microphonics. Because the Preyer threshold is approximately 70 db higher than these other indices, it serves as a good index of sensitivity to moderate to intense sounds. I can think of no mechanism by which acoustic priming can decrease the absolute auditory threshold, so it appears more likely that it exclusively increases sensitivity to high-intensity sounds. This could occur by a disruption of the reflexive uncoupling of the auditory ossicles in response to intense sounds. Similarly, damage to the olivocochlear bundle of Rasmussen could eliminate the centrifugal gating properties of this tract (*7*). Both of these postulated mechanisms would be in agreement with the unilateral effects of acoustic priming on audiogenic seizures and on the Preyer reflex, since they could be readily confined to a single ear or auditory nerve. They also agree with the conclusion of Fuller and Collins (*4*) that the locus of acoustic priming is either "in the ear or in those portions of the auditory system receiving input only from one side."

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16 December 1971; revised 6 March 1972

Decay of Information in Short-Term Memory

Abstract. *Self-paced recall in Broadbent's simultaneous listening task shows particular temporal patterns associated with report strategies. Accuracy is a decreasing function of the interval between presentation and report of an item, irrespective of report strategy. Results are related to an interaction between strategies of response selection and decay of information from memory.*

It is difficult for subjects to report accurately verbal information from more than one source arriving at the ears simultaneously. This is true whether such information is presented dichotically as a different word to each ear (*1*), or binaurally as two simultaneous messages distinguishable only by voice quality (*2*). Broadbent (*1*) showed that while handling simultaneous material was difficult, reporting dichotically heard digits successively (first all the digits heard in one ear, then all of those from the other) was significantly easier than reporting them pair by pair (alternating responses between the left and right ears). That this difference was most pronounced at rapid rates of presentation (one pair arriving every half second) led to the dual postulate that (i) some minimum time is required to shift attention from one message to the other, and (ii) the fast rates of presentation did not allow sufficient time for such switching before the onset of the next pair.

The general difficulty in handling simultaneous material was attributed by Broadbent (*3*) to a limited capacity filter that can pass information for identification or coding from only one source or "channel" at a time. Material not first attended is held up temporarily in a rapidly decaying "echoic" store (*4*) while the attended information is analyzed. Thus, successive report has its primary advantage in requiring the filter to switch only once, while attempts at pair-by-pair report require multiple switching as the system alternates between each source for each pair of presented digits. A great variety of subsequent theoretical and research effort has included both contradictory results and important theoretical alternatives (*5*), for example, that of Yntema and Trask (*6*). The central issue, however, has largely remained that of accounting for Broadbent's original finding that successive recall is more accurate than pair-by-pair report.

In the split-span task, auditory information arrives at the ears simultaneously, or "in parallel," while the report of what has been heard must necessarily be sequential. If the presentation of any list is considered and a constant rate of output is assumed, the interval over which the subject must retain particular items would necessarily be different for different orders of report. Such differences in "storage time" are crucial to any analysis of time dependence in simultaneous listening. This would be especially true if there are particular temporal output patterns associated with different report strategies.

The stimuli were 90 six-digit lists, randomly generated from the spoken numerals 1 to 9. The lists were recorded as sequences of three pairs of simultaneous digits, one member of each pair spoken by a male speaker, and the other member by a female. The lists were presented to both ears through headphones, at a rate of one pair every half second.

All the subjects heard an equal number of lists under two recall conditions. In successive recall, the subject reported the three digits heard in the male voice and then the three digits spoken by the female (or, for half of the subjects, vice versa). In pair-by-pair report, the subject was to give the three pairs in their order of receipt: the two digits of the first simultaneous pair, the second pair, and then the third. Half of the subjects began their report with the male voice of each pair, and half began with the female. Fifteen practice lists were followed by 30 test lists for each condition, with the order of conditions varied between subjects. The subjects, six university undergraduates, were encouraged to respond rapidly after hearing each list but to speak clearly as their responses were being recorded.

As each list was presented, it was rerecorded on one channel of a two-track tape recorder, while the subjects' responses were recorded on the second channel. This series of tapes, bearing a complete record of the experiment (both stimulus lists and responses for each subject), was monitored by a voice-operated relay associated with an ink-writing oscillograph. This produced a visual record of the temporal pattern of stimuli and responses. Time intervals were measured to the nearest 10 msec.

