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Perceptual Processing in Dichotic Listening

Dominic W. Massaro
University of Wisconsin

Subjects heard two lists of 4 items each presented simultaneously to the two ears at a rate of four pairs of items per sec. A recall cue presented immediately after the test list signalled report of 4 of the 8 items. In recall by spatial location, the cue indicated whether the items on the right ear or left ear should be recalled. In recall by category name, the cue indicated the superset category (e.g., letters or words) of the items to be recalled. Recall by spatial location *was not* significantly different than recall by category name. This result argues against the idea of a preperceptual auditory storage that holds information along spatial channels for 1 or 2 sec. The final experiment showed that recall by spatial location *is* significantly better than recall by category name when the report cue is given before, not after, the list presentation. These results show that spatial location can be used to enhance semantic processing and/or memory of 1 of 2 simultaneous items, but only if the relevant location is known at the time of the item presentation.

Over two decades ago, Broadbent (1954) modified the typical immediate memory task by presenting simultaneous lists of auditory items to two different spatial locations. A typical trial involved 3 digits presented to one ear simultaneously with 3 digits to the other ear. The rate of presentation was two pairs/sec, so that the entire list was presented in 1½ sec. Subjects, instructed to recall in whatever order they chose, preferred to recall all of the digits presented to one ear before recalling those on the other. When instructed to recall the items in the temporal order that they were presented, subjects recalled significantly fewer lists than in the case when recall was structured in terms of ear of presentation. Thus, given the digits 723 to one ear and 945 to the other, a subject is more likely to recall the list correctly in the order 723945 or 945723 than in the order 792435 or 974253.

This basic experimental paradigm has received a considerable amount of experimental and theoretical attention, beginning with Broadbent's book in 1958. Broadbent (1958) interpreted his results in terms of each ear operating as a separate channel. Information coming in the two ears was assumed to be stored along two separate channels in a preperceptual auditory store that held information in this primitive form on the order of 2 sec. Lists presented simultaneously to the two ears and stored along these separate channels could be perceived and recalled more effectively if the subject operated along one channel before proceeding to the other channel. Recall by temporal order of presentation, however, required the perceptual process to switch continuously between the channels for accurate recall. If perceptual processing time and switching time were substantial, relative to storage time, performance would be significantly poorer when much more time was needed for switching, as in the case of recall by temporal order of presentation.

The central assumption in Broadbent's interpretation of his results appears to be that the dichotic presentation is a necessary condition for the recall differences observed in the task. That is to say, recall by ear of presentation is superior to recall by temporal order of presentation, not because of something inherently different in the two kinds

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Requests for reprints should be sent to Dominic W. Massaro, Department of Psychology, University of Wisconsin, Madison, Wisconsin 53706.

of recall, but because the items are stored along separate and distinct channels corresponding to spatial location. Savin (1967) provided a test of this assumption by having subjects report two successive pairs of digits presented over a single loudspeaker. Subjects preferred to recall 1 member of the first pair followed by 1 member of the second and then the remaining 2 items from the first and second pairs, respectively. This result showed that dichotic presentation was not a necessary condition for subjects to prefer to recall simultaneous items in a successive rather than in a strict temporal order. Parkinson, Knight, DeMaio, and Connors (1974) replicated Savin's findings with two and three pairs of digits presented binaurally over headphones. The subjects' tendency to recall successive members of the list was somewhat reduced when the temporal synchrony, intensity, and duration of the digits were held constant using digitized speech signals. The majority of the subjects continued to recall the items by successive rather than temporal order, however, showing that Savin's initial observation appeared to be correct.

Although subjects may prefer to recall both dichotic and binaural pairs of items in successive rather than in strict temporal order, successive recall of dichotic lists may still be more efficient than successive recall of binaural lists. If this were the case, it would support the idea that preperceptual auditory memory for a dichotic presentation of items is structured in terms of spatial location. A. Treisman (1970) tested this possibility by asking subjects to recall both dichotic and binaural 6-item lists as either two triplets of successive items or as three pairs of simultaneous items. Given the list $\left\{\begin{matrix}758\\194\end{matrix}\right\}$, correct successive recall would be 758194, 798154, 198754, and so on, while correct temporal recall would be 719584, 179584, 715948, and so on. Subjects recalled about 15% more digits in successive than temporal recall in both the dichotic and binaural presentations. This result showed that the advantage of successive recall is not greater with dichotic than binaural lists, arguing against the idea that the items in dichotic presentation are stored along separate auditory channels in a preperceptual auditory storage. Even more convincing is the auxiliary finding that the number of crossovers (e.g., 798154) between the two tracks of the tape did not differ between the dichotic and binaural presentations. This result showed that the dichotic presentation did not segregate the memory storage of the simultaneous lists relative to the binaural presentation.

