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Repetition blindness between visually different items: the case of pictures and words

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Abstract

Repetition blindness (RB) is the failure to see or recall the second of two visually similar or identical items in rapid serial visual presentation. It was initially demonstrated by Kanwisher (1987), who proposed that a second token of a given word or object type cannot be established when the two items occur close in time. Bavelier and Potter (1992) showed that RB also occurs between visually different items that are phonologically similar. They proposed that RB may occur not only when the targets are physically similar, but also when they have to be registered or encoded in short-term memory (STM) along dimensions on which they are similar. This hypothesis predicts that RB between visually different items should not be restricted to words, but should occur with any stimuli, as long as the task requires these stimuli to be encoded along dimensions on which they are similar. Moreover,

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H. Intraub, while working in collaboration with M.C. Potter, initially discovered repetition blindness between identical pictures and visual scenes in rapid serial visual presentation lists. I am extremely grateful to her and M.C. Potter for sharing these results with me and freely letting me carry on a project they originally initiated. I thank M.C. Potter and N.G. Kanwisher for their invaluable help with the research and comments on earlier versions of the manuscript. I thank D. Stiefbold, L. Walhof, S. Jariv, A. Lipede and K. Raphaelidis for assisting in the research. I am especially indebted to A. Treisman and two anonymous reviewers for their suggestions during the revision of the article. I am also extremely grateful to H. Bromberg and M.C. Potter for going through the painstaking process of editing this paper in a proper English style.

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it also implies that a task that changes the preferred code of targets will affect the size of RB. The first prediction was confirmed by establishing RB between phonologically similar 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”), when using a task that requires phonological encoding (Experiments 1 and 2). The second prediction was also supported: the magnitude of RB depended on whether the task required similar or different codes for pictures and words (Experiments 3 and 4). These experiments confirm that RB between visually different items is due to the similarity of the codes initially used in STM. The results suggest that RB can occur at any step during the instantiation of a token, arising not only from a failure to create a new token, but also from a failure to stabilize an opened token. In this view, tokens are to be seen as dynamical entities, built over time as a function of type activation and task requirements, and varying in stability as a function of the information that is entered into them.

Introduction

The construction of organized and meaningful representations of the visual environment requires parsing the visual flow into separate objects. The instantiation of such “object-specific”¹ representations (termed object-file, token, FINST or episodic representation) during visual processing has been recently supported by much evidence in the object recognition literature (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Kanwisher, 1987, 1991a; Kanwisher & Driver, 1992; Mozer, 1989; Pylyshyn, 1989; Ullman, 1984). Findings of an object-specific priming effect (Kahneman et al., 1992) or of object-based attentional effects (e.g., Driver & Baylis, 1989; Duncan, 1984; Kahneman et al., 1992; Kanwisher, 1991a; Tipper, Brehaut, & Driver, 1990; Tipper, Driver, & Weaver, 1991; Yantis, 1992) support the idea that object representations are set up during visual processing. This framework introduces a dichotomy between object representations (tokens constructed during recognition that maintain the integrity of objects as they move or change) and pre-existing long-term representations (types or categories used in the recognition of the components and objects of a visual scene). Characterizing the rules that govern the relationships between tokens and types is critical for understanding visual processing. For this reason, much recent interest has focused on the processes responsible for the linkage between a previously opened token and newly activated type information, as well as on the processes responsible for the instantiation of a new token versus the updating of an old one.

Several recent studies have helped to characterize the properties of tokens. For

¹Although I will refer to these representations as “object-specific” throughout the paper, it may be more appropriate to term them “perceptual group-specific”.

example, Kahneman et al. (1992), using a naming task, showed an enhanced priming effect when motion suggested that the same object was involved; whereas commonality of color failed to induce this effect. They interpreted these results as showing that the process responsible for the selection of a previously opened token, termed reviewing, can be guided by linking motion, but not by a match of colors across visual displays. Another constraint on the behavior of tokens was reported by Kanwisher (1987). She found that subjects fail to detect the second occurrence of a repeated item in rapid serial visual presentation (RSVP) of a list of items, an effect she termed repetition blindness (RB). The prior identification of an item (C1) hinders the identification of its second occurrence (C2), if it occurs within an interstimulus interval of 400 ms. This phenomenon suggests that the instantiation of two different tokens for two visually identical or similar objects is subject to temporal constraints: in a short amount of time, it is difficult to initiate two distinct tokens from visually similar or identical types.

The purpose of the present study is to explore further the properties that influence the instantiation of new tokens using RB as a measure of failure to instantiate a stable token. In the final section, I discuss the relations of these results to other paradigms.

Studies of the conditions in which RB is observed have suggested that the instantiation of new tokens depends not only on visual types, but also on other codes, if they are used to encode items in short-term memory (STM). Indeed, RB occurs between homophones (ate/eight) and between phonologically similar items (certify/sir, freight/great) that are visually distinct (Bavelier & Potter, 1992; Kanwisher, 1991b). This phonological RB effect suggests that, for written words, the instantiation of a type-token link may rely on either an orthographic or a phonological type. The early involvement of phonology when reading is consistent with recent evidence in the literature that phonological information about a written word becomes available almost immediately (Ferrand & Grainger, 1993; Lukatela & Turvey, 1991; Perfetti & Bell, 1991; Van Orden, 1987; Van Orden, Pennington, & Stone, 1990). The finding of RB between phonologically related but visually different words, and between readily verbalized stimuli such as digits, led Bavelier and Potter (1992) 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” (p. 144).

This interpretation, as well as the framework for tokens developed throughout this paper, relies on the following theoretical assumptions and new hypotheses. First, it assumes that recall depends on unitary tokens; hence, if a token has not been established for a visual stimulus, this stimulus will not be available for recall. Second, it proposes that tokens are built over time through the assembling of different codes (visual, phonological and semantic), all tied to a single spatio-temporal token, but with the codes arriving at somewhat different times. For

instance, phonological codes would arrive more slowly for pictures than for words (Potter & Faulconer, 1975). Third, depending on the encoding task and conditions, one or another code may have priority. For example, recall of rapidly presented lists or sentences is believed to bias subjects to rely on a phonological code. However, if the task requires recall of visual information, visual codes may be preferentially registered in the tokens. Fourth, it is proposed that the stability of a given token is a function of the number and saliency of the codes registered in it. Fifth, once a code has been registered in one token, this same code cannot be registered in another token for a short amount of time. While the first and last assumptions (1 and 5) were part of the original account of RB (Kanwisher, 1987), assumptions 2, 3, and 4 represent new hypotheses. The present study tests these hypotheses.

Taken together the theoretical framework just outlined makes two strong predictions concerning RB. First, when the required task relies on phonological encoding, RB should be found not only between readily nameable stimuli, such as words, letters, or single digits (Bavelier & Potter, 1992), but also between stimuli such as pictures for which a phonological code is not as readily retrieved during perception. In particular, RB would be expected between different stimuli such as a picture and its corresponding word, when the task requires a phonological encoding. 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 requires the use of more or less similar codes. To establish RB between visually different stimuli for which a phonological code is less readily retrieved, in Experiments 1 and 2 I studied RB when using line drawings of objects. Experiment 1 looked at pictures and their corresponding names that were semantically and lexically identical (e.g., the picture of a cat and the word “cat”). Experiment 2 looked at pictures and names that were semantically and lexically different, but for which similar phonological and orthographic representations were thought to be retrieved during processing (e.g., the picture of a sun and the word “son”). Experiments 3 and 4 were designed to test whether the amount of RB can be varied as the level of similarity between the to-be-registered codes of C1 and C2 is manipulated.

