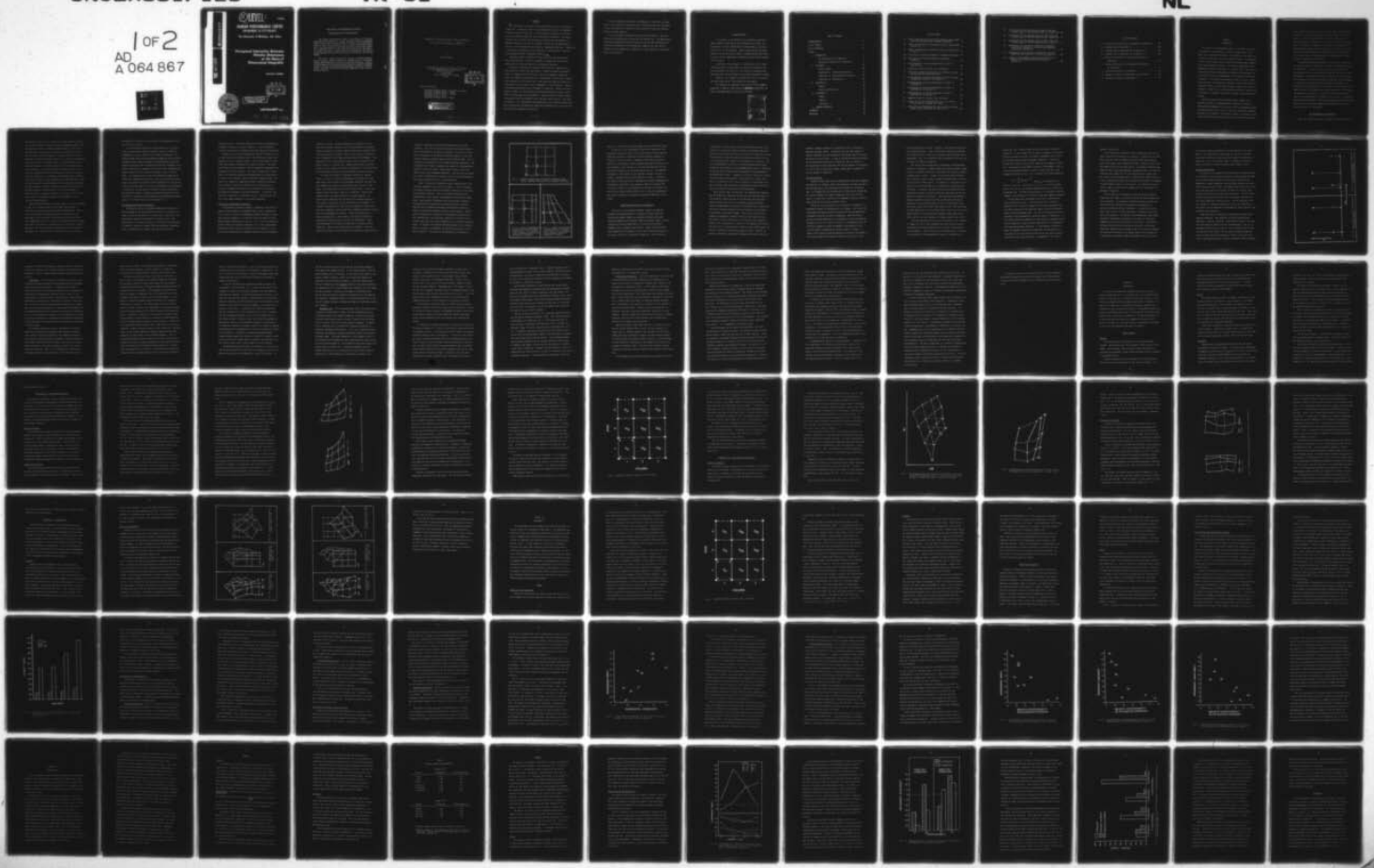
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# *Perceptual Interaction Between Stimulus Dimensions as the Basis of Dimensional Integrality*

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# PERCEPTUAL INTERACTION BETWEEN STIMULUS DIMENSIONS AS THE BASIS OF DIMENSIONAL INTEGRALITY

by

Patricia Somers

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Psychology)
in The University of Michigan
1978

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## ABSTRACT

This paper describes and tests a new psychological theory of dimensional integrality. Integrality refers to the phenomenon of physically independent dimensions appearing fused into a single perceptual attribute such that the physically separable dimensions are not perceptually separable. The theory proposes that all stimuli are perceived as combinations of perceptually independent dimensions, but that for integral stimulus sets the perceptual dimensions do not correspond to the physically independent dimensions. Integrality is demonstrated psychophysically by interaction in psychological similarity space between physically independent dimensions.

Interactive and non-interactive stimulus sets from the same stimulus domain were developed. Similarity judgments indicated that observers perceived both sets using the same pair of perceptual dimensions.

The theory's predictions on speeded classification of interactive and non-interactive stimulus sets were tested. Interacting dimensions produced results in speeded classification tasks typical of phenomenal integrality. First, when compared to the baseline of unidimensional classification, reaction time increased in a "filtering" task, a task requiring selective attention to one dimension as the stimuli varied independently on two dimensions. Amount of interference correlated highly with degree of interaction. Second, observers gained in speed in a task requiring discrimination between two stimuli which differ from each other on two dimensions. Reaction time was directly related to perceived similarity between stimuli--the more similar the pair, the slower the response. This relationship was demonstrated by a difference between speed gain for positively correlated and negatively correlated pairs, consistent with the form of the dimensional interaction.

With non-interacting dimensions, interference in "filtering" and speed gain in classification of correlated pairs correlated highly with the degree to which the dimension irrelevant to classification was more discriminable than the relevant dimension.

It was concluded that speeded classification performance is best predicted by the psychophysical structure of the stimulus set. The demonstrated relationship between classification reaction time and both interaction and relative discriminability of the dimensions suggested that the study of integrality can be beneficially redefined as a direct analysis of the psychophysics of dimensions.

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# CHAPTER I

## INTRODUCTION

To perceive a multidimensional object is not simply to perceive a conglomeration of dimensions, to add the apparent values of an object on its component dimensions. The dimensions of an object are structured by the context in which the object occurs. The perception of both a single object and the relationship between objects depends on how these dimensions interact. This idea was elaborated by the proponents of Gestalt psychology (e.g., Kohler, 1929). More recently, the observation that the perception of dimensional relationships is not uniform has led to the development of the concept of dimensional integrality. The concept distinguishes two types of stimuli, those whose dimensions are perceptually separable, "obvious and compelling" (Torgerson, 1958), and those whose dimensions appear to be unitary or integral, to combine into a single perceived attribute. Hue and size, for example, are separable dimensions; brightness and saturation are integral.