Approaching the problem from a different point of view, Yntema and Trask (1963) suggested that memory for dichotic lists might be understood more in terms of how the items are tagged and retrieved from memory rather than how they are stored before perceptual processing. This tack assumes that if channels exist at all, they must exist after rather than before perceptual processing. They replicated the dichotic listening experiment with two modifications. First, the 6-item lists were made up of items chosen from a master list of 10 digits and 10 words. A pair of dichotic items consisted of a word presented to one ear and a digit presented to the other. The word or digit could occur on either ear regardless of the structure of the other two pairs. Second, besides asking for recall of the lists in terms of temporal order of presentation and in terms of ear of presentation, subjects were also asked to recall the lists in terms of category name. In this case, subjects would first recall the digits in their temporal order and then the words in their temporal order. In recall by category name, subjects would sometimes have to cross over between the ears in order to recall the items correctly. This should have produced much poorer recall than recall by ear of presentation if Broadbent's model is correct. Replicating Broadbent's results, they found that subjects recalled more items correctly when recall was structured in terms of ear of presentation than in terms of temporal order. However, recall by category name was about 10% better than recall by ear of presentation even when the words and digits alternated between the ears. Similar results have been reported by Gray and Wedderburn (1960) and Broadbent and Gregory (1964). These results indicated that subjects had no difficulty crossing over the ears in order to structure recall along a semantic dimension.

Knight and Parkinson (1975) provide additional support for the idea that dichotic items are not maintained along separate spatial locations for 1 or 2 sec. Their observers recalled dichotic lists of 8 items in a whole report. In recall by spatial location, observers were asked to attend to and to report the 4 items from one ear before reporting the 4 items from the unattended ear. In recall by category name, subjects attended to and reported the 4 items from one category before reporting the 4 items from the other, unattended, category. The attention condition was blocked across an experimental session. A recalled item was scored as correct if it was recalled in the correct group of 4 items. For example, if items from the left ear were to be reported first, an item recalled from the right ear would be scored as incorrect if it was reported in the first group of 4 items. Using this criterion for recall, overall report was significantly better when attention and recall were structured in terms of category name than in terms of spatial location.

Given that all of the items had to be recalled in both the spatial-location and category-name conditions, the difference in recall in the two conditions probably reflected what had to be remembered in the two conditions. In recall by category name subjects had to remember only the names of the items, since the superordinate category name was redundant. In recall by spatial location, however, subjects had to remember both the name of the item and the spatial location of its presentation since the name in no way determined its presentation location. The poorer performance in the spatial location condition is consistent with the hypothesis that spatial location information is lost very quickly in memory for dichotic lists.

Smith and Burrows (1974) utilized another task to show that dichotic lists are not maintained along separate auditory channels for 1 or 2 sec after a dichotic presentation of items. Subjects were presented with a relevant 4-item list to one ear simultaneously with an irrelevant 4-item list to the other ear. The subjects were instructed to attend to the relevant test list and to ignore the irrelevant list. The test list was followed by a probe item to the same ear, and the subject's task was to indicate whether or not the probe item was a member of the test list. On some of the trials, the probe item was an item that had not been in the test list but had been presented on the to-be-ignored ear. Subjects responded on 20% of the trials that the irrelevant probe item had been in the test list. This high error rate contrasts with the 4% error rate to a totally new probe item. This experiment shows that some items from the to-be-ignored ear are processed for meaning, and either the spatial location of the item is not recognized correctly or it is forgotten by the time of the probe item. Smith and Groen (1974) found similar results and showed, in addition, that the high error rate was eliminated if the probe item belonged to a different category than the test list. In this case, subjects could respond "no" because of category membership and did not mistake an item from the to-be-ignored ear as a member of the test list.

