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Similarity as an organizing principle in primary memory

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SIMILARITY AS AN ORGANIZING PRINCIPLE IN PRIMARY MEMORY

by

DENNY C. LECOMPTÉ

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTERS OF ARTS

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Similarity as an Organizing Principle in Primary Memory

by

Denny C. Lecompte

Abstract

The role of stimulus similarity as an organizing principle in immediate memory was explored in a series of experiments. Each experiment involved the presentation of a short sequence of items. The items were drawn from two distinct physical categories and arranged such that the category changed after each pair of items. Following list presentation, one item was re-presented, and the subjects tried to recall the item that had directly followed it in the list. Recall was more probable if the re-presented item and the item to be recalled had been presented in the same sensory modality (i.e., auditory or visual), the same voice, or in the same spatial location than if they had been presented in a different modality, voice, or location. It is concluded that stimulus similarity plays a broader role in organizing immediate memory than is generally assumed.
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Similarity as an Organizing Principle in Primary Memory

The organization of memory can be conceptualized as having been imposed either by the rememberer or by whatever is being remembered. Contemporary memory theorists tend to stress the role of the rememberer and so cast their explanations in terms of such willfully controlled processes as rehearsal, imagery, and chunking. This tendency is an expression of the information-processing perspective, which almost completely dominates current thinking about memory. Within this conception, stimuli are retained "in" memory in the form of symbolic codes which are processed according to the organizational strategies of the rememberer. The result is that memory for the sensory details of the stimuli tends to be glossed over, if not entirely ignored. Nowhere is this tendency more apparent than in the neglect of that aspect of remembering that William James (1890) referred to as primary memory.

James (1890) defined primary memory as memory for that which, although part of the temporal past, persists in the psychological present. In other words, whatever is in primary memory has never left conscious mind and so does not need to be "fished up" from the psychological past. Primary memory is therefore closely tied to perception: Although only a pale copy of actual perceptual experience, it faithfully captures many facets of the sensory world.1

To the extent that it succeeds in preserving the stimulus world, primary memory might be expected to be organized in the same way as perception,
and indeed there is evidence to this effect. Thus, for example, the Gestalt principle of proximity, whereby proximal things tend to be perceived as belonging together (see Bower & Hilgard, 1981, pp. 302-310), appears to extend to primary memory in that the immediate reproduction of a short sequence of items is strongly influenced by the timing of the items in the sequence (cf. Frankish, 1985, 1989; Frick, 1989; Ryan, 1969). Such findings encourage the view that primary memory may also lend itself to other Gestalt principles of organization. The purpose of this thesis is to explore the possible application to primary memory of one such principle, namely the principle of similarity.

**Organization by Similarity: Streaming**

The principle of similarity states that similar stimuli are perceived as belonging together (see Bower & Hilgard, 1981). A striking example can be found in a phenomenon known as streaming (Bregman & Campbell, 1971; Warren & Obusek, 1972; Warren, Obusek, Farmer, & Warren, 1969; Warren & Warren, 1970). The standard procedure for inducing this phenomenon involves the playing of three very distinct sounds, such as a hiss, a buzz, and a tone, over and over in rapid succession. Perceptually, this sequence divides into three distinct strands or streams—a hiss stream, a buzz stream, and a tone stream. So strong is this impression that the order in which the three sounds are occurring cannot be discerned. The effect of organization by similarity thus completely dominates any effect of temporal proximity.

Streaming is usually discussed as a phenomenon of perception rather than of memory (e.g., Bregman & Campbell, 1971), but in order for a stream to emerge, the presentation of a stimulus must be held in mind at least until the item is re-presented. Therefore, the very fact of streaming adequately
demonstrates that primary memory can be organized on the basis of stimulus similarity. Less clear is the generality of such organization.

The streaming observed by Warren and his associates (e.g., Warren & Warren, 1970) occurred under a highly circumscribed set of conditions. It seems likely that the most important of these conditions is that the repetition was of the exact same stimulus sound. What is unclear is whether streams would also emerge, even if in a weaker form, out of stimuli that are not identical but merely similar. In other words, can streaming occur on the basis of shared attributes? And if so, which attributes? Another condition of Warren and his associates was that the repeating stimuli were nonverbal: No streaming was found when speech was used instead of nonverbal sounds (Warren et al., 1969), a fact attributed to speech being especially suited to preserving order information (see also Warren & Warren, 1970). Does this mean that primary memory for speech utterances cannot be organized on the basis of physical similarity among the utterances? Another obvious question posed by the findings of Warren and his associates is whether streaming occurs in the visual modality as well as the auditory modality.

It seems safe to assume that the generality of the streaming phenomenon, and probably the answers to these particular questions, will depend on how streaming is defined. Warren and his associates used an extraordinarily strict definition, one requiring that streams be so conspicuous that the temporal sequence of the individual items could not be discerned. Such a definition leaves open the possibility that items within a sequence can be perceptually grouped, or seen as in some sense belonging together, even when the temporal order of the items is clearly discernible. This possibility
strengthens upon consideration of the standard demonstrations of grouping by similarity in visual perception, for the relative spatial positions of the individual items in such demonstrations can typically be indicated without difficulty. The question of concern here, then, is whether primary memory for a sequence of items tends to be organized on the basis of the similarity among the items, even though such organization does not completely eradicate memory for the temporal order of the items.