Figure 1 shows for both recall strategies the percentage of each of the six stimulus digits recalled correctly in their appropriate serial positions. The abscissa reflects the mean latency for reporting these items after the termination of the stimulus list (*7*). The individuals' superior ability in handling successive over pair-by-pair report is seen both in the number of digits reported correctly [87.4 percent compared with 55.5 percent, $F(1,5) = 29.314$, $P < .01$] and in the shorter delay before

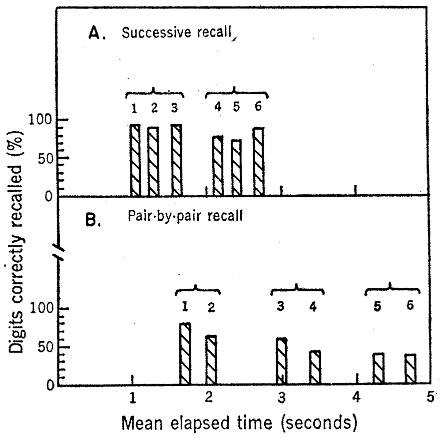

Fig. 1. Accuracy of recall and response latency (mean elapsed time from end of stimulus lists to onset of responses) for each of the six serial positions in successive report and pair-by-pair report.

beginning the response and the more rapid rate of output once the report is begun (*8*). For both conditions there was a general tendency for performance to decrease with later digits, excepted by a slight recency effect for the last digit recalled in successive order [$F(5,25) = 19.247$, $P < .001$)].

The patterning of responses reflects the grouping strategies attempted. Successive report was temporally grouped by the fairly rapid output of the three digits of one speaker, a delay, and the three digits of the other. Pair-by-pair report shows grouping of the two members of each pair, separated by longer delays. These two patterns were consistently reproduced by all subjects.

In these results, is there a difference between successive and pair-by-pair report that is reflected both in performance (percentage recalled) and in response rate, or is performance simply a consequence of response rate? Figure 2 attempts to resolve this question, with performance now related to time in storage for each response item. This latter measure is taken as the total elapsed time from the presentation of a particular digit to the output of that digit by the subject (*7*). A graph of the probability of recall for both conditions as a function of the calculated time in storage yields a good fit to a single monotonic decay function. Pair-by-pair report leads to longer average storage times than successive report [$F(1,5) = 7.610$, $P < .05$] and hence serves to distribute the preponderance of responses along different points of the decay curve (*9*).

The superiority of successive over pair-by-pair report first demonstrated by Broadbent (*1*) was readily replicated in these results. The use of a latency measure with unconstrained responses has shown in addition that (i) the spontaneous temporal grouping of responses differs reliably between the two recall conditions, and (ii) accuracy is a systematic function of time in storage.

Thus, it seems that the dramatic difference in performance between these two report strategies (a difference that has inspired many experiments and models) is directly attributable to differences in time in storage associated with the input-output characteristics of the task. Fitting a continuous function in Fig. 2 implies that the rate of decay of information and the amount of information immediately available at the end of the presentation period are indifferent to the strategy of recall.

The temporal differences between report conditions may reflect the biases of a response selector mechanism perhaps similar in principle to that proposed by Postman *et al.* in another context (*10*). It is known, for example, that subjects prefer successive report under free recall conditions (*1*), that errors made by subjects under pair-by-pair instructions often tend in the direction of this preferred strategy (*11*), and that when one of two simultaneous messages are to be repeated, intrusions from the "wrong" channel relate to their probability in the attended message (*12*). A strategy competition hypothesis seems appropriate to these and our own data. The criterion relevant to selection of items in successive order continues to dominate during pair-by-pair report and leads to covert errors that must be edited by the subject prior to report. This editing process imposes an additional storage time requirement with a concomitant loss of information.

Most previous examinations of time dependence in short-term memory have involved manipulating the retention interval or presentation rate without controlling or measuring response latency. The simple time-in-storage measure has the advantage of including the total elapsed time between input and output. Since response organization and selection presumably requires time over which the stimulus representation may decay, the time-in-storage measure would seem most appropriate for the examination of both the decay hypothesis and the effects of strategies on recall. The function obtained in this study (Fig. 2), where rehearsal would appear to be minimized by the nature of the task, is suggestive of other general functions proposed to describe the decay of information from short-term memory (*13*). These results, then, are interpreted as support for both the significance of decay of information from short-term memory and the relevance of response selection strategies for an explanation of the split-span experiment.

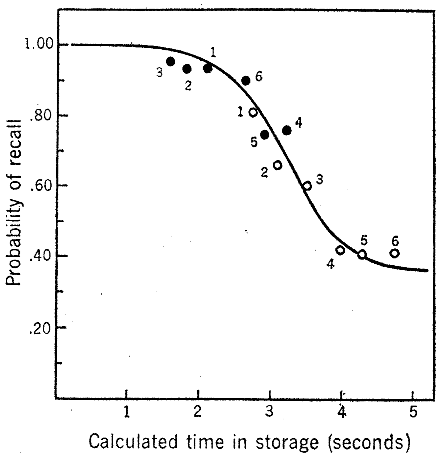

Fig. 2. Probability of recall for successive report (filled circles) and pair-by-pair report (open circles) as a function of calculated time in storage. The small numerals indicate the actual serial order of responses. The curve is based on the equation $y = (1 + at^n)/(1 + bt^n)$, where $a = 2.4 \times 10^{-4}$, $b = 7.0 \times 10^{-4}$, and $n = 6.5$.

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7. The time estimates were extrapolated from the latencies for those lists recalled perfectly,

that is, all six items present and in the correct order.

