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Notes and Comment

A source of error in attempts to distinguish coactivation from separate activation in the perception of redundant targets

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Psychologists periodically show an interest in the question of whether redundant targets or signals improve detection or facilitate recognition. The experimental paradigms occur in several forms. Stimulation can occur across modalities, as in experiments designed to determine whether we can see and hear at the same time (e.g., Bernstein, 1970). Latency or accuracy in detecting an auditory and a visual signal is determined when the signals are presented separately and when the signals occur simultaneously. The redundant signal effect can also be investigated within a modality. In a choice reaction-time (RT) experiment, the latency to discriminate A from B can be determined on single-stimulus trials. Performance on the single-stimulus trials can then be compared with performance on redundant trials in which two As or two Bs appear in the visual field simultaneously. A redundancy gain occurs if the stimulus presentation of AA or BB results in a faster average latency than is obtained for the presentation of A or B. Although these questions seem relatively simple, the outcomes have important theoretical implications for issues ranging from serial versus parallel processing (Mullin, Egeth, & Mordkoff, 1988) to whether we can focus attention simultaneously on two or more separated locations in the visual field.

Those unfamiliar with the literature in this area will be surprised to learn that we still do not know whether it would help if opportunity did knock twice. Various models, with supporting data, have predicted poorer performance with redundancy (e.g., Bjork and Murray, 1977), separate activation (e.g., Van der Heijden, Schreuder, Maris, & Neerincx, 1984), or coactivation (e.g., Miller, 1982).

The older research on the question primarily used recognition accuracy as the dependent variable (e.g., Eriksen, 1966; Keeley & Doherty, 1971), but recent experiments have favored response latency (e.g., Grice, Canham, & Boroughs, 1984; Miller, 1982; Van der Heijden et al., 1984). Quite typically these experiments find a redundancy gain; that is, mean latency is shorter with redundant targets than with single-target presentation. Separate activation models that include independent channels as a special case predict redundancy gains as a result of statistical facilitation (Raab, 1962). Each activation has a randomly varying duration. When two or more activations occur, there is a processing race between them. The average duration of the winning process in the race is shorter than the average duration of the separate processes.

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Coactivation models also predict redundancy gains, but here the gain is attributed to the pooling of the separate inputs into a combined activation. It is to be noted that with separate activation a redundant-target presentation cannot have a latency shorter than the shortest latency for single-target presentation, but with coactivation this limit does not apply.

Miller (1982) proposed a general test to determine whether the gain obtained with redundant stimuli can be adequately accounted for by separate activation. The test makes use of the cumulative probability density functions (CDFs) of the latencies obtained for the redundant targets and for each of the single targets. With separate activation, response latency (t) to redundant targets is determined by the fastest of the individual processes. Thus

$$\begin{aligned} &P(\mathrm{RT} < t/\mathrm{T}_1 \text{ and } \mathrm{T}_2) \\ &\quad = P(\mathrm{RT} < t/\mathrm{T}_1) + P(\mathrm{RT} < t/\mathrm{T}_2) \\ &\qquad - [P(\mathrm{RT} < t/\mathrm{T}_1) \text{ and } P(\mathrm{RT} < t/\mathrm{T}_2)]. \quad (1) \end{aligned}$$

This holds for all values of t. The left term of the expression is the CDF for the redundant-target trials and the first two terms on the right are the CDFs for the two kinds of single-target trials.[1] The last term is the covariance between the separate activations of the two simultaneously presented targets. Miller pointed out that since the last term in the equation is equal to or greater than zero, it follows that with separate activation, for all values of t,

$$\begin{aligned} &P(\mathrm{RT} < t/\mathrm{T}_1 \text{ and } \mathrm{T}_2) \\ &\quad \le P(\mathrm{RT} < t/\mathrm{T}_1) + P(\mathrm{RT} < t/\mathrm{T}_2). \quad (2) \end{aligned}$$

Thus separate activation models require that the probability of RTs smaller than some value of t obtained with redundant targets cannot exceed the sum of the probabilities obtained with single-target presentations. Violation of this inequality requires rejection of separate activation models. On the other hand, coactivation, with the assumed pooling of the activation produced by each target occurrence, is consistent with violations, since the RTs to redundant targets can be faster than the fastest response to a single target.

Miller pointed out that the inequality in Expression 2 can be violated only for relatively small values of t, for as t increases, the left-hand term approaches 1 and the right-hand term approaches 2. However, this does not pose a serious limitation since it is precisely at small values of t that coactivation models predict violations of the inequality.

Miller employed this test in several experiments, and interpreted his data as supporting coactivation (Miller, 1982). Van der Heijden et al. (1984), on the other hand, employed Miller's test on the data of their experiments and concluded in favor of separate activation. Grice et al. (1984) interpreted their data as showing summation in associative strength, but only when the single-target data were obtained in the presence of distracting noise stimuli.

Unfortunately, the test proposed by Miller, although mathematically simple and elegant, runs into potentially serious problems when applied to empirically obtained data. The nexus of the problem is that most RT tasks, whether simple detection or choice, result in some proportion of error trials. With two-choice RT, the presence of 10% errors would suggest that approximately 10% of the *correct* responses consisted of "correct errors," that is, that fast guesses or error processes produced responses that were correct by chance. When CDFs for single-target trials containing these "correct errors" are used to predict the CDFs for the redundant-target trials, the level of performance expected for separate activation and independence is apt to be seriously overestimated. This occurs because the error trials are double weighted in predicting the redundant-target data.