While the origin of the distinction between integral and separable dimensions is phenomenological, integrality can also be characterized psychophysically, in terms of the correspondence between the dimensions explicitly varied in a stimulus set and the dimensions perceived by the observer. One confusing aspect of the concept itself is that integrality has been used variously to describe the nature of

a whole stimulus domain (e.g., color; Shepard, 1964), the orthogonal dimensions of a stimulus subset investigated in a particular experiment (e.g., value and chroma; Garner & Felfoldy, 1970), and an individual object or stimulus (e.g., a single color patch; Lockhead, 1966). An analysis of integrality in terms of the psychophysics of dimensions will clarify the use of the term. In addition, the explication of alternative theories of the psychophysics of integrality will provide a basis for the evaluation of recent operational definitions of integrality (Garner, 1974).

The present experiments demonstrate a new theory of integrality by relating a specific psychophysical pattern to performance criteria for integrality. In brief, the theory states that interaction in psychological similarity space between dimensions that are physically orthogonal is a sufficient condition for obtaining deficits in selective attention to one of these orthogonal dimensions and improvements in classification latency when the dimensions are redundant. The remainder of the introduction will be devoted to a description of this theory in terms of the relationship between dimensions of the stimulus and dimensions as perceived. A contrast with the more traditional views of the psychophysics of integrality will be drawn. In addition, the processing assumptions of the competing theories and their empirical predictions for similarity judgments and speeded classification of integral stimuli will be detailed.

## The Psychophysics of Integrality

There are at least three ways of defining the term "dimension."

One definition refers to the structure of a natural domain of objects. The existence of domains of objects--relative homogeneous groups with few dimensional values in common with other groups--is based on the idea that there is structure in the universe of objects; all values don't co-occur with equal frequency. A domain consists of a set of dimensions or features (following Rosch et al., 1976) that characterize it and distinguish it from other domains. An example would be the domain of rectangles. Dimensions might refer to relationships among sides and angles. The second definition of dimension refers to the physically orthogonal variables characterizing a subset of a domain, usually a stimulus set. For example, an experimenter might choose to investigate rectangles varying orthogonally in height and width. Both of these dimensional characterizations refer to physically measurable concrete properties of objects and have no necessary relation to the perceived properties of these objects. The third definition of dimension refers to perceptual dimensions, which enter into a psychological model for perceptual behavior such as judgments of the similarity between objects.

While the dimensionality of a stimulus domain is easily determined, at least for relatively simple stimuli, there are many ways to partition the stimulus consistent with that dimensionality. That is, for an $n$-dimensional stimulus space, there are many more than $n$ measurements that can be made on each stimulus, but only $n$ of them vary independently at one time. The set of potential physical measurements that can be made in a stimulus space will be called its physical dimensions. The fact that physical dimensions are here referred to in the context of a measuring process implies that they are continuous

and defined with regard to a similar series of measurements carried out on a set of stimuli.

To investigate the perception of the dimensions of a stimulus domain, an experimenter generally chooses a subset of stimuli by independently varying a specific set of physical dimensions. The geometric models used to derive perceptual dimensions from similarity judgments (models underlying nonmetric multidimensional scaling for example) are based on the assumption that similarity judgments are an additive combination of judged similarity along each independent perceptual dimension for the stimulus set (Beals, Krantz, & Tversky, 1968). The important point is that while perceptual dimensions so defined are independent by definition, they do not necessarily correspond to the physical dimensions varied independently in the specific stimulus set being judged. This lack of psychophysical correspondence is the basis of the new theory of integrality being proposed here. The alternative theory of integrality proposes that physical dimensionality is irrelevant to the perception of multidimensional integral stimuli. The latter theory will be described first.

## The Nondimensional View of Integrality

Historically, the basic idea behind dimensional integrality is that the number of salient perceptual dimensions is fewer than the number of physical dimensions in a stimulus set. Specifically, the psychological space can be thought of as unitary; that is, the dimensionality of the physical space is irrelevant to the perception of stimuli in the space. Garner (1974) has stated that "psychologically, if dimensions are integral, they are not perceived as

dimensions at all." Torgerson (1958) uses the term "multidimensional attribute" to describe a similar situation: a single perceptually salient attribute that is composed of more than one physical dimension.

Another way to view the nondimensional theory of integrality is to say that there are no preferred axes in the psychological space corresponding to a set of integral stimuli. Thus, a large number of dimensional descriptions could potentially apply to stimuli in the space, and different sets of dimensions from this population characterize the perception of different stimuli. This view of integrality, in which there is no consistent dimensional characterization of the perception of stimuli in the same set, can be attributed to Shepard (1964). The theories of integrality suggested by Garner, Torgerson, and Shepard have in common the idea that integral stimuli characterized by n physically orthogonal dimensions are not perceived to vary along n psychologically orthogonal consistent dimensions. In addition, they imply that integrality is a characteristic of a stimulus domain, not just of the subset presented in a particular experiment.

## Integrality as Dimensional Interaction

The dimensional interaction theory of integrality views the perception of both integral and separable stimulus sets as dimensional. That is, there is always a correspondence between the number of orthogonal physical dimensions in a stimulus set and the number of orthogonal perceptual dimensions for the set. In this view, the difference between integral and separable dimensions lies in the correspondence between the specific physical dimensions varied orthogonally in the set, and the psychologically orthogonal dimensions on which perceptual

judgments are based. Stimulus dimensions are separable when the physically orthogonal dimensions are also psychologically orthogonal. Stimulus dimensions are integral when the physically orthogonal dimensions psychologically interact. They will do so when an alternative set of dimensions for the domain are psychologically orthogonal. Thus, integrality in this view pertains only to a set of dimensions orthogonally varied in a stimulus set. Another partitioning of the same general stimulus domain would result in separability if that partitioning corresponded to dimensions that perceptually describe the space.