The partial report task has also been utilized to define the nature of the storage of dichotic lists of items (Darwin, Turvey, & Crowder, 1972; Holding, Foulke, & Heise, 1973; Moray, Bates, & Barnett, 1965; M. Treisman & Rostron, 1972). In these studies subjects were presented with dichotic lists of items and cued sometime before or after the list presentation to recall some subset of the items that were presented. In recall by spatial location, the cue corresponded to one of the locations of the list presentation. In recall by category name, the cue signalled recall of those items that belonged to a given category. If recall is cued *before* items have been categorized, dichotic lists stored along separate spatial channels in preperceptual auditory storage should be recalled more readily by spatial location than by category name. If, on the other hand, recall is cued *after* categorization has taken place, cuing recall by spatial location should not have an advantage over cuing recall by category name. Recall performance with the different recall cues, therefore, reveals the nature of the storage of the items at the time of the presentation of the recall cue.

In the Darwin et al. (1972) study, three lists of 3 items each were presented to the left, middle, and right of the head, respectively. After the list presentation, subjects were cued to report the items in terms of either spatial location or category name (digits, letters). However, Darwin et al. also required the subjects to report the spatial location of each item in the category-name condition. Recall was scored as correct in this condition only if both the name and the spatial location were recalled correctly. Accordingly, the relatively poor performance in recall by category name could have been due to an error of spatial location and not category name. The results of A. Treisman (1970) and Smith and Burrows (1974), discussed earlier, show that location information is very fragile given a dichotic presentation. The third experiment of Darwin et al. supports this interpretation, since subjects' recall performance almost doubled when location information was not required in the category recall condition.

In a related experiment, Massaro (1975) provided a direct comparison between recall by category name and recall by spatial location. Two lists of 4 items each were presented simultaneously to the subject's two ears at a rate of four pairs of items per sec. The items were chosen from master sets of 8 digits and 8 letters. Two digits and 2 letters were presented to each ear. A recall cue presented immediately after the test list signified report of 4 of the 8 items. In recall by spatial location, the cue indicated whether the items on the right ear or left ear should be recalled. In recall by category name, the cue indicated the superset category (letter or digits) of the items to be recalled. The results showed that recall by spatial location was, in fact, poorer than recall by category name. This result argues against the idea of a preperceptual auditory storage that holds information along spatial channels for 1 or 2 sec.

Massaro's experiment was somewhat biased in favor of the category-recall condition. The experimenter faced a response-uncertainty problem in comparing recall cued by category name to recall cued by spatial location. It is impossible to control for set-size differences in the two conditions when the same lists are used on both kinds of trials. Subjects cued by spatial location knew that they had to recall 2 letters and 2 digits from sets of 8 letters and 8 digits, respectively. When subjects were cued by category name, they had to recall 4 digits or 4 letters from a master set of 8 digits or 8 letters. In the first case, subjects recalled 4 items from a set of 16, whereas in the second they recalled 4 items from a set of 8. Accordingly, performance in the category condition may have had some advantage because of guessing differences in the two recall conditions.

The problem one faces in correcting for guessing differences is the choice of the appropriate performance model—there is no easy way to validate any guessing model in this task. Because of this, a wide variety of guessing models were utilized in Massaro's 1975 study to correct for guessing differences. The models ranged from a pure guessing model to an analysis based on the assumptions of signal detectability theory. In all of the analyses, recall by category name remained better than or, at least, as good as recall by spatial location.

Experiment 1

Rather than be dependent on the analyses discussed above, however, one can decrease the guessing differences by increasing the size of the master sets. When the master set sizes get sufficiently large, the guessing differences between the two conditions become insignificant (Massaro, 1975). By increasing the number of items in the master sets to 25, we can decrease potential guessing differences to less than 2% when the subjects average at least 50% correct. Therefore, the first experiment replicated Massaro's (1975) study, using master sets of 25 items each.

Method

Taped records were made of a total of 300 trials. Each trial contained simultaneous lists with 2 letters and 2 words in each of the two lists. The 4 letters and 4 words were chosen randomly without replacement from master sets of 25 letters and 25 words. (The letters included all of the letters of the alphabet except W. The 25 words are listed in Table 1. Each word started with a different letter so that they also could be listed alphabetically.) The recording of the tapes was controlled by a PDP-8L computer, which also controlled visual readouts placed in front of the two female speakers, who were seated in separate sound-attenuated chambers. Each speaker read the test lists into one channel of the tape recorder at a rate of 4 items/sec according to the pacing of symbols presented over the visual displays. Each speaker was equally likely to record a list on the left or right channel. The items were read percussively to maintain the distinctiveness of the individual items. Simultaneously with the visual readouts, the computer controlled the presentation and timing of the warning tone and recall-cue tone. The tones were recorded on both channels of the tape recorder. After recording, the tapes were monitored to determine how accurately the two test lists were synchronized. Lists that did not begin and end together were recorded over.

