) acknowledge that these data could also be accounted for by a pre-lexical hypothesis in which RB is happening at the level of letter clusters. This would be a possible explanation given that the letter cluster level has been shown to play a role during word recognition (Humphreys, Evett, & Quinlan, 1990). If so, anagram RB should not be found, nor letter RB within a word. Hence, whether the representations or types on which RB relies are lexical or pre-lexical has still to be directly tested.

In Experiment 1, the role of morphology on RB was assessed; morphological relationships have been shown to influence lexical access independently of orthographic and phonological relationships (see Henderson, 1985, for a review); hence, more RB should be expected between morphologically related words than between their orthographic controls if RB is indeed happening at the lexical level. In Experiments 2 and 3, we looked at the effect of the absolute and relative word frequency on RB. Previous studies have shown effects of absolute and relative frequency in orthographic neighborhood (Whaley, 1978; Forster & Chambers, 1973; Segui & Grainger, 1990); these effects are believed to be either lexical (Scarborough, Cortese & Scarborough, 1977) or post-lexical (Forster & Davis, 1984). If the size of RB is affected by the frequency of the critical words used, this will indicate that RB is not a pre-lexical phenomenon.

Experiment 1

Morphology has been shown to play an important role during word recognition. Data from recognition, production, priming, and detection studies have shown that morphological information is explicitly represented at the lexical level, or at least is not reducible to orthographic and phonological information (see Henderson, 1985, for a review). Pseudo-affixed forms (e.g., <u>undulate</u>) have been shown to have longer latencies than truly affixed forms (e.g., <u>unlucky</u>) in lexical decision and naming tasks (Rubin, Becker, & Freeman, 1979; Taft, 1981), suggesting that recognition processes are sensitive to the morphological structure of words. The latencies for responding to morphologically complex words in a lexical decision task have been found to be dependent on the frequency of the whole word as well as the frequency of the stem (Taft, 1979; Bradley, 1980). Using a repetition priming paradigm, Stanners, Neiser, Hernon & Hall (1979) found that morphologically complex words prime their stems (e.g., <u>boring</u> primes <u>bore</u>). Furthermore, the amount of priming found between morphologically related words depended on the type of morphological relationship existing between the prime and target. Similar effects have been found using detection techniques (Kempley & Morton, 1982; Murrell & Morton, 1974). Moreover, the effects of morphological structure do not seem readily explained by the fact that morphological boundaries typically co-occur with less frequency than morpheme internal letter combinations (Rapp, 1992). Even at very short time of presentation, the morphological effects found were shown to be independent from orthographic or phonological effects

(Grainger, Cole & Segui, 1991). While most of the studies show that morphology is important during word perception, it has also been shown to play a role during word production. For example, Prasada, Pinker, & Snyder (1990) found that high frequency past tense forms were produced more quickly than low frequency past tense forms when subjects were presented with stems with irregular past tense forms (e.g., sing/sang) but not when the stems had regular past tense forms (e.g., walk/walked); the stems were matched for frequency. This finding suggests that whether a form is morphologically regular or irregular is relevant to how it is produced. In summary, these studies show that the morphological structure of words is mentally represented at the lexical stage of processing during word recognition and production, and is not reducible to orthographic or phonological information. Hence, if RB is sensitive to morphology, it would suggest that RB is a lexical phenomenon.

Kanwisher and Potter (1990) found RB between morphologically related words (e.g.; silk/silky). Their experiment used words differing only by the addition of one final letter. The finding of morphological RB was also found using a larger set of stimuli in French (Bavelier, 1988). Bavelier (1988) found RB between prefixed words and their roots (e.g., tache/detache), suffixed words and their roots (e.g., malade/maladie), as well as between two prefixed (e.g., defait/refait) or two suffixed (e.g., sonnette/sonnerie) forms. However, RB was also found between words differing by up to two or three letters at the beginning or the end, that were not morphologically related (e.g., ciseaux/seaux, sac/sacre) (Bavelier, 1988). Hence, it is possible that the RB found between morphologically related words by Kanwisher et al. (1990) and Bavelier (1988) may be due solely to orthographic overlap, and that morphological information plays no role in RB. Experiment 1 was designed to investigate the role of morphological information in RB, independently of the role of orthography. We used the presentation of short lists of words intermixed with rows of symbols. We presented morphologically related words and morphologically unrelated words which had identical amounts of orthographic overlap. We used pairs of verbs, in their present and past forms (e.g. edit/edited). For each pair of verbs, we constructed a pair of orthographic controls, sharing the same orthographic relationships as the verbs (e.g., for edit/edited, we used wand/wander). If morphologically related words lead to a larger amount of RB than their orthographic controls, it will indicate that RB is a lexical phenomenon.

Method

Subjects. Sixteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Material and design. Eight practice trials were followed by 88 experimental and 20 filler trials. Each trial consisted of a sequence of six strings preceded and followed by a row of percentage signs. On the experimental trials, three of the six strings were words written in lower case. The other three strings each consisted of rows of 3, 4 or 5 identical keyboards symbols. The position of the two critical words C1 and C2 was varied but C1 never appeared as the first item and the two critical words were always separated by a third word. On half the trials, only one word intervened between the critical words (lag 1) and on the other half, a row of symbols also intervened between the two critical words (lag 2). The 20 filler trials consisted of two words (sometimes repeated) and four strings of symbols.

Twenty eight pairs of regular verbs and sixteen pairs of irregular verbs were selected. For each pair of verbs a control pair was constructed such that the control words shared the same orthographic overlap as the pair of verbs, but were not morphologically related. For example, the pair edit/edited had wand/wander as its control and the pair take/took had bake/book as its control. We tried to match the frequency of the verbs and their controls as much as possible. The list of the 44 pairs used is given in Appendix A.

There were three main variables counterbalanced within items and subjects: repeated or non repeated, verbs or controls, and which word of the pair appeared first. Identical (wand/wand) or related (wander/wand) repetition was a between items factor, as was lag (1 item between C1 and C2 versus 2 items).

Procedure. A row of asterisks appeared on the screen at the beginning of each trial. When the subject pressed the space bar on the computer keyboard, the asterisks disappeared and the items appeared one at a time in the same place (centered), for 100 ms per item (words or symbol strings).

Subjects were instructed to read the words and ignore the rows of symbols; after each trial they were asked to write down the words they saw, in the order in which they had seen them. They were told that there could be one, two or three words per trial.

Apparatus. The stimuli were presented on a CRT screen with a rapid fade phosphor, controlled by an IBM-XT. The experiment was carried out in normal room illumination.

Results

The percentage of recall of both C1 and C2[1] for the verbs and their orthographic controls is given in Table 1. On some of the trials subjects reported a neighbor of the word they saw, which we did not consider as an RB effect; conservatively, these reports were scored as correct. Specifically, when subjects reported the right verb but the wrong tense, their answer was scored as correct.

In this experiment, there was a general tendency to observe more RB at lag 1 than at lag 2. This trend is in accordance with the finding that RB decreases when lag increases (Kanwisher, 1986). This effect was stronger when C1 and C2 were identical than were they were similar. However, since the lag effect never interacted with the variable of interest (morphological versus orthographic relationships), results for lag 1 and lag 2 were collapsed in the following analyses.

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[1] Most previous repetition blindness experiments report the recall of the first instance (C1) and the second instance (C2) separately. However, when using such a way of scoring in short lists, there is some uncertainty as to whether C1 was missing or has changed serial position. This uncertainty arises only when C1 and C2 are identical, but not when they are similar. Since in Experiments 1, 4, and 5, we were interested in comparing the size of RB between identical versus similar items, the recall of both C1 and C2 seemed to be the only indicator of the RB effect that would not introduce a scoring bias between the two kinds of items.

Table 1

Percentage of trials in which C1 and C2 were both recalled

Repeatedness

Regulars

	Identical Verbs (edit/edit)	Orthographic controls (wand/wand)
NR	85	75
R	49	51
NR-R	36	24

	Pairwise Verbs (edited/edit)	Orthographic controls (wander/wand)
NR	80	84
R	69	66
NR -R	11	18

Irregulars

	Identical Verbs (took/took)	Orthographic controls (book/book)
NR	80	86
R	55	47
NR-R	25	39

	Pairwise Verbs (take/took)	Orthographic controls (bake/book)
NR	84	86
R	81	77
NR -R	3	9

Analyses of variance were carried out on the number of trials in which both C1 and C2 were recalled, for the different conditions. We decided to analyze the trials with regular verbs separately from those with irregulars verbs because under certain theories, regularly and irregularly inflected forms are represented differently (Kempley & Morton, 1982; Pinker & Prince, 1988; Prasada, Pinker & Snyder, 1990; Stanners et al, 1979). Moreover, the amount of orthographic overlap between regular targets was higher than between irregular ones.

For the regular pairs (verbs (e.g., *edit* or *edited*) or controls (e.g., *wand* or *wander*)) there were a main effect of repetition, $F1(1, 15) = 27$, $p1 < .0001$ by subjects, $F2(1, 54) = 38$, $p2 < .0001$ by items, and of type of repetition (identical or related repetition) in the subjects analysis, $F1(1, 15) = 26.7$, $p1 < .0001$. The interaction between these two factors was significant in the subject analysis, $F1(1, 15) = 7.2$, $p1 < .02$, and marginally significant in the item analysis, $F2(1, 54) = 3$, $p2 < .09$, suggesting a larger RB effect between identical (e.g., *edited*/*edited* or *wand*/*wand*) than related targets (*edit*/*edited* or *wander*/*wand*). No other significant effect was found; in particular, morphological relatedness did not interact with repetition ($ps > .5$), suggesting that morphological information did not influence RB.

Because we wanted to test whether morphological relationships lead to greater RB than orthographic relationships alone, it was important to compare morphologically related pairs (verbs (e.g., *edited*/*edit*) with orthographically related pairs (e.g., *wander*/*wand*)) while excluding the identical pairs. Analyses of variance revealed an overall repetition effect, $F1(1, 15) = 7.6$, $p1 < .015$ by subjects, $F2$(1,

25) = 13.8, p2 < .001 by items, but none of the other effects reached significance (ps > .3) in the subject or item analyses. In particular, there was no interaction of morphology and repetition (ps > .3). These results clearly establish that the size of the RB effect is similar whether the targets are morphologically related (11%) or not (18%).

For the irregular pairs (verbs (e.g., took/take) and controls (e.g., book/bake)) there was a main effect of repetition, F1(1, 15) = 23.7, p1 < .0001 by subjects, F2(1, 30) = 36, p2 < .0001 by items, and of identical or related repetition, F1(1, 15) = 26.4, p1 < .0001 by subjects, F2(1, 30) = 6.7, p2 < .014 by items. These two factors interacted, F1(1, 15) = 14.8, p1 < .002 by subjects, F2(1, 30) =16.5, p2 < .0001 by items, due to a larger RB effect between identical than related targets. No other significant effects were found (ps > .08).

As with the regular verbs, we ran separate anovas for the related condition (verbs (e.g., took/take) versus the control condition (e.g., book/bake)), excluding the identical pairs. No effect of repetition was found in the analysis by subjects (p1 > .15) and a marginal effect of repetition was found in the analysis by items (F2(1, 14) = 4, p2 = 0.063), but there was no interaction of morphology and repetition (ps > .4). These results show that the size of the repetition effect is similar whether the targets are morphologically related (3%) or not (9%), and indicate that the main repetition effect found with irregular pairs was mostly due to identical pairs (e.g, take/take or bake/bake). We were however surprised to find no RB effect between different-spelling irregular pairs (e.g., sing/sang or break/broke) given that half of the items used were orthographic neighbors, differing only by one letter. Given the previously reviewed results of RB between orthographically related words, we would expect a RB effect for the 8 orthographic neighbor pairs used. To better understand what happened between irregular pairs, we analyzed the eight items that were orthographic neighbors and the other eight items separately. For the orthographic neighbors, we found a sizeable RB effect (10%), which was marginally significant by a subjects analysis ($p1$ = .08), and significant by items analysis ($F2(1, 7) = 15$, $p2 < .006$); none of the other effects were significant. This confirms the presence of RB between orthographic neighbors; and shows that RB was of the same size between irregular verbs and their controls. For the other set of items, no effect of repetition was observed (size of the effect: 2%; $ps > .7$). These results indicate that morphological relationships do not influence RB, and that the manifestation of RB is dependent on the degree of orthographic/phonological similarity between the items.

Discussion

In Experiment 1, we found the same amount of RB whether C1 and C2 were morphologically related or not. We found that RB between past and present forms of regular verbs was of the same amount as RB between morphologically unrelated words with the same orthographic overlap. Contrary to what might have been expected, morphological relationships did not increase the RB effect. Moreover, the same marginal amount of RB between past and present forms of irregular verbs and their orthographic control was found, suggesting that the fact that C1 and C2 are morphologically related is not enough to enhance a sizeable RB. In fact our findings with the irregular items clearly show that RB is only sensitive to the amount of orthographic overlap and not to morphological relatedness; RB between irregular items was not found when the orthographic overlap between the items used was low, but was found when the orthographic similarity was high. These findings were independent of the morphological relationships shared by the item. These results show that RB is not sensitive to morphological relationships, and that orthographic/phonological relationships are necessary for RB.

Experiment 1 shows that RB is not sensitive to morphological information that is known to play a role during lexical access. In the next two experiments, we looked at whether frequency, which is known to constrain lexical access and the interactions between accessed lexical representations, interacts with RB. If RB is found to be sensitive to frequency, it would suggest that RB is located at a lexical level of representation.

Experiment 2

Frequency is one of the most salient factor in word recognition. High frequency words yield shorter reaction times than low frequency words in lexical decision and naming tasks (Whaley, 1978; Forster & Chambers, 1973). Threshold techniques have shown that high frequency words are easier to detect than low frequency words (Howes & Solomon, 1951). Any model of visual word recognition will have to account for this robust frequency effect. The most widely accepted hypothesis for the major locus of frequency effects is the lexical identification process. This lexical identification process is common to all "lexical tasks" and supposedly precedes retrieval of meaning or pronunciation and task-specific decision processes (see

Monsell, Doyle & Haggard, 1989 for a review). The goal of Experiment 1 is to test whether two of the classical effects of frequency interact with RB.

As mentioned above, lexical access for low frequency words is slower than for high frequency words. Hence, the amount of time elapsing between the access of C1 and the one of C2 should be greater when C1 is a high frequency word and C2 a low frequency one, than vice versa. Moreover, several studies suggest that RB diminishes as the amount of time elapsed between C1 and C2 increases (Kanwisher, 1986; Park & Kanwisher, 1991). So, if RB can be shown to be smaller when C1 is high frequency and C2 low frequency than when C1 is low frequency and C2 is high frequency, it will suggest that RB is located at the level of lexical entries. To test this prediction, we decided to use orthographic neighbors with very different frequencies (e.g., lice/like), and to compare the size of RB between these orthographic neighbors (e.g., like/lice versus lice/like).

Another prediction for RB comes from the classical frequency attenuation effect (Scarborough, Cortese & Scarborough, 1977). It has been shown that in priming tasks, that low frequency words show a stronger repetition advantage than high frequency words; this effect has been termed the frequency attenuation effect. While the exact locus of this effect is still a question of debate, it is believed to occur either during lexical access (Scarborough et al., 1977) or after lexical access in episodic memory (Forster & Davis, 1984), but never before lexical access. Hence, if RB interacts with the frequency attenuation effect, it will indicate that RB is not a pre-lexical effect, but either a lexical or post-lexical one. To test whether the attenuation effect interacts with RB, we compared RB between two low frequency words (e.g., lice/lice) and between two high frequency ones (e.g., like/like).

Method

Subjects. Thirty-two Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Material and design. Six practice trials were followed by 80 experimental and 13 filler trials. As in Experiment 1, each trial consisted of a sequence of six strings preceded and followed by a row of percentage signs. On the experimental trials, three of the six strings were words, written in lower case. The other three strings each consisted of rows of 3, 4 or 5 identical keyboard symbols. The position of the two critical words C1 and C2 was varied but C1 never appeared as the first item and the two critical words were always separated by at least a third word. On half the trials, only one word intervened between C1 and C2 (lag 1); on the other half, a row of symbols also intervened between the two critical words (lag 2). The 13 filler trials consisted of two words (sometimes repeated) and four strings of symbols.

We used 80 pairs of orthographic neighbors. In each pair, the words differed by one letter, preserved letter position, were of the same length and of very different frequency (the frequency values were obtained from the Kucera and Francis (1967)); for example, we used like (1290 per million) and lice (2 per million). The mean frequency of the high frequency target words was 1517 per million and 9 per million for the low frequency target words. The list of pairs used is given in Appendix B. In the non-repeated condition, C1 words were replaced by words of the same length and comparable frequency but entirely different spelling. The mean frequency of the high frequency controls was 2533 per million and 8.5 per million for the low frequency controls.

The two main variables of interest, repeatedness and whether C1 and C2 were repeated as the same word (e.g., like/like) or as neighbors (e.g., lice/like), were counterbalanced across versions; another variable, also counterbalanced across versions, was whether C1 was a high frequency (e.g., like) or a low frequency (e.g., lice) word. The lag variable (one or two intervening items between C1 and C2) was counterbalanced across subjects, but not across items. The 2X2X2 design of this experiment led to 8 versions of the experiment.

Procedure. Each trial began when the subject pressed the space bar on the computer keyboard. The fixation point, a row of asterisks, disappeared and the items appeared one at a time in the same place (centered) for 100 ms each.

Subjects were instructed to read the words and ignore the rows of symbols. After each trial, subjects were asked to write down the words they saw, in the order they had seen them. They were told that there could be one, two or three words per trial.

Apparatus. The stimuli were presented on a CRT screen with a rapid fade phosphor, controlled by an IBM-XT. The experiment was carried out in normal room illumination.

Results.

The percentage of recall of C1 and C2 for identical and orthographic neighbors is given in Table 2. For the non-repeated and neighbor trials, whether the target word was C1 or C2 was clear since the targets were different words. For the identical repeated trials, whether the target word recalled was C1 or C2 was decided according to its position relative to the third (intervening) word. If this was not possible, the word was noted as an occurrence of C2. Note that this method of scoring should increase RB for C1 and decrease RB for C2. On some of the trials subjects reported a neighbor of the word they saw, which we did not consider as an RB effect; conservatively, these reports were scored as correct. These errors were for the most part conversion of low frequency words toward high frequency words; the kind of scoring did not affect the main results of the experiment (a separate analysis where these errors were scored as errors showed that the interaction effects between repetition and frequency were unchanged by the kind of scoring).

In the present experiment, RB always showed a tendency to be larger at lag 1 than at lag 2. Because this effect never interacted with the variables of interest (frequency of C1 and frequency of C2), lag1 and lag2 were collapsed in the following analyses.

The first contrast we were interested in predicted less RB when C2 is a high frequency word and C1 is a low frequency word than when C2 is a low frequency word and C1 a high frequency one. To test this hypothesis, we ran an anova on the neighbor trials. The dependent variable was the percentage of trials in which C2 was recalled given that C1 was recalled. An overall repetition effect was found, $F1(1, 31) = 57$, $p1 < .0001$ by subjects, $F2(1, 79) = 51.8$, $p2 < .0001$ by items, there was no C2 frequency effect ($ps > .15$) and no interaction between frequency and repetition ($ps > .2$). Hence, the size of the RB effect is comparable whether C1 was low and C2 high frequency (16%) (e.g., lice/like) or vice versa (22%) (e.g., like/lice). This result shows that the frequency manipulation of C1 and C2 did not affect the size of RB, and specifically that having a high frequency C2 did not modify the pattern of appearance of RB.

Table 2

Percentage of trials in which C1 was recalled, C2 was recalled given C1 was correct and C2 was recalled

Identical

	HF/HF (like/like)			LF/LF (lice/lice)		
	C1	C2/C1	C2	C1	C2/C1	C2
repeatedness						
NR	94	87	88	92	88	88
R	92	54	56	88	57	61
NR-R		33	32		31	27

Orthographic neighbors

	LF/HF (lice/like)			HF/LF (like/lice)		
	C1	C2/C1	C2	C1	C2/C1	C2
repeatedness						
NR	90	86	87	92	93	91
R	88	70	72	93	71	73
NR-R		16	15		22	18

The second prediction of interest was that the size of RB between identical words should be smaller between low frequency words than high frequency ones. To test that hypothesis, we ran an anova on the identical trials. This anova was carried out on the percentage of trials in which C2 was recalled given that C1 was recalled. We observed an overall repetition effect, $F1(1, 31) = 107$, $p1 < .0001$ by subjects, $F2(1, 79) = 94$, $p2 < .0001$ by items, no C2 frequency effect ($ps > .3$) and more importantly, no interaction of frequency and repetition ($ps > .18$). This absence of interaction shows that the size of the RB effect is comparable between the two occurrences of a high (33%) (e.g., like/like) or low (31%) (e.g., lice/lice) frequency word.

An analysis of variance of the number of time C1 was correctly recalled was conducted with repeatedness, C1 frequency and C2 type (identical vs neighbor) as factors. The only significant effect was a C1 frequency effect, $F1(1, 31) = 7.5$, $p1 < .01$ by subjects, $F2(1, 79) = 5.3$, $p2 < .023$, by items, showing that high frequency words are better recalled than low frequency ones.

An analysis of variance was conducted with repeatedness, C2 frequency and C1 type (identical versus neighbor) as factors and the percentage of trials in which C2 was recalled, given that C1 was correct as the dependent variable. An overall repetition effect, $F1(1, 31) = 128$, $p1 < .0001$ by subjects, $F2(1, 79) = 119$, $p2 < .0001$ by items, and an identical-neighbor effect, $F1(1, 31) = 26$, $p1 < .0001$ by subjects, $F2(1, 79) = 23.5$, $p2 < .0001$ by items, were present. These two factors interacted, $F1(1, 31) = 14$, $p1 < .001$ by subjects, $F2(1, 79) = 14.4$, $p2 < .0001$ by items, showing that when targets are identical the size of the repetition effect is larger than when the targets are orthographic neighbors. There were no other significant effects (ps > .11). Specifically no interaction between the frequency of C2 and repeatedness (ps > .5), showing again that the amount of RB is equivalent whether C2 is high or low frequency.

Although no effect of frequency was observed when we scored neighbor recall as correct , there was a significant effect of frequency when recall of neighbors were scored as incorrect. This was the only result that was different between the two kinds of scoring. When scoring recall of neighbors as errors, high frequency C1 were correctly recalled on 91% of the trials while low frequency C1 were only recalled on 85 % ($F1(1, 31) = 18$, $p1 < .0001$ by subjects, $F2(1, 79) = 14$, $p2 < .0001$ by items) and high frequency C2 were correctly recalled on 71% of the trials, while low frequency C2 were only recalled on 67% ($F1(1, 15) = 3.3$, $p1 < .08$ by subjects, $F2(1, 79) = 3$, $p2 < .09$ by items) Hence, high frequency words were recalled more accurately than low frequency ones.

Discussion

The finding that high frequency words were recalled more accurately than low frequency ones establishes that the technique we used was sensitive to the absolute frequency of the words. However, this main effect of frequency did not interact with the manifestation of RB. In particular, the amount of RB was comparable whether C1 was a low frequency word and C2 a high frequency word or vice-versa. The predicted interaction of RB and frequency, if RB was sensitive to the difference in lexical access time of low and high frequency words, was not found. Although it is known that the difference in access time between high and low frequency words is relatively small (between 20 to 50 ms), such a difference should have resulted in a variation of 40 to 100 ms in the ISI between C1 and C2. A variation in ISI of this size is in the range of the one known to affect RB. Indeed, the comparison of RB at lag 1 and lag 2, when using short lists, suggests that a 100 ms lag is sufficient to manipulate the size of RB. Hence, the present results suggest that RB is not sensitive to the difference in access times of high and low frequency words.

The amount of RB found between two occurrences of a high frequency word (e.g., like/like) as of a low frequency word (e.g., lice/lice) was the same. The possible interaction between the frequency attenuation effect and RB, if RB was happening during or after lexical access, was not found. Although such a failure may have been due to the fact that our technique was not sensitive enough to be affected by the size of the frequency attenuation effect, this seems improbable given that a main effect of frequency was present in our experiment and that the frequency attenuation effect is known to be a large and robust effect.

This set of results suggests that RB is not affected by the effect of absolute frequency on lexical access. On the other hand, it confirms the role of orthographic similarity in RB by clearly establishing the presence of RB between orthographic neighbors; this RB effect, however, was found to be smaller than the one between identical targets.

Experiment 3

The neighborhood frequency of a word has been shown to be a critical factor in word recognition latencies (Grainger, O'Regan, Jacobs

& Segui, 1989). The results indicate that if the presented word is orthographically similar to a more frequent word (e.g., blur similar to blue) then it is harder (as measured by eye fixation duration) to recognize this word compared to a word of equivalent frequency that has no higher frequency orthographic neighbors. This neighborhood frequency effect was also shown to affect the amount and direction of priming (inhibitory or facilitatory) between orthographic neighbors (Segui & Grainger, 1990). These authors found that under unmasked condition, lower frequency neighbor primes interfered with the identification of a higher frequency target (e.g., lice/LIKE); but that under masked priming conditions, higher frequency neighbor primes interfered with the identification of a lower frequency target (e.g., like/LICE). Moreover, it was shown that the relative frequency between the primes and targets (and not the absolute frequency of either prime or targets) was responsible for these effects. These authors also looked at how this relative frequency effect varies as a function of the duration of the prime (Grainger & Segui, personal communication). They found that when the prime is presented for about 100 ms, as it is the case in the RB paradigm, higher frequency neighbor primes interfered very strongly with the identification of a lower frequency target (size of the effect: 64 ms in lexical decision), and lower frequency neighbor primes also interfered strongly with the identification of a higher frequency target (size of the effect: 42 ms in lexical decision). Given that these frequency effects are known to be dependant on the relative frequency between primes and targets, a direct prediction from these data is that higher frequency C1s should lead to more RB than lower frequency C1s when C2 is a low frequency word (e.g., fact/pact vs tact/pact), and that lower frequency C1s should lead to more RB than higher frequency C1s when C2 is a high frequency word (tan/can vs man/can). In Experiment 3, we tested this prediction by holding C2 constant, and preceding it by an orthographic neighbor of similar frequency or of a very different frequency.

Method

Subjects. Sixteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation. None of them had participated in the previous experiment.

Material and design. We selected 32 high frequency words, and 32 low frequency words. For each of them we selected two orthographic neighbors, one of equivalent frequency and the other of opposite frequency (the frequency values were obtained from Kucera and Francis (1967). For example, we used just (872 pm) as a high frequency word, and paired it with must (1013 pm) and gust (2 pm), similarly we used tact (6 pm) as a low frequency word, and paired it with fact (447 pm) and pact (5 pm). So we had 64 triplets of words that were orthographic neighbors, where two of them were of equivalent frequency and the third one was of opposite frequency. For each of those words, we selected a control word of identical length, equivalent frequency, and different spelling. The list of triplets is given in the Appendix C. For the first group of triplets, the mean frequency of the low frequency target words was 11.3 per million (11 per million for their corresponding control words); the mean frequency of the high frequency target words was 1428 per million (883 per million for their corresponding controls). For the other group of triplets, the mean frequency of the low frequency target words was 6.7 per million (6.5 per million for their corresponding control words); the mean frequency of the high frequency target words was 1472 per million (855 per million for their corresponding controls).

The main variable of interest, repeatedness, was counterbalanced across items. Whether C2 was a high or a low frequency word was a between items variable. The two remaining variables, C1 frequency given C2 frequency, and which of the two words of equivalent frequency would appear as C2, were counterbalanced across items. This 2X2X2 design resulted in 8 versions of the experiment. A final between items variable was the lag between C1 and C2: On half the trials, in each of the eight main conditions, one word intervened (lag 1), and on the other half a word plus a row of symbols intervened (lag 2). Each list began with 6 practice trials, followed by 64 experimental and 20 filler trials.

The design, procedure and apparatus were otherwise identical to that of Experiment 2.

Results.

The percentage of recall of C1 and of C2 for each of the 4 frequency conditions is given in Table 3. We used the same method of scoring as in Experiment 2.

