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ABSTRACT

This investigation into the effects of configural properties (properties determined by the interrelationships existing between component parts) used a selective attention task to determine whether intersection is a primary encoding feature or is constructed after slopes and heights are perceived. The method for encoding feature identification, primary encoding features, and the question of whether or not configural superiority can be modified are discussed. The subjects (N=12) were adults with no prior experience in card sorting tasks. The task required subjects to classify stimuli that vary in two of their properties - speed and accuracy. A previous task with stimuli varying in only one dimension served as a baseline. Results indicate that the configural property of intersection is perceived directly rather than constructed from the stimulus components. Modifications to configurations, the experimental methodology and statistical analysis including error analysis are described. The geometric concept of intersection is described as analogous to the statistical concept of crossed interaction and to its mathematical interpretation as a departure from parallelism. The results of the experiment are discussed relative to the usefulness of the findings to graph design. A list of 13 references, 3 figures and 3 tables are attached. (JM)

CONFIGURAL PROPERTIES IN GRAPHIC DISPLAYS AND THEIR EFFECTS ON PROCESSING

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CONFIGURAL PROPERTIES IN GRAPHIC DISPLAYS AND THEIR EFFECTS ON PROCESSING

Introduction

In a previous experiment investigating information processing of graphically displayed information, it was shown that for simple line graphs, slope and height of the line were primary encoding features for this graph type. Primary encoding features are assembled in the 'data-driven' perceptual representations that are invoked when a graphic display is initially recognized (cf. Shriffrin & Schneider, 1977). Operationally, they are the display properties that show no orthogonal interference in a speeded classification task (Garner, 1974).

Slope and overall height are examples of stimulus dimensions serving as primary encoding features. However, dimensions are not the only properties of stimuli that can be represented perceptually. Garner (1978, 1981) has classed properties of stimuli which can serve as encoding features into two types - attributes and configurations. Attributes are the component properties of stimuli of which dimensions are one form. Dichotomous features, such as the presence or absence of a horizontal bar in the letters E or F, are also encoding features.

Configurations are properties of the whole stimulus, determined by the interrelationships existing between its component parts. Furthermore, configural properties cannot be changed without changing some of the other components of the stimulus. Configural properties exist in addition to component properties and whether they are the primary encoding features of the display or are constructed from primary encoding features (i.e., the dimensions or features) must be determined experimentally.

For example, consider the two graphs shown in Figure 1. Both graphs can be defined by the slope and overall heights of the lines labelled a and b in both figures. Note, also, that the difference between Figure 1a and Figure 1b lies in the overall height of line a. Thus slope and overall height may constitute primary encoding features for these displays. However, there is another property that can be used to distinguish the two displays--the property of intersection. In Figure 1a, the two lines intersect; in Figure 1b, they do not intersect. Intersection represents a configural property of the display since it is defined from the interrelationship between the heights and slopes of the two component lines. Also, note that in Figure 1a, it is still possible to perceive the slopes and heights of the individual lines. Thus intersection does not destroy the perception of the component properties, it simply exists as another potential encoding feature of the display.

INSERT FIGURE 1 HERE

The question exists regarding Figure 1 as to whether intersection is a primary encoding feature or is constructed after the slopes and heights are perceived. We can use concepts from the selective attention task popularized by Garner (1970, 1974) to help distinguish one possibility from the other. This task and how it can be used to identify primary encoding features will be briefly described in the next section.

Method for Encoding Feature Identification

The task requires subjects to classify stimuli that vary in two of their stimulus properities--usually dimensions, and measures the speed and accuracy of classification. The actual task requires subjects to classify the stimuli according to one property, ignoring the other. This task is called the orthogonal or filtering task. The use of this procedure in determining primary encoding features starts with a response basis is set by experimenter instruction. This response basis corresponds to an expectancy regarding to-be-presented information. When a stimulus is encounted, it is perceptually represented by its encoding features, be they stimulus features, dimensions and/or configur ions. If the perceptual representation matches the response basis then simply looking up the correct value is sufficient for a response. If, however, a mismatch exists then a reparsing of the representation with a concomitant increase in processing resource or attention is necessary to effect a match. This is again followed by a look-up of the correct value. The efficiency of the value look-up can be gleaned by observing classification performance on a discrimination task--stimuli vary in only one stimulus property. This task serves as a baseline condition for orthogonal task. Therefore, if a reparsing is necessary and more resources required, then the speed of classification for the orthogonal task would be greater than speed for the discrimination task and orthogonal interference results. If no reparsing is called for, then speed on both tasks would be the same. Thus by manipulating the response basis and observing classification performance relative to baseline, primary encoding features can be determined for the stimulus under investigation.

