Speed of discrimination with redundant stimulus attributes¹

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Speed of sorting decks of 32 cards with two alternative stimuli was measured. The stimuli were pairs of dots with attributes of distance between dots, angle of orientation of the pair, and position of the pair to the right or left of center. The attributes varied in relative discriminability and were used in all possible pair- and triple-correlated (redundant) combinations. Results showed an increase in speed of sorting with either an increase in discriminability or an increase in number of redundant attributes. It is argued that the increased speed with addition of redundant attributes is due both to a selective serial processing of attributes (requiring attribute separability) and to an increased discriminability with combined attributes (requiring attribute integrality).

Most studies of the effect of stimulus redundancy on discrimination performance, particularly those involving correlated stimulus attributes, have used accuracy as a measure of performance. These studies have shown that a gain in discrimination accuracy with redundancy depends on the nature of the stimulus attributes. In particular, a gain in absolute judgment accuracy seems to require that the attributes be integral in nature (see Garner, 1962, for review of earlier work; also Garner & Creelman, 1964; and Lockhead, 1966a, b). When the stimulus attributes are discrete elements, such as repeated letters, and discrimination under low visibility conditions is required, redundant elements may also produce a gain in accuracy (Garner & Lee, 1962; Garner & Flowers, in press; Eriksen & Lappin, 1965).

Morton (1969) has shown that speed of card sorting is improved when stimulus attributes are made redundant, but here again the effect of the redundancy appears to be a complex function of the nature of the stimulus attributes. He found a gain in discrimination speed when the number of elements on a stimulus card was perfectly (and compatibly) correlated with the numerals constituting the elements (i.e., his six different stimuli were 1, 22, 333, 4444, 55555, or 666666). When, however, the numeral was simply repeated three times, regardless of the numeral on the card, there was no gain in discrimination speed. Thus, the simple repetition of the numeral gives no gain in performance, even though such a repetition does give a gain in accuracy under low visibility conditions, as mentioned above.

Related to this problem are several experiments in which a pair of stimuli is presented, and S must judge whether or not they are different. Egeth (1966), Nickerson (1967), and Hawkins (1969) have all shown that the speed of making the "difference" judgment is greater when the pair of stimuli differ on more than one stimulus attribute. Methodological differences between these experiments and those more directly concerned with redundancy in discrimination tasks make direct comparison difficult; nevertheless, this evidence does suggest that the addition of redundant stimulus attributes should improve speed of discrimination.

The purpose of the present experiment is to investigate further the effect of stimulus redundancy on speed of discrimination, using card sorting as the task, with pairs of dots as stimuli varying in three attributes singly and in different correlated combinations. In addition, the stimulus attributes vary in discriminability, so that the effect of attribute redundancy can be related to the effect of attribute discriminability.

METHOD

Stimuli

Each stimulus consisted of a white card, 8.9 x 6.3 cm, with the shorter side vertical, and with a small piece cut off of the upper right-hand corner of the card to maintain proper orientation. On each card was a pair of black dots, 2 mm in diam. In a single trial, S was required to sort a deck of 32 cards. In each deck there were just two different kinds of stimuli. The two stimuli differed from each other in respect to the nature of the attributes, the relative discriminability of the attributes, and the number of correlated attributes.

Position of dots (P). One attribute involved the horizontal position of the pair of dots, the pair always being centered vertically. When only position was operative as an attribute, the pair of dots was oriented vertically, and the dots were 10 mm apart, center to center. For a relative discriminability of P1, the midpoint of the pair of dots was either 2 mm to the right or to the left of center; for a relative discriminability of P2, 4 mm; for P3, 8 mm; and for P4, 16 mm to the right or left.

Distance between dots (D). The second attribute involved the distance between the dots. When only distance was operative as an attribute, the pair of dots was centered horizontally and had a vertical orientation. For a relative discriminability of D1, the two distances were 9.5 or 10.5 mm, center to center; for D2, 9 or 11 mm; for D3, 8 or 12 mm; and for D4, 6 or 14 mm.