In this experiment, RB was of equivalent size at lag 1 or at lag 2. Since lag did not interact with any of the other variables, results for lag 1 and lag 2 were collapsed in the following analyses.

Table 3

Percentage of trials in which C1 was recalled, C2 was recalled given C1 was correct and C2 was recalled.

C2 high frequency

	HF/HF (man/can)			LF/HF (tan/can)		
repeatedness	C1	C2/C1	C2	C1	C2/C1	C2
NR	88	81	81	92	73	75
R	83	57	59	84	54	57
NR-R		24	22		19	18

C2 low frequency

	HF/LF (found/mound)			LF/LF (hound/mound)		
repeatedness	C1	C2/C1	C2	C1	C2/C1	C2
NR	85	84	84	90	75	76
R	83	51	52	83	51	57
NR-R		33	32		26	19

Because we were especially interested in the role of relative frequency, we looked at the size of the RB effect when C2 is fixed, as a function of the frequency of C1. For this purpose, we ran separate analyses for low and high frequency C2s. The anovas were run on the percentage of trials in which C2 was recalled given that C1 was recalled.

When C2 was high frequency, there was an overall repetition effect, $\underline{F1}(1, 15) = 17$, $\underline{p1} < .001$ by subjects, $\underline{F2}(1, 31) = 25.8$, $\underline{p2}$ <

.0001 by items, no effect of the frequency of C1 (ps > .3) and no interaction of frequency and repetition (ps > .45). So, the size of the RB effect was comparable when C1 was a high frequency (24%) or low frequency (19%) neighbor of C2. The repetition effect induced by C1 seems to be the same whether C1 is a low or a high frequency word. When C2 was low frequency, there was an overall repetition effect, $F1(1, 15) = 24$, $p1 < .0001$ by subjects, $F2(1, 31) = 37$, $p2 < .0001$ by items, no effect of the frequency of C1 (ps > .4) and no interaction of frequency and repetition (ps > .1). The size of the RB effect is comparable whether C1 was a low frequency (26%) or a high frequency (33%) neighbor of C2. Hence, no effect of relative frequency on RB was found.

A 2X2X2 analysis of variance with repeatedness, C1 frequency and C2 frequency as factors and percentage of trials on which C2 was recalled given that C1 was recalled, as the dependent variable was performed. An overall repetition effect, $F1(1, 15) = 29$, $p1 < .0001$ by subjects, $F2(1, 62) = 63$, $p2 < .0001$ by items, was present; none of the other effects reached significance (ps >.09). Specifically no interaction between the frequency of C2 and the amount of RB, showing again that the amount of RB is equivalent whether C2 is high or low frequency.

Although no effect of frequency was observed when we scored neighbor recall as correct , there was a significant effect of frequency when recall of neighbors were scored as incorrect. When scoring recall of neighbors as errors, high frequency C1s were correctly recalled on 87% of trials while low frequency C1s were only recalled on 77% of trials, $F1(1, 15) = 7.4$, $p1 < .016$ by subjects, $F2(1, 62) =$

17, p2 < .0001, by items, and high frequency C2s were correctly recalled on 63% of trials, while low frequency C2s were only recalled on 55% of trials, $F1(1, 15) = 6.4$, $p1 < .023$ by subjects, $F2(1, 79) = 2.5$, $p2 < .12$ by items. Hence, high frequency words were recalled more accurately than low frequency ones. The rest of the results were the same as the previous analysis.

Discussion

In this experiment, C1 and C2 were always orthographic neighbors; C2 was held constant and the frequency of C1 was varied. RB was found for every kind of pair, confirming that RB happens between orthographic neighbors. High frequency words were recalled more accurately than low frequency ones, but this effect did not interact with RB. The size of the RB effect was the same whether C1 was a low or high frequency neighbor of C2, indicating that RB is not sensitive to the relative frequency relationships of the prime and target. These results suggest that RB is not affected by the frequency organization that affects word recognition. In conclusion, Experiment 3, in accordance with Experiment 2, shows that frequency effects do not interact with RB, and clearly establishes the presence of RB between orthographic neighbors confirming the role of orthographic similarity in RB.

Experiments 1, 2 and 3 show that RB between orthographically related words is not sensitive to lexical factors. The manipulation of the relative frequency of C1 and C2 did not affect the size of RB; morphological relationships lead to the same amount of RB as orthographic relationships; and morphological relationships alone (without orthographic/phonological similarity) failed to produce any

RB. These results strongly suggest that orthographic/phonological similarity is necessary for RB, independently of any lexical factors. While it seems clearly established that orthographic or phonological similarity is necessary for RB, how each these kinds of information comes into play in RB is still unclear. In the following section, we will try to understand the orthographic and phonological dimensions to which RB is sensitive.

III. ORTHOGRAPHIC AND PHONOLOGICAL INFORMATION IN RB

A review of previous findings of orthographic RB (RB between orthographically related words) and phonological RB (RB between phonologically related words) suggests that RB requires either an identical sequence of 3 to 5 letters (theory/the) (Kanwisher, 1991), or of 3 to 5 phonemes (certify/sir) (Kanwisher, 1991), or alternatively an entire syllable to match in C1 and C2. In Experiment 1, RB was found between present and past tense forms of irregular verbs when the forms were orthographic neighbors (sing/sang), confirming that orthographic overlap is sufficient to produce RB whatever the nature of the words used; but, no RB was found between present and past tense forms of irregular verbs when the forms differed by replacement of two to three letters mostly at the end of the word (break/broke). This result seems surprising given that previous studies have found RB between words that also differed by more than two letters. For instance, RB has been found between words differing by the addition of up to three letters at the end of the word (sirloin/sir) (Kanwisher, 1991). However in Kanwisher's experiment, C2 was always included in

C1, unlike in the present experiment. Although the results from the present study could have suggested that RB between words differing by more than one letter is conditional on an inclusion relationships between C1 and C2, such a conclusion is not supported by other findings. RB between words differing by replacement of up to three letters at the end of the word has been found in French (sonnette/sonnerie) (Bavelier, 1988), showing that RB between words differing by more than one letter is not conditional on an inclusion relationship. The main difference between the material of Experiment 1 (shake/shook) and the Bavelier material (sonnette/sonnerie) is the number of letters changed between C1 and C2 (2.5 vs 3.1 letters) relative to the length of the C1s and C2s used (4.2 vs 8.3 letters) in each of the experiment respectively. RB failed to occur when only 1 or 2 letters were shared at the same position by C1 and C2, but did occur when C1 and C2 shared around 4 letters at the same position. This observation suggests that RB requires an identical sequences of 3 to 5 letters to match in C1 and C2.

Although RB between orthographically similar but not identical items has now been clearly established, the status of phonologically similar but not identical items in RB is still unclear. Phonological RB has been mostly tested between phonologically identical items (Bavelier & Potter, 1992). Findings by Kanwisher (1991) of RB between stimuli such as 'certify/sir' suggest the existence of RB between phonologically similar, but not identical items. However, in this experiment, only a small numbers of pairs of items were used and for each pair, C2 was always part of C1. In Experiment 4, we first wanted to investigate whether RB occurs between phonologically similar but not identical items, using a large number of pairs of items, where neither C1 nor C2 is part of the other. In the same experiment, we also compared the role of letter versus phoneme similarity in RB.

Experiment 4

In this experiment, we tested the role of letter similarity in RB, independently of phonological similarity, as well as the role of phoneme similarity, independently of orthographic similarity. For this purpose, we constructed pairs of words that differed either by one and only one letter, but were phonologically dissimilar (reach/react), or that differed by one and only one phoneme, but were orthographically dissimilar (great/freight). This material allowed us to test RB between phonologically similar, but not identical words, and to compare the effect of orthographic versus phonological similarity on RB. Finally, we compared each of these conditions to a third condition where orthography and phonology are identical (doctor/doctor).

Method

Subjects. Eighteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Material and design. Twelve practice trials were followed by 72 experimental and 20 filler trials. As in Experiment 1, each trial consisted of a sequence of six arrays preceded and followed by a row of percentage signs. On the experimental trials, three of the six arrays were words written in lower case. The other three arrays each consisted of rows of 3, 4 or 5 identical keyboards symbols. The position of the two critical words C1 and C2 was varied but C1 never appeared as the first item and the two critical words were always separated by a third word. On half the trials, only one word intervened between C1 and C2 (lag 1), and on the other half, a word plus a row of symbols intervened (lag 2) between the two critical words. The 20 fillers trials consisted of two words (sometimes repeated) and four arrays of symbols.

Twenty-four pairs of orthographically similar but phonologically dissimilar words were used; this set will be named the orthographic set. In each of the pairs, the two words differed only by one letter, but were phonologically very different (reach/react). Another twenty-four pairs of orthographically dissimilar pairs, but phonologically similar were used; this set will be named the phonological set. In each of the pairs, the two words differed by only one phoneme, but were orthographically dissimilar (great/freight). Finally, twenty-four words were selected within the same range of frequency as the previous 48 pairs. These words were used to control for identical repetition; this set will be named the identical set. The list of the 3 different sets used is given in Appendix D[2].

On half the trials, C1 and C2 were related, and on the other half they were non-related. The non-related version was created by replacing C1 by a member of one of the other experimental pairs for the orthographic and phonological condition. For the identical condition, 24 new words were selected to be used as non-related C1s.

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2 We wish to thank E. Dupoux for providing us with this material.

Hence, a given word appeared only once in each experimental list. Which of the words in the orthographic and phonological pairs appeared as C2 (order) was counterbalanced within items and subjects. There were two variables counterbalanced within items and subjects: relatedness and order. The two other variables were between items: type of relationships between C1 and C2 (identical versus orthographic versus phonological) and lag between C1 and C2 (lag 1 versus lag 2).

Procedure. Each trial began when the subject pressed the space bar on the computer keyboard. The row of asterisks present at the same location as the subsequent words disappeared and the items appeared one at a time in the same place (centered), for 100 ms per word.

Subjects were instructed to read the words and ignore the rows of symbols; after each trial they were asked to write down the words they saw, in the order in which they had seen them. They were told that there could be one, two or three words per trial.

Apparatus. The stimuli were presented on a CRT screen with a rapid fade phosphor, controlled by an IBM-XT. The experiment was carried out in normal room illumination.

Results

We used the same method of scoring as in Experiment 2.

Unlike the preceding experiments, the effect of lag seemed to interact with the main variable of interest: the size of RB for each of the different types of trials (identical versus orthographic versus phonological). Indeed, the main 3X2X2 analysis of variance with type of trials, repeatedness and lag as independent variables (carried out on the number of trials in which both C1 and C2 were recalled) showed a three-way interaction between type, repeatedness and lag, $F1(2, 34) = 6.9$, $p1 < .003$, by subjects, $F2(2, 66) = 5.8$, $p2 < .005$, by items, but no interaction between type and repeatedness ($ps > .19$). This pattern of results shows that the amount of RB for each type is not different when one averages across lags, but when one takes lags into consideration, a significantly different pattern of RB emerges between the three types. Hence, we report the results for lag 1 and lag 2 separately. The percentage of recall of both C1 and C2 as a function of the nature of their relatedness, and the lag is given in Table 4.

Analyses of variance were carried out on the number of trials in which both C1 and C2 were recalled. We were interested first in establishing RB for each of the three types, identical, orthographic and phonological; and second, in comparing the amount of RB between each of these types.

Table 4

Percentage of trials in which C1 and C2 were both recalled

	Orthographic (reach/react)		Phonological (great/freight)		Identical (doctor/doctor)	
	Lag1	Lag2	Lag1	Lag2	Lag1	Lag2
repeatedness						
NR	76	81	81	86	80	77
R	44	66	74	67	41	69
NR-R	32	15	7	19	39	8

First, we ran three 2X2 separate ANOVAS with repeatedness and lag as independent variables. These ANOVAS were carried out on the number of times C1 and C2 were recalled. For identical trials, a main effect of repeatedness was found, $F1(1, 17) = 26.5$, $p1 < .0001$, by subjects; $F2(1, 22) = 33.5$, $p2 < .0001$, by items, as well as an interaction between repeatedness and lag, $F1(1, 17) = 12.7$, $p1 < .002$, by subjects; $F2(1, 22) = 14$, $p2 < .001$, by items, indicating a larger RB effect at lag 1 than lag 2. A similar pattern of results was found for the orthographic trials. A main effect of repeatedness was found, $F1(1, 17) = 19.7$, $p1 < .0001$, by subjects; $F2(1, 22) = 27.2$, $p2 < .0001$, by items, as well as an interaction between repeatedness and lag by subjects ($F1(1, 17) = 6.9$, $p1 < .017$). This interaction was also marginally significant by items ($F2(1, 22) = 3.7$, $p2 = .065$). This pattern of results also shows that orthographic RB has a tendency to be larger at lag 1 than at lag 2. For the phonological trials, a main effect of repeatedness was found, $F1(1, 17) = 8.2$, $p1 < .011$, by subjects; $F2(1, 22) = 7.5$, $p2 < .012$, by items; but this effect did not interact with lag ($ps > 0.2$). In fact, unlike the identical or orthographic trials, the size of RB in phonological trials seemed to be bigger at lag 2 than lag 1 (20% versus 8%). This first set of analyses confirms the presence of RB between identical items, and extends the finding of RB to orthographically related, but phonologically different items (*reach*/*react*). Moreover, it also clearly establishes the presence of RB between phonologically related but orthographically dissimilar items (*great*/*freight*).

We were also interested in comparing the size of RB between each of the types of trials. The three contrasts of interest were identical vs orthographic, identical vs phonological and orthographic vs phonological. Hence, three 2X2X2 ANOVA with repeatedness, type of relatedness and lag as dependent variables were carried out on the number of times C1 and C2 were recalled.

For identical vs orthographic trials, main effects of repeatedness, $\underline{F1}(1, 17) = 30.3$, $\underline{p1} < .0001$, by subjects; $\underline{F2}(1,44) = 60$, $\underline{p2} < .0001$, by items, and lag, $\underline{F1}(1, 17) = 18$, $\underline{p1} < .001$, by subjects; $\underline{F2}(1,44) = 5.3$, $\underline{p2} < .025$, by items, were found. An interaction between repeatedness and lag, $\underline{F1}(1, 17) = 16.8$, $\underline{p1} < .001$, by subjects; $\underline{F2}(1,44) = 15.6$, $\underline{p2} < .0001$, by items, showed that the size of RB was larger at lag 1 than lag 2. None of the other effects reached significance ($\underline{ps} > .2$). Specifically, the repetition effect never interacted with the type of relatedness, ($\underline{ps} > .2$), showing that the size of RB is comparable between the identical (23%) and orthographic (23%) conditions. Hence, RB seems to be as strong between identical items as between items that are highly orthographically similar, but phonologically different.

For identical vs phonological trials, we found main effects of repeatedness, $\underline{F1}(1, 17) = 33.8$, $\underline{p1} < .0001$, by subjects; $\underline{F2}(1,44) = 33.7$, $\underline{p2} < .0001$, by items, and of type of relationship, $\underline{F1}(1, 17) = 14.6$, $\underline{p1} < .001$, by subjects; $\underline{F2}(1,44) = 4.5$, $\underline{p2} < .04$, by items. The only other significant effect was a three-way interaction between type, repeatedness and lag, $\underline{F1}(1, 17) = 10.38$, $\underline{p1} < .005$, by subjects; $\underline{F2}(1,44) = 11.1$, $\underline{p2} < .002$, by items, indicating that the amount of RB for identical and phonological trials varied differently with lag. Hence, we decided to analyze lag 1 and lag 2 trials separately. For lag 1 trials, we found an effect of repeatedness, $\underline{F1}(1, 17) = 30.6$, $\underline{p1} < .0001$, by subjects; F2(1, 22) = 39.7, p2 < .0001, by items, and of type (identical versus phonological) F1(1, 17) = 31, p1 < .000, by subjects; F2(1, 22) = 10.2, p2 < .004, by items. Moreover, these two factors interacted, F1(1, 17) = 9.4, p1 < .007, by subjects; F2(1, 22) = 18.3, p2 < .0001, by items, showing that, at lag 1, the amount of RB is significantly larger for identical trials than for phonological ones. For lag 2 trials, repeatedness was the only significant factor, F1(1, 17) = 8.6, p1 < .009, by subjects; F2(1, 22) = 7, p2 < .014, by items.

A similar pattern of results was found for orthographic vs phonological trials: larger RB between orthographically than between phonologically related items at lag 1, F1(1, 17) = 7.3, p1 < .015, by subjects; F2(1, 22) = 8.8, p2 < .007, by items, similar RB at lag 2 (ps >. 6).

Discussion

Experiment 4 confirms that RB occurs between identical items, and shows that RB between orthographically similar words is still present when the words are phonologically dissimilar. This experiment also establishes the presence of RB between phonologically similar words that have almost no orthographic overlap. Hence, phonological RB is not only found between homophones, but also between phonologically similar but not identical words. This experiment shows that sharing most of the letters, but almost no phonemes, or most of the phonemes, but almost no letters are each sufficient to produce RB. So, while morphological relationships failed to elicit RB, either orthographic or phonological similarity seem sufficient and necessary for RB.

The comparison of the amount of the RB effect for orthographic versus identical types showed an equivalent amount of RB between these two types of trials. This could suggest that high orthographic similarity, independently of phonological similarity, produces the same amount of RB as identity. However, more RB was found between identical words than between orthographic neighbors in Experiments 1 and 2. This shows that RB between orthographically similar words can be lower than RB between identical words. It seems that in general RB between orthographic neighbors is lesser or at most equal to RB between identical words. Whether the manipulation of phonological similarity given that the orthographic similarity, is kept constant can modify the amount of RB is left unclear. The comparison of phonological versus identical RB, in Experiment 4 shows that phonological RB is weaker or at best equal to identical RB. This is consistent with the finding of Bavelier and Potter (1992) who found that the amount of RB between differently-spelled homophones is less than the amount of RB between similarly-spelled homophones. The finding in the current experiment that phonological RB is stronger at lag 2 than identical or orthographic RB, could suggest that phonological RB takes a longer time to develop. However, this finding needs to be confirmed, as this pattern was found between items, and was not found for homophones (Bavelier & Potter, 1992). In so far as the constraints of written English allowed us to dissociate orthographic versus phonological similarity, the material used in Experiment 4 suggests that orthographic and phonological information play independent roles in RB.

In Experiment 5, we wished to explore more precisely the nature of the phonological representations that play a role in RB. While the phonological code responsible for RB is not the 'articulatory code' computed during phonological recoding in STM, but rather an earlier code arising during the early processing of words (Bavelier & Potter, 1992), the characteristics of this code are still not known. A classical distinction in the literature about phonological codes is the difference between phonological codes corresponding to the grapheme to phoneme correspondences of English ('assembled' phonology) versus the phonological codes corresponding to the 'lexical' pronunciation of the word ('lexical' phonology). Hence, for example, the phonological code of 'have' if computed from spelling to sound correspondence would be different from the 'lexical' pronunciation of the word. Although, at present, several conflicting accounts of this distinction can be found in the literature, words that differ on these two codes seem to be processed differently. For example, inconsistent words, or words that do not follow the grapheme to phoneme correspondences take longer to name (Coltheart, 1985); they have also been shown to influence the naming time of their consistent neighbors (Glushko, 1979). Priming studies have also shown that lexical decision latencies to a target word such as ROUGH were facilitated when preceded by the rhyme prime TOUGH but inhibited when preceded by the similarly-spelled nonrhyme COUGH (see also, Meyer et al., 1974, Hillinger, 1980). The following experiment was designed to test whether phonological RB is sensitive to 'assembled' versus 'lexical' phonology. We investigated that question by comparing RB between orthographic neighbors whose pronunciation is consistent or inconsistent with the English spelling to sound correspondences.

Experiment 5

In Experiment 5, we varied the phonological relationships between the targets, while keeping the orthographic relationships of the targets constant. For this purpose, we used orthographic neighbors that are either consistent or inconsistent with the spelling-sound correspondences of English (home/dome versus some/come). We compared the size of RB between two consistent (home/dome) or inconsistent (some/come) words and between a consistent and an inconsistent word (some/dome or home/come). If RB arises from a lexical phonological code, less RB should be found between a consistent and an inconsistent word (which sound less similar) than between two consistent or two inconsistent words.

Method

Subjects. Sixteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Material and design. Six practice trials were followed by 72 experimental and 20 filler trials. As in Experiment 1, each trial consisted of a sequence of six strings preceded and followed by a row of percentage signs. On the experimental trials, three of the six strings were words written in lower case. The other three strings each consisted of rows of 3, 4 or 5 identical keyboard symbols. The position of the two critical words C1 and C2 was varied but C1 never appeared as the first item and the two critical words were always separated by a third word (lag 1). On half the trials a row of symbols also intervened between the two critical words (lag 2). The 20 fillers trials consisted of two words (sometimes repeated) and four strings of symbols.

Nine quadruplets of two inconsistent words, that are orthographic neighbors of each others (e.g., four/pour) and two of their consistent neighbors (e.g., sour/hour) were selected. The list of the 9 quadruplets used is given in Appendix E.

There were two main variables counterbalanced within items and subjects: repeatedness, same or different pronunciation. The other two variables, whether C2 followed the pronunciation rule of English (consistent) or not (inconsistent) and whether the lag between C1 and C2 was 1 or 2, were counterbalanced within subjects but across items .

Procedure. Each trial began when the subject pressed the space bar on the computer keyboard. The row of asterisks present at the same location as the subsequent words disappeared and the items appeared one at a time in the same place (centered), for 100 ms per word.

Subjects were instructed to read the words and ignore the rows of symbols; after each trial they were asked to write down the words they saw, in the order in which they had seen them. They were told that there could be one, two or three words per trial.

Apparatus. The stimuli were presented on a CRT screen with a rapid fade phosphor, controlled by an IBM-XT. The experiment was carried out in normal room illumination.

Results

The percentage of recall of both C1 and C2 is given in Table 5. We used the same method of scoring as in Experiment 1. In the current experiment, RB was always of larger or equivalent size at lag 1 as at lag 2. Since lag did not interact with the size of the RB effect in the different conditions, results for lag 1 and lag 2 were collapsed in the following analyses.

Analyses of variance were carried out on the number of trials in which both C1 and C2 were recalled. A 2X2X2 ANOVA with repeatedness, identical/different pronunciation, and type of C2 (consistent vs inconsistent) as dependent variables was carried out on the number of times C1 and C2 were recalled. It revealed an overall repetition effect, $F1(1, 15) = 25.6$, $p1 < .0001$ by subjects, $F2(1, 34) = 39$, $p2 < .0001$ by items, but this effect did not interact with identical/different pronunciation ($ps > .13$) suggesting that the size of RB was comparable whether words were pronounced similarly or differently. The only other significant effect was an interaction between the type of C2 and identical/different pronunciation, $F1(1,15) = 7.8$, $p1 < .013$ by subjects, $F2(1, 34) = 8.7$, $p2 < .006$ by items. Although this effect seemed difficult to interpret, it suggested a different behavior for the different types of C2. Hence, we decided to confirm the RB results separately for consistent and inconsistent words.

Table 5

Percentage of trials in which C1 and C2 were both recalled

	Id. Pronunc.		Diff. Pronunc	
repeatedness	C2 cons. (home/dome)	C2 incons. (some/come)	C2 cons. (some-dome)	C2 incons. (home/come)
NR	60	60	61	69
R	47	45	33	52
NR-R	13	15	28	17

For C2 consistent words, we found a main effect of repetition, $F1(1, 15) = 36.7$, $p1 < .0001$ by subjects, $F2(1, 17) = 18.5$, $p2 < .0001$ by items, and a marginal effect of identical/different pronunciation ($ps < .09$). A marginal interaction between repeatedness and identical/different pronunciation, $F1(1, 15) = 3.9$, $p1 < .07$ by subjects, $F2(1, 17) = 5.2$, $p2 < .035$ by items, indicates a tendency for a smaller amount of RB when a consistent word is preceded by an orthographic neighbor of identical (13%) pronunciation than of different pronunciation (28%). Although this interaction seems difficult to interpret, it certainly confirms that the size of RB is not increased by the similarity in pronunciation of the items used. For C2 inconsistent words, we found a main effect of repetition, $F1(1, 15) = 26.9$, $p < .0001$ by subjects, $F2(1, 17) = 22.6$, $p2 < .0001$ by items, and an identical/different pronunciation effect, $F1(1, 15) = 6.5$, $p1 < .021$ by subjects, $F2(1, 17) = 6.4$, $p2 < .025$ by items, due to a better recall in the different condition than in the identical condition. However, these two factors did not interact (ps >.8) indicating that the size of RB is equivalent whether an inconsistent word is preceded by an orthographic neighbor of identical (15%) or different pronunciation (17%).

Discussion

The results of Experiment 5 show that RB between two consistent or two inconsistent words was not greater than RB between a mixture of consistent and inconsistent words. These data could be accounted for by proposing that phonological RB occurs at the level of 'assembled' phonology. Indeed, this could explain RB between consistent words, as well as RB involving inconsistent words, given that all the inconsistent words we used would lead to the same pronunciation as the consistent ones if their phonology was just computed by grapheme to phoneme correspondences. Although the 'assembled' phonology account is consistent with the results of Experiment 5, phonological RB cannot only be explained at the level of assembled phonology. Indeed, the finding of RB between pairs of words such as ate/eight or journal/colonel, for which spelling to sound correspondences would lead to two different pronunciations of the words, suggests that lexical phonology too can induce RB. It seems that RB will occur when either assembled phonology or lexical phonology of the items used are similar with no further increase in RB when both are similar (inconsistently-spelled pairs). An alternative explanation for this result would be that if two words share a high orthographic similarity, whether their phonological codes are similar or different cannot affect the amount of RB. One hypothesis is that, if C1 and C2 are highly orthographically similar, C2 may only be able to overcome RB at the orthographic level when its orthographic representation is established in a stable token; hence, making it invulnerable to subsequent phonological RB. This hypothesis predicts that when the items are very similar orthographically, phonological similarity cannot affect RB; but that as the words used are less and less orthographically similar, phonological similarity is going to come into play. It could account for results of Experiment 5, as well as the finding in Experiment 4 that RB between orthographic neighbors does not seem to be diminished if the words are phonologically dissimilar.

IV. GENERAL DISCUSSION

The experiments reported here support the view that RB is happening at a perceptual level of encoding, as well as confirm and extend the finding that RB is chiefly determined by orthographic and phonological similarities between words. Experiments 1, 2 and 3 showed that RB is not sensitive to well established lexical factors, such as morphology, absolute frequency or relative frequency. The results of Experiments 1-3 also enabled us to confirm RB between orthographic neighbors, and more importantly to show that orthographic/phonological similarity is sufficient and necessary for RB. The relative role of orthographic and phonological similarity in RB was then explored in Experiments 4 and 5. The results of Experiment 4 suggests that either orthographic similarity or phonological similarity is sufficient for RB. Although the results of Experiment 5 could be explained by assembled phonology, an alternative explanation is that phonological RB can come into play only when the orthographic processing of the words is not shallow.

In the following discussion, we will consider separately orthographic RB and phonological RB. We will first review the characteristics of orthographic RB, and see what mechanisms can best account for this phenomenon. Then, we will explore how the properties of phonological RB can be accounted for, and try to uncover the relationships between orthographic and phonological RB.

1- Orthographic RB

We defined orthographic RB as the RB due to orthographic similarity, independently of phonological similarity. We think orthographic RB is best understood as a perceptual phenomenon, happening at the level of pre-lexical letter-cluster representations. Following Kanwisher's initial hypothesis (1986, 1987), orthographic RB would be due to a refractory period of the process responsible for the consolidation of a stable type-token link. Moreover, we propose that the consolidation of this type-token link is initially controlled by the activation level of pre-lexical letter-clusters representations. Once a token is created, the activated types (orthographic, phonological, syntactic, semantic) have to be integrated in the token in order to stabilize it in short term memory (STM). In this view, orthographic RB arises because the pre-lexical activation due to C2 is interpreted as residual activation from C1: if the activation due to C2 arrives when there is still spurious activation due to the presentation of a similar C1 at the pre-lexical orthographic level, the activation due to C2 will be interpreted by the system as residual information from C1, and so fail to consolidate the new type-token link. Only after the pre-lexical level has resettled to rest values, can a second orthographically similar item lead to the establishment of a new stable token.

