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Visual and Auditory Information Processing in Children and Adults

Abstract. *Children of three ages were compared with adults in a recognition experiment requiring continuous processing of information. The growth in precision for visually presented words is steeper than for auditorially presented words, largely because the former are harder for the first graders and, to a lesser extent, for the third graders. In adults, visual processing of information is at least as good as auditory. The use of receiver operating characteristic curves in describing the data permit greater precision in estimating the capacity of the individual subjects and are particularly useful since the errors of failure to recognize were different from ordinary errors of false recognition, and they occurred in large numbers.*

Many facets of the educational process depend upon accurate recognition of visually and auditorially presented linguistic information. As part of an extended study of the influence of linguistic redundancy upon the learning of verbal materials, we had sought a method which could be used with adults or young children which allowed stimuli to be shown either by eye or ear. We required a method which showed the word-frequency effect (*1*) in adults and bore some resemblance to the task of reading. The usual methods of measuring verbal learning used in our pilot studies (pair associates, serial lists) were too difficult for children or did not show the frequency effect (short-term retention) (*2*). The task finally used was adapted from an experiment with numbers by Shepard and Teghtsoonian (*3*). It requires the continuous processing of sequentially presented information for recognition after filled time intervals of variable length. In this respect the task closely resembles the reading or listening process. It also requires a very simple reponse of the subject—he merely says "old" or "new" at each presentation, so all the problems of response learning and of complex decision processes are avoided.

Ninety three-letter, three-phoneme words—30 very high, 30 very low, and 30 of zero (but still possible) frequency of occurrence in English (and therefore pronounceable)—appeared twice, first as new items, then as old items. There was always a delay of 2, 4, 8, 16, or 32 intervening items of the same set. Our lists were prepared by random selection from a pool to control for idiosyncracy, and they were presented either visually (Selectroslide projector) or auditorially (stereomagnetic tape). Sixty-four subjects were used at each of the four levels: first, third, and fifth reading level, and adult, making a total of 256 subjects. All were tested individually, half (32) of each age group with visually, half (32) with auditorially presented lists.

The major findings have been reported in detail (*4*). Modality was a significant factor in language processing, suggesting that the two are not equally effective avenues for presentation of verbal information at all ages. Moreover, children make more errors than adults both in failure to recognize and in false recognition, even on words of extremely high language frequency. This observation implies that, when some aspect of memory coding for verbal materials is involved, children will be inferior to adults. Following the numerous applications of signal detection theory to human psychophysics (*5, 6*) and recognition memory (*7*), as well as other fields (*8*), we combined the two sorts of errors in a receiver operating characteristic (ROC) curve. While many of the uses and interpretations of ROC curves depend on various theoretical models (*6*), geometrical considerations of ROC plots which are based on very few assumptions (*9*) are very descriptive. A simple total error score can be misleading because two subjects, although having equal scores, may reach the score in different ways. One may make very few errors by failure to recognize (that is, call old patterns "new") and the other may make many such errors. A better picture of the subject's performance is given by the detectability index, d', which relates both the detection rate, p ("new"/new), and the "new" error rate, p ("new/old). There are two very important properties of this index. One is that if the difficulty of a task is fixed during a series of trials, it is not possible for a subject to increase his number of correct detections without also making more errors by failure to recognize. The other is that the detectability index has been shown to be relatively independent of the subject's motivation, the costs of errors, the reward for hits, the experimental conditions, instructions, and the like (*5*).

In view of the descriptive precision of ROC curves, we plotted them for the eight groups of subjects (Fig. 1), to compare the progress of visual and auditory processing of information over the age range. In the graph of Fig. 1 for grade 3, auditory, the child represented by the point lying furthest to the right has a detection rate of .78 and an error rate of .55. There are, however, nine other children represented by points to his left (lower error rates) and lying on or above the horizontal line, p ("new"/new) = .78 (that is, those having an equal or better detection rate). There is a similar (and larger) area lying below and to the right of this point which defines an inferior performance. Norman (*9*) has derived a simple graphical procedure which allows comparisions to be made among experimental conditions, with limited assumptions about the underlying processes. He shows that the unit square (the ROC domain) may be partitioned into four regions in such a way that any arbitrary performance level represented by a single point may be related to that of any other point in the region. Thus in Fig. 1, grade 1, auditory, let us take that point given by the mean value of p ("new"/new) and p ("new"/old) (solid circle) to represent the mean performance level. The pair of straight lines drawn through the point from the two corner points define four regions. The performance levels of subjects whose points lie in the region S are superior; in the region I, inferior; and in the regions A, ambiguous with respect to the mean performance level.