Angular orientation of dots (A). The third attribute involved the angular orientation of the pair of dots. When only angle was operative as an attribute, the dots were centered horizontally and were 10 mm apart, center to center. For a relative discriminability of A1, the pair of dots was rotated either clockwise or counterclockwise from the vertical by 1.5 deg; for A2, 4.7 deg; for A3, 14.5 deg; and for A4, 45 deg.

These attributes and levels of relative discriminability are the same as those used by Imai and Garner (1965), since in their card-sorting task these levels were shown to be about equivalent from one attribute to another. Within an attribute, however, the discriminability levels are only relative, since we have no measure of discriminability other than the dependent variable of speed of discrimination itself.

Redundant Stimulus Sets

These three attributes, with four levels of relative discriminability each, provide 12 different experimental conditions. In addition, two or three stimulus attributes were combined in correlated fashion. Attributes were combined only at the same level of discriminability, so that there are just four levels of discriminability with any stimuli involving correlated attributes. There are three pairs of attributes (DP, PA, and DA) and one triple combination (DAP). These four combinations, at four relative discriminabilities each, provide 16 additional conditions, for a total of 28 conditions.

When two or three attributes were combined in a correlated fashion, right position, clockwise rotation, and greater distance were combined. To illustrate, when all three attributes were combined in correlated fashion, at a relative discriminability level of 4, one stimulus had the pair of dots 6 mm apart, 16 mm to the left of center, rotated 45 deg counterclockwise; the other stimulus had the dots 14 mm apart, 16 mm to the right of center, rotated 45 deg clockwise.

Table 1
Mean Sorting Times (Sec) for All Conditions

Attributes	Relative Discriminability				M
	1	2	3	4	
Distance	28.70	23.56	16.57	15.09	20.98
Angle	23.56	21.53	17.73	16.60	19.85
Position	30.74	20.58	16.41	15.73	20.87
M (single)	27.67	21.89	16.90	15.81	20.56
DA	22.93	19.47	15.95	15.10	18.36
PA	29.19	19.47	16.22	14.74	19.91
DP	28.23	18.96	16.22	14.91	19.58
M (double)	26.78	19.30	16.13	14.91	19.28
DAP	25.27	18.10	15.26	14.14	18.19
M (overall)	26.95	20.24	16.34	15.19	19.68

Procedures

Subjects. Ss were 28 male college students, volunteers who were paid \$2.00 for participating. All conditions were run in a single session, lasting an average of 1.5 h.

Task. S was required to hold the deck of stimulus cards in one hand, face up, and to deal them off into two piles with instructions to "go as fast as you can, but be sure not to make mistakes." Before starting, S looked through the first several cards to be sure he understood what the two different stimuli were. After each deck had been sorted, E recorded total time and number of errors and told the scores to S. The decks were shuffled by hand before each trial.

Order of presentation. S was given 10 of the stimulus decks as practice, in order to stabilize performance before the main experimental trials. Then he was run on all 28 decks, in an order predetermined from a 28 x 28 Latin square, so as to counterbalance conditions and order across Ss. Analysis of data with respect to order of presentation showed a slight continued learning during the first four main trials, but the effect was sufficiently small that additional analyses ignored any effect of order of presentation.

RESULTS

Errors

Mean errors per condition per S ranged from 0 to 3.50. Errors decreased with increased relative discriminability, averaging 2.12, 0.62, 0.18, and 0.13 for the four relative discriminabilities. Errors also decreased with an increased number of correlated attributes, averaging 0.90 for one attribute, 0.76 for two, and 0.38 for three attributes.

The overall rank correlation between mean errors per condition and mean time is .90. Thus, both errors and time indicate the same relative performance, and all additional analyses are concerned only with the time measure.

Time

Mean sorting times per deck of stimulus cards are shown in Table 1 for all conditions.³ For every attribute and combination of attributes there is a regular decrease in sorting time with an increase in relative discriminability; and the average changes in sorting times obtained in this experiment match very closely the changes previously found by Imai and Garner for the same stimuli. Thus, we have confirmation of the general nature of the relation between speed of sorting and relative discriminability.

Furthermore, as the number of correlated stimulus attributes is increased from one to two to three, there is a decrease in sorting time for every level of discriminability. Thus, the use of redundant stimulus attributes clearly increases speed of sorting.