This can be seen most readily if we first examine the redundant-target experiment in which accuracy is the dependent variable. If we toss two coins and wish to determine the probability of getting at least one head, the well-known formula

$$P(\text{at least one head}) = P_1 + P_2 - P_1P_2$$

is exact. But if the obtained probability of recognizing an A presented to the left of the fixation point is .8, and the obtained probability of recognizing an A presented to the right of the fixation point is .7, the probability for recognizing at least one A when the stimulus consists of a simultaneous presentation of an A in each position is not .94. Unlike the response to the coin, which is either a head or a tail, a correct response to the stimulus A can be due to either of two identifiable processes or states: the subject's (1) seeing the stimulus, or (2) making a lucky guess.

We can apply a correction for guessing to the single-stimulus trials. If the a priori probability of a correct guess is .5, a standard correction for guessing would be to assume that the proportion of correct guesses is equal to the proportion of incorrect guesses (errors). The proportion of incorrect responses when the target is to the left of fixation is .2. Thus the corrected value for the probability when a single target is presented in this location is .6. A single target presented to the right of fixation has a corrected proportion of .4. In other words, we are saying that when the target is presented to the left of fixation the subject recognizes the target 60% of the time and guesses on the remaining 40% of the trials, with half of these guesses correct. If we use these corrected values in the formula for independence, we have

$$.6 + .4 - (.6 \times .4) = .76.$$

By this logic we would say that with the redundant target presentation and independent processing of the two separate inputs, the subject should recognize one or both of the stimuli on 76% of the trials. On the remaining 24% of the trials the subject should fail to recognize either of the inputs, and on these occasions he/she would guess. With a .5 a priori probability of a correct guess, the predicted percent correct trials with redundant targets would be 88%. This value is to be contrasted with the predicted 94% accuracy when guessing is not taken into account. Without the correction for guessing, one could achieve performance at the level of independence but erroneously conclude interaction between the two targets.[2] Failure to take guessing into account can lead to an appreciable overprediction of the level of performance expected if redundant targets are processed like two independent opportunities.

The effect of errors can be seen quite clearly when accuracy is the dependent variable, but an analogous effect occurs when response latency is the measure.[3] If the CDFs for single-target trials are used to generate the CDF expected with redundant stimuli under conditions of separate activation and independence, the predicted CDF can be overestimated; how seriously overestimated will depend upon the proportion of errors and whether the errors are uniformly distributed over the range of obtained latencies. To take an extreme example, let us assume that a subject makes 10% fast guesses. Let us further assume that these guesses fall among the fastest 20% of the obtained latencies. Thus when

$$P(\text{RT} < t/\text{T}_1) = .20,$$

half of the trials constituting this area of the CDF are error trials. Thus we can rewrite the above expression as follows:

$$P(\text{RT} < t/\text{T}_1)$$
$$= .1(\text{true discriminations}) + .1(\text{correct guesses}).$$

Assuming the CDFs for T_1 and T_2 are equal, the predicted CDF for redundant trials under independence is

$$P(\text{RT} < t/\text{T}_1 \text{ and } \text{T}_2) = (.1 + .1) + (.1 + .1) - .04 = .36.$$

The fast-guess trials contribute twice to the predicted CDF, but fast guessing contributes only once to the empirically obtained CDF. If we correct for fast guesses the expression becomes

$$P(\text{RT} < t/\text{T}_1 + \text{T}_2) = (.1) + (.1) - .01 + .1 = .29.$$

As noted above, Miller's test is applicable only for values of t in the lower end of the latency range, which makes it especially susceptible to erroneous conclusions in the presence of a significant number of fast-guess trials. The test will overpredict the level of performance expected under conditions of independence and thus is biased against a finding for coactivation.

Fast guesses are not the only source of errors in RT experiments. But whatever the sources of errors may be, there is evidence that errors are not uniformly distributed throughout the range of latencies. When deadline procedures are used, latency operating characteristics (LOCs) are generated (Lappin & Disch, 1972a, 1972b). These demonstrate that accuracy is inversely related to latency, which would place "correct errors" disproportionately in the first half of RT distributions.

Link (1982) showed how failure to analyze error trials can result in serious misinterpretation of differences in mean latency. However, the procedures he suggested for avoiding the pitfalls do not appear to be applicable to the present problem. A.H.C. Van der Heijden (personal communication, February 1988) and Jeff Miller (personal communication, February 1988) have each suggested the following procedure for adjusting the CDFs for the presence of correct guesses. The procedure follows the same logic as employed in my correction for accuracy data (Eriksen, 1966). The observed errors (incorrect guesses) are used as an estimate of the correct guesses and this estimate is subtracted from the proportion of correct responses, in the case of accuracy data, or from the distribution of latencies, when RT is the dependent variable. In what Van der Heijden calls a "kill the twin" procedure, a trial is subtracted from the RT distribution of correct responses whose latency equals or approximates the latency of one of the error trials. Thus for each error trial latency, a trial of corresponding latency is subtracted from the CDF of latencies of correct responses. These corrected single-stimulus CDFs can then be used to generate the predicted CDF for redundant stimuli. It is to be noted that the obtained CDF for redundant targets must also be corrected for correct guesses or hidden errors in order to compare it with the predicted function. The same "kill the twin" procedure is used.

The above correction procedure may not be elegant, but it is straightforward and will produce a more sensitive and less biased test of separate and coactivation models. The assumptions involved are plausible and few. The basic assumption is that overt errors arise from the same sources as the hidden errors. Miller (personal communication, February 1988) further noted that the legitimacy of the correction procedure is strengthened if the percentage of error trials is essentially the same for the single-target trials and for the redundant-target trials.

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NOTES

1. If the single targets do not differ in modality or on other variables, such as position in the visual field, there is only one function for single-target trials.

2. A two-state model of perceiving or guessing is oversimple. I have presented elsewhere (Eriksen, 1966) a method for computing independence from accuracy data for single stimuli that allows for multi possible states of the observer.

3. Miller (1978) made a brief note of this problem.

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