I. REPETITION BLINDNESS BETWEEN PICTURES AND WORDS

If RB is sensitive not only to the similarity of the codes readily retrieved during perception, but also to the similarity of the codes used for registration of the items in STM, RB between visually different items should not be restricted to phonologically similar stimuli that are readily verbalized such as words, letters or digits, but should be observed with any pair of stimuli that will share similar phonological codes when the task favors phonological encoding. This hypothesis

was tested by looking at RB when using less readily nameable stimuli than words in a task that biased toward the use of phonological registration. For this purpose, line drawings were used; it has been shown that pictures access their corresponding phonological information less rapidly than words do (Potter & Faulconer, 1975; Theios & Amrhein, 1989). To determine whether RB occurs between identical pictures, as would be expected if RB is characteristic of all visual stimuli, two pilot experiments were carried out, using recall of short lists or sentences that included pictures in place of some words (see Bavelier, 1992). The experiments showed that RB between pictures, like RB between words, decreases when lag increases; and suggested that RB between pictures is comparable in size to RB between words. In Experiments 1 and 2, the hypothesis of interest was tested by looking at RB between pictures of objects and words, whether semantically and lexically related (Experiment 1; e.g., the picture of a cat and the word “cat”) or just phonologically and orthographically related (Experiment 2; e.g., the picture of a sun and the word “son”). “Rebus” sentences in which C1 and C2 were picturable nouns that could be 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.

EXPERIMENT 1

If no RB is found between a picture of an object and its corresponding word, that would suggest that RB between visually different items is restricted to phonologically similar stimuli that are readily verbalized. If, on the contrary, RB is found between such items, it will establish that RB between visually dissimilar items generalizes to items that are less readily nameable than words, and it will be consistent with the claim that RB between visually dissimilar items is due to the similarity of the codes used for registration.

Method

Subjects

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

Materials and design

Fifty-six sentences containing a repeated picturable noun were constructed. For each sentence, a non-repeated 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 critical 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 56 sentences with their non-repeated C1 controls are given in Appendix A.

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 2×4 design led to eight 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. There were 15 practice sentences containing zero, one or two pictures (repeated or not).

Procedure

The subject fixated on a row of asterisks and pressed the space bar on the computer keyboard to begin each trial. The asterisks then disappeared and were immediately replaced by the sentence, which appeared one item (words except C1 and/or C2) at a time, in the same place, for 83 ms 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. A non-object picture (Kroll & Potter, 1984), acting as a picture mask, was presented at the beginning and the end of each sentence.

Subjects were aware that sentences would contain pictures and they were told to integrate the picture within the sequences 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 and were instructed to ignore it.

Apparatus

The stimuli were presented on a Macplus screen, using the MacLab software (Costin, 1988). Words were printed in the Helvetica font size 24; pictures came from the Snodgrass and Vanderwart (1980) material. Each five-letter word subtended about 2.5° of visual angle; each picture subtended about 3.5° of visual angle. The experiment was carried out in normal room illumination.

Results

For consistency, analyses reported in this experiment as well as in the following experiments were performed on the number of trials in which both C1 and C2 were recalled. Analyses of the recall of C1 and C2 separately were also performed (see Bavelier, 1992); however, they will not be reported unless they led to different results.² The percentage of trials in which C1 and C2 were both recalled for each of the categories is shown in Table 1. Overall recall accuracy for the sentences was high (80%, excluding C1 and C2). In the present experiment, as well as in the experiments reported below, only the effects of interest will be discussed; a complete account of the analyses performed can be found in Bavelier (1992). All the effects reported were significant by subject at the .01 level, unless otherwise noted; item analyses gave equivalent levels of significance except as noted.

The primary focus of Experiment 1 is the finding of RB between a picture and its corresponding word, of a size that is comparable to RB between identical-format items. An analysis of variance (ANOVA) was performed on the per-

Table 1. *Experiment 1: percentage of recall of both C1 and C2 as a function of the format conditions (ww = C1 and C2 words; pp = C1 and C2 pictures; pw = C1 picture and C2 word; wp = C1 word and C2 picture)*

Repeatedness	Identical format		Different format	
	ww (cat/cat)	pp	pw (cat/cat)	wp
Non-repeated	76	71	64	86
Repeated	34	58	28	54
Non-rep. – rep.	42	13	36	32

²Some of the experiments reported in this paper used recall of short lists. Since with this technique there may be some uncertainty as to whether C1 or C2 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.

centage of correct recall of C1 and C2 with repeatedness and format (same or different) as factors. It showed a main effect of repeatedness, $F(1, 15) = 77.0$, no format effect ($p > .59$), and no interaction between the two factors ($ps > .36$), indicating that the size of RB between identical or different-format items was comparable. Two separate ANOVAs for identical and different format were also performed. For identical trials, the size of RB was found to be greater for words (ww) than pictures (pp), $F(1, 15) = 8.4$; the saliency of pictures when embedded in words may have rendered them less subject to RB. For different trials, more errors were observed when the picture appeared first (pw) rather than second (wp), $F(1, 15) = 28.2$; however, this effect did not interact with repeatedness ($p > .58$). This result may indicate that the processing of a picture disrupts the processing of subsequent items more than a word does.

Discussion

Experiment 1 demonstrates that RB can be obtained between pictures and words, establishing that RB occurs between items that are believed initially to access different representations, or types. It has been proposed that pictures access a conceptual representation first, followed by a lexical representation through which phonological and orthographic information becomes available. In contrast, words are thought to access first their lexical representation, enabling a rapid retrieval of phonological information; and to connect more slowly with a conceptual representation (see Potter, 1979; Potter & Faulconer, 1975; Smith & Magee, 1980; Snodgrass, 1980, 1984; Theios & Amrhein, 1989). Hence, despite the fact that the codes most readily retrieved during the perception of words and pictures are different (phonological/linguistic versus conceptual/spatial), RB is still observed between these stimuli. This result supports the hypothesis that RB is sensitive to the similarity of the codes used for registration of the items in STM.

The codes that were registered in STM and that were responsible for RB in Experiment 1 could have been lexical or semantic/conceptual or phonological/orthographic. 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 semantic similarity between C1 and C2. Although semantic similarity, at least when using words (i.e., taxi/cab), always failed to elicit RB (Kanwisher & Potter, 1990), it may play a role when using pictures. To differentiate between a phonological/orthographic (loosely referred to as phonological similarity thereafter) or a lexical and/or conceptual/semantic (loosely referred to as semantic similarity thereafter) account of RB between pictures and their corresponding words, Experiment 2 looked at RB between a picture and a word that are semantically and lexically different, but access similar

phonological/orthographic representations during their processing, such as the picture of a sun and the word “son”.

EXPERIMENT 2

In Experiment 2, the relative contribution of different kinds of type 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” (referred to as the “similar” condition), was compared to RB between the picture of an object and its written homophone, such as a picture of the sun and the word “son” (referred to as the “homophone” condition). If RB is found between pictures and words that access identical semantic, lexical, orthographic and phonological representations but not between pictures and words that access only similar orthographic and/or phonological representations, it would suggest that RB when using pictures is only determined by semantic or lexical similarity. However, if RB is found for both kinds of item, it will indicate that at least part of RB between pictures and words is phonologically/orthographically based.

Method

Subjects

Twenty subjects from the same pool as the previous experiment participated in this experiment. None of them had participated in Experiment 1.