Primary Encoding Features--Dimensions or Configurations?

The stimuli shown in Figure 2 together with the selective attention task allows differential predictions to be generated, depending on whether intersection is perceived directly or indirectly. For example, consider the stimuli shown in Figure 2a. The four stimuli are generated from orthogonal combinations of two slope values and two overall height values of the line labelled a. The line labelled b does not vary in this stimulus set. Thus it is possible to classify the stimuli on the basis of either slope or height. Note, however, that the height dimension is confounded with the configural property of intersection in this figure. That is, the low height condition is also the intersection condition, while the high height condition corresponds to the non-intersection condition. Thus it is not possible from this stimulus set alone to distinguish between height or intersection as the basis for classification. Slope, though, is not confounded with intersection. To circumvent this confounding effect, stimulus set b in Figure 2 is also used. This set is also generated by the orthogonal combination of two slope values and two height values. However, the values were chosen in this case so that the slope dimension becomes confounded with intersection, while height is not confounded.

INSERT FIGURE 2 HERE

The predictions using these figures would be as follows. If slope and height are again the primary encoding features of these displays, implying that the property of intersection is constructed after these feaures are activated, then we would expect no orthogonal interference for either height or slope conditions. If, however, intersection is perceived directly, and thus constitutes a primary encoding feature, then component slopes and heights would be ascertained only after analyzing this wholistic property. This would involve an increased allocation of resources to reparse the representation and thus we would expect orthogonal interference for both slope and height. This expectation would show up as an interaction between the two stimulus sets as summarized in Table 1. That is, when height is confounded with intersection and intersection is the perceived property, then no orthogonal interference should be evidenced using height as the response basis. However, orthogonal interference would be evidenced when slope serves as the response basis. On the other hand, when slope is confounded with intersection, the opposite result should be evidenced; no orthogonal interference with slope as the response basis, but orthogonal interference with height as the response basis. These predictions were tested in this experiment using a card sorting task (Garner & Felfoldy, 1970).

INSERT TABLE 1 HERE

Configural Superiority--Can it be Modified?

If, in fact, the configural property of intersection dominates the component properties that produce it in perception, can we change this dominance without destroying the configuration itself. That is, can we enhance the component properties that form the relationship--increase their perceptual salience--such that the grouping still makes the relationship available but not strongly enough to form a distinct perceptual unit. In his discussion of grouping processes, Pomerantz (1981) identifies local factors--such as similarity and proximity--and global factors--such as good continuation and pragnaz--as causes of grouping Thus it is possible to use these factors to modify the grouping progress. For example, Pomerantz and Schwartzberg (1975) presented evidence showing how proximity affects the grouping of parentheses. They showed that a separation distance of approximately four degrees breaks apart the grouping of these stimuli. However, proximity cannot be used here since it will destroy the configural property.

Similarity, though, can be used as a potential for diminishing the superiority of this configural property. Note, once again, that intersection results from a relationship between a pair of lines. Suppose we try to diminish the 'pair bond' by using different colored lines. Grouping by similarity (i.e., color) would then be possible and a grouping in this way would emphasize the individuality of the lines themselves, and thus may diminish the strength of the relationship. Therefore, in one condition the color of the two lines will be varied to investigate the effect of this grouping factor on the property of intersection.

EXPERIMENT

Method

Subjects

Twelve coworkers at CSI/Datacrown served as subjects in this experiment. Of the twelve, seven subjects had no prior experience in card sorting tasks of this kind. None were paid for their participation.

Stimuli

Four sets of stimuli, corresponding to the slope/intersection and height/intersection confounding conditions as well as no color and different color lines, were used in this experiment. The two noncolored sets are shown in Figure 2a and Figure 2b. Each set consisted of two pairs of straight lines, centered on a single L-shaped framework, spaced 2.5 cm apart.

In the color condition, the horizontal unchanging line was blue, while the variable line was red. From the available pen colors, blue and red were maximally discriminable according to Conover (1959).

