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# PROCESSING REDUNDANT INFORMATION[1]

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When stimuli differed on two dimensions (size and brightness), either of which could furnish sufficient information for a correct response, reaction times were faster than when stimuli differed on only one dimension. This result holds true even when individual differences in dimension preferences are taken into account. A model of parallel processing of the different dimensions is proposed and extended to Posner's taxonomy of information-processing tasks. The model emphasizes *S*'s ability to initiate a successive processing stage as soon as sufficient information for a correct response has been gathered. This ability enables *S* to capitalize on the variance of the times of the component processes by which the values of the different dimensions are determined.

Does an excess of relevant information facilitate or retard the speed of pattern perception? This question of the effects of redundant, relevant stimulus information has been the subject of some speculation (Garner, 1962), but direct experimental study has been lacking. The present investigation explored this issue in the context of the handling of multidimensional visual information in a speeded recognition task. The experimental strategy was to compare reaction times (RTs) from a task where the stimuli differed on only one dimension with a task where the stimuli differed on two dimensions (of equal discriminability), either one of which could furnish sufficient information for correct recognition.

The effects of redundant, relevant information have important implications for the theoretical issue of whether the component processes for determining the values of the different dimensions proceed in serial or parallel fashion (Smith, 1968). However, to generate predictions from parallel or sequential models of the component processes, it is necessary to consider a distinction between *self-terminating* and *exhaustive* outcomes of these processes (Egeth, 1966). When there is more than one component process, as would be the case with a redundant, relevant dimension, a response might be initiated as soon as sufficient information is available, even though some of the component processes are not yet completed. The outcome of the component processes in such a case is said to be self-terminating. (This does not necessarily mean that stimulus processing ceases, but simply that a successive stage is initiated as soon as sufficient information for a correct response is available.) This is in contrast to the case where a response is not initiated, even though sufficient information is available, until all the component processes are completed. In this latter case, the outcome of the component processes is said to be exhaustive.

A parallel model holds that the component processes for the different dimensions are initiated and proceed simultaneously. If it is assumed that (*a*) the times for the completion of a given component process are statistically distributed, (*b*) these distributions for the different dimensions are less than perfectly correlated, (*c*) there is some overlap between these distributions, and (*d*) the processes are self-terminating, then a parallel model predicts that the addition of a redundant, relevant dimension should result in a shortening of RTs. Statistically, such a "redundancy gain" occurs because

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the expected value of the combined distribution of shortest times for the component processes decreases as the number of component processes increases. (See Egeth, 1966, for a thorough presentation of these assumptions and predictions.) The gain would likely be of rather small magnitude (relative to the variance of the component distributions) if the times for the component processes are partially correlated, do not completely overlap, and are not always self-terminating.

A sequential model implies that the component process for one dimension is not initiated until the component process for the other dimension is completed. If the first component process initiated is the one with the shorter mean time and if the outcome is self-terminating, then there would be no effect of adding a redundant, relevant dimension. Any exhaustive model (parallel or sequential) implies that the addition of a redundant, relevant dimension should result in longer RTs compared to a task with only one dimension relevant. Empirical support for either sequential or parallel processing of stimulus dimensions has been equivocal (Egeth, 1966; Hawkins, 1969; Nickerson, 1967; Smith, 1968; Treisman, 1969), with most experimental tests unable to distinguish between a parallel processing model of the kind outlined previously and a serial model in which the order in which the different dimensions are processed varies from trial to trial.

