Journal of Experimental Psychology
1970, Vol. 86, No. 3, 434–439

STIMULUS DISCRIMINABILITY AND S-R COMPATIBILITY: EVIDENCE FOR INDEPENDENT EFFECTS IN CHOICE REACTION TIME[1]

IRVING BIEDERMAN[2] AND ROBERT KAPLAN

State University of New York at Buffalo — *Bell Telephone Laboratories, Piscataway, New Jersey*

In contrast to flexible capacity theories of information-processing behavior, discrete stage models generally assume that the functioning of one stage (e.g., stimulus discrimination) proceeds independently of the demands on some other stage (e.g., response selection). These alternatives were tested by factorially varying stimulus similarity and stimulus–response compatibility in a speeded brightness discrimination task. The independent stage hypothesis was supported by the finding that, in general, the experimental variables did not have interactive effects on the means and higher order cumulants of the reaction time distributions. Some evidence, however, was found for weak interactive effects in the first of two sessions.

Most theories of information-processing behavior postulate a series of stages or subprocesses intervening between stimulus and response (Smith, 1968; Sternberg, 1969). A primary goal of this approach is the analysis of the total reaction time (RT) into the times for each of the components. Critically important in such an effort is the rule of combination for the various components. The simplest assumption, and the one most commonly made, is that the times of the various components are additive. This follows directly from a "flow chart" conception of performance in which the course of processing of one component proceeds independently of the processing load on other components.

The problem of additivity of stages is an old one in psychology, dating back to the work of Donders in 1868 (Woodworth, 1938). Donders assumed that the stages of stimulus discrimination and response selection were additive. This assumption was required by his subtractive method for measuring the times for the two stages in which successively more complex RT situations were studied. Donders' work was attacked by Ach, partly from some inconsistent results found with the subtraction method, but largely on the basis of introspective reports (Woodworth, 1938). In contemporary terms, Ach felt that his capacity for response selection ("motor readiness") was reduced as the requirements for stimulus discrimination were increased. Ach's introspection implied that the same capacity is simultaneously involved in both stimulus discrimination and response selection so that if one is made more difficult, the ability to perform the other will be reduced. An identical prediction is made by some contemporary single-channel theories which hold that the same limited capacity can be flexibly applied to either stimulus discrimination or response selection (e.g., Moray, 1967). The present experiment was designed to test for this interaction by factorially varying stimulus discriminability and stimulus–response (S-R) compatibility.

The test of an interaction between two variables will have relevance for processing stages if a minimum of three conditions are met. First, the variables must each be rea-

[1] This research was performed at Cornell Aeronautical Laboratories, Buffalo, New York, while the second author was an assistant psychologist there. Appreciation is expressed to E. M. Segal and S. Sternberg for their many insightful and critical comments, to E. D. Sussman for his invaluable assistance in the design and construction of the apparatus, and to D. D. Howard for his skillful computer analyses.

[2] Requests for reprints should be sent to I. Biederman, Department of Psychology, State University of New York at Buffalo, 4230 Ridge Lea Road, Buffalo, New York 14226.

sonably presumed to have effects that are specific to separate stages. Second, the experimental operations of manipulating one variable should in no way influence the nature or degree of the manipulations of the other variable. These first two conditions stipulate that the variables be unconfounded, both in their effects on the underlying psychological processes, as well as in the way that they are experimentally manipulated (Sternberg, 1969). Third, the main effects of the variables should be of sizable magnitude so that if an interaction is present, it can be revealed. The present experiment sought to meet these conditions by varying the spatial S-R compatibility of a brightness-discrimination task. It was presumed that the discriminability variable (brightness similarity) involved a task dimension that was unrelated to the compatibility variable.

Sternberg (1969) demonstrated additive effects of discriminability and S-R compatibility in a digit-identification task requiring a vocal response. Discriminability was reduced by the presentation of a checkerboard pattern over the stimulus digit. Compatibility was reduced by requiring *S* to respond with a digit that was one greater than the stimulus. In contrast to Sternberg (1969), Rabbitt (1967) reported a Compatibility × Discriminability interaction in a task where the display was eight lamps arranged in a horizontal line. A many-to-one mapping assignment was employed. In Rabbitt's high-compatibility condition, the four lamps on the left side were assigned to a left finger key and the four lamps on the right side were assigned to a right finger key. In the low-compatibility condition, the assignments were reversed: left lights to the right finger key and right lights to the left finger key.

Reaction times to the individual lamps differed significantly and Rabbitt (1967) attributed this difference to discriminability. The major finding was that of a significant interaction between compatibility and the magnitude of the differences in RTs among the individual lights. Relative to the effect of compatibility (approximately 200 msec.), the differences among the lights were quite small.