The recall-cue tones were presented immediately after the last item in the list. The spatial-report cue indicated that subjects should report items presented to the left or right ears. The category-name cue indicated that subjects should report letters or words. In both report conditions there were two possible report cues, and the subjects were required to report 4 items. The same lists and cues (pure tones) were used in both report conditions. Given these constraints, the two report conditions (location and category) are directly comparable.

Ten observers participated in the experiment for five days. Four observers could be tested simultaneously in separate sound-attenuated rooms. Each day of the experiment consisted of two sessions for a total of 150 trials. On the first practice day, subjects were given one session of recall cued by location and one session cued by category. On the following four experimental days, the two cuing conditions were alternated from day to day. Five of the subjects received the location condition first; the other five subjects received the category condition first.

The tapes were presented over matched headphones at a normal listening intensity. Each trial began with a 200-msec warning tone presented binaurally 500 msec before the list presentation. The frequency of the warning tone was 1200 Hz. The test lists were presented simultaneously to the left and right ears at a rate of 4 items/sec. There were 4 test items on each ear; therefore, the 8 items were presented within 1 sec. The cue tone was presented binaurally at the same loudness as the test items and lasted 200 msec. The binaural presentation localizes the tone in the middle of the head. On any trial the cue tone could be either high (3000 Hz) or low (600 Hz) with equal probability. The cue tone in the spatial location condition indicated either the left or right ear; in the category name condition it indicated the category, words or letters. Given the highly distinctive cue tones and the practiced subjects, the subjects decoded the tones accurately and quickly.

The subjects had 13 sec to write their answers on answer sheets. The master sets of items were available to the subjects, who were asked to try to respond with 4 items in both the category and location conditions.

TABLE 1

TEST ITEMS FOR THE WORD CATEGORY

APE	FAN	KEY	PIN	USE
BAR	GEM	LAD	QUO	VAT
CAT	HAT	MAP	RAG	XEN
DAM	ICE	NUT	SAP	YAM
EAR	JUG	OX	TOY	ZOO

Results and Discussion

The dependent measure is the percentage of items correctly recalled given the recall cue. The results presented in Table 2 show no significant difference between partial report cued by category name and partial report cued by spatial location. Five of the subjects recalled more items by category name, four subjects recalled more items when cued by spatial location, and one subject showed no difference between the two recall conditions. These results substantiate the hypothesis that retrieval of a recently presented dichotic list of items is not easier along spatial-location than category-name dimensions. It also appears that adding voice quality as a redundant dimension does not facilitate retrieval by spatial location. Although the two voices could occur on either ear on a given trial, subjects may still have used voice quality as a dimension for retrieval. Given that the same voice spoke all four times to a given ear on a given trial, recalling by a given location was equivalent to recalling by a given voice once the location of each voice was identified. In recall by category name, subjects had to recall 2 items from each of two different locations and

TABLE 2

Percentage Correct Recall Under the Category and Location Recall Conditions Across the Four Experimental Days, Experiment 1

Observers	Recall condition[a]			
	Location	Category	Location	Category
1	49	44	51	52
2	57	56	59	58
3	66	59	71	64
4	41	39	50	52
5	56	53	64	59
6	56	61	62	65
7	69	66	76	66
8	39	48	41	48
9	32	56	56	56
10	56	70	77	75
M	52	55	61	60

[a] The first five subjects were cued by category name on Days 1 and 3, and by spatial location on Days 2 and 4. The second five subjects received the opposite cuing sequence.

voices. One might expect that recall by spatial location would show more of a disadvantage relative to recall by category name when the same speaker reads the items at both spatial locations.

Table 3 presents the results in terms of proportion of trials on which 0 through 4 items were recalled under the two recall conditions. The results show large differences in the distribution of the recall scores under the spatial-location and category-name conditions. Subjects recalled all 4 items correctly on 26% of the trials when they were cued by spatial location. When recall was cued by category name, on the other hand, 4 items were recalled correctly on only 7% of the trials. In recall by category name subjects correctly recalled 2 or 3 items correctly on 77% of the trials. In contrast, a given number of items was never recalled on more than 26% of the trials in recall by spatial location; the distribution of responses is roughly flat between the totals of 1 and 4 items correct.