In comparing unidimensional conditions with redundant bidimensional conditions, it is necessary to control for individual differences in dimension preferences. Some *S*s might be more adept at processing size, while other *S*s might be faster with brightness. Not all *S*s receiving the unidimensional condition would be assigned their favored dimension. Therefore, faster times on the redundant condition might simply reflect the processing by *S*s of their preferred dimension, and parallel processing need not be postulated to account for a redundancy gain. Consequently, the experimental design called for each *S* to receive both unidimensional conditions, as well as the redundant condition. The redundant condition could then be compared with the fastest unidimensional condition for that *S*. However, if each *S* were to receive two unidimensional conditions and one redundant condition, unspecifiable sources of variability would favor the unidimensional conditions. Since a redundancy gain, if present, is likely to be of small magnitude, pitting a single redundant condition against two unidimensional conditions could, conceivably, obscure the gain—formally, in the same manner that the parallel model predicts that the distribution of faster times of two random variables would be faster than the times for any one of the variables. Consequently, each *S* received two redundancy conditions so that his fastest unidimensional condition could be compared to his fastest redundant condition.

Incorporating a second redundant task into the experimental design (so that each *S* performed four tasks) is justified as a control for variability between the unidimensional tasks only if the following two conditions obtain: (*a*) Positive transfer should not benefit the redundant tasks more than the unidimensional tasks; and (*b*) the mean difference between *S*s' unidimensional tasks must not be greater than the mean difference between their redundant tasks. The rationale for the first condition is obvious, but the rationale for the second is more complex and requires some explanation. Suppose that a particular *S* had a strong dimension preference such that one of his unidimensional tasks, size, was so much faster than his other unidimensional task, brightness, that there was no overlap in the sampling distributions of RTs for the two tasks. In such an instance, the mean time of that *S*'s fastest unidimensional task would be equal to the mean time of his size task. However, if there also was considerable overlap in the sampling distributions for his two redundant tasks, then the mean of the distribution of fastest redundant tasks would likely be faster than the distribution of any one of the redundant tasks. A redundancy gain could then be obtained even if *S* were processing only the size dimension when performing the redundant tasks. The logic of this condition, that the overlap of the sampling distributions of RTs for the two unidimensional tasks must not be less than the overlap of the sampling distributions of the two redundant tasks, is formally identical to the logic of the parallel model for processing different dimensions: the magnitude of the gain of the distribution of fastest times will be related to the degree of overlap of the component distributions.

The present experiment was also designed to explore the effects of stimulus discriminability on the difference in RTs between unidimensional and redundant bidimensional conditions. If the discriminability of the values of a stimulus dimension is reduced by increasing the physical similarity of the values, then it would be expected that the mean of the distribution of times for the component processes would be increased. More important for the present experiment, a reduction in discriminability might also be expected to increase the *variance* of the distribution of component times. Why this occurs is problematical, although the positive correlation between the mean and variance of RT distributions is a common observation. If the parallel, statistically distributed, self-terminating model is accurate, then increasing the variance of the times for the component processes should increase the difference in RTs between unidimensional and redundant bidimensional conditions. In other words, the model predicts that the facilitating effects of redundant information would be increased in situations of low discriminability.

## Method

*Subjects.*—Forty students from the State University of New York at Buffalo participated in the experiment as part of their introductory psychology course requirements.

*Stimuli.*—The stimuli were gray circles mounted on white paper and centered on glass slides. Nine stimuli were generated from all combinations of three shades of gray (6, 9, and 15 ftl.) and three circle sizes (diameters of 10, 13, and 16 mm.) The luminance of the white background was 22 ftl. The preexposure and postexposure fields were also white and had a luminance of 44 ftl.

*Apparatus.*—Stimuli were presented in a Polymetric tachistoscope (Model V-0959T) modified with a rotatable slide carrier. The preexposure and postexposure fields, as well as the background field, were a uniform white. The *S*'s index fingers rested on plastic keys, which activated microswitches. RTs were measured by a Standard Electric timer to the nearest .01 sec. A set of lights on *E*'s panel indicated *S*'s response. The sequence of ready signal, presentation, and reset was controlled by a Lafayette VIII bank timer (Model 1431A). Stimulus presentation and response recording were done by *E*.

*Procedure.*—The *S* was seated and the tachistoscope was adjusted to his line of sight. A display card showing the stimuli and their assignments to fingers was placed by the response panel and remained there while *S* performed. The stimuli were then shown in the tachistoscope and complete instructions were given as to the stimuli, their assignment to responses, and the nature of the task and session. The *S* was told to respond as fast and as accurately as possible.