Within the single-attribute conditions, there is a significantly lower average sorting time for angle than for the other two attributes, but this effect is due almost entirely to the

considerably better performance with that attribute at the lowest discriminability level, a fact that produces a significant interaction between attribute and discriminability level within these single attribute conditions. Within the double-attribute conditions, the DA combination gives significantly faster sorting times than do the other two combinations, and once again the effect is due primarily to the much better performance given by this combination at the lowest level of relative discriminability. These lowest levels of relative discriminability clearly pushed the limits of discriminability for many of the Ss, with individual time scores occasionally going over 80 sec for one deck of cards, and with errors in at least one case going to 50%. Thus, very probably, the best interpretation to give to these differences due to conditions at the lowest levels of relative discriminability is that the measures are too unreliable for the differences to be meaningfully interpreted.

This experiment was designed with special reference to a possible interaction between discriminability level and number of correlated stimulus attributes, and this interaction is significant. However, interpretation of the interaction is not very clear. Basically the interaction is due to a maximum effect of number of attributes with a discriminability level of 2. If we assume that the lesser effect of number of attributes at the lowest discriminability level is due to the inherent unreliability of measures under those conditions, then this interaction would indeed suggest that there is a greater gain in discrimination speed when the need for increased discrimination is greater, and that there might be a level of discriminability high enough so that the addition of a redundant attribute would not improve discrimination speed. When, however, we consider that there is so much more room for improvement in speed with the lower discriminability, then the lack of relative improvement is certainly as striking as the slightly greater absolute improvement. To illustrate, at a discriminability level of 2, combining all three attributes in the stimuli gives a sorting time slower than the slowest time for any single attribute at a discriminability level of 3. And at the discriminability level of 3, combining all three attributes gives a sorting time that is slower than two of the three single attributes at the highest discriminability level and is barely faster than the third.

DISCUSSION

What produces a gain in discrimination speed when two or more stimulus attributes are redundantly combined? Basically, there are two alternative types of answer: First, it may be assumed that the use of two or more correlated attributes produces, in effect, a new stimulus attribute with greater discriminability. Second, it may be assumed that there is some advantage to the organism in processing two or more attributes compared to one. The present results suggest that a combination of these two factors is responsible for the improvement in discrimination speed.

Multiple Attribute Processing

We can distinguish (at a first level) between parallel processing and serial processing of information. If there has been a gain in speed with an increased number of attributes, we would ordinarily assume that processing is in parallel (i.e., occurs simultaneously) with self-termination of the process as soon as sufficient evidence has been obtained to make a decision (see Egeth, 1966). Parallel processing will lead to a gain in speed with correlated attributes as long as the processes themselves are uncorrelated and each process has sufficient variability that a gain can occur by an increase in the combined probability that at least one of the two or more processes will lead to a decision in a specified time.

Fig. 1. Mean sorting time as a function of relative discriminability with one attribute or two correlated attributes. Each plotted point represents the best single attribute or the best double-attribute combination, selected separately for each S at each level of relative discriminability.

Selective serial processing. Ordinarily we exclude serial processing explanations if there has been an increase in speed of processing with increased number of attributes, since it requires more time to process two things one after the other than to process either one alone. However, *selective* serial processing could give a gain in speed if (a) the two or more processes are not equally effective, (b) S selects the better attribute to process first, and (c) he terminates the process by reaching a decision on the basis of the better attribute alone. Thus, selective processing would produce a better average speed with multiple attributes, but would not produce a speed faster than the best single attribute.

Inspection of Table 1 (for data averaged across Ss) gives only slight evidence for selective serial processing, since the best single attribute (either overall or for any one level of discriminability) is generally not as fast as any pair or triple combination in which it occurs. On the other hand, such a comparison leads to a considerably reduced effect of redundant attributes, since the difference between the best single attribute and the double or triple combination in which it occurs is much less than the respective differences between averages. Yet this lowered effect is itself difficult to assess, since the best of three scores is being compared to either one or two scores, and chance factors (giving more opportunity for random effects to produce a lower time score for the single-attribute cases) will produce this lessened effect. A fair comparison would require equal chance factors for the two or more scores being compared.