TABLE 3

Proportion of Trials on Which 0 through 4 Items were Correctly Recalled when Cued by Location and Category, Experiment 1

Recall condition	Number of items recalled				
	0	1	2	3	4
Location	.10	.22	.24	.18	.26
Category	.03	.13	.44	.33	.07

The distribution of responses shows that performance is much more variable when it is cued by spatial location than when it is cued by category name. This result is compatible with the hypothesis that subjects found it difficult to process with equal capacity the inputs along both ears. It appears that subjects processed the items along one ear to a greater extent than the items along another ear. The ear that received the most processing could, of course, vary from trial to trial. When cued by spatial location, subjects would be equally likely to be asked to recall the items processed most or the items processed least. In recall by category name, however, subjects would always have two items to recall that were processed the most and two items that were processed the least. This situation would lead to much more variability in recall by spatial location than recall by category name.

The main conclusion to be reached from Experiment 1 is that dichotic lists are not stored in a preperceptual form for 1 or 2 sec along separate channels corresponding to the spatial location of presentation. This conclusion rests on the failure to find an advantage of recall cued by spatial location over recall cued by category name. Two reservations might be proposed: First, the first study simply failed to reject the null hypothesis, a somewhat unpopular state of affairs. Second, one might argue that there is something inherently difficult about recalling items by spatial location, something that has nothing to do with the nature of memory storage available in the task. Both of these potential criticisms could be eliminated by a study showing that recall cued by spatial location is better than recall cued by category name when the recall cue is presented before but not after the list presentation. Broadbent (1970, 1971) argues convincingly that selection and memory according to a stimulus set is much more efficient than it is during a semantic set. Performance should be better if subjects are asked to listen to and report only those items on the left ear than if they are asked to report only the items of a given semantic class occurring on both ears. The next experiment was aimed at showing that recall according to a stimulus dimension is better than recall according to a meaning dimension if the instruction is given before but not immediately after the dichotic test list.

Experiment 2

It was hypothesized that, although location is not a better mode of cuing partial report immediately *after* the test list presentation, it should be a better mode if the cue is presented *before* the test list presentation. In the cocktail party phenomenon we are able to follow one speaker embedded in a family of many conversations. If subjects can, indeed, attend to one ear at the expense of the message coming in the other, reporting four items at a given location should be easier than reporting two items from each of two locations when the cue is given before the list presentation. When the subject is cued by spatial location before the list, he can listen to and remember the items presented to that ear. In contrast, when he is cued by category name before the list presentation, he must identify each of the items on both ears before he knows if it belongs to the appropriate category. Therefore, cuing by location before the test list will enable the subject to maximize the perceptual processing devoted to the to-be-recalled items. Perceptual processing of the to-be-recalled items must be shared with processing the irrelevant items when the cue specifies category name. Since perceptual processing capacity is limited, the relevant items receive more processing in the location condition than in the category condition. This processing difference should lead to better recall when the *before* cue specifies spatial location rather than category name.

This experiment, therefore, covaried the type of report cue with whether it is presented before or after the test list. First, we expected to find that cuing by spatial location produced better recall than cuing by category name when the cue was presented before the test list. This result would show that the logic of the partial report paradigm is correct: Subjects can recognize and recall information better along an auditory dimension than a meaning dimension if they know the dimension in advance. It follows that, if the information is held in memory along this auditory dimension, recall cued by this dimension should still be superior to recall cued by category name even if the cue occurs after the items are presented. In contrast, if the spatial-location cue is superior to the category-name cue before but not after the list presentation, we can conclude that processing the test list during its presentation transforms the information so that the lists are no longer maintained along separate auditory channels corresponding to spatial location.

Method

Eight subjects participated in the experiment for five consecutive days. Four subjects could be tested simultaneously in separate sound-attenuated rooms. The stimuli for the experiment consisted of the same tapes used in Experiment 1. Each day (excluding Day 1 which was designated as practice) consisted of two sessions of 75 trials each for a total of 150 trials a day. On a given day the subjects recalled by either category or spatial location, the recall condition for each day counterbalanced across subjects. A high or low cue tone followed each list in the same manner as in the previous experiment. Within each session, about ½ of the trials were also cued for recall before the test list was presented. This was accomplished by having the pitch of the recall tone (high or low) written on the answer sheet next to the trial number. The particular trials that were precued were chosen at random. Since the subject was able to look at the answer sheet well before the trial started, the subject had sufficient time to adopt the set to process the precued items. If no precue was present he had to wait until the tone at the end of the list in order to know which items to report.

The initial practice day consisted of two sessions of 75 trials each, with one session cued by location and the other session cued by category. As on the other days, ½ of the trials were also cued before the test list.