The experimental session consisted of four blocks of 60 trials. The interstimulus interval was 10 sec., with a warning buzzer of .5-sec. duration sounding 1 sec. before the stimulus presentation of .5 sec. The *S* was provided error and RT feedback (to the nearest .01 sec.) after each response. Six practice trials were given before each trial block. Approximately 2 min. were required between blocks for instructions to be given for the next task. Stimuli were equiprobable, as were all first-order transitional probabilities.

*Design.*—In all conditions, two stimuli were assigned to the two responses. In the size condition, the two stimuli differed only in size, and brightness was held constant. In the brightness condition, the two stimuli differed only in brightness and the circles were of the same size. In the redundant task, the stimuli differed on both dimensions. Each *S* had two redundant tasks incorporating the same stimuli that were used in his size and brightness tasks. If an *S*'s first redundant task required a large, bright vs. a small, dim stimulus discrimination, his second redundant task would require a small, bright vs. a large, dim stimulus discrimination. Thus, specific positive transfer effects resulting from repetition of the redundant condition were reduced by using different stimuli in the redundant tasks.

High-discriminability tasks were constructed from the extreme values (6 or 15 ftl. and 10 or 16 mm.) of the stimulus dimensions. Low-discriminability tasks were constructed by taking an extreme value and an intermediate value (9 ftl. and 13 mm.) for each dimension.

A within-*S* design was used in which the four conditions were presented in counterbalanced order. Also balanced were the particular stimuli and their assignment to the preferred (vs. nonpreferred) hand.

## Results

Table 1 shows that an overall redundancy gain did occur: the redundant condition was faster than the fastest unidimensional condition (size). The overall effect of conditions was significant, $F$ (3, 114) = 10.36, $p < .01$. That the redundancy gain was not a function of a speed for accuracy tradeoff is evidenced by the higher error rates in the unidimensional conditions. If a speed–accuracy tradeoff were present, it would have reduced the magnitude of the redundancy gain.

The effect of discriminability was also significant, $F$ (1, 38) = 8.39, $p < .01$. As shown in Table 1, the low-discriminability conditions also had greater variability. However, while the redundancy gain was greater in the low-discriminability conditions, as predicted by the parallel processing model, the Conditions × Discriminability interaction was not significant, $F$ (3, 114) = 1.20.

With respect to the issue of serial vs. parallel processing, the more critical analysis of a redundancy gain must be made by comparing each $S$'s fastest unidimensional condition with his fastest redundant condition. In the high-discriminability condition, 17 of the 20 $S$s showed a redundancy gain, 2 showed a redundancy loss, and 1 had identical RTs. In the low-discriminability condition, 16 of the 20 $S$s showed a redundancy gain and 4 showed a redundancy loss. Table 2 shows the mean correct RTs for the fastest unidimensional and redundant conditions; the redundancy gain was highly significant, $F$ (1, 38) = 22.17, $p < .001$. Size was the fastest unidimensional task for 14 of the $S$s in the high-discriminability condition and 13 of the $S$s in the low-discriminability condition. The main effect of discriminability fell just short of significance, $F$ (1, 38) = 4.07, $.10 > p > .05$. The Magnitude of the Redundancy Gain × Discriminability interaction was in the direction predicted by the parallel model, but was not significant.