These regions have been indicated for the auditory data in the four graphs of Fig. 1, auditory. In addition the regions for grade 1 are shown as dashed lines on the graphs for grades 3 and 5 and adults. Thus points for a given grade may be compared with the mean performance of that group or with that of first graders. The proportion of individuals whose performance on the auditory task is superior to first graders increases approximately linearly across the four levels, whereas the increase for vision (the four graphs of Fig. 1, visual) is rapid and nonlinear. Table 1 shows the proportion of subjects at each level whose performance is superior to that of the mean of their own group, and also the proportion whose performance is superior to that of the mean of first graders. By grade 5 only one child has not exceeded the performance of first graders on the visual task. But in the auditory task 6 of the 32 fifth graders have failed to exceed the mean performance level of first graders. However, no adult in either task fails to exceed the first grade performance level.

What interpretation can be made of these facts, by extension from the recognition experiments to the larger world of the developing child? One is that when he begins school his auditory perceptual skills are superior to his visual perceptual skills, but once concentrated tuition begins, heavy demands are made on the intake of information by eye in reading, hence learning is rapid. That the visual performance of a fifth grader is essentially as good as that of an adult is quite

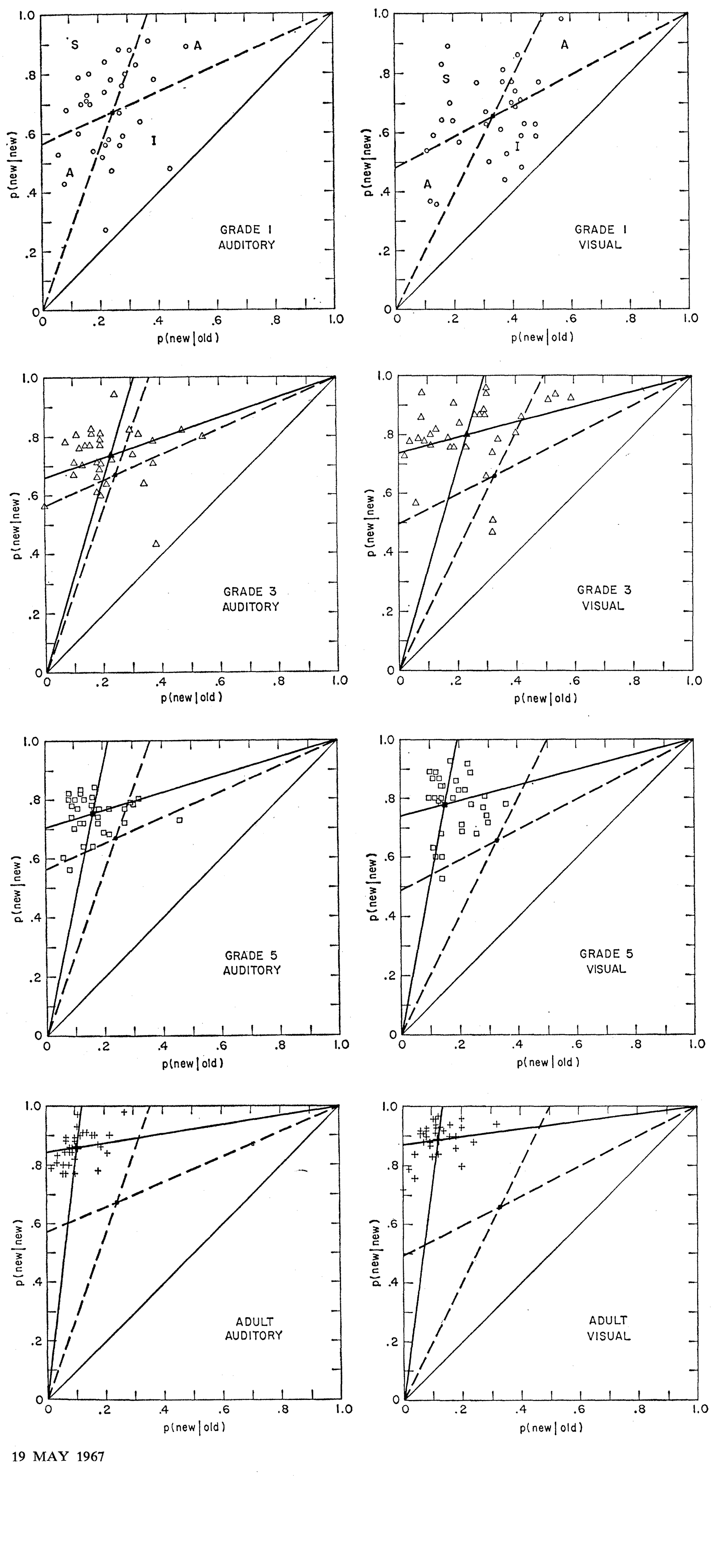

Fig. 1. Each graph shows the proportion of times that "new" was said when the word was presented for the first time, p (*new/new*) (ordinate), plotted against the proportion of times that "new" was said when that word was presented for the second time, p (*new/old*) (abscissa). Each symbol stands for a different subject. The filled symbol in each graph is the point designating the mean performance of the group. The two solid, crossed lines divide the third and fifth grade and adult graphs into four regions. Points lying in the region S indicate superior performances; those in region I inferior performances; those in regions A ambiguous performances, relative to the mean performance. The regions for grade 1 are shown on all graphs by dashed lines.

Table 1. Proportions of subjects ($N = 32$) having a performance level superior to the mean performance level of the reference group on plots of receiver operating characteristic curves.

Grade	Experimental group	
	Auditory	Visual
	Superior to mean performance level of grade 1	
1	0.41	0.34
3	.59	.78
5	.81	.97
Adult	1.00	1.00
	Superior to mean performance level of own grade	
1	0.41	0.34
3	.38	.31
5	.38	.38
Adult	.25	.38

consistent with our finding that a fifth reader and average adult texts have approximately equal redundancy (*10*). The better beginning and slower growth of auditory skill in the recognition task is consistent with our finding that simple sequential constraints of phonemes are essentially equal for first, third, or fifth graders, and for adults (*11*). There is, of course, some further differentiation from first graders to adults when the distribution of phonemic words is considered.