The dimensions used to generate the first set of stimuli were the slope (0.25 or 0.45) and the overall height of the line (1.52 or 2.52 cm). The overall height was defined in terms of the midpoint between the line. The values used to generate the second set of stimuli were 0.12 and 0.70 on the slope dimension and 1.14 and 2.03 cm on the height dimension. Values on both height dimensions were much greater than the five just-noticeable-differences (JNDs) using Ono's (1967) differential sensitivity index, required for 100 percent accurate discrimination under self-paced conditions. The height of the horizontal line was always held constant at 1.5 cm.

For all stimulus sets, there were decks of 32 cards generated in accordance with six experimental conditions; four univariate conditions (each row and column in Figure 2) and two orthogonal conditions. Each deck contained an equal number of cards relevant to that condition. For example, when slope was the relevant dimension, the univariate condition consisted of a deck of 32 cards, 16 of which defined the pair of lines or points at an orientation of 0.25 and another 16 which defined the pair at an orientation of 0.45. The overall height dimension was held constant at 1.52 cm for this condition. Similarly, when overall height was the relevent dimension, 16 cards defined the pair at a height of 1.52 cm and 16 cards defined the pair at 2.52 cm, slope held constant at 0.25. In the orthogonal condition, a deck was made up of eight cards each from the four stimuli which could exist as a result of the combination of two dimensions each having two levels (each cell in Figure 2a, for example).

The process of generating the stimulus cards was semi-automated using a Tektronix 4662 interactive digital plotter driven by PLOT10 software. Standard sheets of 27.9 x 35.6 cm (11x14 in) Bristol Board were partitioned into a 6x3 grid pattern, each grid being 5.6 cm wide x 8.3 cm high. The plotter was scaled such that 2.54 cm (1 in) mapped into 11.1 display units in the x direction and 9.1 units in the y direction. Centered within each grid, the framework was drawn in black ink. The stimulus was then drawn, either in black ink for the no color condition or the appropriate color for the color condition. Eighteen such stimuli were drawn per sheet. The stimuli were then manually cut out, the top left corners clipped to avoid any potential upside-down mixup (and additionally to facilitate error checking), and became part of the appropriate deck. Two decks per condition were generated in this way.

Procedure

Subjects were required to sort the deck of 32 cards into two piles corresponding to the two levels of the relevent dimension. Exemplars of each classificaton level were placed on the table in front of the subject. Each subject was told the purpose of the experiment, handed a deck of cards and told to sort them into two piles consistent with the targets as quickly as possible but without making errors. Time to sort each deck was measured to the nearest one hundreth second using a Model 54035 (Lafayette Instrument Co.) clock/counter. The clock was started by the experimenter when the first card left the deck and stopped when the last card was placed on one of the piles. Upon completion of the task, the subject was told the sorting time. The sorted cards were then set aside for purposes of determining errors, and the next deck was given to the subject. For each condition, subjects sorted the deck of cards two times, the first sort representing practice and not considered in the analyses.

Design

Twenty-four different conditions were generated by combinations of two stimulus sets (slope/intersection, height/intersection confounding), two color conditions (color, no color) and six tasks (four univariate, two orthogonal). Each subject participated under all conditions. Subjects sorted cards corresponding to either the color or no color set first, were given a five-minute break and then sorted cards corresponding to the other set. The color set occurred first for half of the subjects while the no color set occurred first for the other half. Within each color/no color set, order of presentation of the twelve conditions was balanced over the twelve subjects in a Latin square arrangement. An experimental session lasted about 45 minutes.

Results and Discussion

The positive correlation coefficient ($r=0.30$, $p<.001$) between time and errors indicates an absence of any speed-accuracy tradeoff which would otherwise qualify interpretation of the data. However, plots of variances against means for both sorting times and errors indicated variance stabilizing transformations were necessary for both these measures. It was found that a logorithmic transformation for times and a square root transformation for errors were sufficient to induce spherical distributions for both measures. Thus analysis of variance and tests of contrasts were performed on the transformed measures, but for presentation purposes, all measures are expressed in the original metric.