The hypothesis that orthographic RB is occurring at the level of letter clusters representations, rather than lexical orthographic representations, is supported by the findings that lexical factors such as morphology and frequency do not affect RB (Experiments 1, 2 and 3). It is also supported by the findings of orthographic RB between orthographic neighbors that differ not only by one and only one letter (e.g., such as like/lice in Experiments 2 and 3), but also by several letters (such as mark/market in Experiment 1). Moreover, as we reviewed before, RB fails to occur when only 1 or 2 letters were shared at the same position by C1 and C2, but did occur when C1 and C2 shared around 3 to 4 letters at the same location. We think that this set of data cannot easily be accounted for in terms of C2 being misread at the lexical level as C1 (Kanwisher & Potter, 1989). Rather Experiments 1, 2 and 3 suggest that orthographic RB seems best explained as happening at a pre- or sub-lexical level, before lexical factors come into play. This pre-lexical level seems best understood as being organized around clusters of 3 to 4 letters.

This hypothesis also seems consistent with previous RB data between words. It is compatible with the finding that RB between words happens between different case words, by supposing that the representations at the pre-lexical orthographic level are constituted by orthographic representations abstracted from case. This assumption is supported by other sources of evidence showing that letter or word identification happens at an abstract level dissociated from case (Friedman, 1980; Rayner, McConkie, & Zola, 1980; Evett and Humphreys, 1981). It is also compatible with the observation that RB is dependent on the number of letters shared at the same relative position. It can also account for why no letter RB is observed between two different words (e.g., fault/heart) (Kanwisher & Potter, 1990). Moreover, the fact that the prior presentation of a non word can produce RB for an orthographically similar word (Kanwisher, personal communication; Potter, personal communication) points to the pre-lexical orthographic level as the locus of orthographic RB. Hence, a large body of RB data seems to be consistent with the view that orthographic RB is happening at the level of pre-lexical orthographic representations organized around letter clusters.

The assumption that a pre-lexical orthographic level organized around letter clusters is important during the processing of visually presented words is not specific to the RB phenomenon. This level of representation has been fruitfully incorporated into some word recognition models such as BLIRNET (Mozer, 1987), and it is also directly supported by experimental results (Humphreys, Evett & Quinlan, 1990). Humphreys et al. used a technique of 'double mask priming' which is very similar to the RSVP paradigm used in the RB experiments. In the double mask experiments, subjects viewed four fields successively. The first and last fields were always masks, the second field was a lower case word and the third field was an upper case word. Each of these fields was displayed for a constant, brief time. The subjects' task was to recall all the words they saw (as in a RB experiment). Under such conditions of presentation, subjects were rarely aware of seeing the first word, in lower case (C1). When C1 and C2 were orthographically related, the recall of C2 was facilitated. Orthographic RB seems to have very similar characteristics to the orthographic priming observed with this double mask priming technique. Like double mask priming, RB seems to be sensitive to the numbers of letters shared by prime and targets and to the relative position occupied by the letters in prime and target. RB, like double mask priming, is still found when the specific positions of words in the visual field are changed (Kanwisher & Potter, 1989), when case between the two critical items is different (Kanwisher, 1987; Bavelier & Potter, 1992; Marohn et al., 1988), or when the relative length of the strings is varied (RB is found between sirloin/sir as between sin/sir (Kanwisher, 1991; Bavelier, 1988)). RB is additive with the effects of target word frequency (Experiment 2) which is one of the characteristics of double mask priming. RB, like double mask priming, is observed when C1 is a non word. Given that double mask priming is not sensitive to the lexical status of the items used, one would predict that it should be unaffected by morphological relationships, like RB. Further research is also needed to test whether like double mask priming, RB is more sensitive to end-letters than middle clusters, and wether numbers and position of the common letters between C1 and C2 affect RB in a non linear manner. However, we think that the commonalties between these two phenomena are already strong enough to support the hypothesis that these two phenomena arise from a common level of representation: pre-lexical letter-clusters representations.

The level of pre-lexical letter-clusters representations seems at present the best hypothesis to account for RB and double mask priming. While orthographic RB would be due to the fact that the activation following the presentation of C2 is interpreted as residual activation from C1, and so fails to consolidate a new type-token link, double mask priming would be due to the fact that the activation following the presentation of C1 fails to establish a stable type-token link, but facilitates the consolidation of the type-token link when a similar C2 is presented. This view is supported by the findings that RB reverts to priming when C1 is not consciously identified (Kanwisher, 1987; Potter, personal communication). Although a direct comparison of orthographic RB and double mask priming will have to be pursued, these two phenomena seem best explained as type-token phenomena at the level of pre-lexical letter cluster representations.

In the next section, we will examine, with respect to the type-token framework, the status of phonological RB.

2- Phonological RB

We define phonological RB as the RB due to phonological similarity, independently of orthographic/visual similarity. We think that phonological RB is best understood as a problem during the initial registration of phonological representations in STM . However, this initial registration stage is supposed to be separate and prior to the process of rehearsal, responsible for maintaining information in STM (Bavelier & Potter, 1992).

The assumption of two separate phonological codes driven by print is not a new one and is supported by several pieces of evidence (Besner & Davelaar, 1982). It was shown that the information stored in STM is maintained in STM through the use of an articulatory loop for the rehearsal of items, after they have been phonologically recoded (Baddeley, 1966, 1986). The use of the articulatory loop has been shown to be responsible for several classical STM effects, such as the word length effect (Baddeley, Thomson & Buchanan, 1975) and the phonological similarity effect (Conrad, 1964). Both these effects disappear under articulatory suppression, which is known to prevent the functioning of the articulatory loop (Baddeley, 1986). On the other hand, judgments of homophony were found not to be disrupted by articulatory suppression; similarly, pseudo-homophones were found to be easier to recall than non-homophones even under articulatory suppression. This set of findings led Besner and Davelaar (1982) to propose: "There are at least two different phonological codes driven by print and they subserve different functions in the reading process. The first code can be used for lexical access, and is not prevented from operating by suppression. The second phonological code is prevented from operating by suppression, and functions as a durable storage medium for retaining serial order information; this aids verbatim recall and comprehension. " (Besner & Davelaar, 1982, p. 708).

We would like to propose that the phonological codes accessed during word recognition (whether they are pre-lexical or lexical) are responsible for leaving an initial phonological trace in STM, sufficiently durable to support short serial recall and to allow for judgments of homophony, and not prevented from operating by suppression. If there is enough time, this initial weak trace could then be recoded through subvocal articulation, in order to enter the articulatory loop, and give rise to a stronger trace. The assumption of an initial weak phonological trace loaded in STM has already been entertained by Baddeley (1986): "As a result of learning to read and to name objects, a route is built up whereby the phonological representation of a name or a word can be accessed from LTM, leaving a comparatively weak trace within the phonological store." (p.86). It is supported by the finding that pseudo-homophones are better recalled than non-homophones even under articulatory suppression. It would also account for the finding that articulating does not interfere with the recall of RSVP sentences or lists when presented at high rate of presentation (100 ms/items), but that when the rate of presentation is slower (333 ms/items), recall of lists, and to a lesser extent recall of sentences, is disrupted by articulatory suppression (Potter, 1984). This suggest that under time constraints only the initial code is used, but when more processing time is allowed, the articulatory loop can come into play. Recently, a similar assumption has also been proposed by Pollatsek, Lesch, Morris and Rayner (1992). These authors showed that phonological coding plays at least some role during the integration of information across saccades, when using a naming task. They proposed that "phonological coding is used to preserve the 'memory' of a word from one fixation to aid in its identification on the next fixation". (pp. 159)

We propose that phonological RB is due to a failure to establish a second trace in STM from a phonological type that has just been involved in the registration of a previous item in STM. Hence, the same mechanism would be responsible for phonological RB and orthographic RB, but at two very different levels of representation. In phonological RB, the activation at the phonological level due to the presentation of C2 would be interpreted by the system as residual activation from C1, and would fail to be loaded in STM. We would like to propose that this initial code which is loaded in STM is the code that is usually used to stabilize an opened token in STM. Hence, while orthographic RB would be mainly due to the failure to initially consolidate a new type-token link, phonological RB would be due to the failure to stabilize an opened token in STM.

In this view, phonological RB should be affected by the nature of the representations used for stabilization of the information in STM. This claim is supported by the finding that phonological RB seems to be always smaller when the task allows for visual information to play a role in stabilization of the item in STM, than when the task biases the subjects toward phonological encoding (Bavelier, in preparation). For example, phonological RB was found to be less marked for short lists than when recalling sentences. It could be that with lists, the memory load is light enough so as to allow for stabilization of visual features in STM, while with sentences, phonological encoding, which is known to be the more efficient and reliable than visual encoding, dominates. This could also explain why when words are highly similar orthographically, phonological similarity does not seem able to affect the amount of RB.

In summary, we propose that orthographic RB and phonological RB are arising from similar mechanisms, but at two different stages in word processing. Orthographic RB seems best understood as a failure to consolidate a new type-token link, due to a confusion of the activation of C1 and C2 at a pre-lexical letter-cluster level of representation. This led us to propose a parallel between orthographic RB and masked priming. Although a proper comparison of the characteristics of masked priming and orthographic RB will have to be pursued, we feel that their commonalties are already suggestive. Phonological RB seems best accounted for in terms of a failure to initially load the phonological code usually used to stabilize the opened token in STM; such a failure was taken to be due to a confusion of the activation from C1 and C2 at a phonological level of representation. Whether this phonological level of representation is organized along phonemes, cluster of phonemes, syllables or entire words is still unknown. It is clear that the further understanding of phonological RB will require working out the characteristics of phonological RB itself as well as refining the structure and roles of the phonological level of representations during word recognition, and STM storage.

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VI. APPENDICES

Appendix A
Material used in Experiment 1

Regular verbs and their controls

toll	tolled	bush	bushel	curl	curled	sect	sector
hush	hushed	limb	limber	peer	peered	chap	chapel
alter	altered	tract	tractor	rush	rushed	bull	bullet
knock	knocked	blank	blanket	toss	tossed	stud	studio
creak	creaked	digit	digital	erupt	erupted	trump	trumpet
deem	deemed	pare	parent	burn	burned	tale	talent
pose	posed	boot	booth	tempt	tempted	liter	literal
tilt	tilted	dent	dental	enact	enacted	surge	surgeon
boil	boiled	monk	monkey	melt	melted	wick	wicked
dump	dumped	tang	tangle	pound	pounded	plate	plateau
limp	limped	pill	pillar	moan	moaned	soot	soothe
heed	heeded	cave	caveat	fix	fixed	eve	event
crack	cracked	habit	habitat	amend	amended	miner	mineral
edit	edited	wand	wander	mold	molded	cast	castle

Irregular verbs and their controls

sleep	slept	steep	steps	wear	wore	gear	gore
shake	shook	brake	brook	take	took	bake	book
swim	swam	slim	slam	spin	pun	shin	shun
break	broke	bleak	bloke	ride	rode	ripe	rope
feed	fed	reed	red	sing	sang	line	lane
grow	grew	stow	stew	fly	flew	cry	crew
ring	rang	pint	pant	stink	stank	stiff	staff
stride	strode	strike	stroke	meet	met	beet	bet

Appendix B
Material used in Experiment 2

Pairs of neighbors with their corresponding control words.

down (same)	gown (taxi)	good (make)	hood (envy)
know (year)	knob (watt)	never (those)	newer (valid)
more (than)	mole (vest)	since (every)	mince (adorn)
few (ago)	dew (pup)	only (used)	oily (fake)
are (you)	axe (thy)	here (some)	hare (cosy)
were (this)	ware (gist)	can (she)	fan (lid)
two (men)	tao (bug)	far (man)	fir (bye)
with (many)	wits (hazy)	place (think)	plate (stiff)
over (much)	oven (bulb)	other (could)	otter (fairy)
any (now)	ant (hog)	away (four)	sway (limb)
water (going)	cater (ethic)	work (face)	worm (beep)
went (look)	wept (cork)	fact (give)	tact (bury)
home (find)	hose (yell)	most (even)	moss (duck)
until (while)	untie (droop)	has (yet)	ham (pen)
well (side)	weld (hike)	back (city)	rack (trio)
found (night)	hound (lease)	see (got)	bee (nod)
long (next)	lone (gait)	three (world)	threw (admit)
not (had)	net (fly)	for (and)	fox (map)
that (been)	chat (skip)	have (took)	has (lump)
high (come)	sigh (pump)	head (told)	heap (ruin)
set (old)	sew (hid)	less (once)	lets (wrap)
may (her)	mat (rub)	said (eyes)	slid (jump)
hand (form)	hang (fist)	after (these)	alter (prone)
like (case)	lice (mend)	must (each)	mist (bull)
both (take)	moth (clap)	own (use)	owl (fad)
where (under)	whore (unify)	put (war)	pet (inn)
still (might)	spill (boxer)	just (came)	oust (mall)
did (was)	dig (icy)	left (time)	lent (nail)
such (does)	suck (stew)	also (what)	alto (dump)
get (way)	gut (soy)	small (right)	stall (wiped)
say (end)	shy (fur)	part (need)	cart (menu)
him (out)	aim (bus)	but (his)	bun (ale)
your (them)	sour (tick)	our (the)	cur (ewe)
how (off)	bow (nut)	great (asked)	treat (widow)
very (upon)	verb (dove)	last (knew)	lash (comb)
life (room)	lift (bowl)	will (they)	gill (edit)
house (again)	mouse (lilly)	from (when)	frog (dunk)
then (made)	teen (ramp)	years (first)	yearn (bicep)
day (new)	fay (lob)	too (why)	boo (ebb)
one (all)	owe (rag)	state (being)	stare (width)

Appendix C
Material used in Experiment 3

Triplets with low frequency C2 and their corresponding controls:

C1 HF	C2s LF		C1 Ctle	C2s Ctle	
fact	pact	tact	once	suck	thaw
war	wax	wan	yes	hut	fry
did	dip	dig	end	sly	cab
for	fir	fur	its	vow	map
new	sew	dew	put	rim	pod
get	gel	gem	off	ewe	bug
had	fad	lad	own	tow	jam
her	hex	hey	use	toy	nut
how	hog	hop	act	lag	fin
men	den	yen	law	owl	sow
one	ore	owe	day	mop	hip
back	hack	tack	your	sown	hike
case	cage	cave	ever	moss	yell
come	cole	cove	last	moth	bait
have	eave	pave	were	jest	deft
high	nigh	sigh	left	dune	keen
less	lens	lets	fact	dies	wits
made	jade	fade	also	lily	hive
more	mode	mole	been	slid	user
time	dime	lime	some	melt	curb
part	cart	mart	once	chat	wily
cent	dent	lent	wall	bind	wilt
will	gill	sill	when	mead	hike
work	cork	pork	here	hint	vent
year	pear	tear	much	wolf	pump
know	knob	knot	each	hoof	obey
found	hound	mound	think	greet	waist
house	louse	mouse	again	sever	slate
never	lever	fever	under	stare	alter
stage	stale	stake	bring	cater	newer
still	skill	spill	world	bound	mould
water	wager	waver	until	rouse	untie

Triplets with high frequency C2 and their correponding controls:

C1 LF	C2s HF		C1 Ctle	C2s Ctle	
gust	just	must	slap	down	even
ant	any	and	tee	our	was
ape	age	are	bye	nor	two

gut	but	out
tan	can	man
hid	him	his
fay	may	way
nob	not	now
sap	say	saw
sew	see	set
gog	got	god
lame	came	same
heed	head	held
heal	hear	heat
hose	home	hope
lice	like	life
jake	make	take
mast	past	last
hood	good	food
dame	name	game
thee	they	them
fold	hold	told
hook	took	look
dell	fell	hell
sour	four	hour
wand	land	hand
sight	might	right
tight	night	light
stall	small	shall
theme	these	there
chose	those	whose
whine	white	while

soy	has	few
pet	why	yet
wry	who	all
cud	old	air
ale	you	too
doe	let	big
mat	far	car
rib	ago	boy
edit	used	upon
gait	find	sure
loft	talk	film
gene	away	else
yawn	such	long
slot	very	over
sofa	five	both
mint	went	meet
prey	line	wide
kiss	from	into
tart	rest	knew
limb	city	next
wrap	thin	park
flaw	room	blue
clap	girl	give
round	being	great
pound	going	thing
drift	every	field
guess	first	would
smell	state	major
tribe	among	since

Appendix D
Material used in Experiment 4

Orthographic type

safe-cafe	recent-resent	certain-pertain	storm-story
mayor-manor	reach-react	bullet-ballet	tease-tense
defect-defeat	canoe-canon	precise-premise	poet-port
noon-neon	proper-propel	chair-choir	vague-value
bride-bridge	message-massage	motel-model	apple-apply
senior-sensor	relax-relay	saloon-salmon	olive-alive

Phonologic type

towel-foul	crude-brood	nervous-service	great-freight
eagle-evil	boss-sauce	phone-foam	missile-muscle
bite-night	bomb-palm	chair-hare	simple-symbol
lawyer-liar	valid-ballad	curtain-cotton	mobile-noble
cousin-dozen	journal-colonel	locker-liquor	juice-loose
dean-scene	laugh-calf	cellar-sailor	bacon-shaken

Identical type

abandon-abandon	advice-advice	baby-baby	citizen-citizen
doctor-doctor	fantasy-fantasy	gait-gait	guilt-guilt
heavy-heavy	hill-hill	jacket-jacket	gist-gist
league-league	member-member	mildew-mildew	myth-myth
nectar-nectar	noise-noise	nutmeg-nutmeg	odyssey-odyssey
pair-pair	rascal-rascal	shell-shell	thought-thought

Appendix E
Material used in Experiment 5

Exception pairs	Regular pairs
some-come	home-dome
pull-full	dull-hull
wear-tear	fear-dear
toll-roll	doll-moll
four-pour	sour-hour
most-host	lost-cost
bush-push	hush-rush
brwo-prow	crow-grow
hood-wood	food-mood

CHAPTER III

PHONOLOGICAL RB

I. INTRODUCTION

The dichotomy between pre-existing representations (or types), used for the recognition of the components of a visual scene, and episodic[1] representations (or tokens), constructed during recognition to insure the integrity of objects as they move or change has been supported by much evidence in the object recognition literature (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992; Kanwisher, 1987, 1991a; Kanwisher & Driver, 1992; Mozer, 1989; Ullman, 1984). In this view, the perceptual identity of an object is insured by its token, while its categorical identity is retrieved through its corresponding type. For example, if two identical objects are presented at the same time, the type representations associated with each occurrence will be identical; only the token associated with each occurrence will allow for the representations of each occurrence to be distinct. In contrast, two visual events may have a different labelled identity, but the same perceptual identity. A telling example was given

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[1]The use of the term "episodic" may or may not correspond to Tulving's one (1972). As in Tulving's definition, episodic memory is believed here to be concerned with temporally dated episodes or events, and their temporal-spatial relations. However, the present use does not imply that explicit spatial or temporal information can always be retrieved from these episodic representations.

by Kahneman et al. (1992): imagine you are watching a strange man approaching down the street; as the man gets closer to you, you will first detect a human shape, but finally recognize one of your friend. Throughout this episode, the individual preserved its perceptual identity, although its categorical identity or type was varied. Although this type/token distinction is incorporated in several theories of object recognition, the mechanisms responsible for the construction of tokens have still to be defined. A recent perceptual phenomenon, repetition blindness (RB; cf. Kanwisher, 1986, 1987), enables us to investigate the nature of these mechanisms.

RB is the inability of subjects to detect the second occurrence of a repeated item in rapid serial visual presentation (RSVP) of a list of items. In such conditions, the prior presentation of an item (C1) hinders the identification of its second occurrence (C2). Kanwisher (1987) proposed an explanation of RB in terms of a type/token distinction. In this framework, for an object to be consciously identified, its activated type had to be linked with a token in episodic memory. Kanwisher proposed that RB arises because once a type-token link has been established, a new link to a second token from the same type cannot be created for a given period of time.

Kanwisher's initial model proposed that RB is restricted to visual types. This claim has been recently challenged by the discovery of phonological RB (Bavelier & Potter, 1992; ; Bavelier, Prasada & Segui, 1992; Kanwisher, 1991b). RB has been obtained between homophones (ate/eight) or between phonologically similar items (certify/sir, freight/great), that is greater than that found for orthographically but not phonologically matched control pairs. This phonological RB effect suggests that, for words, the establishment of a type-token link may rely on either an orthographic or a phonological type. The early involvement of phonology when using words seems consistent with recent evidence in the literature that phonological information about a written word becomes available almost immediately (Lukatela & Turvey, 1991; Perfetti & Bell, 1991; Van Orden, 1987, 1990). The finding of RB between phonologically related but visually different words, or readily verbalized stimuli (letters, digits), led Bavelier et al. (1992a) to propose that "RB is not invariably dependent on common visual properties of the two targets, but on common attributes of the type that are used for initial registration of the events in STM. RB will arise whenever the codes used in initial registration of C1 and C2 in STM are too similar, regardless of the actual stimuli the subject saw" (pp. 144). In this view, when the attributes of the C2 type used to establish its token in STM are similar to that used to establish the C1 token, a C2 token will often fail to be established in STM. This will occur independently of whether the presentation of C1 and C2 initially activate similar or different types. Hence, phonological RB should not be restricted to stimuli, such as words, for which a phonological representation is readily retrieved during perception, but should be observed between any visual stimuli if their phonological code has to be entered in their token.

This proposal encompasses two main claims. First, when a task that relies on phonological encoding is used, phonological RB should not only be found between readily nameable stimuli, such as words, letters, or single digits (Bavelier & Potter, 1992), but also between stimuli for which a phonological code is not as readily retrieved during perception, such as pictures or line drawings of objects. Second, if RB is indeed sensitive to the similarity of the codes used for registration in STM, the amount of RB should vary as the task requirements bias the initial codes used for registration of C1 and C2 to be similar or dissimilar.

The goal of the present paper is to examine these two claims. In order to establish phonological RB between stimuli for which a phonological code is not readily retrieved, RB when using line drawings of objects was studied. First, it was necessary to confirm that complex visual stimuli, such as line drawings, behave like words with respect to standard RB (i.e., RB between identical items). Experiments 1 and 2 were designed to evaluate RB between identical line drawings in lists and in sentences, and to compare it to RB between identical words. In the next two experiments, mixtures of pictures and words were used to evaluate the claim that phonological RB can be found, even when C1 and C2 are not both readily nameable items. Experiment 3 looked at RB between a line drawing of an object and its corresponding word (e.g., the line drawing of a cat and the word 'cat'). Experiment 4 tested RB between a line drawing of an object and a word phonologically identical, but semantically different, to the corresponding noun of that object (e.g., the line drawing of a sun and the word 'son'). Finally, the last two experiments (Experiments 5 and 6) were designed to test whether the amount of RB is dependent on whether the task requires similar or different codes to be registered in the tokens of C1 and C2.

By comparing pictorial and verbal stimuli, these experiments are also relevant to theories about the time course of conceptual and name retrieval in the processing of pictures and words. It has been proposed that for written words, phonological information is retrieved quite early, and may even constrain semantic access (Van Orden et al., 1990); on the other hand, pictures are believed to access their conceptual/semantic representation first, before a phonological/lexical code is retrieved (Potter, 1979; Potter & Faulconer, 1975; Snodgrass, 1980, 1984; Theios & Amrhein, 1989). This view is supported by the asymmetry between pictures and words in naming and classification tasks. While pictures take longer to name than words (Cattell, 1886; Fraisse, 1960; Paivio, 1971, 1978; Potter & Faulconer, 1975), they are usually categorized equally fast (if anything, picture are faster) (Potter, 1979; Potter & Faulconer, 1975; Snodgrass, 1980, 1984), suggesting that conceptual information is more efficiently retrieved during picture processing and phonological information during word processing. Throughout this paper, the fact that pictures and words are processed differently is going to be exploited to study RB; a discussion of the possible implications of the finding of RB between pictures and words for the further understanding of the processing of pictures and words will be postponed to the general discussion.

II. RB BETWEEN IDENTICAL PICTURES

RB was initially understood as a visual phenomenon arising during the construction of the tokens corresponding to the objects present in our visual scene. However, most RB experiments have used overlearned verbal or readily verbalized stimuli such as words, letters or digits (Bavelier & Potter, 1992; Bavelier, Prasada & Segui, 1992; Kanwisher, 1991b). The recent establishment of RB with single visual features, such as patches of color (Kanwisher, 1991a), shows that RB generalizes to low level visual stimuli. If this account of RB is correct, RB should also be observed when using complex visual patterns. The first two experiments were designed to evaluate RB between complex visual stimuli such as line drawings of objects in short lists (Experiment 1) or sentences (Experiment 2). These experiments allowed me to test whether line drawings behave as expected with respect to RB, which was important given that line drawings were subsequently used to further assess the properties of RB between visually different items.

Experiment 1

In Experiment 1, RB between identical pictures of objects was evaluated. To assess the effect of explicit incentive to name the items, RB for pictures was compared when all-picture trials were blocked and when they were intermixed randomly with all-word trials.

Incentive to name should be lower in the former case. The later case allowed for a direct comparison of RB between words and pictures.

Method

Subjects. Sixteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Materials and design. Two sets of eight pictures were selected (see Appendix A). With each of these sets, an experimental version was constructed. Each of version consisted of twelve practice trials followed by 64 experimental and 20 filler trials. Each trial consisted of a sequence of six arrays preceded and followed by a mask field. On the experimental trials, three of the six arrays were a picture. The other three arrays each consisted of a mask field. Ten different mask fields were constructed by using geometrical shapes and random lines; the purpose of these masks was to look clearly different from a picture of an object, while still efficiently masking the pictures of objects. Two examples of masks are given in Figure 1 (since words were used in the other block of the experiment, a row of symbols was added in each of these masks at the location that words appeared on the screen so as to ensure that words would also be properly masked). The serial position of the two critical items C1 and C2 was varied, but C1 never appeared first, and the two critical items were always separated by the third intervening picture (lag 1). On half the trials a mask field also intervened between the two critical items (lag 2). The 20 filler trials consisted of two pictures (sometimes repeated) and four mask fields.

The identity of the items in each trial was assigned by using random permutations of the 8 pictures.

For each of the experimental trials a repeated version was created by changing the identity of C1 to match C2. In a given version of the experiment, half the experimental trials were repeated, half unrepeated. In order to construct the versions containing a mixture of all-picture and all-word trials, pictures were replaced by words on a random half of repeated trials and a random half of nonrepeated trials. Format (word vs picture) and repeatedness (repeated vs non repeated) was then counterbalanced within items. Hence for each set of picturable nouns there were two all-picture trials versions and four mixed trials versions.

Every subject viewed two versions (two blocks) such that the set of picturable nouns used in each was different. The order of the blocks was counterbalanced between subjects except that the first block always contained all-picture trials and the second block always contained a mixture of all-picture and all-word trials. The all-picture block was presented first to avoid biasing the subject toward a naming strategy for pictures. Repeatedness and format was counterbalanced over subjects and items. A final between-items variable was the lag between C1 and C2: on half the trials in each of the main conditions one item intervened, and on the other half an item plus a mask field intervened.

Procedure. Subjects were first presented with a page showing the eight pictures to be used in that block, and their corresponding names. They were instructed that during the experiment they were to view the items carefully and ignore the mask fields; they were asked to write down after each trial the identity of the items they saw (the word they saw or the name corresponding to the picture they saw), in the order in which they had seen them. They were explicitly told that if they saw a repeated item they should report the item twice. They were also told that there could be one, two, or three items per trial.

Each trial began when the subject pressed the space bar on the computer keyboard. The row of asterisks present at the same location as the subsequent items immediately disappeared and the items appeared one at a time in the same place, for 83 ms per item.

Apparatus. The stimuli were presented on a Macplus screen, using the maclab software (Costin, 1987). Words were printed in the helvetica format, size 24; pictures came from the Snodgrass & Vanderwart (1980) material. The experiment was carried out in normal room illumination.