To clarify the concept of dimensional interaction, consider Figure 1a. This is a spatial representation of the physical differences among stimuli varied on two orthogonal dimensions such that the more different two stimuli are, the farther apart they lie in the space. The intersections of the lines are the stimuli. Solid lines connect stimuli with equal values on one dimension. Dashed lines connect stimuli with equal values on the second dimension. By definition the dimensions that are physically orthogonal appear as right angles in the space, and the configuration is rectangular. If a spatial representation of the similarity judgments of these stimuli were also rectangular, the two physically orthogonal dimensions could not be said to psychologically interact. Figure 1b displays such a spatial representation. Now distance in the space corresponds to psychological dissimilarity, not to physical differences. Again, solid and dashed lines indicate the physically orthogonal stimulus dimensions. They are also psychologically orthogonal. Since the physically orthogonal stimulus dimensions correspond to psychologically

orthogonal dimensions, the stimulus dimensions would be termed separable. Note that the spacing along each psychological dimension does not correspond to the physical intervals. The values on both of the two dimensions are not equally spaced perceptually, nor are the intervals along one dimension equal to those along the other. This is irrelevant to the question of the interaction between dimensions. The rectangularity of Figure 1b captures the property of interdimensional additivity (Tversky & Krantz, 1970; Krantz & Tversky, 1975) with regard to physically orthogonal dimensions: the dissimilarity between two stimuli is monotonically related to the sum of terms representing the distance between the stimuli on each dimension.

Figure 1c displays an alternative spatial representation of dissimilarity judgments of the stimuli of Figure 1a. Solid and dashed lines again represent physically orthogonal dimensions, but here they psychologically interact. There is a systematic departure from rectangularity in this spatial representation of dissimilarity judgments: equal physical differences along the horizontal dimension are psychologically diminished as the second dimension increases. When physically orthogonal dimensions psychologically interact, as these do, the stimulus dimensions would be termed integral. Another piece of evidence for a violation of interdimensional additivity in this configuration is the consistent inequality of similarities for stimulus pairs that are related diagonally and are therefore physically equal. For example, the physical difference between stimuli labelled b and c in Figure 1 is equivalent to that between a and d, as can be seen in Figure 1a. The effect of the psychological interaction in

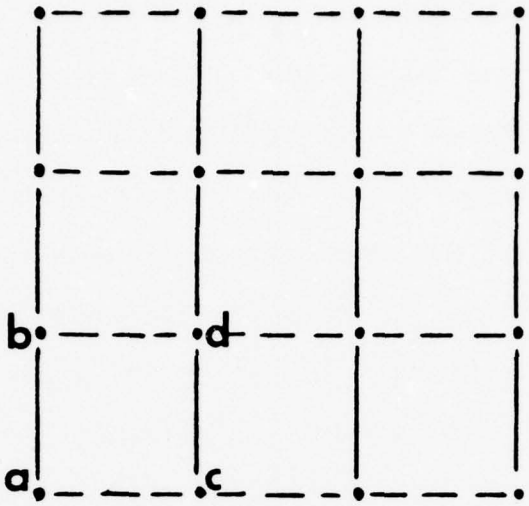



Fig. 1a. Spatial representation of physical differences among stimuli varying on two physically orthogonal dimensions.

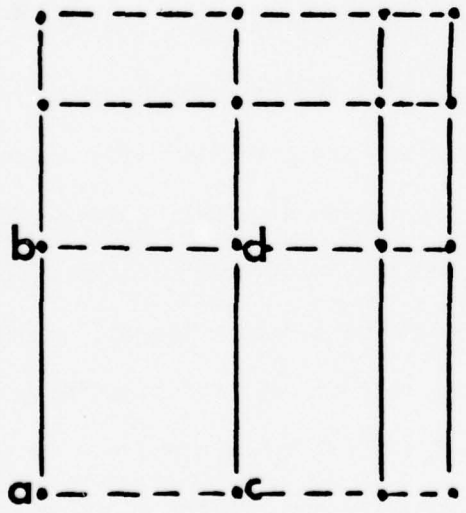



Fig. 1b. Spatial representation of perceived similarity among stimuli of Fig. 1a. The physically orthogonal dimensions are perceptually orthogonal.

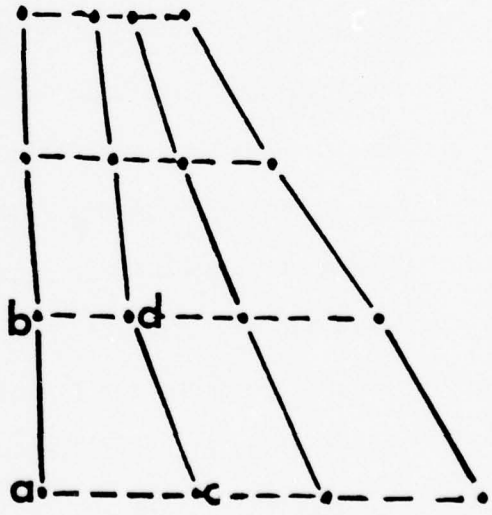



Fig. 1c. Spatial representation of perceived similarity among stimuli of Fig. 1a. The physically orthogonal dimensions perceptually interact.

Figure 1c is to make the pair (b,c) appear more dissimilar than (a,d).

In contrast to the nondimensional theories of integrality, the dimensional interaction theory rests on the proposition that there are separate psychological dimensions on which perceptual judgments of "integral" stimuli are based. Integrality occurs when the physical dimensions corresponding to these separate psychological dimensions are not orthogonal in the stimulus set, for then the dimensions that are physically orthogonal will not be perceived to be so. The dimensions orthogonal in the stimulus set are therefore integral; the term is, however, irrelevant to the stimulus domain as a whole. In addition, the theory implies that there is some degree of context-independence of psychological dimensions, since judgments leading to configurations like that in Figure 1c are hypothesized to be based on an inefficient partitioning of that stimulus subset; that is, they are independent of the context provided by the physically orthogonal dimensions of that subset.

## Operational Definitions of Integrality

The origin of the distinction between integral and separable dimensions was phenomenological. Eventually, however, empirical distinctions between integral and separable dimensions were made following suggestions by Torgerson (1958) and Lockhead (1966), relating integrality to the Euclidean metric in similarity scaling and to redundancy gain in speeded classification. Garner (1974) formalized these suggestions by developing a set of four converging operations to be used as criteria for dimensional integrality. These include the

facilitation of classification time with correlated dimensions, the inability to selectively attend to one of two orthogonal dimensions, and the use of the Euclidean metric as the basis of similarity scaling. The operations are based essentially on perceived similarity or on a classification process related to the perception of similarity. The use of psychological similarity or similarity-based behavior makes perhaps as close contact with the phenomenological basis of integrality as possible while yielding usable measurements of the appearance of multidimensional stimuli. Judgments of similarity require the subject to make no absolute descriptions or measurements of stimulus attributes. By referring to the stimuli presented, the experimenter can make inferences about attributes and appearances without asking for a verbal description of what might not be verbalizable.