The literature already provides evidence of streaming in this weak sense of the term under conditions far less restrictive than those used by Warren and his associates. In particular, a number of studies have found streaming for verbal materials on the basis of sensory modality of presentation. For instance, Murdock and Walker (1969) presented subjects with 10-item lists in which modality shifted randomly within each list. Subjects were required to recall as many of the list items as they could, without regard to their order of presentation. The finding of interest here is that the recalled items tended to be organized by their modality of presentation. In another investigation of recall organization, Ronnberg, Nilsson, and Ohlsson (1982) had subjects free recall lists of items that varied according to modality, language, and amount of semantic categorization. Recall in this experiment tended to be organized by modality rather than by language or semantic category. Other evidence (Madsen, Rollins, & Senf, 1970) indicates that organization by modality tends to give way to organization by presentation order when the rate of item presentation is slower than one item every second.

In addition to evidence that subjects may spontaneously order their recall in a way that reflects the modality in which the items were presented,
there is also evidence that recall performance for mixed-modality lists is higher when the subjects are required to organize recall by presentation modality rather than by order of presentation (Broadbent & Gregory, 1961; Hede, 1973; Penney, 1980). Furthermore, subsequent examination of Penney’s (1980) data showed that the probability of an item being recalled directly after recall of the immediately preceding list item was greater if the two items were in the same modality (Penney, 1982).

Evidence for streaming has also come from the probe recall procedure. In probe recall, a list of items is presented, and one of the list items is presented again as a recall cue or probe for the next item in the list, usually referred to as the target item. Murdock (1967) used this probing procedure with lists in which modality of presentation changed after every pair of items; he found recall to be enhanced when both the probe and target items were auditory as compared to any of the other three possible modality combinations. Thus, probing within at least the auditory modality yields better performance than probing across modalities. Penney and Butt (1986) replicated and extended Murdock’s finding. Specifically, they modified the probe recall method by sometimes asking subjects to report the next item in the same modality rather than simply reporting the next item regardless of modality. They found that, despite the interpolation of two items of the other modality, recall was superior in this new condition, and the effect was greater when the probe and target were auditory than when they were visual.

The Present Study

The purpose of the present research is to explore the generality of streaming in the broad, or weak, sense of the term. The experiments reported
here check for such streaming not only between auditory and visual modalities but also within these modalities.

The evidence for streaming derives from a variety of measures: judgments concerning order of occurrence (Warren et al., 1969), output clustering (Ronnberg, Nilsson, & Ohlsson, 1982), impairment of serial recall performance (Penney, 1980), recall conditionalized on recall of the previous item in a serial recall procedure (Penney, 1982), and probe recall (Murdock, 1967; Penney & Butt, 1986). As has already been noted, the judgment measure used by Warren et al. (1969) is too restrictive for present purposes. Of the others, all except the probe recall measure require the subjects to recall as many items as they can, thereby allowing the possibility of output interference effects. Specifically, organization by similarity that may have characterized the state of the subjects' memories directly after list presentation could have been rapidly lost as the subjects began to recall. This consideration does not apply to the serial probe procedure, which was therefore chosen for the present research.

As noted previously, in the serial probe procedure one of the list items is re-presented directly after list presentation, with the subjects' task being to recall the item that had directly followed it. The idea behind the present research was that if a list comprising two stimulus classes were organized according to these classes, then there should be a stronger association between adjacent items from the same class than between adjacent items from different classes. Thus, streaming can be said to be present to the extent that performance is better when the probe and target items are from the same class than when they are not.
How should the stimulus classes be arranged within the list? Simply alternating stimulus class across successive items (e.g., ABABABAB) would preclude testing under the within-class condition. The problem can be resolved simply by adopting Murdock's (1967) procedure of switching class after every second item (e.g., AABBAABB), for with such lists some of the items would serve as within-class probes and others would serve as between-class probes. This procedure was used throughout the present research.

Seven experiments are reported. Experiment 1 was a straightforward replication of Murdock (1967). Experiment 2 examined whether streaming by modality will occur with nonverbal stimuli. Streaming within the auditory modality was investigated in Experiments 3 and 4, and streaming within the visual modality was investigated in Experiments 5, 6, and 7. In all of these experiments, the same general procedure was followed, and except for the choice of stimulus materials, the methodology was much like that of Murdock (1967). The basic question remained constant throughout this research: Is probability of recall greater when probe and target items belong to the same stimulus class as compared to when they belong to different stimulus classes?

**STREAMING BY MODALITY: EXPERIMENTS 1 AND 2**

The first two experiments concern streaming by auditory and visual presentation modality. Evidence for streaming was sought with verbal stimuli in the first experiment and with nonverbal stimuli in the second.
Experiment 1

The first experiment was essentially a replication of Murdock (1967). Its purpose was simply to check that streaming could be detected by the methodology of the present research.

Method

Materials. A total of 224 lists were prepared. Each list consisted of eight one-syllable words chosen at random from the set bed, lamp, key, dog, shoe, book, tree, pipe, cake, cup, watch, chair, star, and nail. An audio recording of each of the 14 words was made in a clear female voice. This recording was then digitized and stored on a Macintosh Plus computer. The words were also typed into the computer.

The words were presented at a rate of two per second. Within each list, the modality of presentation switched after every other word according to one of the following four patterns: AVVAAVVA, AAVVAAVV, VAAVVAAV, or VVAAVVA, where A represents the auditory presentation of a word and V the visual presentation. Each pattern was assigned to one quarter of the lists. For visual presentation, the words appeared in the center of the computer screen in 18-point Athens font; each word was shown for 500 milliseconds and was immediately replaced by the next word. For auditory presentation, the words were heard through a speaker connected to the computer. The duration of the spoken words was approximately 450 milliseconds, with the balance of the 500 milliseconds being left silent. One second after the onset of the final word of the list, the computer emitted a 250 millisecond beep, followed directly by a probe item. The probe item was one
of the words from the list, presented in the same modality and for the same duration as it had been presented as a list item.