Results

The number of recalls of C1 and C2 was scored in each condition. The percentage of trials in which both[2] C1 and C2 were recalled, for each of the categories, is shown in Table 1. Analyses of variance by subjects and by items were carried out, with repeatedness, lag, and format as variables.

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2 Since, when using this short list technique, there may be some uncertainty as to whether C1 was missing or had changed serial position, the recall of C1 and C2 is a clearer indicator of the RB effect than a separate analysis of C2 reports.

Table 1

Experiment1: Percentage of trials in which C1 and C2 were both recalled

	pictures only		pictures and words			
	pp		pp		ww	
Repeatedness	Lag1	Lag2	Lag1	Lag2	Lag1	Lag2
Non Repeated	55	70	70	70	60	74
Repeated	23	56	15	59	30	57
Non Rep. - Rep.	32	14	55	11	30	17

For the picture-only condition there was an overall repetition effect, $F1(1,15) = 58$, $p1<.0001$, by subjects and $F2(1,15) = 47.4$, $p2<.0001$, by items, as well as a main lag effect, $F1(1,15) = 57.5$, $p1<.0001$, by subjects and $F2(1,15) = 19.7$, $p2<.0001$, by items. Repeatedness and lag interacted, $F1(1,15) = 7.3$, $p1<.016$, by subjects and $F2(1,15) = 4.7$, $p2<.046$, by items, indicating a larger RB at lag 1 than lag 2. Separate analyses of lag 1 and lag 2 confirmed the presence of RB at both lags ($F1(1,15) = 75$, $p1<.0001$, by subjects and $F2(1,15) = 40$, $p2<.0001$, by items, for lag 1; $F1(1,15) = 8.4$, $p1<.011$, by subjects and $F2(1,15) = 7.5$, $p2<.015$, by items, for lag2).

For the picture and word condition (always the second block of trials), there was an overall repetition effect, $F1(1,15) = 50$, $p1<.0001$, by subjects and $F2(1,15) = 90$, $p2<.0001$, by items, as well as a main lag effect, $F1(1,15) = 112$, $p1<.0001$, by subjects and $F2(1,15) = 22$, $p2<.0001$, by items; there was no format effect ($ps > .45$), and no interaction between format and repeatedness ($ps > .67$) indicating that the size of RB between pictures is equivalent to the one between words. Repeatedness and lag interacted, $F1(1,15) = 24.5$, $p1<.0001$, by subjects and $F2(1,15) = 14$, $p2<.002$, by items, indicating a larger RB at lag 1 than at lag 2. None of the other effects were significant, except the three-way interaction between repeatedness, lag and format that was significant by subjects, $F1(1,15) = 14$, $p1<.002$, but not by items, $F1(1,15) = 2.8$, $p1>.11$. Although this result seems difficult to interpret, it may reflect a tendency for a larger RB at lag 1 than lag 2, for pictures than for words. Separate analyses of lag 1 and lag 2 were run. At lag 1, a main effect of repeatedness was found, $F1(1,15) = 154$, $p1<.0001$, by subjects and $F2(1,15) = 115.5$, $p2<.0001$, by items; no effect of format was present ($ps > .65$) , but the interaction between format and repeatedness, $F1(1,15) = 10$, $p1<.007$, by subjects and $F2(1,15) = 18.5$, $p2<.001$, by items, indicated that RB for pictures is larger than RB for words. At lag 2, a main effect of repeatedness was found, $F1(1,15) = 5.4$, $p1<.035$, by subjects and $F2(1,15) = 8.5$, $p2<.01$, by items. None of the other effects was significant.

Finally to see whether incentive to name had an effect on the manifestation of RB between pictures, an analysis of the trials in which C1 and C2 are pictures combining the two different blocks was performed. There was a main effect of repeatedness, $F1(1,15) = 96.1$, $p1<.0001$, by subjects and $F2(1,15) = 89.3$, $p2<.0001$, by items, and of lag, $F1(1,15) = 196.6$, $p1<.0001$, by subjects and $F2(1,15) = 22.0$, $p2<.0001$, by items. These two factors interacted, $F1(1,15) = 41.7$, $p1<.0001$, by subjects and $F2(1,15) = 22.1$, $p2<.0001$, by items, showing a larger RB effect at lag 1 than lag 2. A three-way interaction, between repeatedness, block and lag, was present by subjects, $F1(1,15) = 6.0$, $p1 < .027$, but not by items ($p2 > .19$). These results suggests that RB was not affected by whether pictures were presented alone or mixed within words.

Discussion

This experiment establishes the presence of RB between pictures in recall of short lists. It shows that RB between pictures, like RB between words, decreases when lag increases. It suggests that overall, RB between pictures is of a comparable size to RB between words.

Experiment 2

Experiment 2 was designed to test RB between pictures when they are embedded in sentences, because much of the work on RB has used sentences. Moreover, the use of sentences is assumed to emphasize conceptual information more than does the use of lists. Since conceptual information is thought to be especially salient for pictures, they might not behave similarly in sentences and in lists. "Rebus" sentences in which C1 and C2 were picturable nouns replaced by their corresponding pictures were written. RSVP sentence processing when a picture replaces a noun was first assessed by Potter, Kroll, Yachzel, Carpenter, and Sherman (1986). These authors showed that such rebus sentences are understood and recalled about as accurately as all-word sentences.

Method

Subjects. Twenty-six subjects from the same pool as the previous experiments participated in this experiment.

Materials and design. Thirty-two sentences containing a repeated picturable noun were constructed. For each sentence, a nonrepeated control was produced by replacing the first occurrence of the picturable noun by another picturable noun, that left the semantics and the syntax of the sentence almost unchanged. The two picturable nouns, C1 and C2, were always separated by two to three words, and never appeared first or last in the sentence. The sentences were written so that removal of C2 left an ungrammatical or highly anomalous sentence. The 32 sentences with their nonrepeated C1 controls are given in Appendix B. When presented to the subjects all the items were words except C1 and C2.

The main variable of interest, repeatedness, was counterbalanced within subjects and items. Each version of the experiment contained 32 experimental sentences, and 10 ungrammatical filler sentences containing one or two pictures. Each version was always preceded by 20 practice sentences containing one or two pictures (repeated or not).

Procedure. Each trial began when the subject hit the space bar on the computer keyboard. The row of asterisks then disappeared and was immediately replaced by the sentence appearing one item (words except C1 and C2 as pictures) at a time, in the same place, for 83 milliseconds per item. Each item was centered on the screen. Except for the initial capitalized letter of the first word and proper nouns, all words were in lower case (helvetica, size 24). A non-object picture (Kroll & Potter, 1984), acting as a picture mask, was presented at the beginning and the end of each sentence (see Figure 2).

Subjects were aware that sentences would contain pictures and they were told to integrate the picture within the sequence of words. Subjects were instructed to read the sentence as carefully as possible and to recall it aloud as soon as it ended. They were warned that some sentences would be strange or ungrammatical, but they were to report the items as they saw them and particularly not to add words they had not seen to reconstruct a correct sentence. Before the beginning of the experiment, they were asked to look carefully at a booklet showing 195 pictures with their corresponding names. This booklet contained all the experimental pictures plus other pictures. Subjects were also shown the non-object picture (see Figure 2) and were instructed to ignore it during recall.

Apparatus. The same apparatus as in Experiment 1 was used.

Results

The percentage of recall of C1 and C2, respectively (according to their position of recall within the sentence), was scored. If it was not clear from the serial position whether C1 or C2 had been omitted, the trial was scored conservatively as an omission of C1 (this happened on 5% of the repeated trials). The percentages are reported in Table 2.

Overall recall accuracy for the sentences was high. Recall of C1 averaged 86%, which was comparable to the recall of the other words of the sentences (77% including closed class words, and not including C2). Analyses of variance by subjects and by items were conducted separately for C1 and for C2. There was no effect of repeatedness for C1 (ps >.2); but repeatedness (effect size of 17%) was significant for C2, $\underline{F1}(1, 25) = 16.7$, $\underline{p1} < .0001$, by subjects and $\underline{F2}(1, 31) = 11.5$, $\underline{p2} < .002$, by items.

Table 2

Experiment 2: Percentage of recall of C1 and C2

Repeatedness	C1p	C2p
Non Repeated	84	81
Repeated	80	64
Non Rep. - Rep.	4	17

Discussion

Experiments 2 confirms the presence of RB between identical pictures, and extends it to sentence recall. Together, Experiments 1 and 2 suggest that RB between pictures is comparable to that between words.

III. RB BETWEEN PICTURES AND WORDS

The next two experiments were designed to test whether phonological RB can be found between items other than two phonologically related words. For this purpose, RB between the picture of an object and a word phonologically related to the name of that object was studied. In Experiment 3, RB between the picture of an object and its corresponding word (i.e., the picture of a cat and the word 'cat') was tested. However, this confounded conceptual and phonological similarity. In Experiment 4, these two factors were disambiguated by looking at RB between the picture of an object and a word that was a homophone of the name of the object (i.e., the picture of a sun and the word 'son').

Experiment 3

If no RB is found between a picture of an object and its corresponding word, that would suggest that phonological RB is restricted to orthographic stimuli. If, on the contrary, RB is found between such items, either the phonological similarity or the semantic or lexical similarity between the items could be responsible.

Method

Subjects. Sixteen subjects from the same pool as the previous experiments participated in this experiment, none of whom had participated in Experiment 2.

Materials and design. Fifty-six sentences containing a repeated picturable noun were selected; the thirty-two sentences of Experiment 2 were used and twenty-four new sentences were constructed. For each sentence, a nonrepeated control was produced by replacing the first occurrence of the picturable noun by another picturable noun, that left the semantic and the syntax of the sentence almost unchanged. The two picturable nouns, C1 and C2, were always separated by two to four words, and never appeared first or last in the sentence. The sentences were written so that removal of C2 left an ungrammatical or highly anomalous sentence. The 24 additional sentences with their nonrepeated C1 controls are given in Appendix C.

The main variables of interest, repeatedness and format, were counterbalanced within items and subjects. There were four different possible formats: C1 and C2 both words (ww), C1 and C2 both pictures (pp), C1 a word and C2 a picture (wp), C1 a picture and C2 a word (pw). This 2X4 design led to 8 different versions of the experiment. Each version of the experiment contained 56 experimental sentences, and 14 ungrammatical filler sentences, containing zero, one or two pictures; and was preceded by 15 practice sentences containing, zero, one or two pictures (repeated or not).

Procedure. The same procedure as in Experiment 2 was used. Items were displayed for 83 milliseconds each.

Apparatus. The same apparatus as in Experiment 1 was used.

Results

The percentage of recall of C1 and C2, respectively (according to their position of recall within the sentence), was scored. If it was not clear from the serial position whether C1 or C2 had been omitted, that trial was scored as an omission of C1 (this happened on .6% of the trials). The percentage of recall for each of the four format conditions is reported in Table 3.

Table 3

Experiment 3: Percentage of Recall of C1 and C2

	Identical				Different			
	ww		pp		pw		wp	
Repeatedness	C1w	C2w	C1p	C2p	C1p	C2w	C1w	C2p
Non Repeated	92	83	82	86	88	75	95	90
Repeated	89	41	84	70	88	39	92	61
Non Rep.-Rep.	3	42	-2	16	0	36	3	29

Overall recall accuracy for the sentences was high (80% including closed class words, and excluding C1 and C2). Recall of C1 averaged 85% for pictures and 92% for words which was representative of the other words of the sentences.

Analyses of variance by subjects and by items were conducted separately for C1 and for C2. For C1, with repeatedness and format of C1 as factors, the only effect was a format effect, $F1(1, 15) = 11.5$, $p1<.004$, by subjects and $F2\ (1, 55) = 6.7$, $p2<.012$, by items; this effect shows that C1s in word format were better recalled than C1s in picture format.

For C2, an analysis was run with repeatedness, same-different format and format of C2 as factors. Main effects of repeatedness, $F1(1, 15) = 68.8$, $p1<.0001$, by subjects, and $F2\ (1, 55) = 175$, $p2<.0001$, by items, and of format of C2, $F1$ (1, 15) = 27, $p1<.0001$, by subjects, and $F2$ (1, 31) = 28, $p2<.0001$, by items,were observed. These two factors interacted, , $F1$ (1, 15) = 5.8, $p1<.03$, by subjects, and $F2$ (1, 31) = 7.5, $p2<.0008$, by items, indicating that RB is larger when C2 is a word than when C2 is a picture. No other significant effects ($ps > .07$) were found. In particular, no interaction was found between repeatedness and same-different format ($ps > .15$) indicating that the size of RB between same or different format items was comparable.

Discussion

Experiment 3 demonstrates that RB can be obtained between pictures and words. The results suggest that, in sentences, the size of RB between a picture and a word is comparable to the size of RB between two words or two pictures. It is, however, worth noting that overall RB was found to be smaller when C2 was a picture than when C2 was a word (independently of the format of C1).

The interpretation of the finding of RB between pictures and words is challenging given that pictures and words are believed to access different representations initially. It has been proposed that pictures access a conceptual representation before their lexical representation, through which phonological information becomes available (Potter, 1979; Potter & Faulconer, 1975; Potter et al., 1986; other references). In contrast, words are thought to first access their lexical representation, enabling a rapid retrieval of phonological information; and to connect more slowly with a conceptual representation. Despite the fact that the codes readily retrieved during the perception of words and pictures are supposedly different (phonological/linguistic vs conceptual/spatial), RB is still observed between these stimuli. This result suggests that RB is not sensitive to the similarity of the codes readily accessed during recognition, but rather to the similarity of the codes used for registration of the items in short term memory. The finding of a smaller RB when C2 is a picture than when C2 is a word may be due to the visual dissimilarity of the picture; however, it is also consistent with the fact that retrieval of phonology is delayed for pictures compared to words. Hence, the elapsed time between the retrieval of the phonology of C1 and of C2 would be longer when C1 is a word and C2 a picture than vice versa, possibly leading to a smaller RB in the earlier case than in the latter one.

The codes that have to be registered in short term memory and that would be responsible for RB in the present experiment could be phonological and/or semantic. Potter et al. (1986) proposed that during the processing of RSVP rebus sentences, pictures are integrated in the sentence through their conceptual representations, not their names. In that case, RB for pictures in sentences would be determined by the conceptual similarity between C1 and C2. However, conceptual similarity, at least when using words (i.e., taxi/cab), always failed to elicit RB (Kanwisher & Potter, 1990). To differentiate between a phonological and a conceptual account of RB between pictures and their corresponding words, Experiment 4 looked at RB between a picture and a word that are phonologically similar but semantically unrelated, such as the picture of a sun and the word 'son'.

Experiment 4

When using words, it has been established that phonological similarity is sufficient to produce RB (Bavelier & Potter, 1992; Bavelier, Prasada & Segui, 1992; Kanwisher, 1991b). For example, RB was obtained between pairs of homophones such as eight/ate; the amount of this effect was significantly greater than for orthographic controls that were not phonologically identical. RB was also found between phonologically similar but orthographically dissimilar words, such as freight/great. As reviewed above, the role of phonological similarity in RB between words is consistent with the growing literature showing that phonological information is rapidly retrieved when processing words. In contrast, for pictures, there are at least two reasons for believing that conceptual/semantic information rather than phonological information would be determinant for RB. First, during the processing of RSVP rebus sentences, pictures are believed to be integrated in the sentence through their conceptual representations, not their names (Potter et al., 1986). Second, for pictures, conceptual information rather than phonological information is retrieved initially.

In Experiment 4 the role of conceptual similarity on RB when using pictures was assessed. RB between the picture of an object and its corresponding word, such as the picture of a cat and the word 'cat', was compared to RB between the picture of an object and one of its written homophone, such as a picture of the sun and the word 'son'. If RB is found between phonologically and semantically similar pictures and words, but not between phonologically similar and semantically dissimilar pictures and words, it would suggest that RB when using pictures is mainly determined by semantic similarity. However, if RB is found for both semantically similar and dissimilar pairs, it will indicate that at least part of RB between pictures and words is phonologically based.

Method

Subjects. Twenty subjects from the same pool as the previous experiments participated in this experiment.

Materials and design. For the sentences with critical items that were both phonologically and semantically identical, twenty pictures of objects (whose names were not homophones) were selected. For each picture, two sentences containing this repeated picturable noun were constructed; the same number of words intervened between C1 and C2 in each sentence. For the sentences with critical items that were phonologically similar but semantically different, twenty pictures whose corresponding name was homophonic to another word (e.g., sun-son, ant-aunt, pear-pair) were selected. For each picture-homophone word pair, two sentences were constructed; in one, the picture appeared first and the homophone word second, in the other the homophone word appeared first and the picture second. For a given pair, the same number of words intervened between C1 and C2 in the two sentences.

For each of the 80 sentences constructed, a nonrepeated control was produced by replacing the first critical item (C1) by another item of the same format (word or picture), that left the semantics and the syntax of the sentence almost unchanged. The two critical items, C1 and C2, were always separated by two to four words, and never appeared first or last in the sentence. The sentences were written so that removal of C2 left an ungrammatical or highly anomalous sentence. The 80 sentences with their nonrepeated C1 controls are given in Appendix D.

There were three main variables: repeatedness, format (picture or word) and the nature of the relationship between C1 and C2 ("identical" will be used to refer to phonologically and semantically similar, in contrast to "homophone", which will refer to items phonologically similar but semantically different). Only two different formats were used: C1 as a word and C2 as a picture (wp) versus C1 as a picture and C2 as a word (pw). While repeatedness was counterbalanced within subjects and within items, identical/homophone and format were within subjects, but between items. Each experimental list contained only one of the sentences that was built from a given critical pair; hence, a given item was never used twice as a critical item for a given subject. This 2X2 design resulted in 4 different versions of the experiment. Each version of the experiment contained 40 experimental sentences, and 20 ungrammatical filler sentences that contained one picture; and was preceded by 12 practice sentences containing one picture.

Procedure. The same procedure as in Experiment 2 was used, except the non-object picture was changed (see figure 3). Items were displayed for 100 milliseconds each.

Apparatus. The same apparatus as in Experiment 1 was used.

Results

The main finding of Experiment 4 is a sizeable RB effect between picture-word homophonic pairs, $\underline{F1}(1, 19) = 7.6$, $\underline{p1}<.012$, by subjects, and $\underline{F2}\ (1, 19) = 6.1$, $\underline{p2}<.023$, by items.

Table 4A

Experiment 4: Percentage of Recall of C1 and C2 separately

	Identical (cat-cat)				Homophone (sun-son)			
	pw		wp		pw		wp	
Repeatedness	C1p	C2w	C1w	C2p	C1p	C2w	C1w	C2p
Non Repeated	92	82	90	87	89	77	95	98
Repeated	88	54	95	65	91	63	88	95
Non Rep.-Rep.	4	28	-5	22	-2	14	7	3

The percentage of recall of C1 and C2 separately was scored initially (Table 4A). However, the homophone trials in which C1 is a word and C2 a picture did not behave with respect to RB as did the other trials. In particular, in those trials C1 as well as C2 seemed to be affected by repetition blindness. Analysis by subjects and by items of the recall of C1 indicated a triple interaction between format, identical/homophone and repeatedness, $\underline{F1}(1, 19) = 6.2$, $\underline{p1}<.022$, by subjects, and $\underline{F2}\ (1, 38) = 3.95$, $\underline{p2}<.054$, by items, confirming this trend. Although this pattern of result is important and interesting, its interpretation will be delayed. First, the recall of both C1 and C2 will be analyzed so as to be able to compare the size of the RB effect for the different conditions, as originally planned. The percentage of recall of both C1 and C2 for each of the conditions is reported in Table 4B.

Table 4B

Experiment 4: Percentage of Recall of both C1 and C2

	Identical (cat-cat)		Homophone (sun-son)	
Repeatedness	pw	wp	pw	wp
Non Repeated	76	79	70	94
Repeated	45	61	55	83
Non Rep.-Rep.	31	18	15	11

Overall recall accuracy for the sentences was good. Recall of the words of the sentences (including closed class words) other than C1 and C2 averaged 83%.

Analyses of variance by subjects and by items were conducted on the number of times both C1 and C2 were correctly recalled, with repeatedness, format and identical/homophone as factors. There was a main effect of repeatedness, $\underline{F1}(1, 19) = 18.8$, $\underline{p1}<.0001$, by subjects, and $\underline{F2}\ (1, 38) = 25.8$, $\underline{p2}<.0001$, by items, a main effect of format, $\underline{F1}(1, 19) = 18.6$, $\underline{p1}<.0001$, by subjects, and $\underline{F2}\ (1, 38) = 27.2$, $\underline{p2}<.0001$, by items, and a main effect of identical/homophone, $\underline{F1}(1, 19) = 9.2$, $\underline{p1}<.007$, by subjects, and $\underline{F2}\ (1, 38) = 25.8$, $\underline{p2}<.008$, by items. There were more errors in repeated trials than nonrepeated trials, more errors in pw trials than in wp trials, and more errors in identical trials than in homophone ones. A significant interaction was found between format and identical/homophone, $F1(1, 19) = 5$, $p1 < .037$, by subjects, and $F2\ (1, 38) = 5.8$, $p2 < .02$, by items, probably due to a better recall on homophone trials in the wp format. The interaction between identical/homophones and repeatedness was only marginally significant by subjects ($p1 = .08$) and non significant by items ($p2 > .12$). Although this interaction did not reach significance, the size of RB between identical items was greater than the size of RB between phonologically similar items (25% vs 13%).

The main effect of identical/homophone led us to run separate anovas for identical and homophone trials. For identical trials, a main effect of repeatedness, $F1(1, 19) = 17.4$, $p1 < .001$, by subjects, and $F2\ (1, 19) = 22.1$, $p2 < .0001$, by items, was observed. The main effect of format was marginally significant by subjects ($p1 = .07$) and significant by items ($F2\ (1, 19) = 6.0$, $p2 < .024$) indicating more errors for the pw trials than the wp trials. However, this effect did not interact with repeatedness ($ps > .19$) suggesting that the size of RB was not significantly different whether C1 is a picture and C2 a word or vice versa.

For homophone trials, there was a main effect of repetition, $F1(1, 19) = 7.6$, $p1 < .012$, by subjects, and $F2\ (1, 19) = 6.1$, $p2 < .023$, by items, was present. This result establishes the presence of RB between phonologically similar but semantically and visually different items. A main effect of format was also present, $F1(1, 19) = 18.5$, p1<.0001, by subjects, and F2 (1, 19) = 21.6, p2<.0001, by items, due to more errors for the pw trials than the wp trials; this last effect did not interact with repeatedness (ps>.6).

These analyses confirm the presence of RB for identical trials, and establish RB for homophone trials. Although in each case no statistically significant difference in RB was found between wp and pw trials, raw numbers suggest that RB for wp trials (14.5%) tends to be smaller than RB for pw trials (23%).

The presence of a main effect of format in the main anova also led us to run separate analyses for wp and pw trials, allowing us to do a more refined comparison of RB between identical and homophone trials. For pw trials, a main effect of repeatedness, F1(1, 19) = 13.9, p1<.001, by subjects, and F2 (1, 38) = 17.8, p2<.0001, by items, was observed. None of the other factors reached significance (ps > .09). For the wp trials, main effects of repeatedness, F1(1, 19) = 13.5, p1<.002, by subjects, and F2 (1, 38) = 12.3, p2<.001, by items, and of identical/homophone, F1(1, 19) = 10.1, p1<.005, by subjects, and F2 (1, 38) = 21.1, p2<.0001, by items, were observed. None of the interactions were significant (ps > .4). These results show that the size of RB for homophone trials is not significantly different from the size of RB for identical trials, although it certainly tends to be smaller.

Discussion

The main result of Experiment 4 is that RB is observed between phonologically similar but semantically unrelated pairs of pictures and words. This result establishes first that phonological similarity alone (independently of visual similarity and semantic similarity) is sufficient to produce a sizeable amount of RB. Second, it shows that when the task used requires phonological codes to be entered in STM, RB even when using pictures is mostly dependent on phonological similarity. Hence, although access to phonological information from a picture is slow and is mediated by retrieval of conceptual information, phonological RB can be found when using pictures. This supports the claim that phonological RB is due to the fact that similar phonological codes have to be entered in the tokens of C1 and C2, rather than to the similarity of the first recognition codes retrieved when the stimuli are presented.

Although RB was not significantly affected by the conceptual relationships between the items used, conceptual information did have an effect on RB. First, although the size of RB for phonologically similar but semantically dissimilar pairs was not significantly different from the size of RB for phonologically and semantically similar pairs, raw numbers indicate that RB between homophone trials (13%) is less than RB between identical trials (24.5%). This suggests that semantic/conceptual relationships between the items used may have slightly influenced the size of RB. Second, the manifestation of RB was found to be modified when using semantically unrelated pictures and words. In the wp homophone trials, RB mostly impaired the recall of the C1 word, not the C2 picture. This shows that the conceptual difference between C1 and C2, at least when C2 is a picture, can affect the pattern of RB. These two points indicate that RB is sensitive to conceptual information when using pictures. The weak role of conceptual/semantic relationships in this experiment would be consistent with the proposal that the task conditions (verbatim recall, high memory load) enforced phonological encoding in STM, and that RB is dependent on the similarity of the representation used for encoding in STM.

The results of Experiment 4 suggest a new interpretation of RB. Following the presentation of items so visually different as a picture of a sun and the word "son", it is highly probable that a token will initially be opened for each of these items. RB would then be due to the loss of an opened token, rather than to a failure to establish a new token for C2 (Kanwisher, 1987). The pattern of RB in the wp homophones trials illustrates this point the most clearly. On the repeated version of such trials C2 was recalled, indicating that a token was initiated when C2 was presented; since C1 was well recalled on nonrepeated trials, its presentation should also lead to the opening of a token in the repeated ones. Hence, even though a token for C1 as well as for C2 had been opened, some degree of RB was observed (11%). This shows that RB can arise from the loss of one of two opened tokens. Finally, since RB mostly affected the recall of the C1 word and not the C2 picture, it suggests that if the token of C2 is rendered strong enough by salient information (pictorial/conceptual here), it will be less subject to loss. Taken together, these data suggest that RB can arise from a competition process between the tokens of C1 and C2 for the same phonological code; the failure to register this code in one the tokens would render it more subject to loss. The observation that RB usually affects the recall of C2, and not C1 (Kanwisher, 1986), indicates that the time of arrival, in the absence of other biasing information, determines the outcome of the competition. In this view, RB would occur because of the loss of a token, rather than a failure to initially create a token; this loss would be due to a failure in registering the proper stabilizing information in the token.

To conclude, Experiments 3 and 4 establish phonological RB when using stimuli that are not readily nameable, such as pictures. They demonstrate that phonological RB is not merely found for easily verbalized stimuli, such as words or letters; and they support the claim that phonological RB will be found between any visual stimuli when phonological codes have to be registered in the tokens in STM. Moreover, they suggest that phonological RB may be best explained as resulting from a competition between two opened tokens for the same phonological code, rather than as a failure to create a new token for C2 (Kanwisher, 1987). Following this line of thought, the two following experiments are devoted to testing whether, if the task discourages phonological encoding, phonological RB is reduced.

IV. ROLE OF TASK REQUIREMENTS IN RB

Phonological RB has been suggested to occur because the task or the items used biases subjects toward phonological encoding in STM. If RB is indeed caused by the similarity of the codes used for registration, the amount of RB should vary as the task requirements bias the initial codes used for registration of C1 and C2 to be similar or dissimilar. This claim was tested when manipulating the nature of the codes to be registered in the tokens by explicit instructions (Experiment 5) or implicit ones (Experiment 6).

Experiment 5

Experiment 5 was designed to test whether the size of phonological RB can be manipulated as a function of the way the task requires the subject to initially encode information in STM. For this purpose, a set of phonologically related pairs of items that are visually different (two different pictures of a boat, for example) or identical (two identical pictures of a boat) were used. In all cases the critical items were semantically identical or highly similar. The task manipulation emphasized either phonological encoding or visual encoding. If RB is indeed dependent on the nature of the codes to be registered in the token, RB between phonologically related items should be diminished in the visual task compared to the phonological one. On the other hand, RB between visually identical items should be equivalent in both kinds of task.