While the two views of integrality, the nondimensional theories and the dimensional interaction theory, make the same predictions for some diagnostic operations they are at odds with regard to others. Several problems with the set of converging operations demand a logical and experimental re-analysis of the definition of integrality. Some recent evidence indicates that the operations do not converge as completely as originally thought. Specifically, at least one example of phenomenally integral stimuli has been found to be best described by the City Block metric in similarity scaling (Shepard & Cermak, 1973). New patterns of results in the speeded classification task have led to a proliferation of stimulus types without thought for logical or perceptual relationships among the types. Examples are configural dimensions, described by Pomerantz and Garner (1973) and

asymmetric integral dimensions, one example of which is explored by Pomerantz and Sager (1975). In addition, only one clear example of integral dimensions has been thoroughly investigated, that of the color dimensions value and chroma. In view of the growing confusion surrounding the operational definition of integrality, then, an analysis of the experimental results consistent with the two theories of integrality will be of value in determining whether indeed there is support for a unitary concept of integrality.

Similarity Scaling

Torgerson (1958) noted that the nondimensional similarity judgments characteristic of integral stimuli are captured by a primary quality of the Euclidean metric, that distances are invariant over rotation of axes. He proposed that the Euclidean metric might be most appropriate for scaling judgments of integral dimensions, while the City Block metric, a simple sum of similarities on component dimensions, would be more appropriate for scaling separable stimuli.

The use of the scaling metric as a criterion for integrality is problematic because its interpretation is ambiguous. Two views of the significance of obtaining superior scaling with the Euclidean metric correspond to the two theories of integrality. When the primary quality of the Euclidean metric is considered to be the invariance of distance with rotation of axes, the metric is a measurement model for similarity judgments in which the geometric configuration of the stimulus points in psychological similarity space is primary. In models of this type the distance between any two points corresponds to the shortest smooth curve connecting them that lies wholly on the

surface representing the space. Distance is then defined irrespective of a coordinate system. Since a psychological dimension corresponds to an ordered series of surfaces in the space, many attributes can be represented. Thus, in the Euclidean model considered in this way, any two points will define a dimension.

This view of the Euclidean metric corresponds to nondimensional theories of integrality. Shepard (1964) observed that subjects tended to refer to different attributes in describing the similarity between different pairs of colors. Instead of using consistently preferred axes in the color space, subjects tended to redefine axes in the context of specific stimulus pairs. This behavior is consistent with the notion of the Euclidean model as a representation of nondimensional similarity. In contrast, distances within the City Block metric are measured with regard to specific dimensions, consistent with the perception of dimensions as separable. Data supporting the connection between integrality and the similarity scaling metric include the superiority of the Euclidean metric for the color dimensions value and chroma (Hyman & Well, 1967, 1968; Handel & Imai, 1972) contrasted with the superiority of the City Block metric for the size of a circle and the angle of an inscribed radius (Shepard, 1964; Hyman & Well, 1967), and for size and lightness of a square (Handel & Imai, 1972).

The difficulty with the use of the scaling metric as an indicator of integrality lies in the assumption that the distance invariance characteristic of the Euclidean metric is relevant to scaling similarity judgments. While this use of the Euclidean metric in this way is consistent with the nondimensional concept of integrality, an

alternative class of models renders the scaling metric irrelevant to integrality. In this second class of models, a judgment of the overall similarity between two stimuli can always be decomposed into similarities measured along component orthogonal dimensions. A particular scaling metric refers to the rule for combining the component similarities. One subclass of such models consists of the Minkowski r metrics, in which the distance between two stimuli j and k which vary along orthogonal dimensions (m=1,2,...,p) is given by the following equation:

$$d_{jk} = \left[ \sum_{m=1}^{p} |a_{jm}-a_{km}|^{r} \right]^{\frac{1}{r}}$$

where $a_{jm}$ is the projection of stimulus j on axis m. The range of r is 1 to $\infty$. For the Euclidean metric, r=2; that is, the distance between two points is given by the Pythagorean rule. For the City Block metric, r=1; a global similarity judgment is the simple sum of similarity along each component dimension.

The Euclidean metric considered in this way is simply one of a class of combination rules. If the Euclidean metric is seen as a combination rule, similarity judgments that are best represented by a Euclidean scaling metric are made with regard to specific dimensions, rather than being nondimensional. This use of the Euclidean metric is consistent with the dimensional interaction theory of integrality. In this theory similarity judgments are always based on orthogonal psychological dimensions; integral physical dimensions lack correspondence with these psychological dimensions. If psychological similarity is based on orthogonal psychological dimensions, the determination of the particular rule that best describes the way the subject combined similarities along those dimensions is independent of the integral-

separable distinction.

In the dimensional interaction view of integrality, the scaling metric should not be predictive of integrality. Support for this view comes from the finding by Shepard and Cermak (1973) that perceived similarities among a set of apparently unitary, free-form stimuli were best modelled with the City Block metric. By contrast, Hardzinski and Pachella (1977) found that apparently analyzable stimuli, in which the dimensions were lengths of five lines emanating from a point, were best scaled with a Euclidean metric. Hyman and Well (1967) found that a metric intermediate between the Euclidean and City Block fit judgments of parallelograms varying in size and tilt. For these three types of stimuli, then, the scaling metric appears not to be correlated with phenomenal integrality.

The two theories of integrality do not make directly opposing predictions with regard to similarity scaling, but make different use of the technique. The dimensional interaction theory utilizes similarity scaling to evaluate the psychological orthogonality of physically orthogonal stimulus dimensions. It regards the scaling metric used to arrive at that evaluation as irrelevant to the integrality of dimensions. By contrast, the nondimensional theory makes no specific predictions with regard to the pattern of similarity judgments, but views the scaling metric as critical. The differing attitudes towards similarity scaling are the result of differing assumptions regarding the psychological basis of similarity judgments. The dimensional interaction view assumes there to be a constant set of psychological dimensions underlying judgments within a stimulus

set (and even underlying judgments of similar subsets from a common domain). The nondimensional view assumes no such set of invariant psychological dimensions; dimensions either change from comparison to comparison within a set (Shepard, 1964), or judgments are directly based on the overall similarity between stimuli (Garner, 1974).