Times

The sorting times in seconds averaged over subjects are shown in Table 2 for each graph type, color condition and task.[1] From the table, one can see that, on the average across all conditions, sorting times for both color and no color conditions were about the same. This result is confirmed from a four-way repeated measures analysis of variance, the variables being graph type, color condition, task and subjects, $F(1,11)=0.58$, $p<0.5$. The largest discrepency in sorting times between the color and no color conditions occurs for one of the height sorting univariate tasks using the slope intersection confounding stimulus set. This discrepency contributes to a marginal interaction effect between color condition and graph type, $F(1,11)=0.027$, $.05<p<.10$. This condition corresponds to task, T1, in Figure 2a. Note that this task requires

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[1] For a repeated measures design there is no appropriate error term from which the significance of the four-way interaction of Color x Graph Set x Task x Subject can be tested since each cell has a sample of size one. However, a single df test developed by Tukey (1949) provides a means of evaluating a particular form of this interaction. This test involves further analyzing the interaction sums of squares into two components, one which represents the interaction component distributed on 1 df, the other representing error distributed on the remaining dfs. For the data $F(1,<5)=2.08$, $p<.10$ indicates the interaction component is not significant implying the mean square provides an independent estimate of the error variance.

classifying the stimuli having the lesser sloped line. Since the slope is quite small, the pair of lines tend towards parallelism. This makes detecting the appropriate line somewhat more difficult in the no color conditions. Adding color enhances the detection process by providing additional perceptual opportunity under this speeded condition.

Additionally, there was a significant two-way interaction between Graph Type and Sorting Task, F(5,55)=75.17, p<.001. Pairwise comparisons using a Newman-Keuls test on the means (alpha=.05) showed that the orthogonal slope task in the height/intersection confounding set and the orthogonal height task in the slope/intersection confounding set were not different from one another, but each was reliably slower than any univariate task and the other two orthogonal tasks. This pair of orthogonal tasks is enclosed by the dashed line in Table 2. Comparisons also showed that, on the average, classification when intersection was operative resulted in faster sorting times than the non-intersection conditions. Thus intersection/non-intersection affords finer discrimination than either slope or height alone.

The pattern of data, conforming to predictions, show quite clearly that adding a second line to a graphic display, and allowing the pair of lines to visibly cross at some point, results in a qualitatively different perceptual representation than if the crossing were not present. In an earlier experiment, Simcox (1982) demonstrated that without the crossing, slope and overall height of a line were the primary encoding features. With the crossing, a new property emerges--intersection--that tends to dominate perception. Classification of the component properties--slope and overall height--arises only after increased attention reparses the representation and makes them available.

Furthermore, the data suggest that this configural property is insensitive to the color of the lines comprising it. It seems that the initial processing is wholistic followed by an analysis of the whole into its constituent parts and their properties including color. Navon (1977) and Miller (1981) present similar evidence, using different stimuli and tasks, that wholistic processi is not influenced by the visual characteristics of its constituents so long as the configuration is adequately maintained.

Errors

Table 3 presents the results of the experiment in terms of the error scores. That is, errors averaged over subjects are presented for graph type, color condition and task. However, in contrast to sorting times, these mean values are tempered by individual differences as was the case in the previous card sorting experiment (Simcox, 1982).[2]

INSERT TABLE 3 HERE

The significance of this high order Subject x Treatment interaction means that while the group of subjects showed the overall pattern of results found in Table 3, this relative pattern differs markedly for some individuals. The reason for this is clear enough through close examination of the data; there were only 70 errors made in total from a potential of 12 subjects sorting 24 decks of 36 cards each. Thus the error rate was exceedingly small. Of this total, 40 percent were made in one condition, 10 percent by one subject. Four subjects made no errors in that condition, and this fact alone would be sufficient to yield a strong interaction effect.

Suffice to say that the pattern of errors in Table 3 resembles closely the pattern of times in Table 2. This is confirmed through an analysis of variance on the transformed errors showing a significant Graph Type by Task interaction, $F(1,55)=14.19$, $p<.001$.

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[2] Tukey's test showed a significant component of the four way interaction involving subjects, and the three other variables, $F(1,55)=17.09$, $p<.001$.