The major problem in interpreting Rabbitt's (1967) results, aside from considerations of reliability and the magnitude of the effects, is that it is not clear that the differences in RTs among the lights do, in fact, reflect differences in *stimulus discriminability*. A many-to-one S-R mapping task does not guarantee that differences among stimuli assigned to the same response are due to differences in *perceptual* processes. These differences might just as well have reflected differences in response selection difficulty or the ease with which they could be categorized; i.e., it is possible that Rabbitt's variations in discriminability did not meet the first condition discussed previously. An interaction with compatibility might then be expected.

The present study, like Rabbitt's (1967), used spatially arranged stimuli and responses to determine if additivity holds for spatial, as well as symbolic, S-R arrays. The design also permitted the study of practice effects. Sternberg (1969) reported data only after his *S*s had six practice sessions, while Rabbitt's results were from a single session.

Additivity of mean RTs does not necessarily imply that the involved stage durations are stochastically independent. Over trials, the durations of the stages could be correlated even if the means were additive. If the stages are independent, then the higher order cumulants should be additive (Sternberg, 1964, 1969). Previous studies (e.g., Sternberg, 1969; Taylor, 1966) have provided some information as to the independence of stages. The present study had a sufficient number of trials and *S*s so as to provide additional estimates of the higher order cumulants.

METHOD

Subjects.—Sixteen volunteer employees of Cornell Aeronautical Laboratories, 12 males and 4 females, served as *S*s. All participation occurred during working hours for two 25-min. sessions on successive days.

Apparatus.—The stimulus display was four fast-rise-time electroluminescent lights (see Fig. 1).

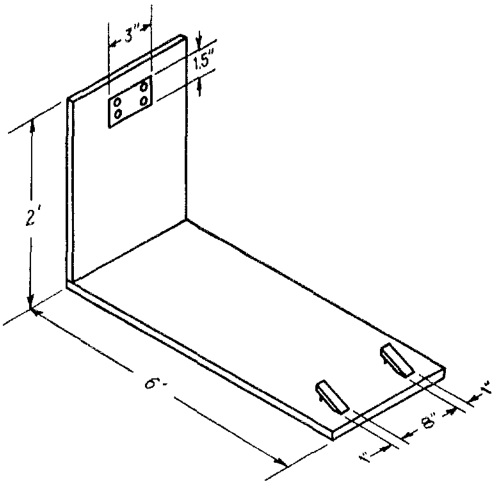

FIG. 1. Experimental apparatus showing stimulus display and response keys.

The lights were .5 in. in diameter and were located at the corners of a 3 × 1.5 in. rectangular panel. The greater horizontal separation of the four lights enabled them to be readily grouped in terms of left versus right pairs. This permitted a more potent compatibility manipulation since a response was a depression of one of two piano-like microswitch keys, corresponding to the left and right index fingers.

Each light was independently controlled by a 400-cps power supply with a range of 0–1,300 v. Variations in voltage produced variations in the luminance of the lights without affecting their hue. In the high-discriminability conditions, the four lights had luminances of 2, 5.5, 15, and 40 ftl; in the low-discriminability condition, the luminances were 5, 9, 17, and 30 ftl. In both conditions, the selected values closely corresponded to an equal interval scale according to the subjective estimates of four observers. The display was viewed binocularly from a distance of 6 ft.

Design and procedure.—On each trial, all four lights were presented, each of a different luminance. The luminance of a given position would change from trial to trial. The *S*'s task was to respond to the brightest of the four lights. In the high-compatibility condition, the response was made with the key on the same side as the brightest light (ipsolateral assignment). If the brightest light was either the upper left or the lower left, *S* was to respond with the left key. In the low-compatibility condition, the response was made with the key on the opposite side of the brightest light (contralateral assignment). The use of four lights prevented *S* from converting a low-compatibility condition into a high-compatibility condition by making an ipsolateral response to the *dimmest* light.

Four blocks of 48 trials were presented during each of two sessions, with a brief rest period between each block of trials. The high- and low-compatibility conditions alternated on successive blocks, with half of the *S*s starting with a high-compatibility block and the other half starting with a low-compatibility block. If *S* started with a high-compatibility block on his first session, he would start with a low-compatibility block on the second.

Discriminability was varied within blocks. There are 24 possible combinations of assigning the four luminance levels to the positions. Each 48-trial block was comprised of all 24 combinations for both levels of discriminability. Thus, each luminance value appeared in each of the four positions an equal number of times. The two discriminability conditions were randomly intermixed, subject to the constraint that the first-order transitional probabilities between positions of highest luminance were equal ($p = .25$). Each stimulus pattern was presented for 1 sec. with an interstimulus interval of 5 sec. A 1,000-cps warning tone of .5 sec. preceded the stimulus by 1 sec.

The *S*s were fully instructed as to the nature of the experimental variables and were urged to respond as fast as possible without making any errors. Forty-eight practice trials were given prior to the first block. Thereafter, 10 practice trials were given prior to each new block.