Speeded Classification

Two results in the speeded classification task--interference from an irrelevantly varying dimension and gain in sorting speed when dimensions are correlated--have been reliably found to occur with the phenomenally integral dimensions value and chroma (Garner & Felfoldy, 1970; Gottwald & Garner, 1975). The speeded classification task itself can be best described with reference to Figure 2a, a spatial representation of the dissimilarities among four stimuli. The four stimuli, labelled a through d, are formed from the orthogonal combination of two bilevel dimensions, labelled x and y. For the conditions of the task relevant to diagnosing integrality, stimuli are classified by the subject into two categories corresponding to the two levels of one dimension, here dimension x.

Three conditions are relevant to distinguishing integral from separable dimensions. One condition, called the unidimensional condition, is used as a baseline: classification latency is obtained for classifying two stimuli that vary unidimensionally, that is, for distinguishing a from c or b from d. This is compared with the time to classify all four stimuli into the same two response categories: stimuli a and b receive one response and stimuli c and d the other. Thus, in the second condition, called the orthogonal condition because

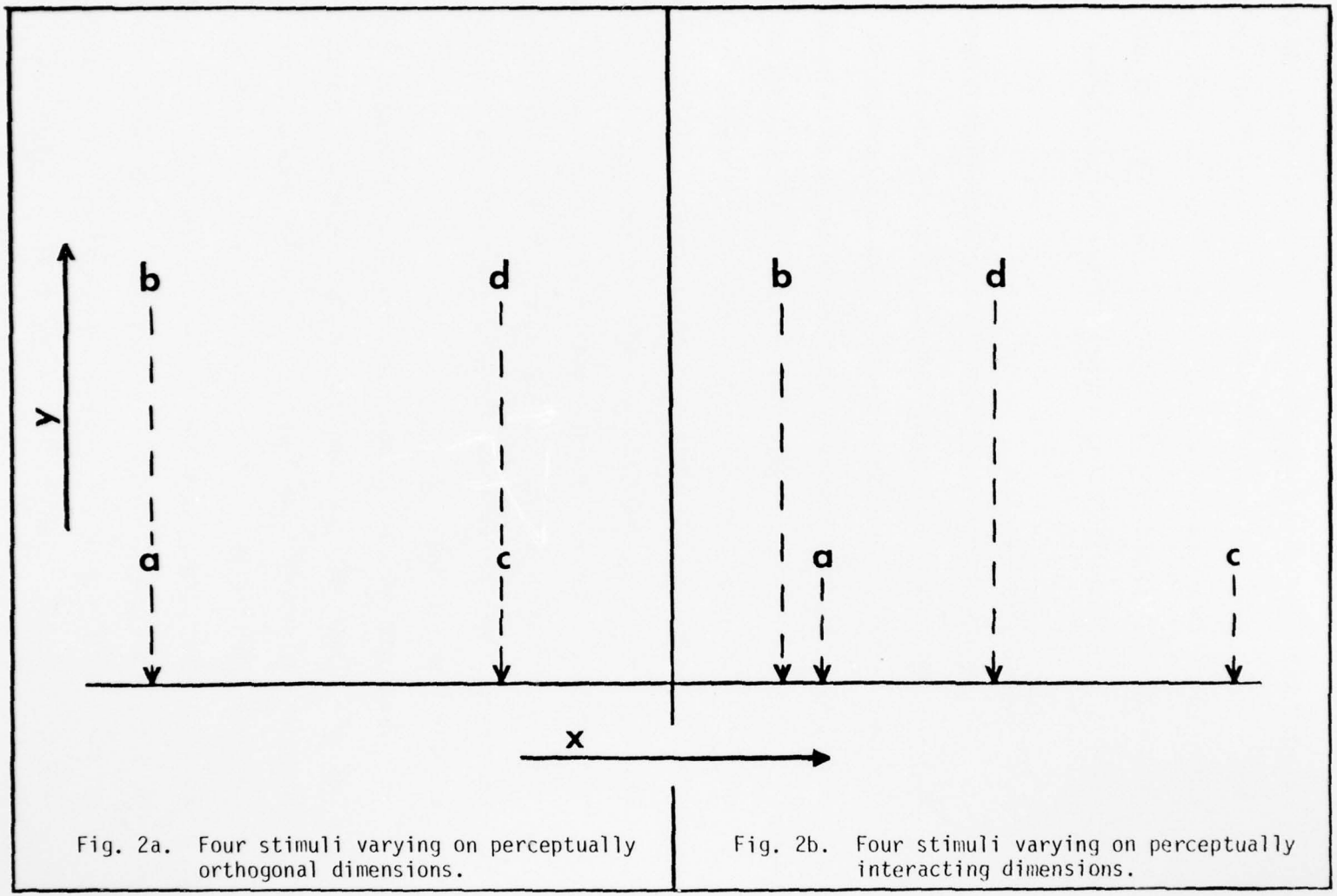



Fig. 2a. Four stimuli varying on perceptually orthogonal dimensions.

Fig. 2b. Four stimuli varying on perceptually interacting dimensions.

dimensions are physically orthogonal, dimension y varies irrelevantly. In the third condition, the correlated condition, the dimensions vary redundantly. That is, subjects must distinguish stimulus a from d or b from c.

Interference. The two theories of integrality predict the same relationship between performance in the unidimensional and orthogonal speeded classification conditions. If dimensions are integral, classification time will increase when dimensions vary orthogonally as compared to the unidimensional condition; that is, there will be interference. The theories differ in their ability to make detailed predictions relating degree of interference to degree of integrality. This is due to the fact that nondimensional theories have no independent way of quantifying integrality. Indeed, when the psychophysical correspondence between stimulus dimensions and percept is unspecified, as it is in these theories, integrality is not a quantitative concept. By contrast, the equation of integrality with dimensional interaction allows comparisons to be made between sets of dimensions that interact in varying amounts.

As originally developed, the use of interference to indicate integrality was based on the assumption that interference results from a failure of selective attention to the dimension relevant to classification. When dimensions are separable, selective attention to the relevant dimension effectively reduces a four onto two stimulus-response mapping to a two onto two mapping, as there is in the unidimensional condition. That is, it is assumed that processing the irrelevant dimension to the point where it is filtered out takes no

more time than it does in the unidimensional condition. When dimensions are integral, however, selective attention is impossible; processing the irrelevant dimension increases classification time.