In Experiment 5A, pairs of pictures corresponding to a given object (e.g., two different pictures of a boat) were used to test these predictions. In the phonological task, subjects were just asked for report of the name of the picture they saw; in the visual task, subjects had to indicate which exact picture they saw. In Experiments 5B and 5C, the predictions were tested by using pictures and their corresponding words. In the phonological task, subjects were just asked to report the name corresponding to the pictures or the words they saw. In the visual task, subjects were asked not only to report the name of the items they saw, but also the format (picture versus written word) in which they were presented.

Experiment 5A

Method

The method was the same as that of Experiment 1 unless otherwise specified. Subjects viewed sequential trials that included three line-drawings and three irrelevant arrays of mask fields (see figure 4 for examples of these mask fields); the six items were always preceded and followed by a mask field.

Subjects. Sixteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation.

Materials and design. Two sets of eight picturable nouns were selected, for which there were two different pictures of each object. An experimental block was constructed from each of these sets. Each of the blocks consisted of twelve practice trials followed by 64 experimental and 20 filler trials.

On half the trials in a block, C1 and C2 had the same picture identity (repeated trials), on the other half they had a different identity (nonrepeated trials). On half the repeated trials, C1 and C2 were identical pictures (identical trials); on the other half, C1 and C2 had the same identity but were different pictures (i.e., two different pictures of a dog) (different trials). Repeatedness and same-different were counterbalanced within subjects and items. A final between item variable was the lag between C1 and C2 (lag 1 versus lag 2). This 2X2 design resulted in a total of 4 versions of the experiment, for each of the two sets of picturable nouns (corresponding to different blocks).

The task was varied between blocks. In one case (visual task), subjects were given a sheet on which the 8 pairs of pictures to be used in that block were represented. The pairs were numbered from 1 to 8, and each member of a pair was indexed as a or b. Subjects were asked to report after each trial the number and the index corresponding to the pictures they viewed, hence obliging them to encode the exact picture format in which the objects were presented. The page with the pictures and index remained beside them throughout the block. In the other case (phonological task), subjects were given a sheet with the 8 written nouns corresponding the pictures used in that block numbered from 1 to 8. Subjects were asked to report the number of the word corresponding to the picture they saw. Hence even when they were presented with two different pictures of a dog, they would give back the same number. Subjects typed their answer at the end of each trial, using a computer keyboard. Examples of the two kinds of cue sheets are given in Appendix E. The order of presentation of the two sets of material and of the tasks (visual vs phonological) were counterbalanced between subjects.

Procedure. The same procedure as in Experiment 1 was used.

Apparatus. The same apparatus than in Experiment 1 was used. Stimuli were taken from the Snodgrass & Vanderwart (1980) as well as from the Potter & Faulconer (1975) picture sets.

Results

The number of recalls of C1 and C2 was scored for each condition. In the visual task, if subjects reported the correct number but the wrong index, the trial was scored as correct (this happened on 17% of the trials). The percentage of trials in which both C1 and C2 were recalled, for each of the categories, is presented in Table 5a.

Table 5A

Experiment 5A: Percentage of trials in which C1 and C2 were both recalled

	Identical	Different
Task/repeatedness		
Phonological Task		
Non Repeated	61	63
Repeated	46	48
Non Rep. - Rep.	15	15
Visual Task		
Non Repeated	55	51
Repeated	41	45
Non Rep. - Rep.	14	6

A 2x2x2 anova with repeatedness, task, and identical/different pictures as variables was carried on the number of time C1 and C2 were both recalled, regardless of whether exact format was recalled correctly. The main effect of repetition was substantial (13%) and statistically reliable, $F1(1, 15) = 22.9$, $p1 < .0001$, by subjects and $F2(1, 15) = 31.5$, $p2 < .0001$, by items. A main effect of task, $F1(1, 15) = 5.5$, p <.032, by subjects and F2(1, 15) = 10, p2 <.006, by items, showed that the visual task led to more errors than the phonological task. A marginal interaction between repeatedness and task was found by subjects (F1(1, 15) = 3.3, p1 <.09, p2 >.15); the three-way interaction between repeatedness, task and identical/different was not significant (ps > .25). None of the other effects were significant.

This unfocused anova, however, bears only indirectly on the hypothesis predicted. The predicted hypothesis involved assigning a contrast weight of +1 to all cells except the different pictures trials-visual task which was assigned a contrast weight of -3. This contrast analysis was carried out on the size of RB (non repeated - repeated). Although the contrast was not statistically significant (F(1, 45) = 2.76, p <.15), the corresponding effect size (r = .24) was small but not negligible. A close look at the analysis showed that the SS of the predicted contrast accounted for 97% of the SS of the factors, suggesting that the lack of effect is not due to the misfit of our prediction, but to the fact that our data were very noisy.

Interestingly, this experiment also gave us the opportunity to test RB between different pictures of the same object, when using a phonological task. Analysis of the different pictures - phonological task trials separately revealed a main effect of repeatedness, F1(1, 15) = 10, p1 <.006, by subjects and, F2(1, 15) = 15, p2 <.002, by items, establishing the presence of sizeable RB (15%).

Discussion

Although the overall variance of the data prevented us from drawing any significant conclusion, the pattern of results of

Experiment 5A suggests that the predicted contrast holds. The finding of an overall large variance is consistent with the fact that subjects reported it to be a very difficult task, and performed relatively poorly. For this reason, I decided to replicate the logic of the experiment using material that would be easier to recall, both under the visual task and the phonological task. For this purpose, I used mixtures of words and pictures. In the phonological task, subjects were just asked to report the name corresponding to the pictures or the words they saw. In the visual task, subjects were asked not only to report the name of the items they saw, but also the format (picture versus written word) in which they were presented. The same experiment was carried out twice with two different set of subjects (5B and 5C). Since they gave slightly different results, both will be reported.

Experiments 5B and 5C

Experiment 5B

Method

The method was the same as that of Experiment 5A unless otherwise specified. The mask fields used in this experiment were identical to the ones used in Experiment 1 (i.e. a row of symbols was added at the location where words appeared on the screen in order to properly mask words; see figure 1).

Subjects. Sixteen Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation. None of the subjects had participated in the previous experiment.

Materials and design. The same design as in Experiment 5A was used, except that the pairs consisted of a picture and their corresponding written name, instead of pairs of pictures representing the same object. The picture and word pairs used were the same as in Experiment 1 (see Appendix A). In the identical trials, C1 and C2 were either both written words or both pictures; in the different trials, C1 and C2 were always in a different format (picture/word or word/picture). In the phonological task, subjects were just asked to report the name corresponding to the pictures or the words they saw. In the visual task, subjects were asked not only to report the name of the items they saw, but also the format (picture versus written word) in which they were presented. Subjects wrote down the name of the items they saw, using a computer keyboard. In the visual task, they were also required to type a 'p' or a 'w', to indicate whether the item they reported was seen as a picture or as a word.

Repeatedness, identical-different, and order of the two tasks as well as blocks were counterbalanced within subjects and items. A final between-items variable was the lag between C1 and C2 (lag 1 versus lag 2).

Results

The number of recalls of C1 and C2 was scored in each condition. If a subject reported the right picture name but the wrong format,the item was scored as correct (this could only occur in the visual task, and happened on 8% of these trials). The percentage of trials in which both C1 and C2 were recalled, for each of the categories, is presented in Table 5b.

A 2x2x2 anova with repeatedness, task, and identical/different format as variables was carried out on the number of times C1 and C2 were both recalled. The main effect of repetition was large (17%) and statistically reliable, $F1(1, 15) = 38.9$, $p1 < .0001$ by subjects, $F2(1, 31) = 70.6$, $p2 < .0001$. A main effect of identical/different trials, $F(1, 15) = 53.1$, $p1 < .0001$ by subjects, $F2(1, 31) = 24.7$, 2, $p < .0001$, indicated more errors for identical than different trials. This last factor interacted with repeatedness, $F(1, 15) = 5.5$, $p1 < .033$ by subjects, $F2(1, 31) = 6.5$, $p2 < .016$, due to a larger RB for identical than for different trials. The interaction between task and repeatedness was only marginally significant by subjects, $F1(1, 15) = 3.3$, $p1 < .09$, $r1 = .42$, but statistically significant by items, $F2(1, 31) = 5.9$, $p2 < .021$, suggesting a larger RB in the phonological task than in the visual task. No other significant effects were found. The interaction between identical/different and repeatedness led to a separate analysis for identical and different trials. For each kind of trials, the only significant effect was a main effect of repetition, by subjects as by items.

Table 5B

Experiment 5B: Percentage of trials in which C1 and C2 were both recalled

Task/Repeatedness	Identical			Different		
	ww	pp	M	pw	wp	M
Phonological Task						
Non Repeated	76	66	71	74	82	78
Repeated	46	41	43	55	72	64
Non Rep. - Rep.	30	25	28	19	10	14
Visual Task						
Non Repeated	70	57	63	72	76	74
Repeated	50	38	44	60	74	67
Non Rep. - Rep.	20	19	19	12	2	7

The proposed hypothesis was tested by carrying out a contrast analysis like that for Experiment 5A. A contrast weight of -3 was assigned to visually dissimilar items (whether wp or pw) in the visual task; the other 3 cells were assigned a contrast weight of +1. This contrast analysis was carried out on the size of RB (non repeated - repeated). The contrast was significant, $\underline{F}(1, 45) = 6.6$, $\underline{p} < .02$, $r = .36$. This result is consistent with the claim that RB for different trials is more affected by the task manipulations than RB for the identical trials.

Another result of interest is the finding of RB between words and pictures. Phonological task trials were analyzed separately. A 2X2X2 anova was carried with repeatedness, identical/different and format of C2 as variables on the number of recalls of both C1 and C2.

Main effects of repeatedness, F1 $(1, 15) = 36$, $p1<.0001$, by subjects, and F2 $(1, 31) = 73.3$, $p<.0001$, by items, and of identical-different format, F1 $(1, 15) = 20.5$, $p1<.0001$, by subjects, and F2 $(1, 31) = 14.6$, $p<.001$, by items, were observed. The interaction between repeatedness and identical/different was marginally significant, F1 $(1, 15) = 4.3$, $p1<.06$, by subjects, and F2 $(1, 31) = 3.9$, $p2< .06$, by items, suggesting a tendency for larger RB between identical than different items. The only other significant effect was an interaction between identical-different format and the format of C2, F1 $(1, 15) = 8.5$, $p1<.001$, by subjects, and F2 $(1, 31) = 8$, $p2< .007$, by items, probably due to fewer errors in the different condition than in the identical condition when C2 is a picture.

Experiment 5C

Method

The method was the same as that of Experiment 5B.

Subjects. Twenty Massachusetts Institute of Technology undergraduates participated in this experiment. All the subjects were native speakers of American English and were paid for their participation. None of the subjects had participated in the previous experiment.

Materials and design. The same design as in Experiment 5B was used.

Results

Nineteen trials per subjects were discarded from the analysis due to an error in setting the duration of the items (these trials were evenly distributed over the different conditions when all subjects were pooled); since there were more subjects in this experiment, the number of useable data points was similar to that in the previous experiment. For each condition, the number of recalls of both C1 and C2 was counted. If a subject reported the right picture name but the wrong format, in the visual task, the item was scored as correct (this happened on 8% of the trials). The percentage of trials in which both C1 and C2 were recalled, for each of the categories, is presented in Table 5c.

Table 5C

Experiment 5C: Percentage of trials in which C1 and C2 were both recalled

	Identical			Different		
Task/Repeatedness	ww	pp	M	pw	wp	M
Phonological Task						
Non Repeated	70	64	67	67	73	70
Repeated	35	44	40	44	63	54
Non Rep. - Rep.	35	20	27	23	10	16
Visual Task						
Non Repeated	72	60	66	65	71	68
Repeated	42	41	42	50	73	62
Non Rep. - Rep.	30	19	24	15	- 2	6

A 2x2x2x2 anova with repeatedness, task, identical/different, and C2 format as variables was carried on the number of times C1 and C2 were both recalled. The main effect of repetition was large (19%) and statistically reliable, $\underline{F1}(1, 19) = 87.4$, $\underline{p1} < .0001$ by subjects, $\underline{F2}(1, 30) = 65.5$, $\underline{p2} < .0001$ by items. A main effect of identical/different trials, $\underline{F}(1, 19) = 12.4$, $\underline{p1} < .002$ by subjects, $\underline{F2}(1, 30) = 14.9$, $\underline{p2} < .001$ by items, indicated more errors for identical than different trials. None of the other main effects was significant. Repeatedness interacted with the three other main factors; there was an interaction between repeatedness and identical/different, $\underline{F}(1, 19) = 7.7$, $\underline{p1} < .012$ by subjects, $\underline{F2}(1, 30) = 7.7$, $\underline{p2} < .009$ by items, due to a larger RB effect for identical than for different trials; an interaction between repeatedness and task, $\underline{F1}(1, 19) = 5.6$, $\underline{p1} < .028$ by subjects, $\underline{F2}(1, 30) = 4.8$, $\underline{p2} < .036$ by items, showing that RB is larger in the phonological task than the visual task; and an interaction between repeatedness and C2 format, $\underline{F1}(1, 19) = 16.8$, $\underline{p1} < .001$ by subjects, $\underline{F2}(1, 30) = 10.8$, $\underline{p2} < .003$ by items, showing that RB is larger when C2 is a word than a picture. Identical/different interacted with C2 format, $\underline{F1}(1, 19) = 10.3$, $\underline{p1} < .005$ by subjects, $\underline{F2}(1, 30) = 7.2$, $\underline{p2} < .012$ by items, due to less errors when C2 is a picture in the different condition than in the other cells. No other significant effects were found. The interaction between identical/different and repeatedness led to run a separate analysis for identical and different trials.

For identical trials, a main effect of repetition was found, $\underline{F1}(1, 19) = 43.5$, $\underline{p1} < .0001$ by subjects, $\underline{F2}(1, 30) = 38.8$, $\underline{p2} < .0001$ by items. Repeatedness interacted with C2 format by subjects, $\underline{F1}(1, 19)$

= 6.4, p1 <.021; this effect was only marginally significant by items, F2(1, 30) = 3.9, p2 <.06. No other effects were significant; especially, there was no interaction between repeatedness and task (p1s>.5).

For different trials, there was a main effect of repetition, F1(1, 19) = 22.0, p1 <.0001 by subjects, F2(1, 30) = 19.6, p2 <.0001 by items, as well as of C2 format, F1(1, 19) = 12.7, p1 <.002 by subjects, F2(1, 30) = 6.4, p2 <.017 by items. Repeatedness interacted with C2 format, F1(1, 19) = 9.1, p1 <.007 by subjects, F2(1, 30) = 8.8, p2 <.006 by items, indicating more RB when C2 is a word than a picture. More importantly, repeatedness and task interacted, F1(1, 19) = 6.1, p1 <.023 by subjects, F2(1, 30) = 4.8, p2 <.036 by items, establishes that RB between visually different items is significantly diminished when using a visual task compared to a phonological one.

The predicted contrast analysis[3] performed on these data led to a significant effect, F(1, 57) = 12.74, p <.001 , r = .43. These results

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3 Note that the predicted contrast (+1, +1, +1, -3) is highly correlated (r =.82) with the following contrast (+1, 0, 0, -1). This latter contrast would correspond to an additive effect of the two main factors, task and identical/different, on the size of RB. Although this could be an alternative explanation for the results found, it is not clear why RB between visually, phonologically and semantically identical items should be expected to diminish in the visual task compared to the phonological one. Moreover, a look at the size of RB across conditions supports the predicted contrast in two of the three experiments (Experiments 5A and 5C) (In Experiment 5A, the predicted contrast accounted for 97.7% of the SS while the additive contrast accounted for 69% of the SS. In Experiment 5 B and 5C, the fact that RB is usually smaller between a mixture of words and pictures than identical items was included in the predicted contrast leading to the following contrast weights (+1, +1, 0, -2) (note that this assumption, independently established by other experiments, is assumed in the additive contrast). In Experiment 5B, the predicted contrast accounted for 80.5% of the SS versus 95% for the additive contrast. In Experiment 5C, the predicted contrast accounted for 96% of the SS versus 86% for the additive contrast)).

support the claim that RB in the different trials is more affected by the task manipulation than RB in identical trials.

Discussion

The three versions of Experiment 5 were consistent with the predicted hypothesis that RB between phonologically related items can be varied as a function of task requirements. When the task relied on a phonological (or possibly semantic) encoding of information in STM, RB was obtained between any phonologically similar items whether visually similar or different. When the task required that a visual discrimination be made between these items, RB seemed was diminished more between visually different than visually identical items. The findings of these experiments are consistent with the view that phonological RB arises because subjects are biased toward phonological encoding in STM.

Moreover, Experiment 5A establishes the presence of RB between different pictures of the same object. Although it could be the case that this RB effect is due solely to the visual similarity of the exemplars, the diminution of RB between these pictures when subjects were required to encode visual information argues against that interpretation. Since the same pictures were displayed in all conditions and visual information must be processed before phonological codes can be retrieved, if visual similarity was responsible for the effect an equivalent amount of RB should have been found when using a visual or a phonological task. The pattern of data suggests that such RB results from a shared phonological (or possibly semantic) representation. When visual encoding is enforced, visual dissimilarity would be more efficient in counteracting the role of phonological (or semantic) similarity in producing RB, resulting in a reduced amount of RB (6%). Experiments 5B and 5C confirm this interpretation and replicate the finding of RB between pictures and their corresponding names as well as the trend for RB between identical items to be larger than (or at least equal to) that between related items. Although RB when C2 is a picture was not significantly smaller than RB when C2 is a word, raw data showed again a trend for the size of RB to be smaller when C2 is a picture rather than a word. Taken together, these data indicates that it is possible to vary the amount of RB between visually dissimilar but phonologically and semantically similar items through task requirements.

There are, however, two possible reasons why the effect of task manipulation was not clear cut. First, the amount of variance in the data suggests that the task manipulation did not easily modify the way information is registered in STM. Second, in all three versions of the experiment, semantic and phonological similarity was confounded; although semantic similarity has not been found to produce RB between words that are synonyms (cab/taxi) (Kanwisher & Potter, 1989), the role of semantic similarity in RB for pictures is unclear. Hence, the effects of task manipulation (which involved a shifting from phonological to visual encoding) could have been weakened by the fact that semantically similar were used.

In Experiment 6, the effect of task manipulation on phonological RB was tested by comparing two reading conditions: silent or with concurrent irrelevant articulation. In one condition, phonological and semantic similarity were dissociated by presenting items that were phonologically identical but semantically different (e.g. a picture of a sun and the word 'son').

Experiment 6

Concurrent irrelevant articulation (articulatory suppression) has been shown by numerous investigators to interfere with short term memory for ordered sequence of words, letters or digits (see Baddeley, 1986 for a review). While articulatory suppression interferes with the component of STM that sustains and permits rehearsal of the phonological representation of words, it does not seem to interfere, with initial retrieval of a word's phonological code during perception (Baddeley, 1979; Besner, 1987a, 1987b; Besner & Davelaar, 1982; Van Orden, 1987). Hence, for words, articulatory suppression allows one to differentiate between a late, post-access phonological effect due to rehearsal in STM (impaired by articulatory suppression), and initial access to a phonological representation (unaffected by articulatory suppression). This observation led Bavelier and Potter (1992a) to argue that if phonological RB between words is disrupted by articulatory suppression, it would suggest that phonological RB is due to phonological confusion after memory registration is achieved. They showed, however, that RB between homophonic words is not disrupted by articulatory suppression, and argued that phonological RB between words is due to a disruption of initial memory registration of C2 and not to a phonological confusion after memory registration is completed.

A similar logic could be applied to pictures. Effects of phonemic similarity, word (name) length and articulatory suppression have been shown when using either nameable pictures or the equivalent written words in an immediate memory task (Schiano & Watkins, 1981). Several subsequent studies have clearly established that concurrent articulation inhibits the phonological encoding of pictures in STM (Brandimonte, Hitch & Bishop, 1992; Broadbent & Broadbent, 1981; Hitch, Woodin & Baker, 1989). However, it is unclear whether, as for words, concurrent articulation interferes only with the component of STM that sustains and permits rehearsal of the phonological representation of these pictures, or interferes also with the initial retrieval of a lexical-phonological code during the perception of the pictures.

Given the difference in the order and speed of accessing phonological information from written words and pictures, it is possible that concurrent articulation would affect this access differently for words and pictures. Specifically, the relatively slow access to lexical-phonological information during picture processing might be disrupted by concurrent articulation, whereas written words a phonological code is so immediately and automatically retrieved that ii would be less disrupted. This is actually supported by the recent finding that concurrent articulation disrupts rhyme decisions and homophone decisions for words written in Kanji (logographic Japanese script) more than in Kana (syllabic Japanese script) (Kinoshita, S. & Saito, H., 1992). If this view holds, the role of phonological similarity in RB should be more diminished for pictures than for words under concurrent articulation.

Not only is a picture's phonological code less available than that of a word, its semantic/conceptual code is more available, and arguably its visual code is more distinctive and salient than is the orthography of a word. Since visual and semantic information is more salient for pictures than for words, concurrent articulation should be expected to enhance the role of visual or semantic information for pictures more than it does for words. This would be consistent with research showing that picture recall can be biased toward the use of visual codes by articulatory suppression (Bradimonte et al., 1992; Hitch et al., 1989). Hence, although the exact way concurrent articulation affects exactly picture processing is still unknown, there may be some room for interference with RB. The present experiment was designed to assess the role of concurrent articulation on RB between pictures and words, whether identical or homophones.

Method

Subjects. Thirty two subjects from the same pool as the previous experiments participated in this experiment. None of them had participated in Experiments 2, 3 or 4.

Materials and design. The material used was taken from Experiments 3 and 4. The 56 sentences used in Experiment 3 were divided between two equal blocks. The 40 sentences containing phonologically similar, but semantically dissimilar pairs of pictures and words were also reused. Given that these 40 sentences were built from 20 pairs of pictures and words, the same pair (in different order) appeared twice, once in each block. One of the sentences was in the repeated condition, and its paired sentence was in the nonrepeated condition counterbalanced over subjects. Thus, each block contained 28 identical sentences and 40 homophone sentences, and 7 ungrammatical filler sentences.

There were three main materials variables: repeatedness, format (picture or word) and the nature of the relationship between C1 and C2 (phonologically and semantically similar items will be termed identical, whereas phonologically similar but semantically different items will be termed homophones). For identical trials, there were four formats: ww, pp, wp and pw. Repeatedness and format were counterbalanced within subjects and within items; this 2X4 design resulted in 8 different versions. For homophone trials, there were two formats: pw or wp. Repeatedness was counterbalanced within subjects and items, but format was within subjects but between items.

The final variable, within subjects and items, was the task. Subjects viewed the sentences silently in one block, and repeated the syllable dadadada... about four times per second in the other block. The orders of the two blocks and the two tasks were counterbalanced[4]. Each block began with 11 practice sentences containing zero, one or two pictures.

Procedure. The same procedure as in Experiment 2 was used. Items were displayed for 100 milliseconds each.

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4 The only factor which was not counterbalanced was the fact that each of the experimental list did not appear in all of the order X task conditions.

Apparatus. The same apparatus as in Experiment 1 was used.

Results

The same method of scoring as in Experiment 4 was used, since it was again noted that homophone trials in which C1 is a word and C2 is a picture did not behave with respect to RB as did the other trials, in the silent condition. In particular, in those trials RB affected the recall of C1 rather than C2. Hence, the percentage of recall of both C1 and C2 was calculated; this percentage for each of the conditions is reported in Table 6.

Table 6

Experiment 6: Percentage of trials in which C1 and C2 were both recalled

	Identical					Homophone		
	ww	pp	pw	wp	M	pw	wp	M
Task/Repeatedness								
Silent								
Non Repeated	82	69	66	90	77	58	80	69
Repeated	41	51	40	65	49	38	70	54
Non Rep. - Rep.	41	18	26	25	27	20	10	15
Articulation								
Non Repeated	72	66	58	78	68	63	73	68
Repeated	40	51	43	52	46	56	80	68
Non Rep. - Rep.	32	15	15	26	22	7	-7	0

Overall recall accuracy for the sentences was good. Recall of the words of the sentences (including closed class words) other than C1 and C2 averaged 81%. Analyses of variance by subjects and by items were conducted on the number of times both C1 and C2 were correctly recalled for identical and homophone trials separately. The effect of order will not be fully reported, because it did not affect the main conclusions of the experiments. For each type of trial, a main effect of order was found due to fewer errors for block 2 than 1. This effect interacted with repeatedness (due to lesser RB for block 2 than block 1); however, the three-way interaction between order, task and repeatedness was always far from significant ($ps > .35$). Hence, analyses of variance with repeatedness, format (pp, pw, wp, ww) and task as factors will be reported.

For the identical trials, there was a main effect of repeatedness, $F1(1, 15) = 29.2$, $p1 < .0001$, by subjects, and $F2\ (1, 55) = 54.5$, $p2 < .0001$, by items, and a main effect of format, $F1(1, 15) = 4.9$, $p1 < .005$, by subjects, and $F2\ (3, 155) = 5.9$, $p2 < .001$ by items, indicating fewer errors in the wp condition. A main effect of task was found by items, $F2\ (1, 55) = 5.9$, $p2 < .018$, but not by subjects, $p1 > .2$, indicating slightly more errors in the articulation condition than in the silent one. None of the other effects were significant. Specifically, there was no interaction between repeatedness and task ($p1 > .45$ and $p2 > .25$), indicating that the size of RB for these identical trials was similar whether subjects were silent or articulated.

For the homophone trials, the main effect of repeatedness was significant by subjects, $F1(1, 15) = 5.6$, $p1 < .031$, and only marginally significant by items, F2 (1, 38) = 2.66, p2=.11, indicating that RB was only marginal. This small amount of RB was due to the articulation condition as indicated by the interaction found between repeatedness and task, F1(1, 15) = 7.1, p1<.017, by subjects, and F2 (1,38) = 5.7, p2<.021 by items. A main effect of type (wp vs pw) was also found, F1(1, 15) = 46.3, p1<.0001, by subjects, and F2 (1, 38) = 14.4, p2<.001 by items, due to fewer errors in the wp trials. Finally a main effect of task was found by items, F2 (1, 38) = 5.5, p2<.025, but not by subjects, p1>.12, with slightly more errors in the silent task than in the articulation task. Given the interaction between task and repeatedness, silent versus articulation trials were analyzed separately. For the silent trials, the findings of Experiment 4 were confirmed. A main effect of repeatedness was found, F1(1, 15) = 12.7, p1<.003, by subjects, and F2 (1,38) = 8.5, p2<.006 by items, confirming the presence of a repetition effect between phonologically similar but semantically unrelated pictures and words. A main effect of format was also present, F1(1, 15) = 20.9, p1<.0001, by subjects, and F2 (1,38) = 17.8, p2<.0001 by items, due to fewer errors in the wp trials than the pw trials. None of the other factors were significant. For the suppression trials, the only significant effect was a main effect of format, F1(1, 15) = 31.3, p1<.0001, by subjects, and F2 (1,38) = 6.8, p2<.013 by items, due to fewer errors in the wp trials. None of the other effects were significant (ps >.19).

Discussion

The main findings of Experiment 6 are that concurrent articulation does not disrupt RB between visually identical items (whether both are pictures or words); that it does not disrupt RB between mixed pictures and words that are phonologically and semantically similar (whether the picture comes first or second); but that it does disrupt RB between phonologically similar but semantically different mixture of pictures and words (whether the picture comes first or second). Because concurrent articulation interacted with RB in one of the experimental conditions, it is clear that the implicit manipulation of the task was effective. Moreover, the results in the silent condition replicate those of Experiment 4. Specifically, RB between phonologically similar but semantically different pictures and words is confirmed, as well as the finding that recall of C1 (size of RB:10%) rather than C2 (size of RB: 0%) is affected by RB in wp homophones trials.

In the absence of any independent knowledge about the levels at which articulatory suppression can affect picture processing, there are certainly several possible explanations for the finding that concurrent articulation disrupts RB between phonologically similar pictures and words when they are semantically different, but does not when they are semantically identical.