TABLE 1

Mean Correct Reaction Time (in msec.) and Percentage of Errors (% E) for Each Experimental Condition

| Task | Discriminability | | | | | |
|---|---|---|---|---|---|---|
| | High | | | Low | | |
| | RT | | % E | RT | | % E |
| | $M$ | Variance | | $M$ | Variance | |
| Brightness | 392 | 33 | 7.2 | 428 | 49 | 8.9 |
| Size | 382 | 37 | 6.4 | 412 | 54 | 8.3 |
| Redundant | 376 | 31 | 5.2 | 395 | 36 | 6.8 |

TABLE 2

Mean Correct Reaction Time (in msec.) for Fastest Unidimensional and Fastest Redundant Conditions for Each $S$

| Discriminability | Fastest unidimensional | Fastest redundant | Difference |
|---|---|---|---|
| High | 378 | 364 | 14 |
| Low | 402 | 380 | 22 |
| $M$ | 390 | 372 | — |

As noted in the introduction, the preceding analysis of fastest unidimensional vs. fastest redundant conditions is justified only if unidimensional task differences and transfer do not favor the redundant conditions. The mean difference between unidimensional tasks was 26.5 msec., which is almost identical to the mean difference between redundant tasks of 27.2 msec. Twenty-four of the 40 $S$s had larger differences between their redundant tasks, and the rest had larger differences between their unidimensional tasks. The condition of equal unidimensional and redundant task differences was thus upheld.

The redundant conditions were slightly favored by an asymmetry in transfer. The second redundant task was, on the average, 10 msec. faster than the first (under both levels of discriminability), while the second unidimensional task averaged 3 msec. faster than the first in the high-discriminability condition and 6 msec. faster than the first in the low-discriminability condition. The magnitude of the redundancy gains can be "corrected" for these transfer differences by reducing the redundancy gain by 7 msec. in the high-discriminability conditions and by 4 msec. in the low-discriminability conditions. Under such a correction, the difference between redundant and fastest unidimensional tasks remains significant at the .01 level, $F$ (1, 38) = 11.62.

## Discussion

The presence of a redundant, relevant stimulus dimension resulted in a shortening of RTs compared to a condition where such a dimension was not present. The model compatible with this finding is one in which the different dimensions are processed in parallel with a response initiated as soon as there is sufficient information for a correct choice. Moreover, the times for the component distributions must be statistically distributed, and the distributions must overlap and be less than perfectly correlated. It is by capitalizing on the variability of the component times that a redundancy gain can be achieved. It is not clear why the magnitude of the redundancy gain did not significantly interact with discriminability, although the data were in the expected direction.

The parallel processing model provides a parsimonious account of the differences in RTs between the information-reduction tasks defined by Posner's (1964) taxonomy. The emphasis from the parallel model is on the human's ability, when performing different tasks, to adopt different "stopping rules," enabling him to process just enough information for a successive stage to be initiated successfully. Posner distinguished between gating (or filtering) tasks, where some of the stimulus information was irrelevant, and condensation tasks, where all of the stimulus information is relevant, but is represented in the response in a condensed form. Fitts and Biederman (1965) demonstrated that a filtering task required substantially less time than a condensation task with the same set of stimuli and responses. With a redundant task, a response can be initiated as soon as the first component process is terminated. With a condensation task, however, a response can only be initiated following termination of *all* relevant component processes. Consequently, the RTs in a condensation task would be related to the distribution of times of the longest component process. Given the conditions of the parallel model, the mean of the distribution of longest times would be greater than the mean of the distribution of times for any one of the components.

RTs from condensation tasks are generally found to be about 100 msec. longer than conservation (or filtering) tasks of the same response entropy (Fitts & Biederman, 1965; Morin, Forrin, & Archer, 1961). This difference is considerably longer than the difference between conservation and redundant tasks found in the present study. The parallel processing model implies that this asymmetry in the effects of adding redundant vs. nonredundant relevant dimensions is a consequence of the shape of the distribution of component times. If these distributions are positively skewed, the difference between the means of the component distributions taken individually and the mean of the distribution of longest times will be greater than the difference between the means of the individual distributions and the mean of the distribution of shortest times.

Finally, what would be the effects of combining relevant dimensions which differed considerably in discriminability so that there was no overlap in the distribution of component times? According to the parallel model, RTs from a conservation task with the most discriminable dimension as relevant would be equal to RTs from a redundant task. Similarly, RTs from a conservation task with the least discriminable dimension as relevant would be equal to RTs from a condensation task.

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