An essentially equivalent view of the effect of integrality is that the lack of interference with separable dimensions is based on the perceptual identity of stimuli that receive the same response. The inevitable processing of irrelevant information when dimensions are integral destroys this identity. The advantage of the dimensional interaction theory of integrality lies in its quantification of the perceptual difference of stimuli to be classified together: as the amount of interaction between dimensions increases this perceptual difference also increases. The theory assumes that classification speed is directly related to the "compactness" of a response category along the relevant dimension and to the discriminability between categories. Dimensional interaction is the systematic influence of perceived intervals on one dimension by variation on a second dimension. Such an influence might be thought of as the failure of a filter, but it is more specific and systematic than a simple deficit of selective attention. Because interaction consists of the alteration of perceived values on the relevant dimension, assumptions about post-alteration processing can refer simply to that relevant dimension. Thus, an underlying psychological model might be one in which classification responses are based on category prototypes for the relevant dimension, with classification time increasing with the distance of a stimulus from the prototype for its category. The essence of the dimensional interaction theory, however, does not lie in a particular mechanistic

model of classification behavior; it lies in the direct application of psychophysical data to patterns of performance in speeded tasks. The use of similarity scaling provides a measure of perceptual interaction between dimensions that can be directly related to interference in speeded classification.

Figure 2b illustrates the relationship between similarity and interference. The four stimuli a, b, c, and d are the result of the orthogonal variation of two stimulus dimensions, but the dimensions psychologically interact. As with the non-interacting stimulus set of Figure 2a, the dimension relevant to classification is the horizontal dimension, labelled x, and the perceived value of each stimulus on that dimension, as derived from similarity judgments, is indicated by projections of the stimuli. A comparison with Figure 2a demonstrates that each response class in the interacting set is more ill-defined than the corresponding response class of the non-interacting set. When dimensions don't interact, stimuli to be classified together are perceptually identical on the dimension relevant to classification. As dimensional interaction increases, stimuli to be classified together are perceived to be increasingly less similar on the dimension relevant to classification. In addition, the perceived boundary between response classes becomes less certain as interaction increases; stimuli a and d, which are to receive opposite responses, are perceived to be very similar, while stimuli b and c appear to be very different.

One quantification of the amount of interaction in a stimulus set that can be derived directly from similarity judgments is the ratio of perceived similarity of one diagonal pair to that of the other. In

the non-interacting stimulus set, Figure 2a, the distance between a and d equals that between b and c. In the interacting set, Figure 2b, these distances are far from equal. As the ratio of the longer to the shorter diagonal increases, stimuli to be classified together are perceived to be increasingly different. As with the nondimensional theory of integrality, four perceived values on the relevant dimension (as compared with two in the unidimensional condition) are to be mapped onto two responses. In addition, the degree of interference that results should be directly related to the uncertainty of that mapping. The dimensional interaction theory of integrality predicts that as the ratio of diagonal distances increases the amount of interference should also increase.

Redundancy gain. For the nondimensional theory, the prediction of a decrease in classification latency from the unidimensional to the correlated condition with integral dimensions is based on the assumption that classification speed is directly related to the discriminability of stimuli that are to receive opposite responses. To predict that no redundancy gain is obtained with separable dimensions, two additional assumptions are necessary. First, it is assumed that when dimensions are separable, subjects selectively attend to one dimension (Lockhead, 1966). The second assumption is that analogous stimuli in the correlated and unidimensional pairs have perceptually equal values on the dimension attended to. Discriminability would then be equal for the two types of stimulus pairs. Obtaining redundancy gain with integral dimensions has been hypothesized to occur because selective attention to a single dimension is not possible, resulting in an

increase in discriminability between redundantly related stimuli. As an example, Lockhead's (1972) "blob processing" model suggests that subjects locate integral stimuli in psychological space without analyzing the stimuli into component dimensions. Stimuli falling farther apart in the space are more discriminable, leading to faster and more accurate responses. Redundancy gain in this model is due to the fact that "adjacent correlated stimuli are separated farther in the discrimination space than are adjacent univariate stimuli." It must be noted, however, that redundancy gain might still be obtained with separable dimensions, if the dimensions are processed in parallel.

The dimensional interaction theory of integrality also assumes a correlation between classification speed and discriminability. The use of similarity scaling to provide an independent estimate of discriminability reveals, however, that when dimensions interact correlated stimuli are not necessarily more discriminable than unidimensional stimuli.

If integrality is based on dimensional interaction, the particular form of the interaction is critical for determining classification time for redundant stimuli. An interaction can either increase the apparent difference between stimuli or decrease it. In Figure 2b, the stimulus pair (b,c) is more discriminable than either unidimensional pair, but the pair (a,d) is less discriminable than the unidimensional controls. Thus, for (b,c) classification time should decrease from the unidimensional control resulting in the typical redundancy gain, but for (a,d) classification time should increase. According to the dimensional interaction view, then, integrality does not automatically increase

the discriminability of redundant stimuli. Whether redundancy gain is obtained depends on whether the correlated condition utilizes positively correlated pairs like (a,d) or negatively correlated pairs like (b,c). Of course, which direction of correlation yields redundancy gain depends on the specific interaction involved.

The predicted difference in classification time for positively correlated and negatively correlated pairs has unfortunately not been tested for the classical integral dimensions value and chroma. Only positively correlated pairs were used (Garner & Felfoldy, 1970). Clark and Brownell (1976) found a significant difference between correlated conditions using position and direction of arrow, but it is not clear that the effect is perceptual; as Clark and Brownell note, direction has symbolic but not intrinsic meaning.

The most significant discovery of a correlated condition difference was made by Pomerantz and Garner (1975). The stimuli were pairs of parentheses with dimensions left vs. right element and left vs. right curvature. Negatively correlated pairs [(( vs. ))] took significantly longer to classify than positively correlated pairs [() vs. )(]. In addition, negatively correlated pairs took slightly longer to sort than the unidimensional controls, while positively correlated pairs were sorted faster than the controls. The difference between the correlated conditions was not accorded theoretical significance by Pomerantz and Cramer, since the analysis was based on a nondimensional view of integrality. Instead, the resulting lack of overall redundancy gain was used to define a new type of dimensional relationship, configural dimensions. A more parsimonious explanation is that the

negatively correlated pairs are more similar than are the positively correlated pairs: the dimensions interact.

Relative discriminability. Both the nondimensional and dimensional interaction theories attribute interference and redundancy gain in speeded classification to integrality, although their concepts of the psychophysics of integrality differ. A third aspect of dimensional psychophysics has also been hypothesized to lead to similar speeded classification performance: both interference and redundancy gain could occur if discriminability along the dimension irrelevant to classification is greater than discriminability along the relevant dimension. Such a relationship is not actually an alternative to the theories of integrality described above. Rather, unequal discriminability of dimensions could occur along with dimensional integrality in either framework. However, speeded classification results typical of integral dimensions could also occur when dimensions are psychophysically separable but of unequal discriminability.