RESULTS

For each *S*, mean correct RTs were computed for the four treatment conditions in each session. As shown in Fig. 2, the main effects of discriminability and compatibility were both of sizable magnitude, 141 and 55 msec., respectively, and highly significant, $F(1, 15) = 134.58$, $p < .001$, for discriminability and, $F(1, 15) = 63.35$, $p < .001$,

TABLE 1

MEANS AND F RATIOS OF THE UNBIASED ESTIMATES OF THE FIRST FOUR CUMULANTS AS A FUNCTION OF DISCRIMINABITITY AND COMPATIBILITY

Cond.	Cumulant			
	k_1 (sec.)	k_2 (sec.^{2})	k_3 (sec.^{3})	k_4 (sec.^{4})
HiC-HiD	.500	7.193	1,039	273 × 10^3
HiC-LoD	.634	32.267	10,261	5,509 × 10^3
LoC-HiD	.548	9.000	1,106	250 × 10^3
LoC-LoD	.696	34.206	11,059	6,191 × 10^3
F Ratio (1, 15)				
D	134.62***	40.91***	12.84**	6.98*
C	66.75***	.46	.04	.03
D × C	2.13	.00	.02	.02

Note.—Cumulants were computed individually for each *S* and then averaged over *S*s. Discriminability and compatibility are here referred to as D and C, respectively.

* $p < .05$.
** $p < .01$
*** $p < .001$

for compatibility (see Table 1). The interaction between these two variables was not significant; F (1, 15) = 2.13. Mean RTs in the second session averaged 48 msec. less than in the first session; F (1, 15) = 8.07, $p < .05$.

While the overall Compatibility × Discriminability interaction was not significant, a slightly different picture emerged when the sessions were analyzed separately. In the first session, the effect of discriminability was 24 msec. greater in the low-compatibility condition than in the high-compatibility condition (see Fig. 2). The data from this first session yielded a significant Compatibility × Discriminability interaction, F (1, 15) = 5.11, $p < .05$. In the second session, this difference in the effect of discriminability was only 3 msec., and it was in the direction opposite to that found in the first session (Fig. 2). The Compatibility × Discriminability interaction in the second session fell far short of significance, F (1, 15) = .15. The change from Session 1 to Session 2 in the magnitude of the Compatibility × Discriminability interaction accounted for a significant triple interaction of Compatibility × Discriminability × Sessions, F (1, 15) = 4.89, $p < .05$.

Overall, it must be emphasized that the Compatibility × Discriminability × Practice interactions were all quite weak relative to

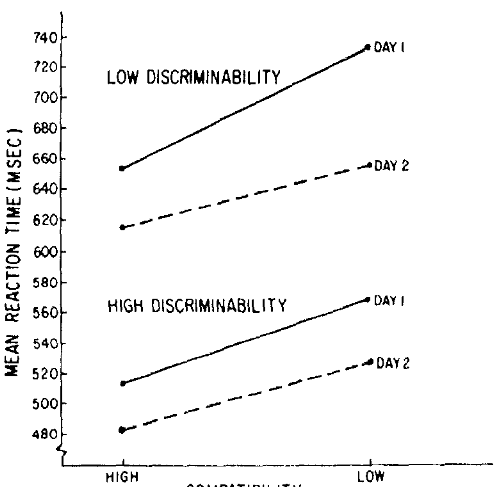

FIG. 2. Mean correct RT as a function of stimulus discriminability, S-R compatibility, and practice.

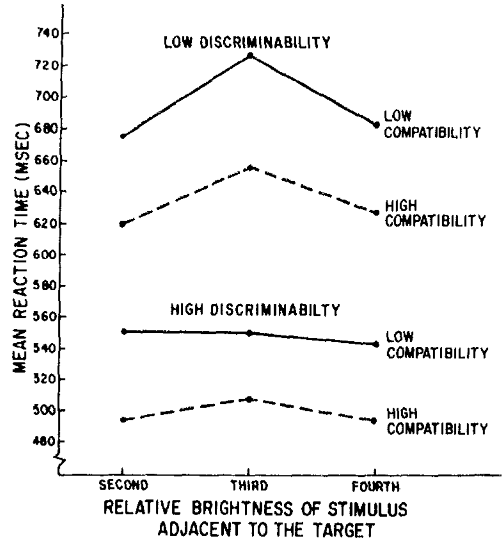

FIG. 3. Mean correct RT as a function of stimulus discriminability, S-R compatibility, and the relative brightness of the stimulus light adjacent to the target (brightest) light.

the main effects. Hays' (1963) ω^2 measure of the strength of the association of variables in an analysis of variance showed that the main effects of compatibility, discriminability, and practice together accounted for 39.7% of the RT variance. The three double interactions (all nonsignificant) and the triple interaction of these three variables together accounted for less than .4% of the RT variance. Even in the first session, the significant Compatibility × Discriminability interaction accounted for less than 1% of the RT variance compared to 35% attributable to the main effects of compatibility and discriminability.