GENERAL DISCUSSION

This experiment has presented evidence that the configural property of intersection is perceived directly rather then constructed from the stimulus components that make it available. It has also demonstrated that as a result of this wholistic perception, the perception of the component parts--the individual slopes and heights of the lines--requires additional processing resource. Additionally, the experimental results indicate that neither height nor slope of an individual line is seperable with intersection in Garner's (1970) sense of the term. Integrality of height or slope with intersection cannot be established, though, without the correlated stimulus condition as part of the selective attention task.

Relevence to Display Design

The reason this experiment was done in the first place was to shed some light on the perceptual processing of graphic displays and how the design of these displays affects the processing. For example, we are all somewhat familiar with the concept of an interaction from statistical literature. As an adjunct to its mathematical interpretation, an interaction between two variables is interpreted geometrically as a departure from parallelism. A particular type of interaction, termed crossover interaction, occurs in a two-factor design when the value of the dependent variable at levels a_1b_1 of factors A and B respectively is less than the variables' value at factor levels a_1b_2, the variable value at levels a_2b_1 is greater than the value at a_2b_2.

One way of representing this interaction is by a pair of intersecting lines, akin to the stimulus of Figure 1a. Another popular way of representing this interaction, especially if the factors are qualitative is the bar graph form shown in Figure 3 and adapted from a similar display presented in a textbook on Experimental Design. The results of prior experimentation (Simcox, 1982; Experiment 2) showed that the perceptual interpretation of a display translates more easily into certain conceptual interpretation than others. For example, a line graph encoded in terms of slope and overall height of the line translates into messages concerning trend and average level information more readily than messages concerning value information. This type of information is more easily conveyed by a bar graph. In a similar vein, the direct perception of intersection in the line graph of Figure 1a should make the crossover interaction more easily accessible than the corresponding presentation in the bar graph, where the perception of intersection must be inferred.

However, the ease of extracting the interaction concept is not without its costs. The costs are in terms of an inability, by graphic means alone, to emphasize, simultaneously, the underlying average levels of the dependent variable as a function of the factors. As the results show, an increased cognitive effort is necessary to extract this component property. Thus if this information is important, then the text must direct the reader's attention to the component lines. And, as we have seen, making the component lines dissimilar does little to alleviate the problem.

It is not clear from the experiment how one could design a display to make both types of information equally accessible. Thus it becomes imperitive, as with all display design problems, that we have a clear understanding of what information we want to primarily convey graphically.

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List of Figures & Tables

TABLE 1

Experimental Predictions

Stimulus Set	Classifying Dimension	Orthogonal Interference
Height Confounded With Intersection (A)	Height	No
	Slope	Yes
Slope Confounded With Intersection (B)	Height	Yes
	Slope	No

TABLE 2

Sorting Times as a Function of Graph Type and Task

		TASK					
		Single Dimension				Orthogonal Dimension	
Graph Type	Dimension Sorted	Color	No Color	Color	No Color	Color	No Color
Height/ Intersection	Height	14.23	14.43	15.21	15.04	14.39	15.44
	Slope	16.45	15.91	15.90	16.17	21.57	22.62
Slope/ Intersection	Height	15.32	17.64	17.00	17.71	22.19	21.84
	Slope	14.08	14.64	14.31	14.97	14.63	15.67

TABLE 3

Classification Errors as a Function of Graph Type and Task

		TASK					
		Single Dimension				Orthogonal Dimension	
Graph Type	Dimension Sorted	Color	No Color	Color	No Color	Color	No Color
Height/ Intersection	Height	0.17	0.00	0.08	0.17	0.00	0.00
	Slope	0.42	0.17	0.08	0.17	2.33	0.92
Slope/ Intersection	Height	0.08	0.08	0.33	0.00	0.33	0.25
	Slope	0.08	0.08	0.00	0.08	0.00	0.00