8. A number of alternate scoring methods have seen use in the assessment of relative recall efficiency in split-span studies. [See, for example, N. Moray and T. Barnett, *Acta Psychol.* **24**, 253 (1963).] These range in rigor from a comparison of the number of lists perfectly recalled, with its emphasis on maintaining order information (64.1 compared to 16.7 percent), to simply the total number of digits recalled in any order, a score undoubtedly inflated by guessing (95.9 compared to 87.2 percent). The difference in these two recall conditions, however, is significant for all of the scoring methods used.
9. As seen in Fig. 2, the order of report does not always coincide with the total calculated time in storage. Time in storage is a function of both presentation rate and rate of recall. In successive report, for example, when the subject responds with the first digit of the first channel to be reported, the time in storage is equal to the 500 msec between the first and second stimulus pair, the 500 msec between the second and third pair, plus the time elapsed before his response. Because of the pattern of output rate, this first response has in fact to be retained longer than either his second or his third response.
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9 December 1971; revised 10 March 1972 ■

Wavelength Effect on Visual Latency

Abstract. *Chromatic stimuli were matched in luminance to a homogeneous white background field. The relative visual latency, as measured by subjective simultaneity, of 621-nanometer (red) light was 20 to 25 milliseconds less than that for 549-nanometer (green) light. When the chromatic stimuli were different in luminance from the background field, no differences in visual latency related to the wavelength of light were observed. The procedure of matching the luminance of test fields to that of a background field appears to be crucial for observing a visual latency difference related to wavelength.*

Whether visual latency is affected by the wavelength of light is of importance both for theories of color vision and for the explanation of a number of visual effects, such as the Fechner-Benham colors. However, the literature concerning the effect of wavelength on visual latency is contradictory.

Piéron (*1*), using reaction time, reported that wavelength did affect visual latency, with the longer wavelengths having shorter latencies. On the other hand, Holmes (*2*), using the same measure of visual latency as Piéron, reported no dependence of visual latency on wavelength. The studies by Guth (*3*) and Pollack (*4*) appeared to have settled the issue when both investigators, controlling for equality of luminance of the stimuli, found no dependence of visual latency on wavelength. However, heterochromatic flicker experiments (*5, 6*), although not involving direct measurements of relative visual latency, yielded results which indicated that visual latency did, indeed, depend on the wavelength of the stimuli.

An examination of the procedures used in the experiments mentioned above indicates that visual latency differences related to wavelength are found only when the technique of hue substitution is used: a portion of an illuminated background field is replaced by a chromatic stimulus of equivalent luminance. In hue substitution a chromatic change is effected but the luminance remains constant across the entire field. The studies showing no chromatic effect (*2–4*) involved a method of incremental stimulus presentation: chromatic lights were added to a background field to produce test fields higher in luminance than the background field.

The studies mentioned above differed with respect to variables other than the presence or absence of luminance increments. I report measurements of the effects of wavelength on visual latency both with and without luminance increments; the same apparatus was used for both measurements. Apparent movement was used as the measure of relative visual latency (*7*). Asynchrony of stimulus onset was manipulated to produce apparent simultaneity.

The primary difficulty in instrumenting a hue substitution experiment is in producing field substitutions without luminance transients. My solution (*8*) was to provide a rectangular background of white light reflected from the front of shutter faces and blades. When the shutter blades were opened by a solenoid, a circular beam of chromatic light from behind replaced the portion of the background white light reflected from the shutter blades. Figure 1 shows the temporal relationships of the test fields and the background field for the condition that green (549 nm) leads red (621 nm) by 25 msec. The image of the shutters was blurred to mask minor discontinuities and eliminate sharp edges (*9*). Before exposure of the test fields the background field was completely homogeneous. The retinal illuminance of the shutter image was 1.04 trolands with an artificial pupil 3 mm in diameter. Two test fields (shown as dotted circles in the inset of Fig. 1), each 0.72° in diameter, were separated vertically by 1° from center to center. A black fixation dot was centered in the space between the edges of the test fields. Chromatic stimuli were produced by Schott 549-nm and 621-nm interference filters (*10*) and heterochromatic flicker photometry was used to equate the chromatic stimuli to the background field. A single light source was

Table 1. Interstimulus intervals for perception of simultaneity. The mean and standard error (S.E.) of six points (representing six psychometric distributions) were calculated for each stimulus condition. Positive interstimulus intervals indicate that the top field was first. Negative interstimulus intervals indicate that the bottom field was first.

Subject	Stimulus condition (nm)		Interstimulus interval (msec)		Mean latency difference (msec)
	Top	Bottom	Mean	S.E.	
		Both test fields equal to the background field			
JA	549	621	24.7	1.40	
JA	621	549	−26.5	1.49	26.6*
MI	549	621	21.0	1.60	
MI	621	549	−22.3	2.36	21.7*
		Both test fields raised 0.5 log unit			
JA	549	621	0.5	1.38	0.5
MI	549	621	2.5	1.75	2.5
		Background field lowered 0.5 log unit			
JA	549	621	1.3	1.29	1.3
MI	549	621	1.8	1.04	1.8

* Indicates those latency differences significantly different from zero ($P < .01$).