**Design.** There were two within-subjects conditions: same-class, in which probe and target items belonged to the same stimulus class, and different-class, in which the probe and target items belonged to different stimulus classes. Stimulus class in this experiment was defined in terms of presentation modality. The same-class and different-class conditions comprised two subconditions: For the same-class condition, these were the auditory probe/auditory target and visual probe/visual target subconditions, and for the different-class condition, they were the auditory probe/visual target and visual probe/auditory target subconditions.

Probing each serial position, from the second to the last, in each of the four presentation patterns required 28 lists; accordingly, the 224 lists were arranged into 8 blocks of 28 lists each. The order of testing subconditions—and hence the order of testing the two primary conditions—was randomized within each block.

All subjects saw the 224 lists in the same order. Furthermore, each list always appeared in the same presentation pattern. Hence, the subcondition associated with each list was determined by the serial position of the probe item. For instance, in an AAVVAAVV list, presenting the second item as the probe would provide a data point for the auditory-visual subcondition. To equalize order effects across the four subconditions, the serial position of the probe item for each list was rotated across subjects so that each list served in each subcondition for one quarter of the subjects. Counterbalancing order effects with respect to the four subconditions necessarily counterbalanced the
same-class and different-class conditions, because same-class and different-class conditions were simply aggregates of the subconditions.

Because serial position was not of primary interest, the 14 stimulus words were not rotated across the 8 serial positions within a list. On the other hand, all of the stimulus words were assigned as targets to the four subconditions, and thereby to the same-class and different-class conditions, equally often.

**Procedure.** The subjects were tested up to four at a time. They were presented with a sequence of lists, each of which comprised four auditorily presented words and four visually presented words. Following the last word within each list there was a brief pause, then a beep, and then a representation of one of the words in the same modality as it had occurred as a list item. The subjects responded by writing the item that had directly followed this probe item. They were allowed approximately 4 seconds to respond.

Prior to the experiment proper, the experimenter described the different patterns of modality alternation and the probe recall procedure. Eight practice lists were given, two of each pattern. For the practice lists, as well as for the experiment proper, subjects were encouraged to guess when they were unsure of the correct answer; when they could not, they drew a dash in the appropriate space on the response sheet. Care was taken to ensure that the subjects understood that they were to recall the item that followed the probe item regardless of its modality.

**Subjects.** Sixteen university undergraduates served as subjects, either for extra credit or in partial fulfillment of a course requirement.
Results and Discussion

Streaming is operationalized as a higher level of performance in the same-class condition than in the different-class condition. The probability of recall was .51 for the same-class condition and .26 for the different-class condition; the same-class advantage was reliable, $t(15) = 7.52$, $p < .001$. Thus, earlier findings of streaming in mixed-modality lists (e.g., Murdock, 1967) were replicated.

Although comparing the same-class and different-class conditions indicates whether streaming is present, comparisons among the four subconditions may shed light on the nature of this streaming. Probability of recall in the auditory-auditory subcondition (.72) differed appreciably from that in the auditory-visual (.25), visual-auditory (.27), and visual-visual (.30) subconditions; these difference were reliable, $t$’s(15) = 8.17, 6.88, and 6.88, respectively, all $p$’s < .001. Additionally, the difference between the visual-visual subcondition and the auditory-visual subcondition was marginally reliable, $t(15) = 2.07$, $p = .056$. No other pairwise comparisons approached reliability, $p > .25$ in each case.

Serial position functions were not of central interest in this study; nevertheless, they were determined for each of the four subconditions. These data, as well as serial position data for each of the other experiments reported here, are presented in Appendix B.

The superior performance of the auditory stimuli is consistent with the general dominance of auditory stimuli in immediate memory (see Penney, 1989). The extent of this dominance was recently illustrated by Greene (1989), who found that in mixed-modality lists, auditory stimuli actually inhibited
recall of visual stimuli: Relative to pure auditory lists, recall of auditorily presented items was enhanced, and relative to pure visual lists, recall of visually presented items was depressed.

Could the present results have arisen merely because of the auditory dominance? If no visual stimuli were remembered and all auditory stimuli were remembered, the auditory-auditory subcondition would show perfect recall while the other three subconditions would show no recall. Hence, there would be a same-class advantage, indicating streaming as defined here. If auditory dominance accounted completely for the present results, then recall of visual targets should be better with an auditory probe than with a visual probe because memory for the auditory probe would be better than memory for the visual probe. The advantage, however, is in the other direction: Recall of visual targets was better when the probe item was visual rather than auditory (cf. Penney & Butt, 1986). The observed streaming cannot, therefore, be explained solely in terms of auditory dominance.

Experiment 2

It is clear from Experiment 1, as well as from previous research (Murdock, 1967; Penney & Butt, 1986), that verbal stimuli can stream according to their presentation modality. The present experiment was designed to determine whether streaming according to modality can also occur with nonverbal stimuli.

As already noted, streaming was originally observed with nonverbal materials (Warren et al. 1969; Warren & Obusek, 1972), but the stimuli in these studies were all auditory, and repetition was of the exact same stimuli
rather than of an attribute of the stimuli. In the present experiment, evidence was sought for streaming of nonverbal sounds and pictures.

**Method**

**Materials.** The stimuli were eight items that could take the form of either sounds or pictures. The sounds were chosen, through pilot research, from a set of sound effects albums. The main criteria were that each could be readily identified from a 450-millisecond segment and could be given a brief verbal label. The eight items were **bugle** (a snippet of reveille), **cuckoo** (as in a cuckoo clock), **glass** (a window breaking), **gun** (a machine gun firing), **horn** (three honks of a car horn), **saw** (wood sawing), **water** (a liquid being poured), and **whistle** (three blasts of a policeman's whistle). A picture was chosen or constructed to correspond to each sound. For **gun**, **saw**, and **whistle**, the pictures were selected from Snodgrass and Vanderwart (1980). For **bugle** and **glass**, the Snodgrass and Vanderwart pictures representing a trumpet and a window were modified so they more closely matched the corresponding sounds; specifically, the valves were removed from the trumpet, and the glass in the window was shown as shattered. Finally, a research associate with a modicum of artistic talent drew pictures to represent **cuckoo**, **horn**, and **water**. All pictures are shown in Appendix A.