Materials and design

Twenty pictures of objects (whose names were not homophones) were selected. Two sentences each containing a repeated picturable noun were constructed. The same number of words intervened between C1 and C2 in each sentence of a pair; C1 was a picture in one sentence and C2 in the other. Twenty pictures whose corresponding name was homophonic to another word (e.g., sun–son, ant–aunt, pear–pair) were also selected. Two sentences were constructed for each picture–homophone word pair; 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. A non-repeated control was produced for each of the 80 sentences constructed 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 non-repeated C1 controls are given in Appendix B.

There were three main variables: repeatedness, format (picture or word) and the nature of the relationship between C1 and C2 (“similar” 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). Although repeatedness was counterbalanced within subjects and within items, similar/homophone and format were within subjects, but between items. Each experimental list contained only one of the sentences that were built from a given critical pair; hence, a given item was never used twice as a critical item for a given subject. This 2×2 design resulted in four different versions of the experiment. Each version of the experiment contained 40 experimental sentences and 20 ungrammatical filler sentences that contained one picture. Twelve practice sentences were included which contained one picture.

Procedure

The same procedure as in Experiment 1 was used. Items were displayed for 100 ms each.

Apparatus

The same apparatus as in Experiment 1 was used.

Results

Table 2 shows the main results scored as in Experiment 1. Overall recall accuracy for the sentences was good. Recall of the words of the sentences other than C1 and C2 averaged 83%. All the effects reported were significant by subject at the .01 level, unless otherwise noted, and item analyses gave similar results except as noted.

An ANOVA with similarity (homophone or not), picture/word first and repeatedness was performed on the percentage of recall of both C1 and C2. There was a sizeable RB effect, $F(1, 19) = 18.8$; the interaction between similarity and repeatedness was only marginally significant by subject ($p = .08$) and non-

Table 2. *Experiment 2: percentage of recall of both C1 and C2 as a function of the similarity conditions (pw = C1 picture and C2 word; wp = C1 word and C2 picture)*

Repeatedness	Similar (cat/cat)		Homophone (sun-son)	
	pw	wp	pw	wp
Non-repeated	76	79	70	94
Repeated	45	61	55	83
Non-rep. – rep.	31	18	15	11

significant by item ($p > .12$). As in Experiment 1, significantly more errors were found when the picture appeared first (pw) rather than second (wp), $F(1, 19) = 18.6$; this effect did not interact with repeatedness ($ps > .15$). Although the similar/homophone and repeatedness interaction did not reach significance, RB between similar (cat/cat) items was numerically greater than RB between phonologically related items (son/sun) (25% vs. 13%). A separate analysis of the homophone trials confirmed a sizeable RB effect between picture–word homophonic pairs, $F(1, 19) = 7.6$.

For one cell, the analysis of the recall of both C1 and C2 differed from the one of C1 and C2 separately. When C1 was a word and C2 a picture, in the homophone trials, the recall of C1 as well as C2 seemed to be affected by RB. Analysis by subject and by item of the recall of C1 indicated a triple interaction between format, similar/homophone and repeatedness, $F(1, 19) = 6.2$, $p < .022$, by subject, and $F(1, 38) = 3.95$, $p < .054$, by item, confirming this trend. This pattern of result suggests that when C2 is extremely salient, C1 may be omitted rather than C2.

Discussion

The main new result of Experiment 2 is that RB was observed between phonologically related but semantically unrelated pairs of pictures and words (i.e., the picture of a sun and the word “son”). This result shows that phonological and/or orthographic similarity alone (independent of visual, lexical and semantic similarity) is sufficient to produce a sizeable amount of RB. Although access to phonological and/or orthographic information from pictures is slow and is mediated by retrieval of semantic and lexical information, RB can be found when using phonologically and orthographically similar but semantically and lexically different pictures and words. Although the difference between

phonological and semantic RB (13% vs. 24.5%) did not reach significance, it was sizeable and suggests that semantic relationships may have some influence on the amount of RB. Moreover, in the wp homophone trials, RB mostly impaired the recall of the C1 word, not the C2 picture, as if conceptual dissimilarity helped to stabilize the C2 picture. These two points suggest that the pattern of RB can be affected by conceptual information when using pictures.

The finding that the recall of C1 can be subject to RB when C1 is a word and C2 a homophonic picture (wp homophone trials) suggests that RB can occur even though tokens for C1 and for C2 were initially instantiated. Indeed, since C2 was recalled, its presentation had clearly led to the instantiation of a token; since C1 appeared first and was well recalled on non-repeated trials, its presentation should also have led to the opening of a token on the repeated trials. Hence, even though a token for C1 as well as for C2 had been opened, some degree of RB was observed (11%). This suggests that RB can arise from the loss of one of two opened tokens. Moreover, 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. The observation that RB usually affects the recall of C2, and not C1 (Kanwisher, 1987), could indicate that time of arrival, in the absence of other biasing information, determines the relative stability of tokens. It may also be the case that RB between visually identical items, which is characterized by the loss of C2, is of a different nature than RB between visually different items. RB between visually identical items may result from a failure initially to create a new token of the second item, while RB between visually different items may occur because of the loss of one or another opened token.

To conclude, Experiments 1 and 2 establish RB between visually dissimilar items such as words and pictures. They demonstrate that phonological RB is not merely found for easily verbalized stimuli, such as words, letters or numbers, and they support the claim that RB will be found between any visual stimuli if similar codes are to be used to stabilize their tokens in STM. Moreover, they suggest that RB between visually different items may be best explained as resulting from the loss of an opened token rather than from a failure to create a new token for C2 (Kanwisher, 1987). In this view, the instantiation of a new token is actually a two-step process, involving first an opening process (possibly relying on pre-attentive visual information; see Trick & Pylyshyn, 1993, for support of such a process) and then a stabilization process (possibly relying on the codes used for registration in STM). This view predicts that task requirements, by varying the nature of the codes preferentially registered in STM, should affect the size of RB between visually different items, but not between visually identical items. Experiments 3 and 4 tested whether the size of RB can be varied as a function of the similarity of the codes required to be registered in STM.

II. ROLE OF TASK REQUIREMENTS IN REPETITION BLINDNESS

I proposed that RB between visually different but phonologically similar items occurs 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 by manipulating the nature of the codes to be registered in the tokens by explicit instructions (Experiment 3) or implicit ones (Experiment 4).

EXPERIMENT 3

Experiment 3 was designed to test whether the size of RB between visually dissimilar items can be manipulated as a function of the way the task requires subjects to initially encode information in STM. For this purpose, pictures and their corresponding words were presented. The task manipulation emphasized either phonological encoding or visual encoding. In the phonological task, subjects were 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. 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 each task.

Method

Subjects

Thirty-six³ 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

Two sets of eight picturable nouns were selected. Stimuli were taken from the Snodgrass and Vanderwart (1980) as well as from the Potter and Faulconer (1975)

³Although these 36 subjects were originally run in two separate groups (16 subjects and 20 subjects), the results from these two groups were collapsed since they did not differ significantly.

picture sets. An experimental block was constructed from these two sets of eight nouns. Each of the blocks consisted of 12 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 consisted of pictures or words. 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 the picture of an object, while still efficiently masking the pictures of objects (a row of symbols was added in each of these masks at the location where words appeared on the screen so that words would also be properly masked). The serial position of the two critical items C1 and C2 was varied in the list; the first position in the sequence of six items was, however, always occupied by a mask. The two critical items were separated by one item (picture or word) on half the trials (lag 1: one intervening item), and by one item and a mask field on the other half (lag 2: two intervening items). The 20 filler trials consisted of two pictures (sometimes repeated) intermixed with four mask fields.