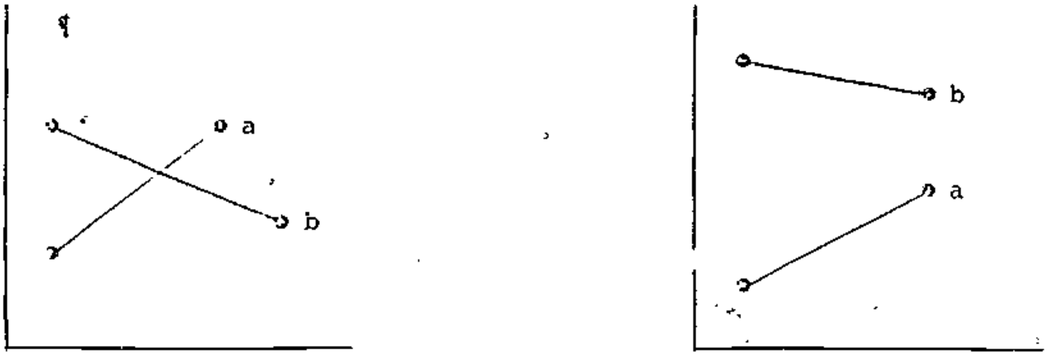
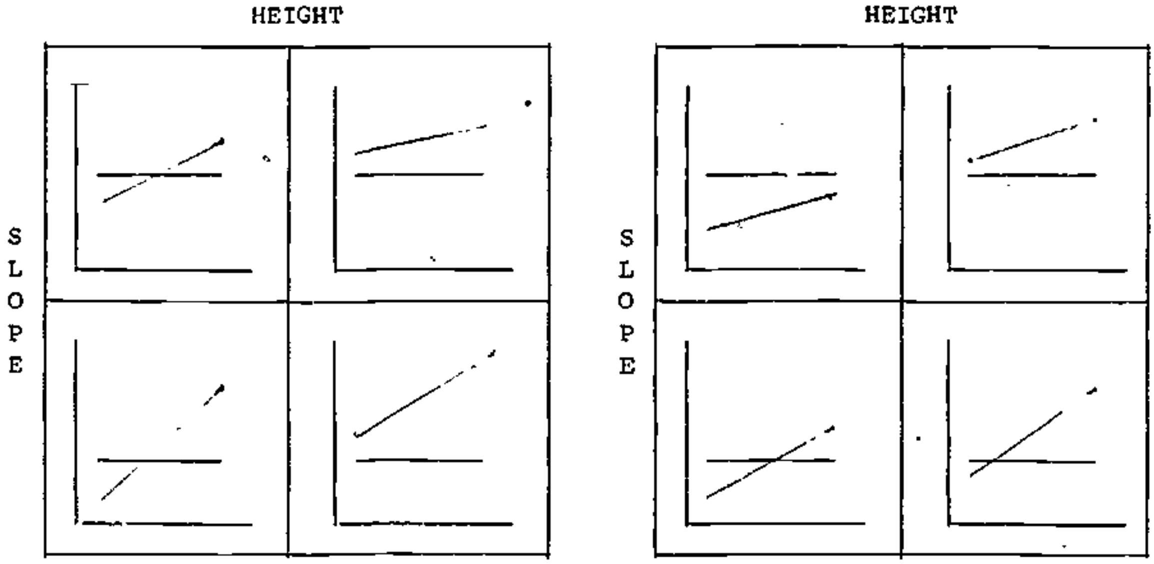


Figure 1 Line Graphs Showing Intersection and Non-Intersection



Height Confounded with Intersection

Slope Confounded with Intersection

Figure 2 Sets of Stimuli Generated From Orthogonal Combinations of Slope and Height Dimensions

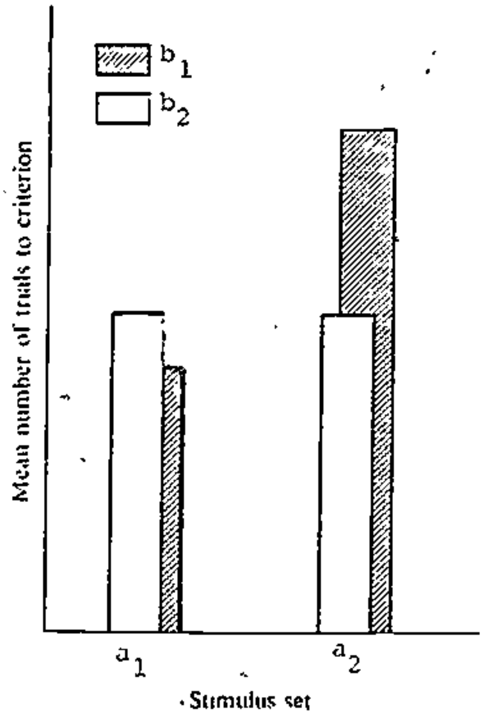


FIGURE 3

Alternative Representation of an Interactive Effect