The presentation lists consisted of 112 random permutations of the eight stimulus items. The eight sounds and their corresponding pictures were digitized for computer presentation. The duration of each digitized sound was approximately 450 milliseconds, with none longer than 470 milliseconds; they were heard through an external speaker connected to a computer. Each picture was displayed on the computer screen for 500 milliseconds.
Design. The lists were presented to all subjects in the same order, and each list always followed the same alternation pattern: SPPSSPPS, SSPPSSPP, PSSPPSSP, and PPSSPPSS, where S represents a sound and P represents a picture. Counterbalancing of the stimulus items with respect to conditions and subconditions was exactly as described for Experiment 1.

The same-class condition comprised the sound probe/sound target and picture probe/picture target subconditions, and the different-class condition comprised the sound probe/picture target and picture probe/sound target subconditions.

Procedure. The procedure differed from Experiment 1 only slightly. Before explaining the details of the procedure, the experimenter demonstrated the stimuli. Each of the eight sounds was played three times while the corresponding picture was presented on the screen. This procedure was repeated for a total of three cycles. For the first two cycles, the appropriate labels were displayed beneath the pictures. For the third cycle, the pictures appeared without their labels, and subjects wrote the appropriate verbal labels as picture-sound pairs were presented. All subjects labeled all items correctly.

The only other procedural differences between this experiment and Experiment 1 were that the subjects were given 16 practice lists (four from each subcondition) rather than 8 and were allowed 5 seconds rather than 4 seconds to respond to each probe item.

Subjects. The subjects were 32 university undergraduates who participated for extra credit or in partial fulfillment of a course requirement.

Results and Discussion

Probability of recall was .39 in the same-class condition and .33 in the
different-class condition. The extent to which the same-class probability exceeded the different-class probability was reliable, $t(31) = 3.28, p = .001$. Thus, streaming has been demonstrated with lists comprising pictures and nonverbal sounds.

Recall probability in the sound-sound subcondition (.41) differed reliably from recall probability in the sound-picture (.30) [$t(31) = 5.09, p < .001$], picture-sound (.36) [$t(31) = 2.55, p = .016$], and picture-picture (.36) [$t(31) = 2.69, p = .01$] subconditions. The sound-picture subcondition was reliably different from the picture-sound [$t(31) = 3.03, p = .005$] and picture-picture [$t(31) = 2.83, p < .008$] subconditions. There were no other reliable differences among the subcondition means. In general, the pattern is similar to that shown in Experiment 1, with auditory stimuli dominating visual stimuli. The auditory advantage was not as large in this experiment as in Experiment 1, perhaps because sounds do not ascend in conscious mind to the same extent as spoken words. Such an explanation predicts that spoken words would tend to dominate sounds if mixed within a list. This possibility is addressed in the next experiment.

As in the Experiment 1, the present results cannot be accounted for merely as a result of auditory dominance because recall of pictures was better when the probe was a picture than when it was a sound, even though memory for sounds was, overall, better than memory for pictures.

Taken together, Experiments 1 and 2 demonstrate that modality of presentation influences the organization of immediate memory, regardless of whether the stimulus items are verbal or nonverbal.
ALL-AUDITORY STREAMING: EXPERIMENTS 3 AND 4

The next two experiments sought evidence for attribute streaming within the auditory modality. Warren and his colleagues (e.g., Warren & Obusek, 1972) demonstrated streaming within the auditory modality, but they did so by repeating the same nonverbal item. The purpose of Experiments 3 and 4 was to see whether streams would form for physically similar auditory stimuli. Experiment 3 used a mixture of verbal and nonverbal stimuli, and Experiment 4 used all verbal stimuli.

Experiment 3

In this experiment the two classes of items were nonverbal sounds and spoken words corresponding to these sounds. The same-class conditions therefore consisted of word probe/word target and sound probe/sound target subconditions and the different-class condition consisted of word probe/sound target and sound probe/word target subconditions.

Method

Materials and design. The item lists were as in Experiment 2 except that every instance of cuckoo was replaced by skid. The source of the skid sound was the same as that of the other sounds (see Experiment 2). The eight words (i.e., the labels for the sounds) were spoken in a male voice. List patterns and counterbalancing procedures were exactly as in Experiment 2. All items, both words and sounds, were digitized and stored on computer in the manner described for Experiment 2. They were presented to the subjects through an external speaker connected to a computer.
Procedure. The procedure was the same as that of Experiment 2 with the sole exception that, in introducing the experiment, the experimenter presented the name of each item in turn, followed by three presentations of the corresponding sound. The experiment itself, including practice of the procedure, then proceeded exactly as in Experiment 2.

Subjects. Sixteen university undergraduates participated for extra credit or to fulfill a course requirement.

Results and Discussion

As before, the critical test for streaming is whether recall in the same-class condition exceeds recall in the different-class condition. The mean probability of recall was .43 in the same-class condition and .36 in the different-class condition; the same-class advantage was reliable, $t(15) = 2.58, p = .01$. Attribute streaming within the auditory modality has therefore been demonstrated.