On half of the trials in a block, C1 and C2 had the same identity (repeated trials); on the other half they had a different identity (non-repeated trials). On half the repeated trials, C1 and C2 were presented in an identical format (identical trials: i.e. picture/picture, word/word); on the other half, C1 and C2 had the same identity but were in a different format (different trials: picture/word, word/picture). Repeatedness and identical–different format were counterbalanced within subjects and items. A final between-item variable was the number of items intervening between C1 and C2 (1 item, termed lag 1, versus 2 items, termed lag 2). This 2×2 design resulted in a total of four 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 asked not only to report the name of the items they saw, but also the format (picture vs. written word) in which they were presented. In the other case (phonological task), subjects were just asked to report the name corresponding to the pictures or the words they saw. 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. The order of presentation of the two sets of material and of the tasks (visual vs. phonological) were counterbalanced between subjects.

Procedure

Subjects were first presented with a page showing the eight pictures to be used in that block, and their corresponding names. The instructions were to view the

items carefully and ignore the mask fields. If they saw a repeated item they were to report the item twice. Subjects 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 immediately disappeared, and the items appeared one at a time at the same place, for 83 ms per item.

Apparatus

The same apparatus as in Experiment 1 was used.

Results

The percentage of trials in which both C1 and C2 were recalled, for each of the categories, is presented in Table 3.⁴ 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). All the effects reported were significant by subject at the .01 level, unless otherwise noted, and item analyses gave similar results except as noted.

We predicted that for different-format items the size of RB should be affected

Table 3. *Experiment 3: percentage of trials in which C1 and C2 were both recalled as a function of the format conditions (ww = C1 and C2 words; pp = C1 and C2 pictures; pw = C1 picture and C2 word; wp = C1 word and C2 picture)*

Task/repeatedness	Identical format			Different format		
	ww	pp (cat/cat)	M	pw	wp (cat/cat)	M
<i>Phonological task</i>						
Non-repeated	73	65	69	70	77	73
Repeated	40	43	41	49	67	58
Non-rep. – rep.	33	22	27	21	10	15
<i>Visual task</i>						
Non-repeated	71	58	64	68	73	70
Repeated	45	40	42	55	73	64
Non-rep. – rep.	26	18	22	13	0	6

⁴For 20 of the subjects, 19 trials per subject had to be discarded 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.)

by the task, while for identical-format items it should not. Two separate ANOVAs with task, repeatedness and trial types as factors performed on the percentage of correct recall of both C1 and C2 confirmed this prediction: for identical-format trials, a main effect of repeatedness was found, $F(1, 35) = 69.8$, but there were no effects of task or interaction between task and repeatedness ($ps > .16$). A tendency for a larger RB for words (ww) than pictures (pp) trials was also noted in the subject analysis, $F(1, 35) = 4.5$, $p < .04$ ($p > .07$ in the item analysis). For the different-format trials, there was a main effect of repetition, $F(1, 35) = 47.5$, and an interaction between repeatedness and task, $F(1, 35) = 6.0$, $p < .02$. Significantly more errors were found when the picture appeared first (pw) rather than second (wp), $F(1, 35) = 26$; this effect interacted with repeatedness, $F(1, 35) = 15.5$, due to a larger RB effect for pw trials. These analyses show that the size of RB between different items is significantly smaller in the visual task than in the phonological task, while the size of RB between identical items is equivalent in each task. Another ANOVA with identical/different and repeatedness as factors revealed that the size of RB is smaller for different-format than for identical-format, $F(1, 35) = 14.7$. This finding confirms the hypothesis that the size of RB tends to decrease as the similarity between the items decreases.

Although the previous results are consistent with our predictions, a more direct statistical approach to test the predicted hypothesis involved performing a contrast analysis. The predicted hypothesis assigned a contrast weight of +1 to each of the identical format cells, 0 to the different format/phonological task cell and –2 to the different format/visual task cell. These weights predict less RB between different than identical items, and an effect of task manipulation only on the different items. This contrast analysis was carried out on the size of RB (non-repeated – repeated). The contrast was significant, $F(1, 105) = 23.03$, $r = .42$. This result supports the claim that RB for different trials is more affected by the task manipulations than RB for the identical trials.

Discussion

Experiment 3 establishes that RB between visually different items can indeed be varied as a function of task requirements. While the size of RB was found to be diminished by the task requirements between visually different items, the same task requirements did not affect the size of RB between visually identical items. This finding is consistent with the view that RB between visually different items arises because subjects are biased toward the use of a similar code for registration in STM. Hence, when visual encoding is enforced, visual dissimilarity is more efficient in counteracting the role of the similarity of the other codes (here, lexical, semantic, orthographic or phonological) in producing RB, resulting in a reduced amount of RB (6%). Experiment 3 also establishes the presence of RB

between pictures and their corresponding names when using short lists, as well as confirms the finding that RB between identical items is usually larger than (or at least equal to) that between related items.

In Experiment 3, semantic, lexical and phonological similarity were confounded; although semantic similarity has not been found to produce RB between words that are synonyms (cab/taxi) (Kanwisher & Potter, 1990), the role of semantic similarity in RB for pictures is unclear. The finding in Experiment 2 of a tendency for more RB between semantically (or lexically) equivalent pictures and words than between homophone pictures and words suggests a possible role for semantic/lexical similarity. Moreover, the fact that pictures are known to access their semantic representation before their lexical representation could allow for a role of semantic similarity when studying RB between pictures. Experiment 4 was designed to test the effect of task manipulation on RB between phonologically related pictures and words that are either semantically/lexically related or not. This experiment allowed us to confirm that the effect of task requirements on RB generalizes to other stimuli and tasks, and to test for a possible role of semantic/lexical similarity in RB when using pictures.

EXPERIMENT 4

Three types of repeated stimuli were used: identical items (two pictures or two words); items different in format but identical in name and meaning (e.g., the picture of a cat and the word “cat”); and items different in format and meaning but identical in pronunciation (e.g., the picture of a sun and the word “son”). Two tasks were compared: reading silently or with concurrent irrelevant articulation (CA). CA has been shown by numerous investigators to interfere with STM for ordered sequences of words, letters or digits (see Baddeley, 1986, for a review). While CA 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, 1966; Besner, 1987a, 1987b; Besner & Davelaar, 1982; Van Orden, 1987). Hence, for words, CA allows one to differentiate between a late, post-access phonological effect due to rehearsal in STM (impaired by CA), and initial access to a phonological representation (unaffected by CA). This observation led Bavelier and Potter (1992) to argue that if RB between homophonic words is reduced by CA, it would suggest that such RB is due to phonological confusion after memory registration is achieved. They showed, however, that RB between homophonic words is not reduced by CA, and argued that RB between homophones 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. Indeed, effects of phonemic

similarity, word (name) length and articulatory suppression have been shown when using either nameable pictures or their equivalent written words in an immediate memory task (Schiano & Watkins, 1981). Several subsequent studies have clearly established that CA inhibits the phonological encoding of pictures in STM (Brandimonte, Hitch, & Bishop, 1992; Broadbent & Broadbent, 1981; Hitch, Woodin, & Baker, 1989). However, it is possible that for pictures CA interferes not only with the component of STM that sustains and permits rehearsal of the phonological representation of these pictures, but also with the initial retrieval of a lexical/phonological code during the perception of the pictures. For example, CA was shown to disrupt rhyme decisions and homophone decisions for words written in Kanji (logographic Japanese script) more than in Kana (syllabic Japanese script) (Kinoshita & Saito, 1992). The relatively slow access to lexical/phonological information during picture (or logographic) processing seems to be disrupted by CA, whereas for written words (or scripts) a phonological code is so immediately and automatically retrieved that CA does not affect its retrieval. Moreover, CA has also been observed to enhance the role of visual/semantic information during picture processing. For example, Brandimonte et al. (1992) as well as Hitch et al. (1989) showed that CA biases subjects toward the use of visual codes during picture recall. These observations suggest that CA impairs phonological retrieval and emphasizes conceptual/visual encoding more for pictures than for words. Thus by comparing RB in silent versus CA conditions, Experiment 4 tests whether a shift in preferred encoding from phonological to semantic/visual can affect the size of RB. Moreover, the study of the amount of RB in the condition that emphasizes conceptual encoding enables one to test directly for a role of semantic/lexical similarity on RB.