Egeth and Pachella (1969) noted that such a situation, in which the more salient dimension masks the less salient, accounts for a common result in absolute judgment, that the amount of information transmitted about a dimension is greater when that dimension appears in isolation than when another dimension covaries. A similar explanation was offered for interference in the speeded classification task by Somers and Pachella (1977). The more salient dimension, though irrelevant to the task, attracts attention and increases classification time.

That redundancy gain could be obtained with separable dimensions

of unequal discriminability was suggested by Garner (Garner & Felfoldy, 1970). When dimensions are correlated, the more discriminable dimension can be used for classification, leading to a decrease in classification time as compared to the unidimensional control, which utilizes the less discriminable dimension.

Unequal discriminability of dimensions is similar to dimensional interaction in that in each case the irrelevant dimension influences the perception of the relevant dimension. They differ in that influence based on interaction is a systematic distortion of perceived similarity, while masking depends only on the particular levels chosen on the dimensions. Two dimensions that are of equal discriminability but don't interact are in principle perceptually identifiable. Since they correspond to independent perceptual dimensions, the influence of the irrelevant dimension can be eliminated by choosing stimuli that are less discriminable but that still vary on that dimension. The influence of an interacting dimension cannot be eliminated without redefining the dimension: it is independent of particular values.

Confusion between the two effects can nevertheless arise due to the definition of interaction itself: discriminability along an interacting dimension varies with the level of the other dimension. There is, therefore, no meaningful measure of the discriminability along the influenced dimension in a group of stimuli for which the physically orthogonal dimensions psychologically interact. The analysis of similarity judgments, however, provides a critical empirical prediction that distinguishes the effects of dimensional interaction from those of unequal discriminability of non-interacting dimensions: classification latency for positively and negatively correlated conditions will

differ with dimensional interaction but will not differ with unequal discriminability alone. An increase in the discriminability of the irrelevant dimension increases the discriminability of positively correlated and negatively correlated pairs equally, as can be seen by comparing different groups of four adjacent stimuli in the non-interacting stimulus set pictured in Figure 1b. By contrast, an increase in dimensional interaction increases the disparity in similarity between positively and negatively correlated pairs.

To summarize, the dimensional interaction theory predicts that the results in speeded classification typical of integral dimensions, interference and redundancy gain, occur when physically orthogonal dimensions perceptually interact. At a more detailed level, the theory predicts that interference is correlated with amount of interaction, and that redundancy gain occurs only with the correlated condition in which discriminability is increased over unidimensional discriminability. The purpose of the experiments described here is to test these predictions. The demonstration of the validity of the dimensional interaction theory of integrality is not a claim that interaction is the only basis of integrality. It will be demonstrated, however, that interaction is at least one basis of integrality.

The demonstration consists of three experiments. The goal of the first experiment is to identify two stimulus sets, two pairs of physically orthogonal stimulus dimensions from a single stimulus domain, with the following characteristics: the dimensions of one stimulus set must be perceptually orthogonal and the dimensions of the other perceptually interact. These two stimulus sets will be

referred to as the non-interacting and interacting stimulus sets. In addition, to claim that the same perceptually orthogonal dimensions are the basis of judgments for the interacting stimulus set, those judgments must be consistent with the physical values of the perceptually orthogonal dimensions in that set. Interdimensional additivity in dissimilarity judgments is used as an indicator of perceptual orthogonality of physically orthogonal dimensions.

The second experiment tests speeded classification predictions for the two stimulus sets derived from Experiment I. Perceptually orthogonal dimensions should result in no interference and no redundancy gain, if discriminability is matched for the two dimensions. The effects of unequal discriminability of dimensions can therefore also be assessed with this stimulus set. Perceptually interacting dimensions will yield interference: selective attention to the influenced dimension will be difficult. Furthermore, the amount of interference should be proportional to the degree of interaction in a stimulus subset. Redundancy gain for the interacting set will depend on the pertinent distances; the difference between the two correlated conditions should be consistent with the nature of the dimensional interaction so that redundancy gain will be obtained with the more discriminable correlated pair. The goal of Experiment II is twofold: to demonstrate that the typical integrality pattern is obtained with interacting dimensions, and to demonstrate the basis of this relationship in a correlation between classification speed and dissimilarity. The third experiment further explores the effects of interaction and relative discriminability of dimensions on selective attention in speeded classification.

If integrality consists of a misdefinition of stimulus dimensions, the methods developed here should be of general use for the discovery of physical stimulus parameters that do correspond to perceptual dimensions.

# CHAPTER II

# EXPERIMENT I

This set of experiments was designed to identify two pairs of stimulus dimensions, that is two stimulus sets, for a single stimulus domain such that one pair of dimensions contributed additively to dissimilarity judgments while the other psychologically interacted. Evidence for a single pair of psychological dimensions underlying the perception of both stimulus sets would be a correspondence between the perceived differences among stimuli and the physical differences among stimuli along a single pair of dimensions. The general procedure was to obtain and analyze dissimilarity judgments of stimulus pairs in series of stimulus sets, each set formed by the orthogonal combination of two of the many potential dimensions of a domain.

## General Method

### Subjects

The subjects were two paid University of Michigan graduate students. Both were 26 years old, had normal vision, and were right-handed. One was female. Both had some previous experience with psychological experiments, though neither had made similarity judgments in experiments before.

These two subjects were used throughout all three experiments. The goal was to test predictions for each subject separately. This

strategy was adopted because pilot work indicated that subjects could not be expected to have exactly the same set of psychologically independent dimensions for a single stimulus domain. Principles relating dissimilarity judgments to classification speed, however, were expected to generalize over subjects.

## Stimuli

The stimulus domain was that of triangles, constrained to avoid singularities such as isosceles or right triangles. All triangles were presented base-down, with a constant base length of 2.54 cm. The lower right-hand interior angle was greater than 90 deg, so that the left side of each triangle was longer than the right. Thus, there were no triangles that were identical within a rotational transformation. Because the base was held constant, the stimulus domain could be described by two orthogonal dimensions.

Stimuli were presented on a cathode ray tube (CRT) controlled by a PDP-1 computer. Projecting the longest side of a triangle horizontally and vertically, the triangles ranged from 2.67 to 14.25 deg of visual angle horizontally and from 1.21 to 2.03 deg vertically.