Probability of recall was .63 in the word-word subcondition, .22 in the sound-sound subcondition, .26 in the word-sound subcondition, and .45 in the word-word subcondition. Analyses revealed that performance in the word-word subcondition differed reliably from performance in the word-sound [$t(15) = 7.76, p < .001$], sound-word [$t(15) = 3.69, p = .002$], and sound-sound [$t(15) = 8.35, p < .001$] subconditions. Additionally, performance in the word-sound subcondition differed reliably from that in the sound-word [$t(15) = 6.37, p < .001$] and sound-sound subconditions [$t(15) = 2.37, p = .03$], and that in the sound-word subcondition differed reliably from that in the sound-sound subcondition [$t(15) = 7.09, p < .001$].
The present pattern of results is in some ways similar to that of Experiment 2, but with the words dominating the nonverbal sounds rather than the nonverbal sounds dominating the pictures. Data from Greene's (1989) study may help to understand the relation between the results of these two experiments. Greene found that auditory items dominated visual items in mixed-modality lists, and in another experiment he found that silently mouthed visual items dominated nonmouthed visual items: Recall of the nonmouthed items was lower in the mixed lists (i.e., mouthed/nonmouthed) than in the pure nonmouthed lists, and recall of the mouthed items was higher in the mixed lists than in pure mouthed lists. Of particular relevance to present purposes is Greene's finding that when auditory items and silently mouthed visual items were mixed within a single list, it was recall of the mouthed items that was inhibited. Thus, mouthed visual items dominated nonmouthed visual items, but were themselves dominated by auditory items. In the same way, sounds dominated pictures in Experiment 2, but were dominated by words in Experiment 3. These results, along with those of Greene, suggest that there is a hierarchy of dominance in primary memory, with spoken words near the top of this hierarchy and written words and pictures toward the bottom.

Of more relevance to the present purpose is the finding that recall of nonverbal sounds was lower when the probe item was also a nonverbal sound than when it was a word, which means that the pattern of results for the four subconditions can be accounted for solely in terms of the difference in overall level recall of the words and sounds. If words are remembered better, then level of performance in the word-sound subcondition should be
higher than in the sound-sound subcondition because of a better memory for the probe. Furthermore, level of performance should be lower in the sound-word subcondition than in the word-word subcondition because of poorer memory for the probe. Thus, although the data of this experiment meet the operational definition of streaming, the possibility that they do so for relatively uninteresting reasons cannot be ruled out.

Experiment 4

In the present experiment, all items were verbal, and the stimulus classes were defined by presentation voice. Specifically, subjects heard a series of word lists in which half of the words in each list were spoken in a male voice and half were spoken in a female voice.

Method. The method closely followed that of Experiment 1. The only difference was that the two classes of items were male-voiced and female-voiced words rather than written and female-voiced words. Therefore, the same-class condition consisted of those instances in which both the probe item and the target item were presented in the same voice and the constituent subconditions were male voice probe/male voice target and female voice probe/female voice target. The different-class condition consisted of those instances in which the probe item and the target item were presented in different voices and the constituent subconditions were male voice probe/female voice target and female voice probe/male voice target.

The subjects were sixteen university undergraduates. They participated for extra credit or to fulfill a course requirement.
Results

The average probability of recall was .55 for the same-class condition and .45 for the different-class condition. The advantage for the same-class condition was statistically reliable, $t(15) = 4.49, p < .001$. Thus, streaming has been shown for entirely spoken lists.

There was no reliable difference between the male voice-male voice subcondition (.54) and the female voice-female voice subcondition (.55), $t(15) < 1$, or between the male voice-female voice subcondition (.44) and the female voice-male voice subcondition (.46), $t(15) < 1$. Performance in the male voice-male voice subcondition was different from performance in both the male voice-female voice and the female voice-male voice subconditions, $t's(15) = 3.67$ and $3.65$, respectively, $p < .005$ in both cases. Likewise, performance in the female voice-female voice subcondition was different from performance in both the male voice-female voice and female voice-male voice subconditions, $t's(15) = 3.32$ and $4.32$, $p < .005$ in both cases. In contrast to the situation in the three previous experiments, streaming was, at least to a first approximation, symmetric in its effects. Such a finding is perhaps unsurprising, for there seems to be no obvious a priori reason for the dominance of one voice over another.

ALL-VISUAL STREAMING: EXPERIMENTS 5-7

In the research described so far, streaming has been shown with mixed lists of auditory and visual stimuli and with pure lists of auditory stimuli. The purpose of the remaining three experiments was to seek evidence for streaming within purely visual lists. In the case of mixed-modality lists, the
advantage of the same-class condition was associated primarily with the auditory stimuli. It does not necessarily follow, however, that visual streaming would not occur with all-visual lists.

Experiment 5

This experiment parallels Experiment 3 in that it compares verbal and nonverbal stimuli, but it differs from Experiment 3 in that all stimuli were presented visually. Specifically, in each list, subjects saw pictures mixed with the written words which name those pictures.

Method

The stimuli were the 14 items used in Experiment 1, except that each was presented either as a written word or as a picture. The pictures were from Snodgrass and Vanderwart (1980; see Appendix A). The only other ways in which this experiment differed from Experiment 1 were that (a) the subjects were asked not to move their lips or otherwise vocalize the words or the names of the pictures, the idea being to discourage the subjects from relying on articulatory or auditory memory to perform the task, and (b) each item was displayed for 500 milliseconds and was followed immediately by the next item.

Sixteen university undergraduates served as subjects. All subjects participated for extra credit or in partial fulfillment of a course requirement.

Results

There was no advantage whatsoever for the same-class condition: Probability of recall was .50 for the same-class condition and .51 for the different-class condition. This experiment therefore provides no evidence of streaming within a mixed list of pictures and words.
The means for the picture-word (.52), word-picture (.50), picture-picture (.49), and word-word (.51) subconditions were all very similar. Pairwise comparisons failed to show any reliable differences among these means, $t(15) < 1$ in each case.