Method

Subjects

Sixteen subjects from the same pool as the previous experiments participated in this experiment. None of them had participated in Experiments 1, 2, or 3.

Materials and design

The material used was taken from Experiments 1 and 2. The 56 sentences used in Experiment 1 were divided between two equal blocks. The 40 sentences used in Experiment 2 containing phonologically similar but semantically different pairs of pictures and words were also reused. Each block in Experiment 4 contained 28 identical sentences and 20 homophone sentences, and 9 ungrammatical filler

sentences. Given that the 40 homophone sentences were built from 20 pairs of pictures and words, the same pair (in different order) appeared twice (once in each block) during the whole experiment. One of the sentences was in the repeated condition, and its paired sentence was in the non-repeated condition counterbalanced over subjects.

There were three main variables: repeatedness, visual format (picture or word) and the nature of the relationship between C1 and C2 (phonologically and semantically similar or phonologically similar but semantically different). For phonologically and semantically similar trials (the homophones), there were four formats: ww, pp, wp and pw. Repeatedness and format were counterbalanced within subjects and within items; this 2×4 design resulted in eight different versions. For phonologically similar but semantically different trials, there were only two formats: pw or wp. Repeatedness was counterbalanced within subjects and items, format was within subjects and between items. Items were randomized within blocks. The final variable, within subjects and items, was the concurrent suppression 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.⁵ Each block began with 11 practice sentences containing zero, one or two pictures.

Procedure

The same procedure as in Experiment 1 was used. Items were displayed for 100 ms each.

Apparatus

The same apparatus as in Experiment 1 was used.

Results

The same method of scoring and analysis was used as in Experiment 1. The percentage of recall of both C1 and C2 for each of the conditions is shown in Table 4. Overall recall accuracy for the sentences was good. Recall of the words of the sentences other than C1 and C2 averaged 81%. All the effects reported were significant by subject at the .01 level, unless otherwise noted, and item

⁵The only factor that was not counterbalanced was that each of the experimental lists did not appear in all the order of Block \times Task conditions.

Table 4. *Experiment 4: percentage of trials in which C1 and C2 were both recalled as a function of the format and similarity conditions (ww = C1 and C2 words; pp = C1 and C2 pictures; pw = C1 picture and C2 word; wp = C1 word and C2 picture)*

	Identical (cat/cat)			Similar (cat/cat)			Homophone (sun/son)		
	ww	pp	M	pw	wp	M	pw	wp	M
<i>Silent</i>									
Non-repeated	82	69	75	66	90	78	58	80	69
Repeated	41	51	46	40	65	52	38	70	54
Non-rep. – rep.	41	18	29	26	25	25	20	10	15
<i>Articulation</i>									
Non-repeated	72	66	69	58	78	68	63	73	68
Repeated	40	51	45	43	52	47	56	80	68
Non-rep. – rep.	32	15	23	15	26	21	7	–7	0

analyses gave similar results except as noted. For simplicity, the three main kinds of trials were termed respectively: “identical” for trials with visually, phonologically and semantically identical items; “similar” for these with visually different, but phonologically and semantically identical items; and “homophone” for those with visually and semantically different but phonologically similar items.

ANOVAs were performed for each kind of trial on the percentage of recall of both C1 and C2. A comparison of the role of articulatory suppression on RB for each of the conditions indicated that task requirements affected the pattern of RB for homophone trials but neither for identical nor similar trials. For identical trials, a main effect of repeatedness was found, $F(1, 15) = 18.5$, confirming the presence of RB. No other significant effect was observed. Specifically, there was no interaction between repeatedness and task ($ps > .29$), indicating that the size of RB was similar whether subjects were silent or articulated. This result supports Bavelier and Potter’s finding (1992) that RB between identical items is not affected by concurrent suppression. Consistent with Experiments 1 and 3, a tendency for more RB between words (ww) than pictures (pp) was observed ($p < .054$). The analysis of similar trials revealed a main effect of repeatedness, $F(1, 15) = 16$, confirming the presence of RB. Again, there was no interaction between repeatedness and task ($p > .6$), indicating that the size of RB for these trials was similar whether subjects read silently or articulated. As in the previous experiments, more errors were observed when the picture appeared first (pw) rather than second (wp), $F(1, 15) = 12.4$, and this effect did not interact with the size of RB. In the analysis of homophone trials, the main effect of repeatedness was significant by subject, $F(1, 15) = 5.6$, $p < .03$, and only marginally significant by item, $p = .11$. There was an interaction between repeatedness and task,

$F(1, 15) = 7.1$, $p < .017$. Separate analyses of the silent and articulation condition confirmed the presence of RB in the silent condition, $F(1, 15) = 12.7$, replicating the findings of Experiment 2, and showed no significant effect of repeatedness for the articulation trials ($p > .8$). Thus RB was eliminated when subjects articulated in the homophone condition. The analysis of the homophone trials also revealed a main effect of task by item, $F(1, 38) = 5.5$, $p < .025$, but not by subject, $p > .12$, indicating slightly more errors in the silent task than in the articulation task, probably due to the decrease in RB in the articulation condition. Again, more errors were observed when the picture appeared first (pw) than when it was second (wp), $F(1, 15) = 46.3$, and this effect did not interact with repetition. An analysis of the recall of C1 and C2 separately with identical, similar and homophone trials revealed a repeatedness effect on C1, $F(1, 15) = 7.4$, $p < .016$. This effect did not interact with the type of trial ($ps > .8$), indicating some amount of RB on C1 for each type of trial.

As in Experiment 3, a more direct test of the role of task requirement was performed using contrast analysis on similar and homophone trials. A change in the size of RB as a function of task was predicted only for visually and semantically different items. This hypothesis involved assigning a weight of +1 to each of the similar cells (i.e., silent or articulating), a weight of zero to the homophone trials in the silent cell, and a weight of -2 to the homophone trials in the articulation cell. These weights predict less RB between homophones than similar items, and an effect of task manipulation only on the homophone items. This contrast analysis was carried out on the size of RB (non-repeated - repeated). The contrast was significant, $F(1, 45) = 16.34$, $r = .51$. This result supports the claim that RB for semantically different items is more diminished by CA than RB for semantically/lexically identical items.

Discussion

The results of Experiment 4 are consistent with those of Experiments 1 and 2. Specifically, RB between homophone pictures and words is confirmed, and also the finding that recall of C1 as well as C2 can be impaired during RB. Moreover, Experiment 4 clearly demonstrates that task manipulations can affect the size of RB. The results are consistent with the hypothesis that the size of RB between visually different items is dependent on the similarity of the codes used for registration. CA, which by impairing the efficiency of phonological encoding probably emphasizes semantic information, reduced RB more between semantically and lexically different pairs of pictures and words than between pairs of pictures and words that were semantically and lexically identical. This result is striking for it reveals for the first time that semantic similarity (or possibly lexical

similarity that is not phonological) can produce RB. Moreover, as predicted, the amount of RB between identical items was not varied by the task requirements.