This pattern of results could be interpreted as indicating that RB between semantically different pictures and words arises from a phonological confusion during the maintenance of these items in STM. The absence of any effect of articulation when the items are semantically similar could then be interpreted as meaning that in this case RB arises from semantic confusion effect during maintenance of these items in STM. Such an interpretation would lead to the conclusion that RB between a picture and a word (disrupted by articulation) and RB between words (unaffected by articulation) are two distinct phenomena. In this view, RB can arise both during the perceptual stage of processing and during the maintenance of information in STM. This view, however, is weakened by the finding that RB between two identical pictures (that could happen both at the perceptual and the memory level, according to this view) is often less than RB between pictures and words (that could happen only at the memory level, according to this view) (Experiments 4 and 6); as well as by the observation that the pattern of errors for confusion effects in STM is different from the one observed for RB. Indeed, the phonological similarity effect in STM is typically reflected in the difficulty of recalling item order, not the items themselves, in contrast to RB which is always manifested by the failure to recall one of the critical items.

An alternative interpretation of the results of Experiment 6 is that concurrent articulation delays access to an early phonological code for pictures but not for words, and biased subjects toward semantic encoding in STM, in the present conditions using sentence recall. For words, since a phonological code is efficiently retrieved regardless of the task (Besner & Davelaar, 1982), phonological codes would be used for the stabilization of their corresponding token even under concurrent articulation. Hence, articulatory suppression would not disrupt RB between words. For pictures, articulatory suppression would delay the retrieval of phonology, suppressing RB between phonologically related but semantically different words. The fact that RB for phonologically and semantically related picture-word pairs is still present is consistent with the hypothesis that semantic information is predominantly used to stabilize pictures in STM under concurrent articulation.

In this view, one could expect phonological RB between words to be diminished under articulatory suppression if the task was a semantic one (such as a plausibility judgement) rather than a phonological one (verbatim recall). Although this hypothesis has not been tested, some recent data are consistent with the present assumption that articulatory suppression can bias toward semantic encoding in STM. For example, the phonological similarity effect found in semantic categorization tasks (Van Orden, 1987), that has been attributed to an early phonological code, has been shown to disappear under concurrent articulation (Quinn, 1989). The same logic should hold for visual encoding. Since visual encoding of pictures has been shown to be enhanced under concurrent articulation (at least relative to phonological encoding), one may have expected RB between a word-picture pair to be diminished even when the two are semantically identical. The failure to find such a diminution in the present experiment could be due to the use of verbatim recall of rather long sentences, possibly diminishing the effect of visual dissimilarity.

Although it is clear that a more thorough investigation of the role of concurrent articulation on picture processing will be necessary to fully understand the present result, this experiment already makes clear that task requirements can modify the amount of RB, and that semantic information when using pictures (or possibly lexical information that is not phonological) may also determine the amount of RB. This latter observation may explain why effects of the visual tasks in Experiments 5A, 5B and 5C, in which semantically equivalent pairs were used, were relatively difficult to establish. It would also be consistent with the failure to find RB between pictures of different objects with the same name but two different underlying meanings (e.g., a palm tree and the palm of a hand; Kanwisher, 1991b), although an alternative explanation of that result could be the pictorial difference between the two objects, which was greater than that in Experiment 5A's different condition.

To conclude, Experiments 5 and 6 indicate that the size of RB between visually dissimilar items can be varied as a function of the information the task requires to be encoded in the token. They confirm the conclusion of Experiment 4 that the amount of RB is also determined by the nature of the code most effective in stabilizing the token of a given item. They also demonstrate that semantic similarity (whether purely conceptual or lexical-semantic) can influence the size of RB when using pictures.

V. GENERAL DISCUSSION

In this paper, phonological RB was shown to generalize to items that are not readily verbalized, such as pictures (Experiment 3 and 4). RB between visually different items (whether phonologically and/or semantically related) was shown to arise when the tokens of these items compete for a single code that is important for their stabilization (Experiments 3, 4, 5, 6). Accordingly, RB was found to be dependent on the information the task requires to be registered in the tokens (Experiments 3, 4, 5 and 6), and to be modulated by the nature of the initial recognition codes (Experiments 4 and 6).

Experiments 1 and 2 established RB between complex visual stimuli such as pictures in lists, as well as in sentences, and showed that RB between identical pictures is comparable to RB between identical words (Experiment 1). Experiment 3 replicated that result for identical pictures or words in sentences, and established RB between a mixture of pictures and words. This finding confirms earlier work indicating that visual similarity is not necessary for RB. Although such a result is consistent with the claim that phonological similarity can induce RB between a picture and its corresponding word, the latter finding could also be explained by semantic similarity. The goal of Experiment 4 was to disambiguate the contribution of these two kinds of information. RB between phonologically and semantically similar items (i.e., the picture of a cat and the word 'cat') was compared to RB between phonologically similar but semantically dissimilar items (i.e., the picture of a sun and the word 'son'). The finding of RB in this latter case shows that phonological similarity alone is sufficient to produce some degree of RB, and shows that phonological RB can be found when using stimuli that are not readily verbalized. Experiments 5A, 5B and 5C indicated that, to a certain extent, phonological/semantic RB can be manipulated by the way information is initially stabilized in STM. When subjects were asked to explicitly encode the visual attributes of items, RB between phonologically and semantically similar items was diminished when these items were visually dissimilar. Experiment 6 established that phonological RB between pictures and words (e.g., picture of a sun/word 'son') can be manipulated by the task requirement; it also suggested that semantic similarity can play a role in RB when using pictures.

The present experiments suggest two important characteristics of RB between visually different items. First, such RB is a function of the similarity of the code or codes that will be registered in the tokens of C1 and C2 in STM; such codes are determined by the nature of the items (e.g., shape and meaning for pictures, orthography and phonology for words) and modulated by the requirement of the task. Second, such RB represents a failure to stabilize an already opened token, rather than a failure to open a new token (Kanwisher, 1987). In the next two sections I will review evidence supporting these two points, and discuss their implications. In the final section, I will discuss the implications of the present finding of RB between pictures and words for theories concerning the processing of pictures and words.

1- RB between visually different items is determined by the similarity of the codes registered in the tokens of C1 and C2 in STM

The first claim is that RB will arise when similar codes have to be registered in the tokens of C1 and C2. In this view, different kinds of code could be entered in a given token. The first codes registered in the token would be the recognition codes initially retrieved during processing of the item; then, if the task biases encoding toward other kinds of codes, these other codes would also be registered. The failure to register one of the required codes in the token would result in a weaker token, rendering it more subject to loss. This view is mainly supported by the study of phonologically or semantically induced RB between pictures and words.

First, it was established that RB occurs when the task requires similar codes to be registered in the tokens of C1 and C2, even though the codes readily retrieved during recognition for each of these items differed. The use of pictures and words dissociated the codes needed for registration and the codes readily accessed during recognition. Studies comparing the processing of words and pictures have shown that the first codes retrieved during recognition of pictured objects are pictorial and conceptual, whereas for written words the initial code is lexical, encompassing orthography, phonology, and articulation (Potter, 1979; Theios et al., 1989; Snodgrass, 1980). Using a task that biases toward phonological encoding in STM, RB between phonologically similar pictures and words was observed in Experiments 3, 4, 5 (phonological task), and 6 (silent); RB was obtained whether the pictures and words were semantically equivalent or not. These findings support the claim that RB occurs when similar codes have to be registered in the tokens of C1 and C2. Although the dissimilarity of the codes immediately accessed during recognition does not prevent RB from occurring, it seems to modify the pattern of RB. Hence, in the wp homophone trials, RB was found to affect the recall of C1 rather than that of C2. This effect suggests that the rapidly retrieved conceptual/pictorial code for the picture advantaged the C2 token in the competition between the C1 and C2 tokens for the same phonological code.

Second, by changing task requirements to vary the nature of the code to be registered in the token the amount of RB was shown to vary as predicted. RB was obtained between phonologically related but semantically distinct pictures and words, when the preferred encoding for token stabilization and recall is phonological. However, if a visual (or conceptual) bias was induced, the same RB effect was reduced. In Experiments 5 and 6, the stimulus materials were held constant while the task varied. Tasks that required the subject to distinguish between two visually different items (e.g., between a picture and a word) or that hampered the retrieval of a common phonological code for visually and semantically distinct items reduced RB for these items. Again these results indicate that RB is dependent on the similarity of the codes that will have to be registered in the tokens of C1 and C2.

In the present experiments, the use of pictures and words allowed us to disambiguate between codes readily retrieved during perception and codes required to be registered in the tokens in STM. It is plausible that such a distinction is often difficult to draw because the information required to be registered in STM is usually of the same nature as the code readily retrieved from perception. Only when a strong task-related constraint biases the preferred encoding in STM, may this code be different from the ones readily retrieved during perception. In this view, phonological or semantic RB is observed because the task or/and the items used bias subjects toward registering a phonological or a semantic code in the tokens (Experiments 4 , 5 and 6).

2- RB results from competition between the tokens of C1 and C2 for the same type

The second theoretical claim concerns the mechanism responsible for RB. While I agree with Kanwisher (1987) that RB is best understood as a problem in establishing two tokens from the same type, I wish to propose that such a problem can arise not only during the creation of a new token, but also during the attempted construction or stabilization of a newly opened token. The distinction between the creation of a token and its construction is based on the idea that the establishment of a token is not a all-or-none process, but rather a dynamical process during which the information encoded in the token, and so its stability, will vary. Such a distinction is captured, for example, in Kahneman and Treisman's object-file framework (1984). It is proposed that initially spatio-temporal constraints will lead to the parsing of the visual scene into object tokens or object-files. Once an object token is created, the codes that are retrieved during perception of that object would have to be entered in the token in order to mediate conscious perception. This second step is what I term the construction of a token. The present experiments suggest that the codes involved in the construction process, i.e. those entered in the token, are a function of the codes readily retrieved during perception as well as a function of the task requirements. The present results are also compatible with the idea that tokens, as memory representations, are more or less labile; and they support the claim that the information entered in a token during the construction process controls its stability. Thus, salient information, such as picturehood among words or distinct conceptual information for a picture, will render a token more stable; in general, given the efficiency of phonological encoding in STM, phonological information will be the most efficient information to stabilize a token, provided that the object has a name.

The claim that RB can arise from a failure to construct and stabilize an opened token (Bavelier & Potter, 1992; Bavelier, Prasada & Segui, 1992) is mainly supported by the pattern of manifestation of phonological RB. First, in the repeated wp trials (Experiment 4 and 6's silent condition), it occasionally happened that although subjects would correctly recall C1 as a word, they would also sometimes recall having seen a picture at the C2 location without being able to give its exact name. Although this observation is anecdotal, such an event suggests that a token was created when C2 was presented, in which some salient information about its distinctive pictorial format was entered. Second, RB was found to affect the recall of C1 instead of C2 on some trials, particularly, when C1 was a word, C2 a picture and they were phonologically identical but semantically different (i.e., 'son' and the picture of a sun) (Experiments 4 and 6). This indicates that the presentation of C2 initially led to the creation of a token, in which some visual and conceptual information about C2 was entered. The failure to report C1 rather than C2, in the repeated trials, suggests that RB arose from a competition between the tokens of C1 and C2 for a single phonological code, allowing RB to appear as an impairment in the recall of C1. Finally, an analysis of the pattern of errors in list experiments with homophonic words (Bavelier & Potter, 1992; Bavelier, Prasada & Segui, 1992) (always three items to recall) suggests that when C1 and C2 are phonologically similar but visually different words, subjects seem more aware that there were three visual events than when C1 and C2 are visually similar words. In these experiments, failure to correctly recall a word can either result from its omission or from the recall of an unrelated word instead (in all the scoring, recall of a related item -for example, an orthographic neighbor- was scored as correct). One could expect that the more aware subjects are of the presence of three items, the higher the ratio of replacement errors to omission errors. A comparison of the distribution of errors in the nonrepeated trials and repeated trials in which C1 and C2 were identical confirmed this view. The ratio of replacement errors over the total number of errors was computed in each condition; the difference between these ratio indicated that the contribution of replacement errors was larger (size of the effect +17%) in the nonrepeated trials than in the repeated trials. In contrast, the contribution of replacement errors in the nonrepeated trials and the homophone repeated trials was found to be equivalent (size of the effect -5%; larger for homophone repeated trials). Hence, replacement errors are relatively more frequent in nonrepeated or homophone repeated trials than in identical repeated trials, suggesting that the presentation of C2 may have been more often detected as a visual event in the former trials than in the latter. Taken together, these results indicate that, when using RSVP, if C1 and C2 are visually different a token will be created for C2 as well as for C1; in these cases, RB seems to arise from a competition for the registration of the same code during the establishment of the tokens of C1 and C2.

While up to now I have only discussed RB as it is observed when using RSVP, the claim that RB can arise from a competition process for the same stabilizing code during the construction of tokens seems also supported by the pattern of RB found in spatial arrays. Kanwisher (1991a) initially demonstrated spatial RB when briefly flashing a visual display with 4 letters, two of them being identical. Recently, Kanwisher and Driver (1992b) reported that when flashing a visual display with 2 items, even on trials where RB occurs subjects report having seen two objects and not one. This pattern of results indicates that two distinct tokens were initially created. Because the same identity information had to be registered in each of them they competed, eventually leading to only one of the token having access to the identity information. The deprived token, although more labile, may sometimes be saved in this case by the presence of salient spatial information.

In general, it seems that RB due to the failure to create a new token for C2 may be restricted to visually similar items with RSVP or with displays that are both temporally and spatially sequential; RB due to the competition of two opened tokens for the same codes seems to account for phonologically and/or semantically induced RB using RSVP, as well as for RB observed in simultaneously presented spatial arrays.

3- Picture versus word processing

Although throughout the paper I exploited the fact that pictures and words are processed differently, I wish now to briefly discuss what the finding of RB between pictures and words may imply for the further understanding of the processes and structures representing those kinds of visual stimuli. The most commonly accepted current view about picture and word processing is that they converge on a single conceptual code. In this view, different surface forms (words or pictures) gain equal access to a common abstract semantic code (Potter, 1979; Potter et al., 1986; Snodgrass, 1984; Theios et al., 1989). This claim is supported by the finding of cross-form priming between pictures and words (Kroll & Potter, 1984; Vanderwart, 1984), by the finding that pictures and words are equally effective in probing the meaning of a sentence or a scene (Potter, Valian & Faulconer, 1977; Potter & Elliot, 1977), and by the finding that even in tasks that are primarily linguistic, like understanding a rapidly presented sentence, pictures can replace concrete nouns with relatively little impairment in sentence comprehension (Potter et al., 1986). Access to this common conceptual code is believed to be mediated by two different pathways. While written words are initially processed through a linguistic pathway, leading to lexical retrieval and fast access to phonological information, pictures are initially processed through a pictorial form-specific pathway, resulting in rapid access to spatial, featural, and conceptual properties (see Theios et al., 1989, for a review). For a picture to retrieve its corresponding phonological code, its conceptual code has to be accessed first, and then used to find and select a lexical entry or lemma, leading eventually to a phonological code (Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1990). This view is supported, for example, by the classical finding that pictures take longer to name than written words (Cattell, 1886).

The finding of phonological RB between pictures and words suggests that, at least in a verbal recall task, a picture activates the same phonological representation as its corresponding word. Such an assumption is consistent with the framework just described. The fact that phonological RB can be obtained between a picture and a word when they are semantically different (Experiments 4 and 5) seems surprising, however, given the supposed primacy of conceptual information during picture processing. For example, the time to categorize pictures is usually shorter than the time to categorize words, suggesting that conceptual information is more efficiently retrieved during picture processing than word processing (Rosch, 1975; Potter et al., 1975; Smith & Magee, 1980). The primacy of conceptual information during picture processing could have been sufficient to help overcome RB between phonologically similar but semantically dissimilar words and pictures. A close look at the data suggest that, although RB was obtained, the conceptual information retrieved from the picture did play a role. First, RB between homophonic pictures and words had a tendency to be less than RB between semantically identical pictures and words (25% versus 13% in Experiment 4; 27% vs 15% in Experiment 6). Second, in the wp trials, the C2 picture seemed to be saved from RB when it was conceptually different from the C1 word. These data suggest that conceptual information was readily retrieved during picture processing, and less so during word processing. Conceptual information for words may also have been less salient in the present experiments, given that the presentation of a word, unlike a picture, has been proposed to trigger the activation of not only its meaning but also those of its orthographically, phonologically and semantically related neighbors (Levelt et al., 1990; Swinney, 1979; Tanenhaus, Flaningan & Seidenberg, 1980; Tanenhaus, Leiman & Seidenberg, 1979). Hence, for example, the presentation of the word 'son' could result in the activation of the meaning of 'sun'. This fanning of activation may reduce the strength of activation of the conceptual code corresponding to the presented word, as well as reducing the semantic difference between the critical C1 and C2. This suggests that conceptual information may be found to play a greater role when looking at RB between "homophonic" pictures than RB between words and pictures.

The finding of RB between pictures and words seems, so far, consistent with what is known of the processing of these kinds of stimuli. However, a challenging aspect of that result is that it supposes an early involvement of phonological encoding for pictures, even during sentence processing. Previous data suggested that readers do not routinely understand rebus sentences by covertly naming the picture before integrating with the rest of the sentence, but rather by using a purely conceptual representation (Potter et al., 1977; Potter et al. 1986). This view is supported by the finding that even though pictures take about 250 ms longer to name than words, integrating them into a sentence stream in which items are presented sequentially for about 100 ms can be achieved by the reader with little if any disruption. This disparity between picture naming and the processing and recall of rebus sentences was interpreted by Potter et al. as showing that pictures are integrated in the sentence through their readily available conceptual representation, and not through their slowly retrieved lexical/phonological representations. This view is consistent with experiments using a plausibility judgment task when presenting RSVP rebus sentences with picture puns (e.g., a Yale lock standing for a 'lock' (of hair)). Subjects had difficulties when required to use a purely lexical/phonological representation to integrate the picture in the sentence (Potter, 1981; Potter & Carpenter, 1984). On the other hand, subjects did show some ability to carry out this task (treating the Yale lock as a "lock" of hair) indicating that the picture's name was rather rapidly retrieved. These data support the claim that phonological representations are not the sole mediating representations used in reading; nevertheless, they are consistent with the view that these representations can come into play relatively rapidly during RSVP sentence processing.

This observation would be compatible with the dynamical account of the flow of information into individual tokens previously proposed. In this view, the appropriate visual types (initially, of course orthographic or pictorial) would be first entered in the token, then conceptual, and lexical types. If one assumes that the information entered in the token is the only information feeding "upward" to the various levels of sentence processing, several kinds of information will indeed be able to mediate reading[5]. This view supposes that tokens are a pre-condition for further on-line sentence processing. Although naming a picture is delayed compared to naming a word, pictures

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5 This account was originally suggested to me by M. C. Potter.

would be easily integrated into a sentence stream because delay in accessing a phonological type does not mean delay in initially setting up a token with its corresponding conceptual information. Hence, as suggested by Potter et al (1986), on-line integration of a picture in a sentence would be initially secured by conceptual/semantic information readily retrieved and registered in the token. This could explain the primacy of the C2 picture, in the wp homophone trials. Moreover, the observation by Kanwisher (1986) that subjects typically judge as ungrammatical sentences for which RB occurred, suggests that RB happens (at least for identical words) before the syntactic and semantic relationships of the items in the sentence are computed, or in other words, before any information could be registered in the token to be passed "upwards" to the sentence processor. This would be consistent with the claim that tokens are a precondition for further sentence processing. As RB is better understood, it may prove to be a useful tool to investigate the mechanisms involved in sentence processing, or at least in RSVP sentence processing.

To conclude, this paper reveals two important characteristics of RB: first, it shows that phonological RB is due to the similarity of the codes used for stabilization of the tokens in STM rather than to the similarity of the codes first retrieved during perception; second, it suggests that tokens, at least for RB, are to be seen as dynamical entities, which are built over time (albeit a very short time) as a function of type activation and task requirements, and which are more or less stable, as a function of the information that is entered into them and the efficiency of STM. Taken together, these data support the view that RB could occur at any step during the establishment of a token, arising not only from a failure to create a new token (Kanwisher, 1987), but also from a failure to construct and stabilize an opened token (Bavelier & Potter, 1992; Bavelier, Prasada & Segui, 1992).

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Author Notes

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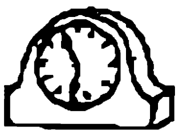
VII. APPENDICES

Appendix A

The two sets of eight picturable nouns used in Experiments 1 and 6B

Set 1:



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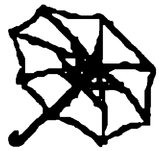
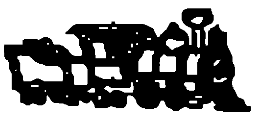
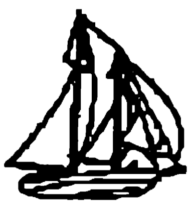


umbrella

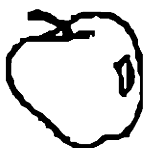
monkey



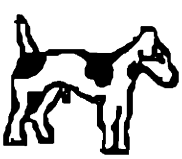
train



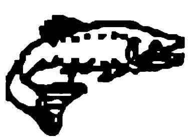
sailboat



apple



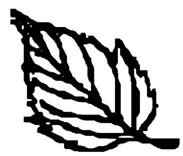
dog



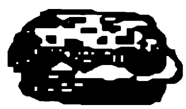
fish

Set 2:

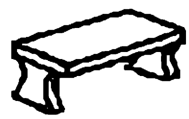
butterfly



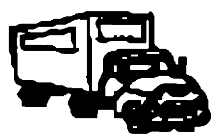
leaf



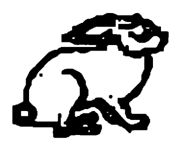
sandwich



bench

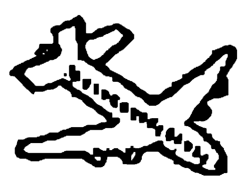


truck



rabbit

cat



plane

Appendix B
Sentences used in Experiment 2 (nonrepeated C1 word in brackets)

1-I replaced my old clock [watch] by a larger (large) clock for the test.
2- Mary threw away the old asparagus [tomato] and cooked fresh asparagus for Joe.
3- That old car [truck] passed our car very quickly.
4- Paul added a cherry [strawberry] to the strawberry on the plate.
5- Tom chased her cat [dog] and the cat ran away.
6- The police sent a bus [helicopter] to rescue the bus in the mountains.
7- They stole my father's desk [drum] and the desk in the living room.
8- The speeding bicycle [train] hit a bicycle at the crossing.
9- Yesterday's cake [sandwich] and this cake were truly disgusting.
10- We cooked the pumpkin [corn] but the pumpkin you bought is still in the refrigerator.
11- The young lion [monkey] provoked the old lion in the next cage.
12- A large bottle [pitcher] hid the bottle we were looking for.
13- The blue of my dress [jacket] matches your dress perfectly.
14- Laura put the pencil [pen] with Mark's pencil in the pot.
15- This french cigarette [cigar] is stronger than the cigarette I used to smoke.
16- I put the broken screwdriver [pliers] with the other screwdriver in the tool box.
17- They stole Mark's motorcycle [violin] and the motorcycle belonging to his grandfather.
18- You need a yellow apple [banana] and a green apple for this pie.
19- Michael almost dropped his glass [cup] and Joan's glass on the way to the kitchen.
20- I always keep this key [purse] and the key of my house in a different place.
21- One dessert spoon [fork] and a large spoon were missing from the table.
22- They decided to build a small church [windmill] instead of the church I used to go.
23- Mary decided to buy a lamp [table] and repair the lamp in the cellar.
24- Mike could not decide between his old sweater [coat] and his new sweater that he was afraid of staining.
25- I took his umbrella [hat] instead of the umbrella my mother gave me.
26- Terry traded in his guitar [trumpet] for a guitar of the sixties.
27- I found a rotten pineapple [lemon] and a good pineapple in the basket.
28- I ate a tiny carrot [celery] but kept a big carrot for the salad.
29- I think I prefer the other doll [plane] to the doll you chose.
30- The old couch [chair] and the brown couch were both sold.
31- I lost my old glasses [pipe] and broke the glasses I just bought.

32- I threw away an old toothbrush [comb] and bought a new toothbrush at the store.

Appendix C
Additional sentences used in Experiment 3 (nonrepeated C1 word in brackets)

1. In the accident he broke his right leg [foot] but my leg was fine.
2. She took off the ring [cap] and put another ring on her finger.
3. In the garden the boy caught a butterfly [caterpillar] and let the butterfly go.
4. After John used the ladder [hammer] he took the ladder to the shed.
5.The soldier reloaded the gun [cannon] before firing the gun again.
6. In the drawer was a red mitten [sock] but the other sock I lost was under the bed.
7. The boy scouts built a sled [fence] and painted a sled for the children.
8. As I opened the door [window] the back door to the kitchen slammed.
9.As Dan looked at the sun [star] the setting sun glowed brightly
10. She will pick up the box [envelope] because that box has to be sent very quickly
11. After Sam played with the kite [bat] he stored the kite and string in the closet
12. She matched the flower [ribbon] to the flower in her hair.
13. Although he did not own a harp [piano] he played the harp very well.
14. The young frog [alligator] escaped from an alligator that was ferocious
15. This lightbulb [candle] burned out but the lightbulb in the kitchen is fine.
16. Here is some fresh fish [bread] and some frozen fish is in the refrigerator.
17. In this play they used a silver helmet [crown] as a crown for the princess.
18. We saw only one sailboat [swan] from our sailboat last time.
19. We moved this vase [telephone] and put the telephone I just got in its place.
20. A tropical snake [spider] can eat a smaller snake when food is scarce.
21. They fixed this lock [chain] but the lock of the cellar is still broken.
22. There was a great advertisement for a television [toaster] on the television last week.
23. The soft sound of a whistle [bell] preceded a louder bell that woke us up.
24. I put the skirt on the stool [hanger] and left the stool in the room.

Appendix D
Sentences used in Experiment 4 (nonrepeated C1 word in brackets)

C1 and C2 phonologically and semantically similar

1. After I ate the cake (celery) I discovered the cake was six days old.
Kelly liked the lemon cake (pie) but the chocolate
2. Ben knocked over his glass (chair) which hit my glass and broke it.
My glass (cup) is the only glass with a crack in it.
3. I pushed my bread into the toaster (slot) even though the toaster was full.
A demon possessed my toaster (house) and now my toaster will not work.
4. The chef poured oil into the bottle (pot) until the huge bottle on the shelf was empty.
The winetaster uncorked the bottle (champagne) while holding the bottle firmly.
5. I adjusted the lamp (table) so the lamp would cast more light upon my drawing.
I tried to steady the lamp (table) but the lamp came crashing to the floor.
6. The magician pulled off his cap (hat) to reveal a cap underneath.
When Dick wore his lucky cap (outfit) he put his cap on backward.
7. Erin used to go to church (confession) until her church burned down.
Underneath this old church (house) is a church which is even older.
8. The day Sam got a new glasses (shoes) his old glasses disappeared.
I love to wear my glasses (spectacles) because these glasses make me look intellectual.
9. The waiter replaced my dirty fork (ustensil) with a clean fork while muttering apologies.
Sarah accidentally used Bob's fork (spoon) instead of the fork by her plate.
10. As Jill bit into the asparagus (carrot) she realized the asparagus was still on the fire.
When Mario prepared the asparagus (meal) he overlooked some asparagus in the back of the refrigerator.
11. Myrtle ordered a steamed artichoke (potato) but a baked artichoke is what she really longed for.
I cut the spines off the artichokes (leaves) and placed the artichokes in boiling water.
12. The secretary sat at his desk (workstation) though the tiny desk was too short for him.
Alex moved his desk (dresser) around until the desk was the focal pint of the room.
13. Kristin's doll (teddy) and my doll had tea and mudpies together.
This new doll (puppet) is the doll that Grandma brought for Jeannie.
14. I searched the bathroom for my new toothbrush (comb) and found your toothbrush instead.