**Experiment 6**

This experiment represents another attempt to find all-visual streaming. This time the item classes were differentiated by spatial location rather than by their form. Several studies have shown immediate memory for visual stimuli to be especially sensitive to spatial locations (e.g., Frick, 1985). Hence, in this experiment, half of the items in each list were shown in the upper half of a computer screen and the other half were shown in the lower half.

**Method**

**Materials.** The list items were the digits 1-8. Eighty-four 8-digit lists were prepared by randomizing these digits within the constraint that adjacent digits differed by more than 1. Stimulus class was defined in terms of the location of presentation of the stimulus items on the computer screen: Four of the digits within each list were presented in the upper half of the Macintosh Plus computer screen, and four were presented in the bottom half. The digits were displayed in large typeface (48-point Athens font). The vertical displacement between the two screen locations was approximately 5 cm. Since the subjects were seated with their eyes approximately 0.5 meters from the screen, the visual angle corresponding to this displacement was approximately 6°. There was no horizontal displacement. The probe item appeared in the same font in a location equidistant between the list item locations.
Design. The design was similar to that of the first five experiments. The lists alternated location in pairs following the four patterns used in previous experiments. Counterbalancing also followed that of the earlier experiments. The two conditions of interest, as always, were the same-class condition and the different-class condition. The same-class condition consisted of the top probe/top target and bottom probe/bottom target subconditions, and the different-class condition consisted of the top probe/bottom target and bottom probe/top target subconditions.

Procedure. The experiment was described to the subjects. To prevent the use of auditory memory, the experimenter asked the subjects not to pronounce the list items to themselves, nor even to move their lips during list presentation. Each digit in a list was shown for 500 milliseconds and was followed directly by the next digit. A probe digit followed each list. The probe digit was shown for 500 milliseconds and was separated from the offset of the last list digit by a 500 millisecond blank interval. The subjects reported the digit that had directly followed the probe digit in the list by entering their responses on the computer keyboard.

Subjects. Subjects were 20 university undergraduates who participated as part of a course requirement or in return for extra credit in a psychology course.

Results

Probability of recall was .53 in the same-class condition and .48 in the different-class condition. The same-class advantage was statistically reliable, \( t(19) = 3.22, p < .005 \), which means that streaming has therefore been demonstrated within an all-visual list. On the other hand, the same-class advantage was somewhat small, which means that the effect of organization
on probe recall was not particularly strong.

No reliable differences were found between the top-top subcondition (.54) and the bottom-bottom subcondition (.52), \( t(19) = 1.07, p > .25 \), or between the bottom-top (.48) and the top-bottom subconditions (.47), \( t(19) < 1 \). Probability of recall in the top-top subcondition was reliably greater than in the top-bottom and bottom-top subconditions, \( t's(19) = 2.42 \) and \( 2.49 \), respectively, both \( p < .03 \). No other differences were statistically reliable.

Experiment 7

Experiment 6 demonstrated all-visual streaming, but the magnitude of the effect was small. The purpose of this experiment was to seek a more powerful effect. To this end, several measures were taken. First, although stimulus class was again defined in terms of spatial location, the difference between the two locations was increased. One location was the top left-hand corner of the computer screen and the other was the bottom right-hand corner. Second, subjects were required to chant during presentation of the items. The idea here was to encourage the use of a visual form of memory (cf. Frick, 1985), and thereby to sustain the distinction between the stimulus classes. Third, items were presented at a fast rate—one every 200 milliseconds. This rate was judged by the experimenter, on the basis of informal self-testing, to be most conducive to streaming.

Because the chanting and rapid rate of presentation made the task rather difficult, the list length was shortened to four items. Additionally, to ensure that the subjects were indeed attending to both of the relevant corners of the screen, a certain proportion of the lists included a nondigit symbol. The subjects were required to detect these symbols.
Method

Materials. Seventy lists were constructed. Of these, 60 were regular lists, comprising four of the digits 1-6. The digits were chosen at random within the constraint that in each block of 12 regular lists, the 6 digits were evenly distributed with respect to serial position, so that each appeared twice in each position. The other 10 lists were catch lists. These were prepared in the same manner as the regular lists except that one of the digits, selected at random, was replaced with one of three non-digit characters: $L$, $Y$, or $C$. For half of the catch lists, the non-digit character appeared in the top-left corner, and for the other half, it appeared in the bottom-right corner. Two catch lists were scattered at random among the 12 regular lists of each block.

The items were presented on a Macintosh Plus computer at a rate of one every 200 milliseconds. Each item remained in view for all 200 milliseconds. The last item of each list was followed by a 250 millisecond beep, which served to signal the probe item. The probe item appeared in the middle of the screen 17 milliseconds after the onset of the beep and remained in view for 250 milliseconds.

Design. As in the previous experiments, there were two within-subjects conditions, the same-class condition and the different-class condition. In this experiment, stimulus class was defined in terms of spatial location. In the same-class condition, both probe item and target item appeared in the same corner of the screen; in the different-class condition, the probe item and target item appeared in different corners of the screen. Each condition comprised two subconditions. Referring to the top-left corner as location $T$ and the bottom-right corner as location $B$, the subconditions for the same-class
condition were TT and BB and those for the different-class condition were TB and BT.

The lists were presented in the same order for all subjects. Each successive block of 14 lists included 2 catch lists and 12 regular lists. For any given subject, the 12 regular lists included three examples of each of the four patterns of list presentation: TBBT, TTBB, BTTB, BBTT. For one of these examples, the target digit was in the second position, for another it was in the third, and for the remaining example it was in the fourth position. These positions were rotated among subjects so that, over all subjects, the target item of any given list was located at the second, third, and fourth positions equally often.