Concurrent articulation apparently eliminated homophonic RB between pictures and words (when phonology was all they shared), without eliminating RB between pictures and words that shared semantic and lexical representations: thus, it was only the latter information, not phonology, that could have been the basis for RB. Such a role for semantic/lexical information in RB when using pictures and words would 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; Yin, Wojciulik, & Kanwisher, 1993).

The pattern of results observed in Experiment 4 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 (see Baddeley, 1986, for a review). However, the finding that concurrent articulation improves performance in the homophone repeated trials relative to the silent condition is at odds with the classical effects of CA on STM maintenance, which is to reduce performance to the same low level regardless of phonological similarity. Moreover, such an interpretation would also require two different mechanisms for RB between homophone pictures and words (reduced by articulation) and RB between homophone words (unaffected by articulation) (see Bavelier & Potter, 1992). The hypothesis of two different, independent levels at which RB can happen not only lacks parsimony but also seems inconsistent with several pieces of data. For example, RB between two identical pictures (that could happen both at the perceptual and the memory level, according to this view) can be less (see Experiments 1 and 4) than RB between pictures and words (that could happen only at the memory level, according to this view). Moreover, several of the characteristics of confusion effects in STM seem inconsistent with the observed properties of RB (see the General discussion).

An alternative interpretation of the results of Experiment 4 is suggested by the observation that CA delays access to an early phonological code for pictures but not for words. Hence, CA may bias subjects toward a semantic encoding of pictures in STM. But since a phonological code is retrieved efficiently for words regardless of the task (Besner & Davelaar, 1982), subjects may still rely on phonological encoding for words under CA (see Fig. 1).⁶ According to this view, phonological codes for words contribute to the stabilization of their corresponding token even under CA. Hence, CA should not reduce RB between words. For pictures, CA delays the initial retrieval of phonology, and so reduces RB between homophone pictures and words. The finding of RB for phonologically and semantically related picture–word pairs under CA is consistent with the hypoth-

⁶I am grateful to A. Treisman for originally designing this figure and suggesting its use.

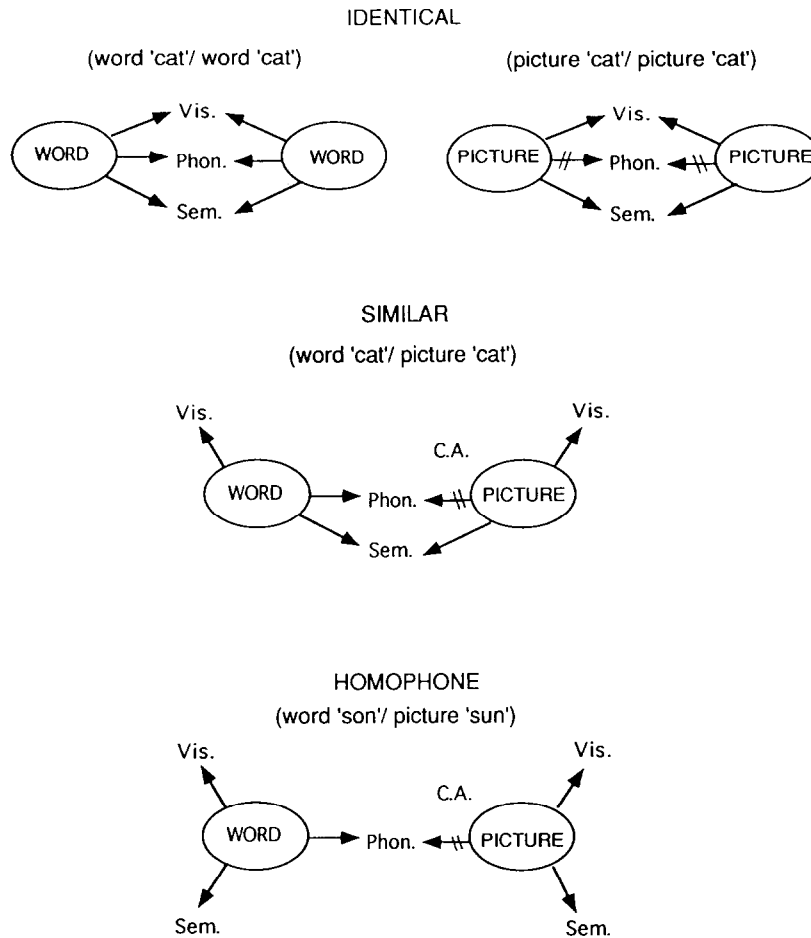


Fig. 1. Schematic representation of the three kinds of similarity studied. Codes written in between the two targets are common to these targets; the other codes are different. Codes that concurrent articulation disrupts are noted by a broken arrow (i.e. //). Vis. = visual code, Phon. = phonological code, Sem. = semantic code, C.A. = concurrent articulation.

esis that, when using pictures, CA biases subjects toward the use of semantic information which can still produce some RB.

To conclude, Experiments 3 and 4 indicate that the size of RB between visually dissimilar items can be varied as a function of the codes the task requires to be registered in the token. They confirm the findings of Experiments 1 and 2 that the amount of RB between visually different items can be determined by the nature of the code used for stabilizing the token of a given item in STM. They also demonstrate that semantic similarity (whether purely conceptual or lexical-semantic) can influence the size of RB when using pictures (see Yin et al., 1993).

GENERAL DISCUSSION

Experiment 1 establishes RB between pictures and their corresponding written names, when using sentences. This finding extends earlier work indicating that visual similarity is not necessary for RB, and shows that RB between visually dissimilar items is not restricted to the use of stimuli as readily nameable as words. The goal of Experiment 2 was to examine the contribution of different kinds of information to RB between visually dissimilar items. RB between phonologically and semantically similar items (e.g., the picture of a cat and the word “cat”) was compared to RB between phonologically/orthographically similar but semantically and lexically dissimilar items (i.e., the picture of a sun and the word “son”). The finding of RB in the latter case shows that phonological/orthographic similarity alone is sufficient to produce some degree of RB. These findings are consistent with the claim that RB between visually dissimilar items is governed by the similarity of the codes that are initially used for registration of the items in STM. Experiment 3 indicates that the amount of RB between visually dissimilar items can be manipulated by varying the nature of the information initially registered in STM. When subjects were asked explicitly to encode the visual attributes of items, RB between phonologically and semantically similar items was diminished for visually dissimilar items compared to identical ones. Experiment 4 confirms that the task can affect RB, and suggests that semantic/lexical similarity can play a role in RB when using pictures. Taken together, these experiments show that RB between visually different items occurs for items that are less readily verbalized than words, such as pictures (Experiments 1 and 2), and that it arises whenever the initial registration in STM of the items relies on the same or similar codes (Experiments 3 and 4). Although there was a larger RB effect between visually identical items than between visually different items, this finding was modulated by the fact that the saliency of the targets seems to influence the amount of RB. So, in sentences pictures (which were much more salient than words) seemed to be less prone to RB (Experiments 1, 2 and 4).

The present findings suggest two important characteristics of the processes responsible for the instantiation of new tokens (under time pressure). First, if a given code is used for registration in a token, this code will subsequently be less efficiently registered in another separate token that needs to be established within the next few hundred milliseconds. The present experiments show that the nature of the codes to be registered is determined by the nature of the items (e.g., shape and meaning for pictures, orthography and phonology for words) as well as by the requirements of the task. Second, a failure to register codes into a newly opened token may result in the loss of that token. In this view, RB between visually dissimilar items seems best explained as a failure to stabilize an already opened

token, rather than a failure to open a new token (Kanwisher, 1987). In the following sections, evidence supporting these two points will be reviewed.