A second difficulty with this type of comparison is that the best single attribute may not be the same for each S, with the consequence that using overall averages for all Ss may obscure very real evidence of selective serial processing. Thus, two attributes might be equally good on the average for all Ss, even though half the Ss were better on one and half on the other. Therefore, any test for serial selective processing should be made on an individual basis, not with overall averages.

Both of these problems can be considerably overcome by the following comparison: We determine the best single attribute for each S and compare it to the best attribute pair for that same S. This comparison allows for individual differences, and also substantially handles the problem of equal chance factors because there are three single attributes and also three pairs of attributes.

Thus, each score is the best of three. Furthermore, we can determine the best single and the best pair of attributes separately for each discriminability level to avoid the possibility that the best attribute or pair of attributes changes from one discriminability level to another.

Figure 1 shows average data for this comparison. The average for the best single attribute is 17.84 sec, and that for the best pair of attributes is 17.04. This comparison thus shows a considerable reduction in the effect of adding redundant attributes as contrasted with the use of overall averages in Table 1, which show a drop from 20.56 to 19.28. And at the two highest levels of relative discriminability, the average reduction in time is 0.43 sec, compared to 0.76 when overall averages are used.

This reduction in the effect of adding redundant attributes when best singles are compared to best doubles for individual Ss strongly suggests that there is some selective serial processing. Additional casual evidence for this conclusion comes from the report of several Ss that they were in fact making the discrimination on the basis of just one attribute rather than two.

Discriminability Effects

While the effect of redundancy is reduced with this comparison, it is not eliminated. Furthermore, for 26 of the 28 Ss, the best double attribute gave better performance than the best single attribute. We could attribute this residual gain either to some parallel processing or to a resultant increase in stimulus discriminability. We feel that it is due primarily to a gain in discriminability, a conclusion based on the following rationale:

We have very clear evidence that an increase in discriminability of a single attribute produces a substantial gain in speed of discrimination, and that the effect of an increase in discriminability by direct manipulation of physical differences on a single attribute is large compared to the gain produced by increasing number of attributes. Since the addition of correlated attributes produces a gain in discrimination speed and also produces a physical change in the stimulus differences, a first assumption should be that the gain in speed with addition of attributes is basically due to the same factor as the gain in speed produced with increased relative discriminability.

Such concepts of separability and integrality of stimulus attributes as used by Shepard (1964), Lockhead (1966a), Handel (1967), and Hyman and Well (1968) are very pertinent to this argument, since if attributes are to be processed as multiple attributes, they must in some sense be separable, while, if they are to be processed as a new combined attribute of some sort, they must in some sense be integral. Our argument with respect to selective serial processing was that these particular attributes are in some sense separable, since Ss at least attempt to make a decision by attending to only one attribute. Additionally, we argue that these particular attributes are in some sense integral, and that this integrality has made possible a recombination of pairs and triplets of attributes into a composite with an increased discriminability.

Each of the stimuli used in this experiment can be thought of as a pair of dots with attributes defined in terms of the pair, or as two single dots with attributes defined in terms of the locations of these single dots. If we consider the dots as pairs, then the attributes are reasonably separable. For example, the distance between the two dots can be judged quite separably from the location of the dots to the right or left of center, and the angle formed by the pair of dots can be judged without respect to location or distance between dots. On the other hand, consider only the top dot of a pair, and assume that S makes his decision based on just the relative location of the single dot. If we combine the attributes of position and distance, the difference in location between the top dots of the two different stimuli is

greater than with either attribute alone. Thus, the combination of the two attributes can be considered to have increased the discriminability of the two stimuli in a deck in a manner quite like simply increasing the distance between the two dots on a single stimulus.

Thus, these particular stimuli can be considered as both separable and integral. The separability makes selective serial processing possible; and the integrality makes it possible for an increase in number of attributes to increase discriminability. Consequences of both separability and integrality have occurred with these particular stimulus attributes.

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NOTES

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3. Analysis of variance was carried out on time scores, and all effects described are significant at the .01 level or less.

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