I hated mom's old toothbrush (dentist) because her stiff toothbrush made my gums bleed.
15. I looked impatiently for the clock (time) but no clock was to be found.
I hit the clock (stool) because the clock was ringing.
16. Maggie bought a new guitar (drum) when her guitar was stolen.
Behind this guitar (accordion) is the guitar which is on sale.
17. The hunter reached for his gun (rifle) and aimed his gun at the frightened bird.
18. The loveliest fox (animal) is the red fox that lives behind our house.
The cruel hunter aimed at the silver fox (snake) while the poor fox cowered into the bushes.
19. When we built the cabin my hammer (shovel) was the best hammer we had.
This hammer (tool) is the same hammer my grandfather used to work with.
20. The second flute (violin) joined the first flute in a thrilling duet.
By far the most beautiful flute (instrument) was a handcrafted flute from Mexico.

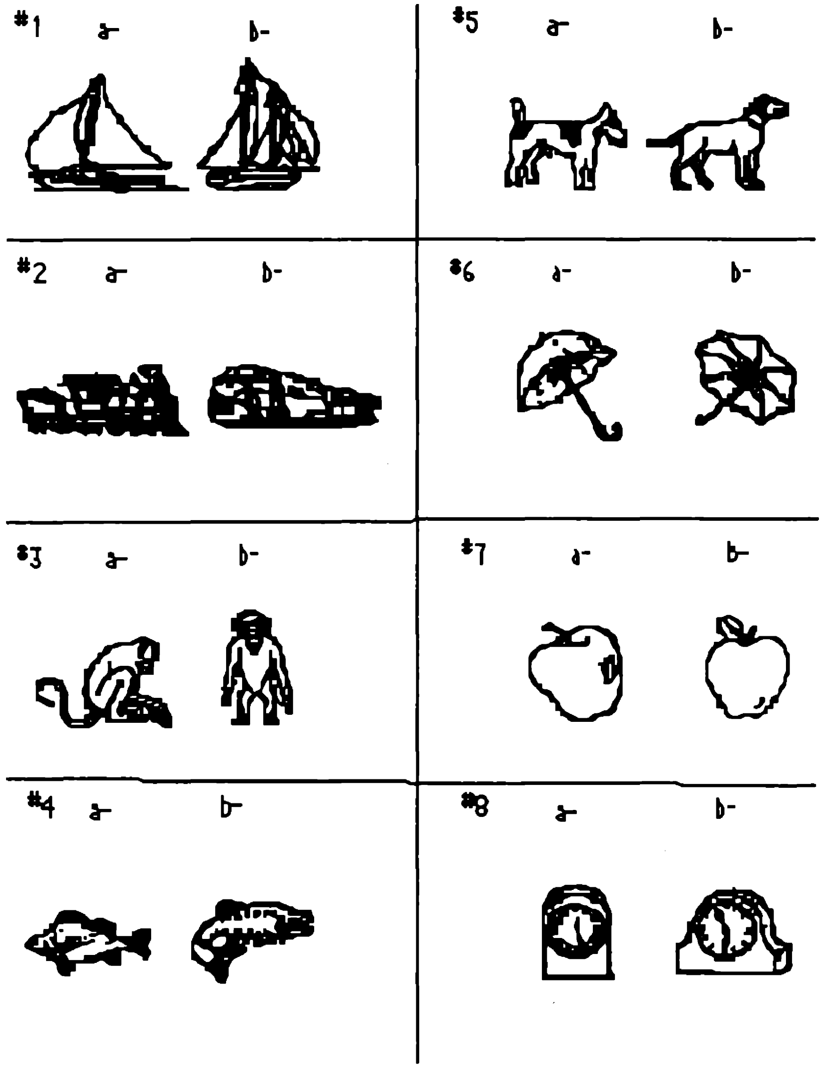
C1 and C2 phonologically similar but semantically dissimilar

1. The giant ant (fly) scared my aunt who is extremely skittish.
I was glad when my cruel aunt (uncle) saw the ant which crawled into her soup.
2. Amy punched me in the eye (ear) today so naturally I slapped her.
Yesterday I (he) dropped my (his) glass eye and scared everyone in the class.
3. Todd began to bawl (cry) after losing his ball in the woods.
Mark got hit by the ball (car) and began to bawl like a baby.
4. Sally screamed at the horse (elephant) until she was hoarse from yelling.
I was so hoarse (sick) my very own horse did not respond to my voice.
5. While the orchestra played Pachebel's canon (fugue) the loud cannon made too much noise.
I heard the loud cannon (horn) while Pachebel's canon was being performed.
6. I shall wring (cover) my hands until my ring is found.
Tony knew that if he lost the ring (key) his bride would surely wring his neck.
7. Walking on coals with my bare feet (leg) is a feat I have not accomplished.
Lucy's first extraordinary feat (act) was to use her feet to draw.
8. The baby bear (monkey) climbed onto my bare shoulders.
My bare (left) foot touched the bear as it walked past where I was hiding.
9. It could be (appear) that the bee does not like to sting people.

If I could catch that bee (chicken) it could be my pet.
10. The bread (cake) was made with specially bred wheat.
The farmer who bred (grew) this grain for the bread is a genius.
11. My doctor knows (understands) more about my nose than I care to find out.
That woman with the big nose (lips) is sure she knows who murdered the butler.
12. He grabbed the drowning man by the toe (leg) and began to tow him toward the shore.
The lifeguard tried to tow (pull) Jim by his toe but Jim's foot fell off.
13. Julia's beau (father) gave her a bow which she secretly thought was ugly.
Sylvia wore a bow (necklace) to impress her beau but it fell off.
14. Bill used his shoe (boot) to try to shoo the mouse out of the corner
Kelly saw the mouse and tried to shoo (kick) it with her shoe but it did not move.
15. I heard that sprinkling flour (paprika) all around a flower helps it grow.
The chef walked in with a flower (banana) for Kristin and flour on his nose.
16. It was plain (clear) to see that the plane was out of control.
The smallest plane (helicopter/car) was very plain and had no camouflage
17. The tribal chief will sacrifice his son (nephew) to the sun when he turns twelve.
Just when the sun (moon) rose my son was born.
18. I saw a pair (bunch) of gloves and a pear sitting on the table.
Craig dropped a rotten pear (apple) on his brand new pair of pants.
19. The big eyed deer (goat) quickly became very deer to us.
Although it had grown very dear (special) to us our deer had to be sold.
20. The nun (ballerina) decided that she liked none of the skirts in the store.
Last year none (all) of us liked the nun who ran our school.

Appendix E
Example of answer sheet for the visual task and the phonological task

Answer sheet for the visual task



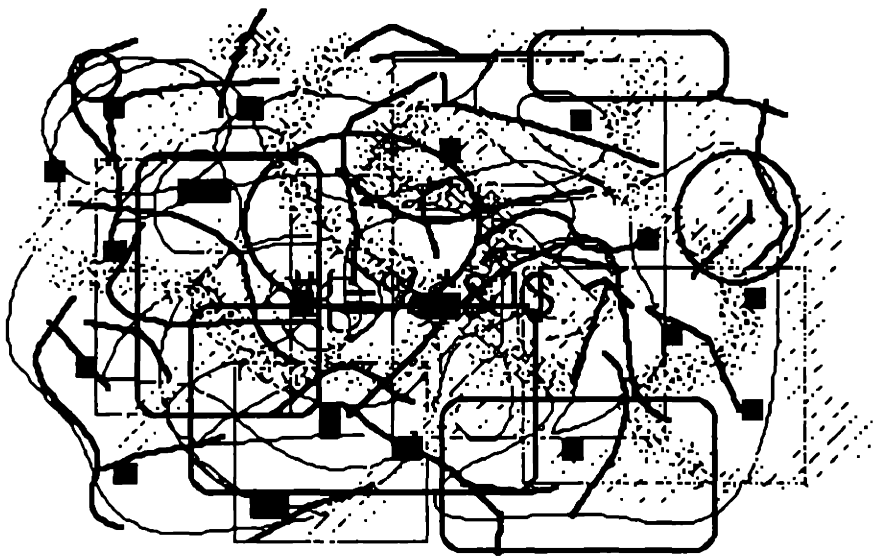
Answer sheet for the phonological task

#1 sailboat	#5 dog
#2 train	#6 umbrella
#3 monkey	#7 apple
#4 fish	#8 clock

VIII. FIGURES

Figure 1

Two examples of masks from Experiments 1, 5B and 5C



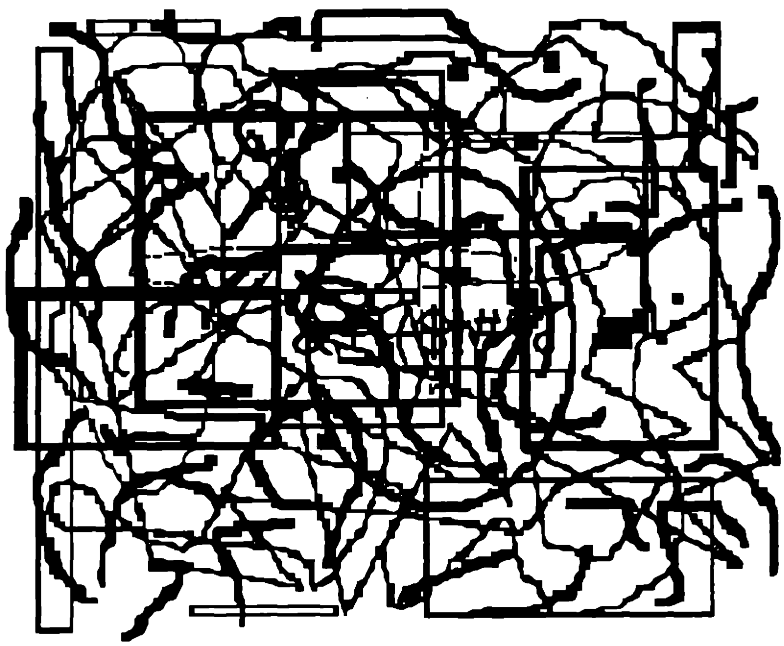


Figure 2

Example of the non-object picture used in Experiments 2 and 3

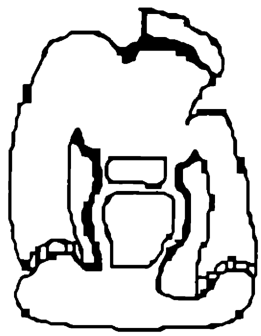


Figure 3

Example of the non-object picture used in Experiments 4 and 6

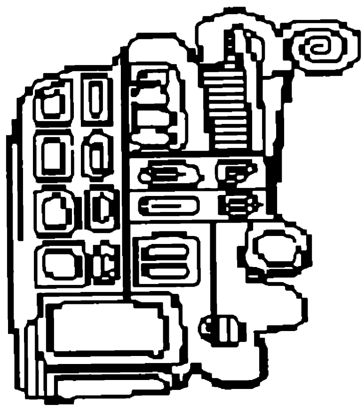
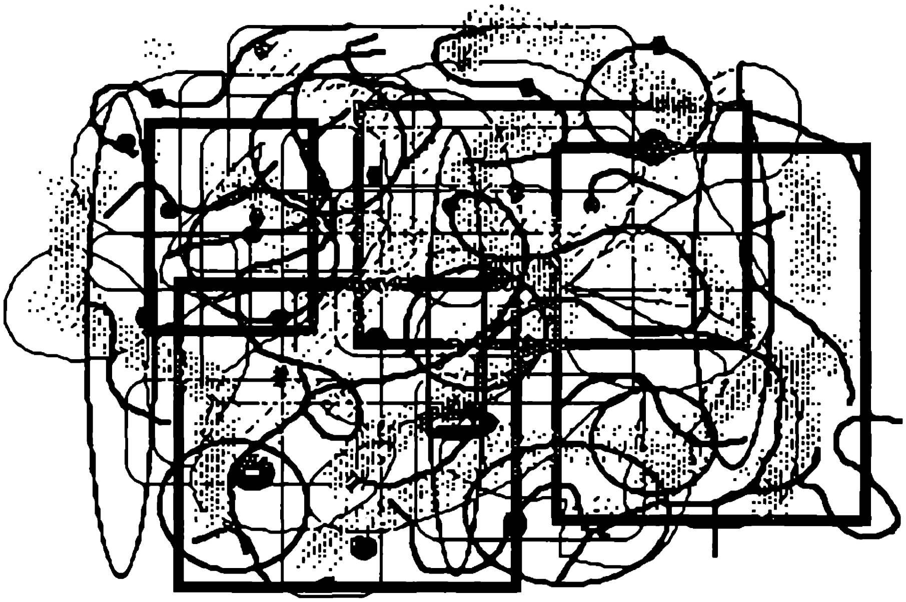
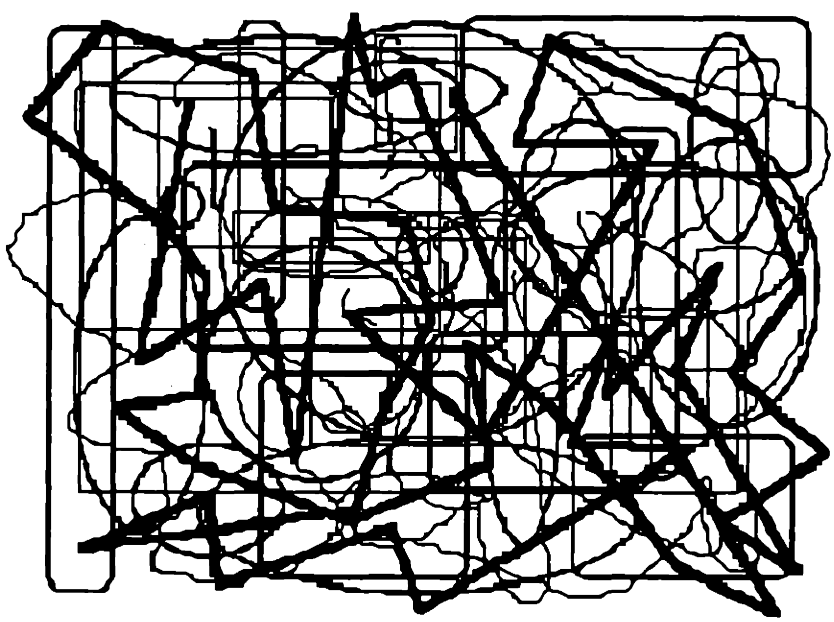


Figure 4

Two examples of masks from Experiment 5A





CHAPTER IV

SUMMARY AND CONCLUSIONS

I. RB: THE PHENOMENON AND ITS STANDARD INTERPRETATION

1- The Phenomenon

RB is characterized by the inability of subjects to detect the second occurrence (C2) of a repeated item in rapid serial visual presentation (RSVP) of a list of items. This effect is particularly striking when it occurs in sentences that have a repeated word in them; subjects generally omit the second occurrence of the repeated word when recalling the sentence, even if the omission leads them to produce an ungrammatical or semantically anomalous sentence (Kanwisher, 1986, 1987). Hence, when presented with the following RSVP sentence "It was work (C1) time and so work (C2) had to be done.", subjects will characteristically recall "It was work time so ---- has to be done.".

Since its establishment, several important characteristics of the phenomenon have been worked out:

(1) RB occurs at rate of presentation of around 100 ms per item. As the rate of presentation decreases, the amount of RB diminishes (Kanwisher, 1986). When the duration of C1 and C2 is held constant, RB seems to be more affected by the amount of time elapsing between the critical items, than by the number of intervening items (Park & Kanwisher, 1991).

(2) RB cannot simply be explained by the lack of spatial cues differentiating the two occurrences. RB is still observed when the RSVP stream progresses rightward across the display so that each word is viewed at a different location (Kanwisher & Potter, 1989); moreover, RB is also found, although it is somewhat diminished with briefly presented spatial arrays containing a repeated item (Kanwisher, 1991a; Kanwisher & Driver, 1992).

(3) RB reverses to positive priming when the first occurrence C1 does not have to be recalled. For example, Kanwisher showed that threshold recognition of the last word in a RSVP stream is helped, not hindered, by the prior occurrence of this word in the list (however, not all experiments have shown facilitation).

(4) RB has been shown to occur not only between visually identical items, such as words or letters or even elementary features such as patches of color (Kanwisher, 1986, 1987, 1991a), but also between visually similar items. Indeed, RB is found between letters or words in different case, suggesting that RB is sensitive to abstract configural information. Moreover, RB was also established between orthographically similar but not identical words, such as cape and cap (Kanwisher & Potter, 1990), showing that orthographic similarity is sufficient to induce RB.

(5) Finally, when words are presented auditorily via compressed speech at rates comparable to those producing visual RB for the same material, no RB was found using sentences (Kanwisher & Potter, 1989) while some RB was found using lists (Miller & Mackay, 1991).

2- Interpretation of the RB phenomenon

Kanwisher (1986, 1987) proposed a two-stage model of visual encoding in which first the visual input activates its corresponding type (a pre-existing long term memory representation that is accessed during recognition), and then, in a second step, a token of the type is created. The token is a specific representation of the event available in episodic memory for recall. In this model RB is attributed to the inability to individuate a second new token from the same type at a very short lag. Thus, only the first instance (C1) is represented episodically; the second instance (C2) becomes assimilated to the first event. RB would then result from a refractory period of the process responsible for establishing type-token links.

In this model, the level at which RB occurs is the level of visual types. Activation of a visual type would be a pre-requisite to initiate a new token; RB would then be due to an inhibitory period of the initiation process, not of the activation of the type itself. Moreover, although it was never stated explicitly, Kanwisher's model suggests that once a token is created on the basis of type activation, all the attributes of this type are retrieved and attached to the token; in that sense, tokenization would be a all or none process.

3- Scope of the RB phenomenon

The study of RB is particularly interesting because it enables us to investigate the mechanism responsible for the existence of episodic[1]

[1]The use of the term "episodic" may or may not correspond to Tulving's use (1972). As in Tulving's definition, episodic memory is believed here to

representations of objects (or tokens) separate from their general description (or type) in a long-term recognition network. The dichotomy between pre-existing representations that are used for recognition of familiar objects (i.e., retrieving their identity), and episodic representations that maintain the integrity of that object as it moves or changes, has been supported by much evidence in the object recognition literature (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992; Kanwisher, 1987; Kanwisher & Driver, 1992). Although this type-token distinction is supported by data from several fields of vision research, as well as being incorporated in most of the theories of object recognition, the mechanisms responsible for the establishment of tokens from activated types are still very much unknown. RB, as a failure to establish tokens, seems to be one powerful and available tool to work out these mechanisms.

4- Toward the further understanding of RB

Many questions still need to be addressed before our understanding of RB is complete. Although I do not wish to list them all here, I suggest that they will fall into the two following categories:

- At what level or levels during perceptual processing does RB arises?

- What kind of mechanism is responsible for RB?

---

be concerned with temporally dated episodes or events, and their temporal-spatial relations. However, the present use does not imply that explicit spatial or temporal information can always be retrieved from these episodic representations.

While the first question will require establishing where RB occurs in the processing pathway, the second question is focused on the investigation of how RB is instantiated in this processing pathway. The experimental work presented in this thesis is mostly concerned with the question of where RB occurs during processing; however, these results indirectly suggest constraints on the possible mechanisms responsible for RB.

II. PHONOLOGICAL REPETITION BLINDNESS

The goal of this section is to summarize and highlight the principal results of the three papers presented as the first three chapters in this thesis.

1- Establishment of Phonological RB

I wanted to investigate whether, as initially claimed by Kanwisher (1986, 1987), abstract visual resemblance of C1 and C2 is necessary in order to observe RB. First, RB between letters differing in case was found (Bavelier & Potter, 1992, Experiment 1), confirming that exact visual identity is not necessary for RB (Kanwisher, 1987; Marohn & Hochhaus, 1988). Second, RB between digits in different format such as 9/nine and between homophonic words such as eight/ate was observed (Bavelier & Potter, Experiments 2 and 5). Similarly, RB between pictures of objects and their corresponding written nouns (for example the picture of a cat and the word 'cat') was found (Bavelier, 1992, Experiments 3, 4 and 5). These findings indicated that RB may be located at a higher level of processing than that of visual types. There are two dimensions on which these pairs of stimuli are identical: conceptual and phonological. The conceptual hypothesis would posit that RB between such items is found because they share a common conceptual type. However, no RB had been found between noun synonyms, such as rug and carpet (Kanwisher & Potter, 1990), casting some doubts on a conceptual explanation of RB, at least for words. The phonological hypothesis would claim that RB between such items occurs because they share a common phonological representation.

To disambiguate the contribution of conceptual and phonological similarity in RB, RB between items that are phonologically similar but visually and semantically dissimilar was evaluated. RB between homophones such as eight/ate (Bavelier & Potter, 1992, Experiments 3, 4, 6 and 7) was obtained, and it was shown that partial orthographic overlap could not account for this result (Bavelier & Potter, 1992, Experiment 4). Similarly, RB between picture of an object and a written word phonologically similar to the word naming of that object, such as the picture of a sun and the word son (Bavelier, 1992, Experiments 4 and 5) was also obtained. Taken together, these results show that phonological similarity per se is sufficient to produce RB. RB induced by phonological similarity per se will be termed phonological RB.

2- Some Properties of Phonological RB

Phonological RB has been found when using recall of short lists as well as sentences. As in standard RB experiments, the amount of phonological RB diminishes as the lag between C1 and C2 increases.

How phonological RB varies as a function of the elapsed time between C1 and C2 and the number of items between C1 and C2 is, however, still unknown.

In general, phonological RB seems less than or at most equal to RB between identical items. Interestingly, there seems to be a tendency for phonological RB to be of a comparable size to identical RB in sentences, while in short lists phonological RB tends to be or is significantly smaller than identical RB.

Phonological RB is not restricted to phonological identity, but is also found between phonologically similar but not identical items, such as great/freight (Bavelier, Prasada, & Segui, 1992, Experiment 4).

3- Further Characterization of Phonological RB

a- Phonological RB as due to the phonological similarity of the codes used for registration in STM

The claim that RB will arise when similar codes have to be registered for C1 and C2 in STM is supported by the study of phonologically induced RB between pictures and words and by suggestions in the results that the amount of RB between visually different items can be manipulated by task requirements.

First, the use of pictures and words allowed us to disambiguate the contribution to RB of the codes used for registration and the codes readily accessed during the recognition processes. Studies comparing the processing of words and pictures have shown that the first code retrieved during recognition for pictures is a conceptual/spatial code, while for words, it is a lexical/phonological code (Potter, 1979; Potter & Faulconer, 1975; Snodgrass, 1980, 1984; Theios & Amrhein, 1989). Hence, pictures and words differ in which codes are readily retrieved during recognition. When a recall task which biases subjects toward phonological encoding in STM was used, RB between pictures and words was observed (Bavelier, 1992, Experiments 3, 4, the phonological task in 5, the silent condition in 6). This shows that RB can be found when the codes used for registration of C1 and C2 in STM are similar, even though the codes readily retrieved for C1 and C2 during recognition have a different nature.

Second, data were obtained that are consistent with the idea that task requirements, by varying the nature of the code to be registered in the token, can affect the size of RB. When the duration of presentation is extremely short and verbatim recalled is required, as in most of the RSVP experiments studied, the preferred encoding for token stabilization and recall will probably be phonological, independently of the nature of the most salient recognition codes; accordingly, phonological RB was found in these conditions. However, if a visual (or conceptual) bias was induced by requiring visual discrimination (or emphasizing conceptual encoding), RB for these stimuli was diminished (Bavelier, 1992, Experiments 5 and 6). Hence, given fixed items, the amount of RB was found to vary as a function of the task requirements. Again this result indicates that RB is dependent on the similarity of the codes that will have to be registered in the tokens of C1 and C2 (see Bavelier, 1992, Experiments 5 and 6, and general discussion for a more detailed review).

b- Phonological RB as resulting from a competition between the tokens of C1 and C2 for the same phonological type

The claim that phonological RB arises from a competition between the tokens of C1 and C2 for the same phonological type, and not from a failure to create an initial token for C2 (Kanwisher, 1986, 1987) is supported by the pattern of errors observed during phonological RB experiments (see Bavelier, 1992, General Discussion). The data show that, when C1 and C2 are visually different, a token is initially created for C2 as well as for C1. RB would then result from the loss of one of these tokens, probably due to the failure to register the same code (i.e., phonological) in two distinct tokens that occurred nearby. The pattern of errors observed suggests that such a failure may arise from a competition for the registration of the same code during the establishment of the tokens of C1 and C2.

c- Phonological RB as located at an early level of phonological encoding

Phonological codes are thought to be involved in perception at least in two ways: during recognition per se and in short term memory. When a word is presented, its phonological representation or type is activated in the recognition network (Lukatela & Turvey, 1991; Perfetti & Bell, 1991; Van Orden, 1987; Van Orden, Pennington & Stone, 1990); this phonological code retrieved during recognition per se will be termed the 'early phonological code'. In order to be recalled, the information stored in STM (tokens) is normally maintained through the use of an articulatory loop, which insures the rehearsal of the phonological representations of the items (Baddeley, 1986); the phonological code used for rehearsal in STM will be termed the 'late phonological code'. The phonological effect we observed in RB could occur either at the level of the early phonological code or the late one. In the first case, RB would occur before or during registration in STM; hence, RB could still be considered as arising from a problem at the interface between recognition and short term memory; this explanation would be compatible with the interpretation of RB as a problem arising during the establishment of tokens in STM. In the latter case, RB would occur at the level of a phonological representation held in STM, after registration in STM is completed; phonological RB would arise from a problem within STM, during the maintenance of information in STM (Conrad, 1964; Baddeley, 1986), and so phonological RB would be accounted for by a limitation in the maintenance of tokens in STM.

In order to test these two hypotheses, the effect of concurrent articulation on the manifestation of phonological RB was assessed. For words, irrelevant concurrent articulation appears to suppress the components of STM that are responsible for the maintenance of phonological information in STM (Murray, 1968), while not affecting the retrieval, in the recognition network, of phonological types (Besner, 1987a, 1987b; Besner & Davelaar, 1982; Besner, Davies & Daniels, 1981; Van Orden et al., 1990). Hence, if concurrent articulation is found to affect phonological RB between homophonic words, it would suggest that this effect is due to a problem in maintenance of information in STM, and not to a problem in establishing tokens.

Concurrent articulation was, however, found to have no effect on RB between words, whether identical or phonologically related (Bavelier & Potter, 1992, Experiment 7; Bavelier, unpublished experiment). These results indicate that RB between homophonic words is unlikely to be due to a phonological confusion during the maintenance of phonological information in STM. Rather, phonological RB between words seems to arise during the establishment of tokens, when phonological types are registered in STM.

Although a similar logic could be applied to pictures, given the difference in accessing phonological information for words and for pictures, there are few reasons to expect that articulatory suppression would affect word processing and picture processing similarly. There are some indications that articulatory suppression indeed affects not only the maintenance in STM of the phonological codes corresponding to pictures but also the initial retrieval of a phonological code during picture processing. This hypothesis is consistent with the finding that concurrent articulation disrupts RB between phonologically similar pictures and words when they were semantically different, but not when they were semantically identical (Bavelier, 1992, Experiment 6). Although there are certainly several possible explanations for this finding, it is consistent with other characteristics of phonological RB if interpreted as meaning that concurrent articulation delays access to a phonological code for pictures and not for words, and biases subjects toward semantic encoding in STM (see Bavelier, 1992, Experiment 6, for a fuller discussion of this point).

In general, the present work shows that RB is sensitive to some characteristics of STM. For example, RB is influenced by the kind of codes the task requires (see 3-a and -b). However, RB is not merely reducible to a similarity effect during the maintenance of an initially well-registered item in STM (Conrad, 1964; Baddeley, 1986). RB seems to be best understood as arising at the interface between perception and short term memory.

To sum up, phonological RB reflects a limitation in the establishment and stabilization of tokens in STM. In this regard, the characteristics of phonological RB bear on the type-token model initially proposed by Kanwisher. In the next section, I will first review why Kanwisher's model fails to account for phonological RB, and then describe a possible type-token framework incorporating the characteristics suggested by the study of phonological RB.

III. A NEW TYPE/TOKEN ACCOUNT OF RB

The goal of this section is to review the limitations of the type-token framework proposed by Kanwisher, and to propose a set of modifications suggested by the study of RB between visually different items. For clarity, establishment of a token will always be used to refer to all the steps involved in the process of tokenization; creation or opening of a token will be restricted to the initial instantiation of a token and stabilization or construction of a token to the later stages of tokenization, after a token has been instantiated.