RB between visually different items is proposed to arise from the loss of a token during the attempted stabilization of newly opened tokens. The distinction between the opening of a token and its stabilization is based on the idea that the instantiation of a token is not a one-step process, but rather a dynamical process during which the information registered in the token, and hence its stability, will vary. The failure to register some codes in a token would result in a weaker token, rendering it more subject to loss. The mechanism responsible for RB would then be very similar to the one originally proposed by Kanwisher (1987). RB would arise because, once a code has been registered in a token, the subsequent reactivation of that code may not be interpreted as corresponding to a new object, but rather considered to belong to the token in which it was previously registered. The claim that RB can arise from a failure to stabilize an opened token (Bavelier, 1992; Bavelier & Potter, 1992) is primarily supported by the finding that RB can occur even when there is reason to believe that distinct tokens for C1 and for C2 were initially opened. The finding that RB can affect the recall of C1 and not only C2 (Experiments 2 and 4, homophone wp trials) suggests that the token for C1 can be opened and subsequently lost. Moreover, in the repeated wp trials (homophone or similar, Experiment 2 and Experiment 4'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. This anecdotal observation suggests that a token was initially opened when C2 was presented, in which some salient information about its distinction pictorial format was entered. Also, an analysis of the pattern of errors in three-words list experiments with homophonic words 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 (as indicated by a larger ratio of replacement to omission errors in the first case than in the second; see, Bavelier, 1992, p. 127). Finally, the size of RB is diminished when C2 is salient (e.g., C2 in a picture format among words), supporting the idea that the saliency of the information registered in tokens controls their stability and so the amount of RB. Taken together, these findings suggest that, for RB between visually different items, initially a token for C1 as well as C2 was opened, but subsequently one of these was lost.

The claim that registration codes are determined not only by the nature of the items but also by the requirements of the task is mainly supported by the findings of RB between pictures and words. In each of the experiments presented, RB occurred when the task required similar codes to be registered in the tokens of C1 and C2, even though the codes most readily retrieved during recognition for each

of these items differed. 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; Snodgrass, 1980; Theios & Amrhein, 1989). 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 (see Fig. 1). RB was obtained between phonologically related but visually distinct items, when the preferred encoding for initial registration and recall was phonological. However, if a visual bias was induced, the RB effect was reduced (Experiment 3). Similarly, RB was obtained between phonologically related but semantically different pictures and words, when the preferred encoding for initial registration was phonological; but the RB effect disappeared when the encoding impaired phonological information, probably leading subjects to emphasize semantic information in order to store the items efficiently (Experiment 4). The idea that similarity of registration codes rather than solely perceptual codes governs the manifestation of RB implies that semantic information should also be observed to play a role in RB. Experiment 4 showed that semantic similarity (or possibly lexical information that is not phonological) can induce RB. Although the role of semantic versus lexical (that is not phonological) similarity on RB will have to be further explored, the present result already supports the idea that RB will occur whenever the codes that are important in the stabilization of tokens in the studied task are similar, independently of the exact nature of these codes (visual, phonological, semantic or lexical). In the present experiments, the use of pictures and words allowed one to disambiguate between codes readily retrieved during perception and codes registered in the tokens in STM. Such a distinction may, however, be often difficult to draw because the information 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 subject toward a specific encoding in STM may this code be different from the ones readily retrieved during perception. In this view, RB between visually different items is observed because the task or/and the items used bias subjects toward registering similar codes in the tokens (Experiments 2, 3 and 4). More generally, these data show that the instantiation of new tokens may be sensitive not only to the properties of the stimuli used but also to the task requirements. Although I have been arguing that RB is sensitive to the similarity of the codes registered in the tokens, an alternative characterization would be that RB is sensitive to the similarity of the “attended” dimensions of the stimuli (Kanwisher, 1991a). It is not clear how one could dissociate attended and STM-registered dimensions, however.

The present study has provided evidence for three main properties for tokens:

- (1) The instantiation of the episodic token of an event is a dynamical process

- during which one or more codes that specify the object or event are registered in the token. The stability of the token is a function of the number and saliency of the codes registered into it.
- (2) A given code cannot efficiently be registered into more than one token in a short amount of time.
 - (3) The codes that will be registered in STM are determined both by the perceptual properties of the stimulus and by the nature of the preferred encoding in STM.

These proposed properties of tokens are consistent with other findings in the literature. A standard assumption in perceptual processing is that the presentation of an item triggers a spreading of activation through its different codes (McClelland & Rumelhart, 1981; Potter & Faulconer, 1975). The experimental evidence clearly indicates that these codes become available at different times, consistent with the idea of a dynamical build-up of tokens as codes are available. Another striking piece of evidence that registration of information in a token can be dynamical was initially reported by Pylyshyn and Storm (1988). These authors showed that subjects are able to track several separate moving dots as long as these dots preserve spatio-temporal continuity. Recently, however, Yantis (1992) showed that subjects could track the dots only when they treated them as representing a single object undergoing change, indicating that the dynamical update of information in a given object token is quite efficient. Constraints on the speed at which codes can be registered in tokens have been found in other paradigms than RB. A general limit on the number of tokens that can be instantiated in a short amount of time has been shown by the diminution of effects based on object selectivity as the number of items to tokenize increases (e.g., reduction of object-specific priming when there are more than two objects in the preview field, Kahneman et al., 1992; reduction of the Tipper effect when there is more than one distractor, Neumann & De Schepper, 1991). This general limitation is also consistent with the subitizing phenomenon (see Trick & Pylyshyn, 1993). Moreover, problems in instantiating tokens for similar items are not only observed with the RB paradigm but also in some other procedures (e.g., the repeated-letter inferiority effect, Bjork & Murray, 1977; Egeth & Santee, 1981; Frick, 1987; the homogeneity effect, Mozer, 1989; Schneider and Shiffrin, 1977, Experiment 3). Although these effects were not initially described as an impairment in setting up or stabilizing tokens, they may all be interpreted as such (see Mozer, 1989, for a discussion). Other evidence for constraints on the number of tokens a given code can be registered in comes from the work of Kahneman et al. (1992). These authors reported a tendency for no or even a negative priming effect when the target belonged to a different object in the preview field than in the target field. Under these conditions, codes that were previously registered in a given token (during the preview field) would have to be registered into a distinct

token when viewing the target field. Hence, the weak or even negative priming effect observed also argues for a specific difficulty in registering the same codes in two distinct tokens. Moreover, this negative priming effect was stronger under conditions that allowed a token to be instantiated for each of the stimuli in the preview field (low perceptual load preview field), therefore confirming that this effect is contingent on codes being initially assigned to specific tokens. Along the same lines, a recent study of visual extinction with unilateral parietal damage by Baylis, Driver, and Rafal (1993) showed that the extinction effect was more severe if the two objects were the same on the attributes to be reported. Again, this result is consistent with a specific impairment when having to register a same code in two different tokens. Moreover, it confirms that codes registered in tokens can be manipulated as a function of the task. Similar evidence for the role of the task in token instantiation comes from studies of spatial RB by Kanwisher, Driver, and Machado (1993). These authors flashed a visual display with two colored letters, and asked subjects to report either the color of the letters or their identity. When color was to be recalled, RB was found between identically colored letters independently of their letter identity. When letter identity was to be recalled, RB was observed between identical identity letters independently of the color. Suggestions for a role of task requirements on tokenization may also come from the Tipper negative priming effect (Neill, 1977; Tipper, 1985), if one agrees that a token for the distractor as well as for the target is instantiated in this paradigm (see Treisman, 1992, for support of this view). Several recent experiments on the Tipper effect show that the nature of the effect varies as a function of the task (visual for a physical similarity task, Neill, 1991; semantic for a category task, Tipper and Driver, 1988; spatial for a location task, Tipper et al., 1990). Again this pattern of finding suggests that the task requirements, and not only the nature of the stimuli used, can control the kind of information registered in tokens.