Because the target item could occur in only three positions, any one pattern would assign two-thirds of the subjects to one condition and one-third to the other. For example, for the TBBT pattern, two thirds of the subjects (those for which the target was in the second or fourth position) would be tested in the different-class condition, and one-third (those for which the target was in the third position) would be tested in the same-class condition. Although the distribution of patterns was random within each block, this imbalance is likely to introduce a small effect of testing order. To correct the problem, half of the subjects in each of the three groups used in rotating serial positions saw a given list in one pattern, and half saw it in another pattern. Specifically, lists shown to one half of the subjects in the TBBT pattern were shown to the other half in the BBTT; similarly, the TTBB, BTTB, and BBTT patterns became BTTB, TTBB, and TBBT, respectively. In
this way, each list was tested under the same-class and different-class conditions equally often.

The first block of 14 lists were considered as practice lists, leaving four blocks (48 regular lists and 8 catch lists) for the experiment proper. The blocks followed one another without a pause and so were not apparent to the subjects.

Procedure. The subjects were tested individually. They were presented with a long series of 4-digit lists. The digits appeared on a computer screen, two in the top-left corner and two in the bottom-right corner, at a rapid rate. The last digit was followed by a probe digit, which appeared in the center of the screen and was accompanied by a beep. The subject responded to this probe item by reporting, by way of the computer keyboard, the digit that had occurred directly after it in the list, regardless of whether the two had occurred during list presentation in the same or different corners of the screen. The subjects chanted "aybee" throughout the presentation and testing of each list. They were encouraged to chant at a rate of about two utterances per second and were monitored continually. Rate of list presentation was controlled by the subject.

The subjects were warned that a few of the lists would contain a non-digit item. After each such list, they were to disregard the probe and enter the number 9; since only the digits 1-6 were used in the lists, 9 was never otherwise a correct answer. The experimenter emphasized that the subjects should be careful not to miss any of these lists.

Subjects. Twenty-three university undergraduates were tested. The data for five of these subjects were discarded because of failure to identify all of the
eight catch trials of the experiment proper. Two of these subjects missed one
catch list, two missed two, and one missed four. The pattern of data would
not be discernibly different if these subjects were included. All subjects
participated in return for extra credit in a psychology course.

Results

The purpose of this experiment was to seek a robust all-visual streaming
effect—or, at least, one larger than that found in Experiment 6. Such an effect
was found. Probability of recall was .48 in the same-class condition and .33 in
the different-class condition, and the same-class advantage was reliable, t(17) =
4.88, p < .001.

Recall probabilities for the subconditions were .50 for TT, .46 for BB, .36
for TB, and .31 for BT, where T represents the top-left corner and B the lower-
right corner. The difference between performance in the TT and BB
subconditions was not reliable t(17) = 1.11, p > .25, nor was the difference
between performance in the TB and BT subconditions, t(17) < 1. Probability of
recall in the TT subcondition differed reliably from that in both the TB
subcondition, t(17) = 3.04, p = .007, and the BT subcondition, t(17) = 5.44, p =
.001. Similarly, probability of recall in the BB subcondition differed reliably
from that in both the TB subcondition, t(17) = 2.17, p = .04, and the BT
subcondition, t(17) = 3.74, p = .002.

SUMMARY AND CONCLUSIONS

The perceptual world is, in some degree, organized according to the
principle of similarity. In other words, similar objects are seen in some sense
as belonging together. The research reported in this thesis explored the
possibility that the same principle extends to immediate memory for a sequence of items.

Experiments by Warren and his colleagues (Warren et al., 1969; Warren & Obusek, 1972; Warren & Warren, 1970) have demonstrated the organization of primary memory by similarity through the phenomenon of "streaming," or the perceptual segregation of sequentially occurring stimuli on the basis of their similarity. In all of their experiments, however, streaming was obtained by repeating exactly the same nonverbal sound. The present study explored the generality of streaming, asking whether it might be produced—albeit to a smaller extent—by repeating mere stimulus attributes. In each of several experiments, subjects were asked to remember short lists of items, with half of the items of each list sharing one stimulus attribute, and half sharing another. The attributes differed from experiment to experiment. Streaming was defined in terms of serial probe recall. The idea was that, if like items are grouped together more than are unlike items, then cuing recall of an item with a similar item should increase probability of recall from that observed when cuing with a dissimilar item.

Streaming was found when auditory and visual stimuli were mixed within a list, both with verbal (Experiment 1) and nonverbal (Experiment 2) stimuli. It was also found with lists of spoken words and nonverbal sounds (Experiment 3), and for words spoken in a male voice and words spoken in a female voice (Experiment 4). Within the visual modality, no evidence of streaming was found with pictures and written words (Experiment 5), but a streaming effect was found when classes were defined in terms of spatial location (Experiments 6 and 7).
The instances of streaming found in the first three experiments differed from those in the later experiments in that the level of recall for the two classes of stimuli were quite unequal. As discussed previously, the evidence for streaming within Experiments 1 and 2 is unambiguous in that within-class probing increased recall for the "weaker" class, contrary to what would be expected if streaming were merely a consequence of the difference in level of recall for the two classes. In Experiment 3, however, a level-of-recall explanation could not be ruled out.

Mention should perhaps be made of another experiment conducted to see whether streaming can occur with classes defined by their semantic content rather than their physical characteristics. Although primary memory is distinguished by its sensory nature, it also preserves meaning. Indeed, it may be virtually impossible not to be aware of the meaning of, for example, a word that lingers in mind beyond its presentation. The additional experiment generally followed the methodology of the other experiments reported here. Half of the items in each list were digits, and half were common male names. The names were chosen to match the number of letters and number of syllables in the digits written out as words. All items were presented visually; in order to reduce any orthographic differences between classes, they were shown in capitals. The data failed to produce clear support for streaming by semantic category: Probability of recall was .41 in the same-class condition and .39 in the different-class, and the difference between these means did not reach conventional levels of statistical significance. Although a firm conclusion should be withheld until further evidence is in
hand, this finding does suggest that semantic attributes are not as effective as some physical attributes in organizing primary memory.