1- Limitations of Kanwisher's type/token framework

As previously reviewed, Kanwisher (1987, 1991) proposed that RB arises because only one token can be linked to a given visual (abstract visual) type at a time; moreover, this author proposed that once a type-token link is created, all the attributes of the type are retrieved and attached to the token. By suggesting that the level of visual types is responsible for controlling the creation of new tokens, this model predicts that visually different items will each lead to the creation of a new token. It then supposes that all the attributes of the type can be retrieved and attached to the opened token. Since, for visually different items, a type-token link would have already been successfully established for each of them, similarity of some of their type-attributes should not lead to RB. Hence, by arguing that RB arises from a failure to create a new type-token link at the level of visual types, Kanwisher's model does not seem able to easily account for RB between visually different items.

2- Modified type/token framework

The study of RB between visually different items suggests the following main modifications to the type-token framework. First, I propose that the establishment of a token in STM, available for conscious recall, is a dynamical process. Hence, once a token is opened, its type-attributes will be retrieved progressively, and not at once; the nature of the information entered in the token will thus evolve over time. Second, I propose that the construction of tokens is only be dependent on the structural properties of the stimulus, but also on the characteristics of

STM. In this view, tokens as memory representations in STM are more or less labile, as a function of the saliency of the code entered into them (for example, a picture's format is a salient code when it is presented among word), as well as the efficiency of those codes in STM (phonological codes are known to be more efficient than visual ones for maintenance in STM).

In this new view, when C1 and C2 are visually different, a new token will be initiated for each of them. If the types of C1 and C2 have one of their attributes (a phonological code, for example) in common, their respective tokens may compete for this similar code. As a result of the competition, this code may fail to be registered in one of the tokens. This would render this token more easily subject to loss, especially if the code that failed to be registered was important for the stabilization of this token. Normally, it will be C2 that loses the competition because of the temporal priority of C1. In this view, RB could occur at any step during the establishment of a token, arising not only from a failure to create a new token, as proposed by Kanwisher (1987), but also from a failure to construct and stabilize an opened token.

The hypothesis that repetition effects, such as RB or the homogeneity effect (i.e., underestimation of the number of items presented; Frick, 1987), could arise from distinct stages of visual processing has already be entertained by Mozer (1989). This author argued for two qualitatively distinct repetition effects, one involving the repetition of a visual form and the other repetition of object identity, both resulting from spatial uncertainty at two different stages of visual processing. The present proposal generalizes that claim to temporal uncertainty, and refines the notion of "repetition of object identity". By doing so, it reveals a possible role for STM characteristics in repetition effects, which, as far as I was able to determine, was not incorporated in previous type-token accounts of these effects.

The introduction of a role for STM components in these repetition effects may give a new view on the debate of whether these effects arise from memory errors or perception errors. In the proposed model, RB would arise at the interface between perception and memory. In this sense, it could be viewed as a perceptual error as well as a memory error. However, this memory error would be due to a failure to initially establish a stable memory representation for the item, and not to the failure to maintain an already established memory representation, as normally referred to by "memory error" (Conrad, 1964; Schneider & Shiffrin, 1977; Baddeley, 1986). Hence, while repetition effects would not be merely reducible to a similarity effect while remembering similar items in STM, they would be sensitive to the properties of STM that are inflencing the initial establishment of a memory representation.

In the next section, I will review how the body of work on RB can be accounted for in this modified framework.

IV- INTERPRETATION OF RB IN THE NEW FRAMEWORK

In this section, I will discuss how our present knowledge of RB can fit into the modified model, and will investigate new implications concerning the RB phenomenon.

1- RB between visually dissimilar items

In the modified model, RB between visually different but phonologically or semantically similar items arises when an opened token fails to register its corresponding salient phonological or semantic type. As in Kanwisher's model (1987), this failure is believed to be due to a constraint on the number of tokens the same type can be "attached to" at a given time. This constraint would lead to competition between the tokens of C1 and C2 for any common type-attributes. If, as a result of this competition, the most salient type of the presented item (for example, the phonological code for a word) fails to be entered into its corresponding token, recall of the item would be hindered, leading to a sizeable RB. However, if, as a result of the competition, only a less salient type (for example, phonological code for picture) of the presented item fails to be entered in the token, recall of the item should be less hindered. This view is supported by the findings that RB between pictures and words has a tendency to be larger when C1 is a picture and C2 a word, than vice versa, when using a task that biases toward phonological encoding (Bavelier, 1992, Experiments 3, 4, 5B, 5C and 6). Failure to register the phonological type should be more damaging for a C2 word than for a C2 picture.

The outcome of the competition between the tokens of C1 and C2 would be determined by the strength of these tokens. The more equal in strength the tokens of C1 and C2, the less the amount of RB observed; moreover, in these conditions, C1 as well as C2 may be hindered by RB. When one token is much stronger than the other RB will be larger, and will only affect the recall of the weaker token. The pattern of RB between homophonic words and pictures supports this account. In this case the token of the C2 picture would be strengthened by the registration of its salient and easily available pictorial/conceptual type. A relatively stable C1 token (because of its time of arrival) would then compete phonologically with a relatively strong C2 token, leading to a smaller RB effect, sometimes resulting in loss of C1 instead of C2 (see section II-3c). Such a competitive process would also be consistent with the finding that phonological RB is modified as a function of the task requirements. Task requirements have been proposed to affect the nature of the codes, especially the less salient ones, that will be entered in the token. Hence, even though C1 and C2 have different salient codes (for example, a picture and a word), the task may force the same kind of type (for example phonological) to be entered in their tokens. If the tokens of C1 and C2 compete for a code that is important for the stabilization of at least one of them, RB will occur. This, for example, is what seems to occur between pictures and words when using a task that biases toward the registration of phonological codes (Bavelier, 1992, Experiments 4, 5 and 6).

2- Toward semantic RB

By arguing that RB occurs when the token of C1 and C2 compete for a code that is important to the stabilization of at least one of them, this model predicts a role for semantic/conceptual codes in RB when using pictures. Indeed, conceptual codes are supposed to be a salient code for pictures; hence, when this code fails to be registered in the corresponding token, the token will be weakened and more easily subject to loss. A possible role for conceptual similarity on RB for pictures is supported by the tendency for a larger RB between pictures and words that share phonology when they are semantically related than when different (Bavelier, 1992. Experiments 4 and 6) as well as by the finding that concurrent articulation does not disrupt RB between mixture of pictures and words when they are semantically related (Bavelier, 1992, Experiment 6).

This view is also consistent with the failure to find RB based on semantic similarity between words (Kanwisher & Potter, 1990). The most salient initial code for words is supposed to be lexical/phonological. Similarly, it would further predict little or no RB between two phonologically related but semantically different pictures. Each of the pictures should be saved from RB by their respective salient conceptual code. This view is confirmed by the failure of Kanwisher (1991b) to find RB between these kind of pictures in short lists (e.g., the picture of a palm-tree and the palm of a hand). However, RB between such pictures could perhaps be produced if the saliency of conceptual codes were weakened while enhancing the role of the phonological code. Although it is not clear that such a deep manipulation of the codes entered in the token can be achieved, the use of rebus sentences with picture puns may be able to diminish the saliency of conceptual information for pictures by forcing subjects to rely on phonological encoding in STM. If so, phonological RB between conceptually different pictures may be observed.

3- Spatial RB

Spatial RB refers to RB found when briefly presenting an array containing a repeated item. Spatial RB was established with simple visual features such as colors, as well as with letters (Kanwisher, 1991a; Mozer, 1989). Recently, Kanwisher & Driver (1992b) reported that when flashing a visual display with 2 items, on trials where RB occurs, subjects report seeing two objects and not one, even though they can report the identity of only one. This pattern of results supports the view that RB can arise from competition after a token has been created for each of the items. It suggests that two distinct tokens were initially created; but as the same identity information (or possibly, phonological code) had to be registered in each of them, they competed and information was entered in only one of the tokens. The deprived token, although more labile, may be saved in this case by the presence of salient spatial information (note this was not the case in most of Mozer's experiments, 1989). This would account for the ability of subjects to report the presence of the item, without being able to identify it.

These authors also found results supporting the view that the kinds of types that will be registered can be manipulated by the task requirements. Subjects were presented with a display containing two colored letters. When subjects were asked to recall the identity of the letters, RB was observed only if the two letters had the same identity; whether they were in the same or a different color did not modify the pattern of RB. Similarly, when subjects were asked to recall the color of the letters presented, RB was only observed when the two letters had an identical color, whether their identity was similar or different. This result confirms the hypothesis that task requirements can manipulate the nature of the types that will be entered in the token, and clearly demonstrates that RB can occur even though the types readily activated during recognition for each of the items will be different.

Taken together, the data from spatial RB suggest that the mechanisms responsible for spatial RB could be very similar to the one responsible for phonological RB in RSVP presentation. If so, phonological RB should be found in spatial arrays; moreover, the size of this RB should be found to vary as a function of task requirements, not only when manipulating independent type levels (such as in Kanwisher & Driver, 1992), but also when manipulating tightly associated type levels (as phonological vs visual for pictures). Finally, this view also predicts that, when using spatial arrays, RB between visually similar but phonologically dissimilar items should be diminished compared to RB between visually and phonologically similar items (especially when using a phonological task, such as recall).

4- RB between visually identical or similar items

As we just reviewed, phonological and/or semantic RB using RSVP as well as visually identical RB using spatial displays seem best explained by a competition between the tokens of C1 and C2 leading to a failure to stabilize one of these tokens. I would argue, however, that RB between visually similar items in RSVP presentation is mostly due to a failure to establish a new token for C2, as proposed by Kanwisher (1987). This view is supported by the finding, using RSVP, of a similar amount of RB between identical words, on the one hand, and visually similar but phonologically dissimilar words (e.g. reach-react), on the other hand (Bavelier, Prasada, & Segui., 1992). If the finding that phonological dissimilarity cannot save visually similar items from RB in RSVP is confirmed when using stimuli in which these two dimensions can be independently manipulated (unlike English words), it will clearly indicate that RB can arise from visual similarity alone, independent of the similarity of other type-attributes. Such RB would then have very different characteristics from phonological or (by hypothesis) spatial RB, for it should not be sensitive to the nature of the codes entered in the tokens, to the task requirements, or to the strength of the tokens in STM.

In this view, as low level vision becomes more and more deprived of the cues it usually relies on to initiate tokens (distinctive spatial information, motion information, spatial frequency differences, luminance or chromatic contrast), the more likely that there will be a failure to initiate a new token when an item is repeated. This predicts that RB in RSVP should be sensitive not only to the nature of C1 and C2, but also to the visual format of the items intervening between C1 and C2. For example, the more dissimilar the visual format of C2 and its preceding item is, the more probable it will be that a token for C2 is instantiated by low level vision, ultimately leading to a smaller amount of RB. (This view is confirmed by the following finding. In RSVP list experiments manipulating mixtures of pictures and words, when C1 and C2 are in the same format there is less RB when the visual format of the item intervening between them differs from them.)

5- RB and Attention

Although relatively little is yet known about how attention affects RB, Kanwisher & Driver (1992b) reported recently that, in a spatial array, when more attention is pre-allocated to one of two items presented, more RB is observed (loss of information about the nonattended item) than when attention is not manipulated. This result is compatible with the proposed model which supposes that the more unequal the competition between the tokens of C1 and C2, the more RB. Indeed, it seems plausible that allocating attention to one of the items will favor its token during the competition process, hence leading to more RB.

In other experiments, Kanwisher (1991a) found the same amount of RB whether attention is focused on both C1 and C2 or distributed over the four items displayed. Subjects were presented with four-item displays, in which two items were either pre-cued or post-cued for recall. Their task was to recall the two cued items. An equivalent amount of RB was found in the pre-cue and the post-cue conditions. Although one may have expected less RB in the pre-cue condition than in the post-cue condition, Kanwisher's result would be consistent with the proposal that RB is dependent on the relative strength of the tokens of C1 and C2, and suggests that the absolute strength of the token (as long as it is below the threshold of stabilization) does not modify the amount of RB. Hence, when the two tokens have the same initial strength, whether high or low, the same amount of RB will be observed; however, the amount of RB will increase when one token is initially made much stronger than the other.

This account would be consistent with the tendency to find less RB in spatial arrays than when using stationary RSVP presentation in which the token of C1 is made stronger by its temporal advantage (Kanwisher, 1991a, Experiment 1) (although this may be better explained by the presence of a spatial distinction; this could be tested by looking at the size of RB in moving RSVP (see Kanwisher 1991). This hypothesis would also predict that if C2 is made extremely stable compared to C1, the recall of C1 and not C2 would be hindered by RB. Note however that if C1 is presented long enough so that its token can be stabilized by the time C2 arrives, making C2 more or less stable should not affect the recall of C1.

6- Auditory RB: Repetition Deafness

In the present framework, RB occurs not only when initiating new visual tokens, but also when having to stabilize opened tokens in STM. Although the former is certainly specific to visually presented items, the latter seems to arise from a more general processing limitation at the interface between recognition and short term memory. It seems that the type-token distinction will be relevant to any perceptual system in which a recognition network has to interact with an episodic memory. Auditory presented stimuli, as well as visually presented stimuli, have to be individuated through episodic representations. Following this line of thought, auditory RB should be observed.

This claim stands in contradiction with the failure to find repetition deafness by Kanwisher and Potter (1991). These authors reported an absence of repetition deafness in sentences when using compressed speech. However, more recently, repetition deafness was observed in lists using compressed speech by Miller and MacKay (1991). Moreover, there are indications in the literature that subjects can have difficulty in establishing separate tokens for auditorily presented stimuli. For example, when subjects are asked to estimate the number of events, they tend to underestimate their numbers. This effect was observed for visual events, such as flashes of light (Cheatham & White, 1952), but also for auditory events such as pulses of sound (Cheatham & White, 1952). Moreover, as in the visual modality, tones of similar types were found harder to process than tones of different types (Harvey & Treisman, 1973). These data suggest that, like the visual system, the auditory system has also difficulty in establishing token of near-by similar events. Whether repetition deafness between words can be found in lists as well as in sentences seems to still be an empirical question, given the limited rates of presentation and techniques that have been used till now.

To conclude, RB seems best characterized as a failure to establish a stable token in STM. This failure may arise initially as a failure to initiate a new visual token (Kanwisher, 1987), or later when information is entered in the token. This last proposal assumes that different kinds of information may be entered in the token at different times, and that tokens, as episodic representations, can differ in strength in STM. The failure to establish a token could be implemented as a signal detection problem; it would correspond to a failure to detect two distinct signals (events) in the pattern of activation of the type over time, even though the type is activated by each of two items (Bavelier & Jordan, 1992). Depending on the level of types at which this signal detection problem arises, it could lead to either a failure to create a new token from the single visual type-event detected, or to a competition between the tokens of C1 and C2 for the same type-event.

V. OTHER VISUAL PHENOMENA IN THE NEW FRAMEWORK

In this section, I wish to explore the implications of the modified type-token framework for the understanding of visual phenomena other than RB. Since the type-token distinction has been already proposed to account for several visual phenomena, such as visual search or illusory conjunction (Treisman, 1988; Kahneman & Treisman, 1984; Kanwisher, 1991a; Mozer, 1989), it is already clear that a type-token framework is well suited for those effects. Hence, I will instead speculate on how the new assumptions proposed in the modified model bear on the interpretation of these phenomena.

1- Tokens in RB and in other visual phenomena

Kanwisher (1991a) noted that accounting for RB in the same type-token framework as for other visual phenomena raises a paradox about the relationships between types and tokens. To account for RB, Kanwisher proposed that type activation is a prerequisite for the instantiation of a new token (type-first route). However, this view is at odds with the assumption entertained by Treisman (1988; Treisman & Gelade, 1980) that type activation is mediated by the integration of feature information in the token (token-first route).

The paradox relies on the explanation of RB as a failure to initiate a new token; however, any RB that has been interpreted as a failure to stabilize an opened token would be consistent with a token-first model (if the establishment of a token is taken to be a graded process, during which tokens can be lost). The case of RB as a failure to initiate a new token would be a special one, in which, because of the impoverishment of the information available at a low level of visual processing, types at a higher level of representation would, by default, trigger the creation of new tokens. Hence, such RB should be restricted to conditions in which there are few lower-level cues available for the instantiation of a token for C2.

Such a view implies a graded change in the nature of RB as more and more distinguishing information can be used by low level vision. Hence, the more distinguishable C2 is as a visual event during presentation, the more should RB be due to a failure to stabilize an opened token. On the face of it, the finding of a similar amount of RB when C2 appears to be the only red letter among white ones (Kanwisher, 1991a), but somewhat reduced RB when C2 is a picture (Bavelier, 1992) could suggest a different role for arbitrary distinguishing information (such as red versus white for letters) versus implicitly distinguishing information (picture versus word format for a given concept). This would weaken the claim that low level vision processes determine the nature of the RB observed. However, several results suggest that color identity is a poor feature as a trigger for low level vision processes (e.g., color fails to pull attention, as noted by Jonides & Yantis,1988; and fails to initiate a reviewing process, as noted Kahneman, Treisman, & Gibbs, 1992). Hence, the relative role of arbitrary vs implicit distinguishing information seems to still be an empirical question.

2- Repetition Priming

The presented model accounts for repetition priming by assuming that the establishment of a token is facilitated by repetition, as long as the conditions for RB do not hold. This facilitation can occur either during the creation of a new token or when information is entered in the token. Since the model only accounts for short term priming (ISI lesser than 1000ms), such as masked priming and short term unmasked priming, only these kinds of priming will be reviewed.

A- Masked Priming

In a typical masked priming paradigm, two words or letter strings are briefly presented. The first target or masked prime (C1) is presented after a mask and for a duration such that subjects cannot identify it and are not aware of its presence on most trials. Immediately following C1, the second target (C2) is presented, in a different case than C1, for a duration such that subjects can usually identify it. Typically, a repetition advantage (higher accuracy, faster RTs) is observed when C1 and C2 are the same word. Leaving aside lexical decision, which has special post-lexical processing components, naming or threshold identification results show that masked priming occurs for a C2 word when C1 is orthographically identical or similar, independently of whether C1 is a word or a nonword (Humphreys, Besner & Quinlan, 1988; Humphreys, Evett & Quinlan, 1990). Masked priming has been interpreted as resulting from the fact that C1 is taken to belong to the same visual event as C2 (see Humphreys et al., 1990 for a review).

The hypothesis that masked priming results, like RB, from a failure to initiate two distinct tokens for C1 and C2 is supported by two main observations. First, RB for orthographically related words in RSVP (or in other words, RB due to a failure to initiate a new token for C2) and masked priming have been shown to be sensitive to the same dimensions of the stimuli (see Bavelier, Prasada, & Segui, 1992, for a review). Second, in RSVP experiments RB has been found to reverse to facilitatory priming on trials in which C1 is not recalled (Kanwisher, 1986; Potter, personal communication). These data support the view that masked priming is similar to cases of RB that are due to a failure to create a new token for C2.

Whether masked priming could also arise from a failure to stabilize two distinct tokens for C1 and C2 is still unclear. This would require first to investigate the dimensions of the stimuli (phonological, semantic, morphologic) to which RB between visually dissimilar items is sensitive.

B- Unmasked priming

In the unmasked priming paradigm, two targets are presented as in the masked priming paradigm. However, the prime (C1) is always presented such that it can be consciously identified. Then C2 is presented for a variable duration depending on whether subjects are asked for a reaction time task (naming, lexical decision, old/new) or a threshold detection task. Under these conditions, a repetition advantage (higher accuracy, faster RTs) is observed when C1 and C2 are identical.

In the proposed model, this facilitatory effect would be accounted for by a facilitation of the establishment of the second token (whether due to residual spreading of activation (Rumelhart & McClelland, 1981) or due to a backward processing (Kahneman et al., 1992)). Constraints from the model arises when one consider the role of the duration of presentation of C1 and C2 in determining the repetition effect observed. The model predicts that masked priming, repetition blindness and unmasked priming are a function of the stability of the token of C1. If a token for C1 fails to be created, a "masked priming" effect should be observed; if a token for C1 is created, but is not stabilized by the time C2 is presented, a "repetition blindness" effect should be obtained; if the token of C1 has been stabilized by the time C2 is presented, an "unmasked priming" effect should be present.

C- Priming across saccades

Recent research about the integration of information across saccades shows that it can involve relatively abstract levels of representations (see Irwin, 1992, and Pollatsek & Rayner, 1990, for reviews). The communalities between RB and transsaccadic priming are suggestive. For each of these phenomena that were initially thought of as visual, an important role of other kinds of information, such as phonology, has been shown (Bavelier & Potter, 1992; Bavelier, 1992; Pollatsek, Lesch, Morris & Rayner, 1992; Pollatsek, Rayner & Collins, 1984; Pollatsek, Rayner & Henderson, 1990). Both phenomena have also indicated that conscious encoding of location information is usually rather inaccurate, and in all conditions, difficult to achieve compared to conscious encoding of identity information. The body of results from transsaccadic priming seems consistent with the view that tokens are usually instantiated by low level vision from spatio-temporal constraints, that this spatio-temporal information is relatively hard to register in these tokens, and that different kind of information can be contained in a token (visual or phonological, for example). If, indeed, the tokens in RB and in transsaccadic priming are similar entities, one should expect the role of phonological information in transsaccadic priming experiments using pictures to be mostly due to the use of a naming task that biased subjects toward phonological encoding; and thus, these phonological effects should be reduced or suppressed when asking for a non-phonological task, as in RB. Similarly, although no semantic effect has been found in transsaccadic priming with pictures when using a naming task (Pollatsek et al. 1984), semantic priming might be found if a task forcing semantic encoding was used.

3- Visual Search

In a visual search paradigm, subjects are asked to decide as fast as possible whether or not specified target is present in a display. When the target is defined by a single visual feature (for example, color or size), the search time for the target stays constant as the number of items in the display increases, as if the search was done in parallel across the display. When the target is defined by a conjunction of visual features (for example, red circle), the time to find a (present) target in the display increases as the number of distractors (red square and blue circle) in the display increases. This pattern of result suggested that in this case subjects have to check each item in the display sequentially (see Treisman & Gelade, 1980). This distinction between parallel and serial search was interpreted as due to the fact that while identification of conjunction targets was totally dependent on correct localization, and so required the spotlight of attention, identification of single feature targets could be correct even when mislocated in the display.

However, several recent results have shown that search for conjunction targets can be almost parallel, rather than serial (see Treisman & Sato, 1990 for a review). To account for these results, several authors (Cave & Wolfe, 1990; Treisman & Sato, 1990) proposed that spatial selection could be achieved by enhancing the signal to noise ratio at the level of the location maps. This spatial selection process would favor the establishment of the token for the types located at the selected location. This view is consistent with the assumption of the modified model that low level vision mechanisms would be usually responsible for the initiation of the tokenization process.

However, the ranking found by Treisman & Sato (1990) from the best cue to the poorest cue for this new mechanism of spatial selection (and so tokenization) was size then color then motion then orientation. This ordering seems strangely reversed compared with the current knowledge of the properties of low level vision segregation mechanism. In particular, several lines of research have shown motion, luminance, orientation, spatial frequency (i.e., size) and depth cues to be involved in the early segregation of the visual scene, whereas color and shape seemed less determinant. Whether such an inconsistency is due to the fact that in Treisman et al. experiments, the four kinds of cue were not matched for salience seems to still be an empirical question.

4- Iconic memory and Visual short term memory

The goal of the following section is to explore how the type-token model fits with the theoretical ideas developed about visual memory. One recent framework for visual memory involves: a visual sensory memory (iconic memory), a postcategorical memory containing information about the identity of visual stimuli as well as episodic information about these stimuli, and an output stage or response buffer (see Coltheart, 1984 for a review). Although the existence of a major processing bottleneck in this system was demonstrated by the partial-report superiority effect (Sperling, 1960, 1967), between which levels this bottleneck occurs and how it occurs is still controversial. While one view holds that transfer of information from iconic memory to the postcategorical store is the major bottleneck (termed the precategorical view of selection, Kahneman & Treisman, 1984; Sperling, 1960; Von Wright, 1972), another view argues that the transfer of information from the postcategorical memory to the response stage is the major bottleneck (termed the postcategorical view of selection, Mewhort, Campbell, Marchetti & Campbell, 1981; Coltheart, 1984). Type-token models may offer a new stance on that debate, by proposing that the processing bottleneck is located during the establishment of a stable token.

In the type-token framework, selecting an item for report corresponds to establishing a stable token for that item in STM. In the present model, the establishment of a token is a function of the salience of the type (or alternatively, the signal to noise ratio of the type location in the location maps). The more salient the to-be-selected types, the more efficient the selection process. In this view, the pre- vs post-categorical distinction falls. Efficient selection could be observed for either "pre-categorical" or "post-categorical" tasks, if the to-be-selected type is salient enough to favor the establishment of its corresponding token. The most efficient kind of selection should be observed when the to-be-selected type is salient enough to instantiate a token directly, or in other words when no information has to be first registered into the token in order for the selection to be achieved. This may occur in what has been named the 'pop-out' effect. In contrast, the most inefficient kind of selection should be observed when most of the type information has to be registered in the token for the selection to be achieved, as when looking for a word among pronounceable non-words. Hence, because establishing a token is proposed to be a dynamical rather than an all-or-none process, the efficiency of selection is also predicted to be graded.

In this view, the parallel spatial selection mechanism proposed for visual search would render selection more efficient. This predicts that the speed of visual search should correlate with the amount of partial-report superiority as the efficiency of the spatial selection mechanism is varied (following the same logic as Treisman & Sato, 1990). It is also interesting to note that this selection mechanism, because it relies on the organization of representations in spatial map should be available only for selection from spatial arrays, but not for selection of items sequentially displayed over time (as in an RSVP stream presented at the same location). More generally, given the difference in the way spatial information and temporal information are represented in the nervous system, one may expect selection from a spatial array and selection from a sequential stream to reflect different mechanisms.

5- Short term memory

One classical debate around visual phenomena which result in an inaccuracy of recall is to establish whether they arise from a perceptual error or a memory error. Hence, the interpretation of several visual phenomena (such as illusory conjunction, homogeneity effects, RB), initially understood as perceptual errors, has been challenged as resulting from memory errors and not perceptual ones (see Mozer, 1989 for a discussion). In such a view, for example, RB would arise because subjects have more trouble remembering repetitions of an item than distinct items, and not because of a problem when perceptually encoding repetitions of an item.

By proposing that the construction of tokens can be influenced by short term memory characteristics, the proposed new type-token framework redefines this classical dichotomy between "memory" and "perceptual" errors. The new framework calls for a distinction between memory errors due to a problem in maintenance of well-established information in STM (termed "maintenance effect"), and memory errors due to a problem in initial establishment of information in STM (termed "establishment effect"). While the former errors would be responsible for the similarity effects described in STM (Baddeley, 1986), the latter would be responsible for RB and other "perceptual" homogeneity effects. This distinction is supported experimentally by the pattern of errors found in standard immediate memory tasks and in RB: RB disappears if the rate of presentation decreases to approach the rates of presentation under which maintenance effects are found (Kanwisher, 1987; Mozer, 1989); RB is still present in lists as short as three items, which would not produce maintenance problems if presented at slower rates; moreover, maintenance problems in STM are usually characterized by mis-ordering during recall of the items; in contrast, establishment effects during RB are characterized by the loss of the item. This last point is central to the difference between RB and similarity effects during maintenance in STM; only studies that score correct recall independently of the order are directly looking at establishment errors.

In this view, RB is neither a memory nor a perceptual phenomena, but lies at the interface between perception and memory. By showing that RB can be influenced by the preferred encoding in STM, the work presented here establishes a role for short term memory properties in RB; at the same time, by showing how the salience of a perceptual code can affect the pattern of RB, the present work also confirms the role of perceptual characteristics in RB. The further study of RB seems to provide an opportunity for bridging the gap between "perception" and "memory", by showing how perceptual properties and memory properties can affect each other.

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