There seems to be convergent evidence for interpreting the present findings in the type-token framework. However, alternative explanations⁷ may come to mind. For example, RB between visually different items such as homophones could be due to an inhibition of the lexical entries between homophones. Indeed, several studies have shown that given a word that is a homophone (e.g., ROWS), both meanings and lexical entries associated with the sound representation of the homophone (e.g., rows and rose) are initially activated, and later one of the activated lexical entries is selected (Lesch & Pollatsek, 1993; Pollatsek, Lesch, Morris, & Rayner, 1992; Van Orden, 1987, 1991). If such a selection renders the other entries less available for a subsequent recognition, it could be the source of RB between homophones. An account of homophonic processing in terms of inhibition of the lexical entries between homophones seems, however, difficult to hold given other data of the literature. Indeed, it has been shown that phonologi-

⁷I thank A. Treisman and an anonymous reviewer for suggesting these alternative explanations.

cal coactivation is not merely limited to homophonic words (Perfetti & Bell, 1991; Seidenberg, Waters, Barnes, & Tanenhaus, 1984) and that selection does not always require inhibition (see the verification procedure by Lesch & Pollatsek, 1993; Paap, Newsome, McDonald, & Schvaneveldt, 1982). A common framework to account for this set of data is that as the visual presentation of a target initially activates its corresponding orthographic representation, this activation spreads automatically through the orthographic and phonological neighborhood of the target, eventually leading to different semantic activation (see Van Orden, 1991). Then a selection process (whether it is a verification process, Paap et al., 1982, or a time-course competition process, Seidenberg et al., 1984) enables one of the items to be registered in STM. The present account of RB can naturally be encompassed by this framework. RB between orthographically similar items would occur at the level of the initially activated orthographic representations, due to a failure to initiate a new token; while RB between phonologically similar items would occur at the level of the activated phonological representations while or after the selection process takes place, probably due to a failure to select a previously selected code as a newly activated one (see Bavelier et al., 1993, for further details). Consistent with this view, the amount of RB was found to be sensitive to the organization (as revealed by naming, eye movement and lexical decision studies, Jared, McRae, & Seidenberg, 1990; Segui & Grainger, 1990) of the orthographic and phonological neighborhoods of C1 (Bavelier et al., 1993). Similarly, RB between visually different items was established not only with homophones, but also between phonologically similar words which are orthographically dissimilar (e.g., towel/foul; Bavelier et al., 1993; Kanwisher, 1991b).

Another plausible account of RB could be as a classical STM confusion effect (Baddeley, 1966; Conrad, 1964; Wickelgren, 1965, 1966). The underlined sensitivity of RB to phonological similarity and task requirements is, indeed, highly reminiscent of STM effects. A few critical differences, however, have to be considered (see Kanwisher, 1987). First, while RB appears as a failure to recall repeated items, STM confusion has been classically characterized by mis-ordering during the recall of the items (Wickelgren, 1965), rendering a direct comparison of these phenomena often meaningless. Some STM experiments report item recall, and indeed show that the recall of the second occurrence of the repetition is impaired. However, such an impairment is only observed when the two occurrences of the repetition are separated by at least two items or more; at shorter lag, the repetition facilitates the recall (see Jahnke, 1969). Thus, the STM confusion effect tends to increase as the lag increases between C1 and C2 (although the evidence is not equivocal; cf. Crowder, 1968; Crowder & Melton, 1965; Obonai & Tsatsuno, 1954). These characteristics stand in opposition to the findings that RB is typically stronger with lag 0 and decreases as the lag increases (Kanwisher, 1987; Bavelier & Potter, 1992). Second, STM effects such as the Ranschburg effect disappear when using a large vocabulary of items (Hinrichs, Mewaldt, & Redding, 1973; Greene, 1991), while RB is found whatever the size

of the vocabulary of items. Third, RB is observed with very rapid presentation; as the rate of presentation is slowed down to match the order of the one used in STM studies, RB disappears (Kanwisher, 1987; Park & Kanwisher, 1993). Fourth, RB is still present in lists as short as three items; with such a light memory load, STM confusions would not be expected. Finally, we have shown that concurrent articulation, which usually reduces phonological confusions in STM, does not reduce RB except in the special case of a picture homophone (Experiment 4; Bavelier & Potter, 1992, Experiment 7). These observations do not prove that RB cannot be accounted for as an STM confusion. However, any STM confusion explanation of RB will have to account for these discrepancies in order to stand as a viable alternative explanation.

At the moment, RB seems to be best understood as an encoding phenomenon occurring at the interface between perception and memory, while memory traces for the objects in the visual field are set up. By showing that RB can be influenced by the preferred encoding in STM, the present work establishes a role for STM properties in RB; at the same time, by suggesting that the salience of a perceptual code can affect the pattern of RB, this work also confirms the role of perceptual characteristics in RB. These properties of RB suggest that tokens are to be seen as dynamical entities, which are built over time as a function of type activation and task requirements. Although the hypothesis of a refractory period for linking type nodes with new tokens was originally entertained by Kanwisher (1987), it could also be the case that a type node can set up a new token only if it is not already engaged in stabilizing another token. If so, the amount of time a type node would be unavailable for a new tokenization would not be fixed, but vary with the stability of the first token and the efficiency of STM.

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Appendix A: sentences used in Experiment 1 (non-repeated 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 to.
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.
33. In the accident he broke his right leg [foot] but my leg was fine.
34. She took off the ring [cap] and put another ring on her finger.
35. In the garden the boy caught a butterfly [caterpillar] and let the butterfly go.
36. After John used the ladder [hammer] he took the ladder to the shed.
37. The soldier reloaded the gun [cannon] before firing the gun again.

38. In the drawer was a red mitten [sock] but the other sock I lost was under the bed.
39. The boy scouts built a sled [fence] and painted a sled for the children.
40. As I opened the door [window] the back door to the kitchen slammed.
41. She will pick up the box [envelope] because that box has to be sent very quickly.
42. After Sam played with the kite [bat] he stored the kite and string in the closet.
43. She matched the flower [ribbon] to the flower in her hair.
44. Although he did not own a harp [piano] he played the harp very well.
45. The young frog [alligator] escaped from an alligator that was ferocious.
46. This lightbulb [candle] burned out but the lightbulb in the kitchen is fine.
47. Here is some fresh fish [bread] and some frozen fish is in the refrigerator.
48. In this play they used a silver helmet [crown] as a crown for the princess.
49. We saw only one sailboat [swan] from our sailboat last time.
50. We moved this vase [telephone] and put the telephone I just got in its place.
51. A tropical snake [spider] can eat a smaller snake when food is scarce.
52. They fixed this lock [chain] but the lock of the cellar is still broken.
53. There was a great advertisement for a television [toaster] on the television last week.
54. The soft sound of a whistle [bell] preceded a louder bell that woke us up.
55. I put the skirt on the stool [hanger] and left the stool in the room.
56. As Dan looked at the sun [star] the setting sun glowed brightly.

Appendix B: sentences used in Experiment 2 (non-repeated 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 cake was her favorite.
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 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 [utensil] 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 point 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.
The policeman used his gun [chain] to knock the gun out of the burgler's hand.
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 (his) 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. The 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] 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 dear [goat] quickly became very dear 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.