A useful fruit for the educator might come from an exploration of a given child's preformance index for visual and auditory material. Not only could his auditory and visual performance be related to each other, they could be related to group norms obtained in a standardized recognition-memory experiment, and to other independent indices of ability such as mental ability subtest scores, school grades, or even actual reading performance. The advantage of the recognition task is its minimal demands on auditory or visual perception, making it useful over a wide range of ages. The advantage of the ROC plot lies in the freedom of the detectability index from perturbation by criterion, motivation, implicit (but unspecified) reward and cost schemes, and other variables extraneous to the test situation.

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Discrimination Learning and Inhibition

Terrace's conclusions in his recent report (*1*) are not supported by the evidence he presents and opposite conclusions seem to follow. He argues that when a subject learns to discriminate between two stimuli (S+ and S−) without errors, the negative stimulus (S−) does not acquire an inhibitory function. He supports this conclusion by showing that there is no generalization gradient around S−, or in other words, that this gradient has zero slope. However, to evaluate this argument we must take into account the absolute values of the points of which the gradient is composed. These are all zero or very close to zero. The animals did not respond in the presence of any stimulus similar to the original S− when they learned without errors. Since they did not respond, and the animal cannot make scores of less than zero, we cannot infer that inhibition around S− is greater than that away from S−. The score at S− cannot be lower than zero when this experimental design is used, and therefore the lack of slope may only reflect this design. We cannot discriminate between an increase or no increase of inhibition at S− with Terrace's data. Can we interpret the zero scores, as Terrace does, as indicating that there is no inhibition when the subject learns to discriminate without errors? (He states: " . . . it is nonetheless clear that S− controls the tendency not to respond, that is, functions as an inhibitory stimulus, only after a subject has learned to discriminate with errors.") This question can be answered by looking at the scores of the group which learned S− with errors. Their rates of responding are much greater than zero when the stimuli presented moves away from S−. When the subjects learn to discriminate without errors, however, these rates of responding stay at zero or very close to it when the stimuli move away from S−. Therefore, rates of responding to stimuli away from S− are lower when the subjects learn to discriminate without errors than when they learn to discriminate with errors. Since the amount of responding is used as a measure of inhibition, one must infer that there is greater inhibition due to S−, when the subjects learn to discriminate without errors, as the stimulus moves away from S−; but this conclusion is the opposite of that made by Terrace. Far from supporting the evidence that Terrace quotes in favor of the idea that S−, when learned without errors, does not have an inhibitory function, the facts presented in the report cast strong doubt on Terrace's previous interpretations of such data.

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When, given the same set of data, two scientists reach opposite conclusions, it is likely that each used different decision rules. In this case, the data in question are generalization gradients of wavelength that were obtained after a subject was trained to discriminate between a white vertical line on a black background (S+) and a homogeneous circular patch of monochromatic (either 550 or 580 nm) light (S−). The gradients of those subjects who learned the discrimination without errors were flat, with all of the data