The 24 stimulus patterns were classified into one of three categories based upon which light intensity was adjacent to the brightest (target) light. The three categories were (*a*) brightest and second brightest lights on the same side, (*b*) brightest and third brightest lights on the same side, and (*c*) brightest and least bright lights on the same side. Little difference was found among the three types of patterns in the high-discriminability condition (see Fig. 3). The significant main effect for patterns, F (2, 30) = 9.47, $p < .01$, as evidenced by the significant Discriminability × Patterns interaction, $F(2, 30) = 6.05$, $p < .05$, primarily arose from the low-discriminability condition. In that condition, faster RTs were produced when either the second or the fourth brightest lights were on the same side as the (brightest) target light (Fig. 3).

The aforementioned RT data were consistent with the phenomenal appearance of the patterns as described by four observers. In the high-discriminability trials, the target light stood out from the other three with no obvious effect from the brightness of the adjacent light. In the low-discriminability condition, when the target and second brightest lights were on the same side, the effective immediate cue seemed to be the overall brightness of that side. An observer was only secondarily aware of which one of the two lights was the brighter. When the target and the fourth brightest lights were on the same side, the relative *difference* in brightness between the two lights on that side was more readily apparent than the relative brightness of the target versus the second brightest lights. When the target and third brightest light were on the same side, neither the spatial assimilation nor the spatial contrast cues were effective. For that pattern, as in the high-discriminability conditions, *S*s were primarily aware of responding to a specific light.

The overall error rates for the low-discriminability condition were 5.50% versus .94% in the high-discriminability condition. An analysis of variance for the error data showed that only this main effect of discriminability was significant, $F(1, 15) = 22.22$, $p < .001$. The F ratio for the Compatibility × Discriminability interaction was less than 1.00.

Table 1 shows the values of the unbiased estimates of the first four cumulants as a function of discriminability and compatibility. The cumulants were computed individually for each *S* and then averaged across *S*s. For the second, third, and fourth cumulants only the effect of discriminability was significant. (The first and second cumulants are the mean and variance.) Most important, the Compatibility × Discriminability interactions were not significant; the F ratios for this interaction in the three higher cumulants were less than 1.00. The main effect and interactions of the practice variable (not shown) also fell far short of significance in the analyses of k_2, k_3, and k_4.

An analysis was also made of trial-to-trial sequential (repetition) effects. The RTs following erroneous trials were not included. Each correct RT on Trial $N + 1$ was classified according to whether the target was: (*a*) in the same position as on Trial *N*, (*b*) on the same side but on a different row as on Trial *N*, and (*c*) on the other side as on Trial *N*. In *a* and *b*, the same responses were made on Trial *N* as on Trial $N + 1$. Sequential effects were absent. Mean RTs for *a*, *b*, and *c* were 594, 592, and 587 msec., respectively; $F(2, 30) = .50$, *ns*.

Discussion

The results, particularly from the second session, were consistent with the hypothesis of additivity between stimulus discriminability and S-R compatibility. The proportion of the RT variance accounted for by interactions among compatibility, discriminability, and practice was negligible. The error data indicate that the evidence for additivity of RTs was not a consequence of a speed for accuracy trade-off since the effect of discriminability on errors was constant across both levels of compatibility.

The experiment was not analytic as to why the weak Compatibility × Discriminibility interaction, present in the first session, disappeared in the second session. One possibility is that, initially, the same central capacity is used to monitor stimulus discrimination and response selection. As the input and output stages become more efficient with practice, requirements for central involvement are diminished.

The absence of any Discriminability × Compatibility interaction in the higher order cumulants supports the hypothesis that the stages involved in stimulus discrimination and response selection are stochastically independent, as well as additive. However, this was not necessarily a strict test of the hypothesis of stochastic independence since the main effect of compatibility was not significant on the higher order cumulants.

There were several ways in which stimulus processing could have been accomplished in the experimental task. The *S*s could have made absolute judgments of the brightness of the four lights and simply responded to the one that yielded the highest value or met some standard stored in memory. This mode, which does not involve spatial interactions, is consistent with the data from the high-discriminability condition. However, the difference among patterns in the low-discriminability condition argues for the use of both spatial contrast and spatial assimilation criteria in addition to the criteria of absolute judgements for individual positions evidenced in the high-discriminability condition. The experiment was not analytic as to whether these criteria were applied serially or simultaneously. The important point, however, was that the pattern effects did not interact with compatibility. Whatever *S*s were doing to determine which light was the brightest in the high-compatiblity condition, they were also doing in the low-compatibility condition.

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(Received June 29, 1970)

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* Asterisk indicates author for whom address is given.