Previous findings of streaming by sensory modality have been interpreted in terms of the structural properties of the processing system, and specifically of separate auditory and visual short-term stores (e.g., Murdock, 1967; Nilsson, 1973; Penney & Butt, 1986). The present findings clearly detract from this explanation, for if streaming by auditory and visual modalities indicates separate auditory and visual stores, then separate stores would have to be invoked for verbal and nonverbal auditory stimuli, male and female voices, and for different spatial locations. And as new instances of streaming are discovered, yet more stores would be needed.

The results of the research reported here suggest that the organization of primary memory is not the same as the organization of memory proper. For example, the results of Experiment 5 showed no evidence of streaming for lists of pictures and words even though other research has shown that presenting an item as a picture rather as a word often has an appreciable effect on memory proper (see Paivio, 1986). Similarly, the sensory modality of item presentation and, within the auditory modality, the voice of item presentation were shown here to have clear effects on the organization of primary memory whereas the effect of such variables on memory proper is typically modest (see Penney, 1989). Conversely, it appears from the experiment noted above that semantic characteristics of to-be-remembered items have little if any effect on the organization of primary memory, whereas other research has shown that such characteristics have an appreciable effect on the organization of memory proper (e.g., Tulving, 1962;
Bower, Clark, Lesgold, & Winzenz, 1969). In short, one very general virtue of the research reported in this thesis is that it underscores the functional distinction between primary memory and memory proper.
REFERENCES


Footnotes

1The concept of primary memory was ignored during the era of behaviorism. It was resurrected by Waugh and Norman (1965), but their usage reflected the information-processing Zeitgeist: They cast the concept in terms of a store and control processes, placing more emphasis on internal control than did James. It is James' (1890) conception of primary memory which is addressed here, a conception that—while not denying rememberer control—emphasizes the influence of the stimuli being remembered.
APPENDIX A: Pictures Used in Experiments 2 and 5

Pictures for Experiment 2

horn  glass  water

gun  saw  whistle

bugle  cuckoo
Pictures for Experiment 5

watch
tree
star

shoe
pipe
nail

lamp
key
cup
Pictures for Experiment 5 (continued)

dog
chair
cake

book
bed
APPENDIX B: Serial Position Functions for Each Experiment

This appendix presents probability of recall according to serial position for each of the seven experiments. These data should be interpreted with caution. Items were not counterbalanced with respect to serial position; thus, item selection effects cannot be ruled out. Furthermore, the number of observations contributing to each data point is small, resulting in rather unstable serial position functions.

Table B-1

Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 1

<table>
<thead>
<tr>
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<th>Serial Position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>auditory-visual</td>
<td>.11</td>
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<tr>
<td>visual-auditory</td>
<td>.20</td>
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<tr>
<td>auditory-auditory</td>
<td>.55</td>
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<tr>
<td>visual-visual</td>
<td>.10</td>
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</table>
Table B-2

**Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 2**

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</tr>
</thead>
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<td></td>
<td>2</td>
</tr>
<tr>
<td>sound-picture</td>
<td>.22</td>
</tr>
<tr>
<td>picture-sound</td>
<td>.28</td>
</tr>
<tr>
<td>sound-sound</td>
<td>.33</td>
</tr>
<tr>
<td>visual-visual</td>
<td>.37</td>
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Table B-3

Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 3

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<th>5</th>
<th>6</th>
<th>7</th>
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<td>Subconditions</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>word-sound</td>
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<td>.16</td>
<td>.11</td>
<td>.11</td>
<td>.23</td>
<td>.31</td>
<td>.81</td>
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<td>sound-word</td>
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<td>.25</td>
<td>.22</td>
<td>.42</td>
<td>.53</td>
<td>.70</td>
<td>.80</td>
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<td>word-word</td>
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<td>.39</td>
<td>.53</td>
<td>.56</td>
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<td>.78</td>
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<tr>
<td>sound-sound</td>
<td>.09</td>
<td>.17</td>
<td>.14</td>
<td>.09</td>
<td>.08</td>
<td>.17</td>
<td>.78</td>
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Table B-4

Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 4

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<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>.26</td>
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<td>female-male voice</td>
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<td>.26</td>
<td>.33</td>
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<td>.75</td>
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<td>male-male voice</td>
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<td>female-female voice</td>
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<td>.39</td>
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Table B-5

Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 5

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<th>Serial Position</th>
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</thead>
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<td>2</td>
</tr>
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<td>picture-word</td>
<td>.29</td>
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<td>word-picture</td>
<td>.30</td>
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<tr>
<td>word-word</td>
<td>.30</td>
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<td>picture-picture</td>
<td>.30</td>
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</tbody>
</table>

Table B-6

Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 6

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</tr>
<tr>
<td>top-bottom</td>
<td>.42</td>
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<td>bottom-top</td>
<td>.40</td>
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<tr>
<td>top-top</td>
<td>.40</td>
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<tr>
<td>bottom-bottom</td>
<td>.48</td>
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Table B-7

Probability of Recall as a Function of Serial Position for Each of Four Subconditions: Experiment 7

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<td>2</td>
</tr>
<tr>
<td>top-bottom</td>
<td>.28</td>
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<tr>
<td>bottom-top</td>
<td>.18</td>
</tr>
<tr>
<td>top-top</td>
<td>.36</td>
</tr>
<tr>
<td>bottom-bottom</td>
<td>.31</td>
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