The particular items that were cued for recall before the test list were balanced within subjects. Those items that were not precued in the initial day of a particular recall condition were precued for the second day under the same recall condition. Thus within each recall condition for each subject, each trial occurred twice, once with a precue and once without. Similarly, each trial occurred twice for recall by spatial location and twice for recall by category name. All other procedural details were the same as Experiment 1.

Results and Discussion

Figure 1 shows that the time of the cue presentation has a very large effect when recall was cued by spatial location but no effect when recall was cued by category name. Giving the cue before the test list improved performance by about 24% when recall was cued by spatial location and only by about 3% when recall was cued by category name. The interaction of the time and nature of the cue was significant, $F(1, 7) = 93.2$, $p < .001$, $MS_e = 22.12$.

The finding that recall cued by spatial location is not superior to recall cued by category name when the cue follows the test list replicates Experiment 1. The new predicted result is that recall cued by spatial location does lead to better performance when the cue is given before the test list.

General Discussion

The present experiments support the assumption of two successive stages of processing dichotic lists of items. An item can be localized in space before the meaning of the item is determined. If subjects are told to report the items from a particular location before the list is presented, they can devote most of their processing capacity to the items localized at that location. If the report cue refers to category name, however, items localized along both locations must be processed for meaning in order to determine if they belong to the appropriate semantic category. If subjects are limited in the number of items that can be processed and remembered, recall by spatial location should be better than recall by category name when the report cue is given before the test list.

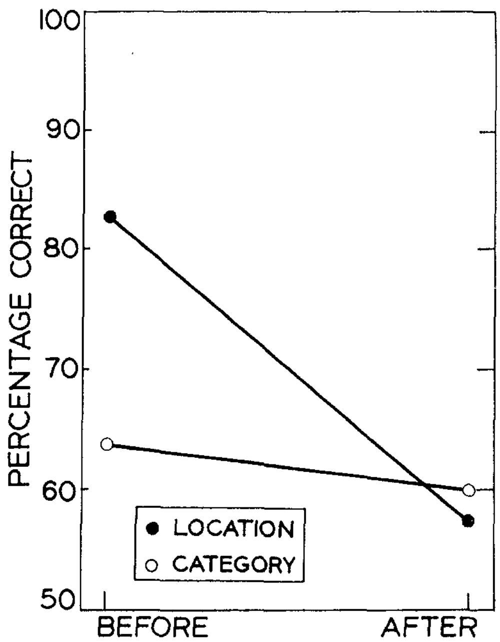

Figure 1. Percentage of items recalled correctly under the category and location recall conditions when the recall cue was given before and after the stimulus list.

In contrast to the before-cue condition, recall by spatial location shows no advantage over recall by category name when the report cue is delayed until after the test list. This argues against the idea that dichotic lists are stored in preperceptual auditory storage for 1 or 2 sec along separate channels corresponding to spatial location. The same result implies that the spatial location of an item in dichotic lists must be remembered in terms of an abstract association rather than along some channel in preperceptual memory organized by spatial location. Immediately after a list of four pairs of items has been presented, most of the items will have been categorized. To remember that the digit 7 came from the left it is necessary to tag the code for 7 with *left* (Yntema & Trask, 1963). No tag appears to be necessary to remember that 7 is a digit since this information is already stored in long-term memory. In recall by category name, it is sufficient to remember just the items themselves, whereas their spatial location must also be remembered in recall by spatial location.

The storage of a dichotic list of items does not appear to be maintained along separate spatial channels in a preperceptual form as first assumed by Broadbent (1958). The similarity of recall of binaural and dichotic lists of items shows that the storage of dichotic items is not that different from the storage of binaural items (Parkinson et al., 1974; A. Treisman, 1970). The ability to recall dichotic items by semantic class shows that dichotic presentation does not prevent semantic analysis of the items as they are presented. These dichotic listening experiments, therefore, do not provide support for a preperceptual auditory storage that holds information for 1 or 2 sec along stimulus channels corresponding to spatial locations.

The fact that preperceptual auditory storage does not appear to extend to 1 or 2 sec after an item is presented agrees with a series of experiments in recognition masking (Massaro, 1975). In a typical study, subjects were required to recognize a short test tone as high or low in pitch. A masking tone presented within ¼ sec after the onset of the test tone interfered with auditory recognition. This result provides support for an auditory storage that maintains the stimulus in preperceptual form for roughly ¼ sec, an estimate also supported by the negative findings of the present study of the partial report paradigm with a postcue.

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