## Procedure

Subjects were instructed that they were to rate the overall dissimilarity of pairs of triangles. Full instructions, reproduced in Appendix A, were given at the beginning of the first three sessions. After these sessions a formal reading of the instructions was considered unnecessary. Each of the sixteen triangles in a stimulus set was presented alone to familiarize the subject with the range of

variation in the set. The stimuli were presented in random order (a different random order for each session) with presentation rate controlled by the subject.

The subject then rated the dissimilarity of each of the 120 possible stimulus pairs on a ten point scale. The two triangles of a pair were presented one above the other, with each centered on a point midway across the CRT horizontally and 4.3 cm above or below midpoint vertically. This was done so that the leftmost points of the triangles did not line up. Which pair of a triangle was on top was determined randomly for each pair.

When a stimulus pair appeared on the CRT the subject made a dissimilarity rating by pushing the appropriate one of ten microswitches on a panel. The left-most button was one on the scale; the rightmost was ten. Each button was tagged with its number. In addition, at the left end of the panel was a tag reading "low dissimilarity" and at the right end a tag reading "high dissimilarity" to avoid confusion with the scale.

The task was self-paced. A stimulus pair remained on the CRT until the subject pushed a response button. The CRT was then blank for 400 msec followed by a new stimulus pair.

Each of the 120 possible pairs for a set appeared once. After a two min rest period a new run of 120 trials began. In each run, the 120 pairs appeared in a different random order. A session consisted of seven runs, that is, seven judgments of each stimulus pair. For subject M.S. a session lasted about 50 min; for subject S.T. a session lasted 35 min. The same stimulus set was presented for three sessions

before presenting a new set.

## Experiment Ia: Interacting Dimensions

The purpose of developing a stimulus set that varied along a pair of physically orthogonal but perceptually interacting dimensions had two aspects. The first was to allow a test of the speeded classification predictions for such a set. The second was to provide data from which to derive the specification of perceptually non-interacting dimensions; the stimulus dimensions that physically interact in a form identical to the psychological interaction of this set correspond to the perceptual dimensions.

### Stimulus Parameters

The two dimensions, chosen on the basis of pilot data, were the height of the triangle (H) and the length of the right side of the triangle (R). Height is measured by a perpendicular dropped from the top vertex to a line extended from the base. Since the base is of constant length, height is equivalent to area. The term "height" is used rather than "area" for consistency in units of measurement of the stimulus dimensions. Four values of height--1.3, 2.2, 3.8, 5.4 cm--and four values of right side--5.7, 7.9, 10.2, 12.4 cm--were orthogonally combined to produce 16 triangles, pictured in Appendix B.

### Results and Discussion

The first session, and the first run of the second and third sessions were considered to be practice. The remaining 12 dissimilarity judgments for each stimulus pair were averaged. These 120 mean

dissimilarity ratings were scaled separately for each subject using the nonmetric multidimensional scaling program CONSCAL (Noma & Johnson, 1977). CONSCAL uses an algorithm similar to that used by Kruskal (1964) to arrive at a geometric representation of the dissimilarities data. Stress is a measure of the poorness of fit of a given scaling solution to the data. To avoid the possibility that any scaling solution represented only a local minimum in stress and not the overall best solution each scaling analysis was repeated three times, starting from a different random configuration of points. The configuration with the lowest stress was used.

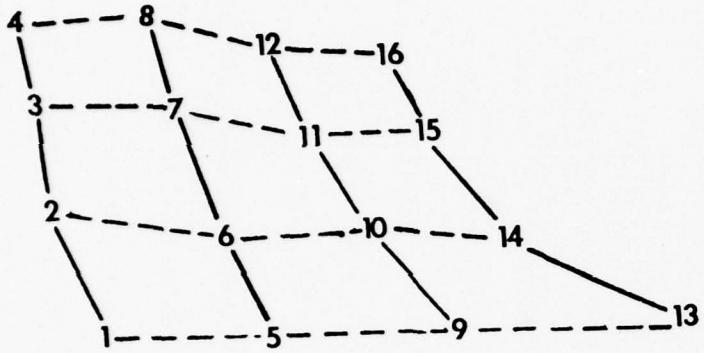
For both subjects a two-dimensional Euclidean solution gave a good fit to the data. Stress of the two-dimensional solution decreased substantially over a one-dimensional solution and both dimensions were interpretable. A three-dimensional solution offered little additional decrease in stress and the third dimension was not interpretable. For M.S. stress of the one-, two-, and three-dimensional solutions was .31, .06, and .04. For S.T. stress for these solutions was .28, .07, and .06. By contrast, stress of the two-dimensional configurations using the City Block metric was .09 for M.S. and .31 for S.T.

These values of stress can be evaluated to some extent by comparing them to stress values of random configurations generated by a Monte Carlo technique. Klahr (1969) found that 95 percent of the final configurations of 16 points had stress less than .50 in one dimension, .30 in two dimensions, and .20 in 3 dimensions. Stress of the configurations in the present study were substantially lower than these values, indicating that there was structure in the data. A

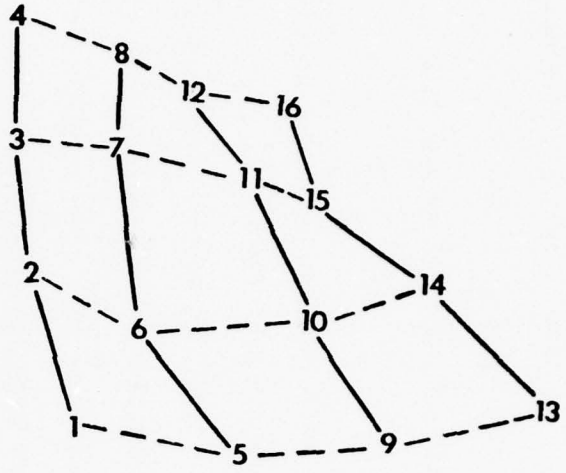
more useful comparison can be made to the data of Brown and Andrews (1968) who found stress of scaling solutions for similarity of 16 random polygons to be .34, .28, and .12 in one, two, and three dimensions.

Figure 3 presents the two-dimensional configurations for subjects M.S. and S.T. Solid lines connect stimuli of equal physical height and dashed lines connect stimuli of equal physical length of right side. Values on the dimensions increase from left to right in the configuration and from bottom to top. The dimensions clearly interact: as the length of the right side increases, equal differences in height are perceptually diminished. Conversely, the perception of the length of the right side is not nearly as influenced by height. Lines connecting triangles of equal right side are essentially parallel.

It is possible in CONSCAL to constrain the configuration by specifying coordinates for each point on any dimensions desired. The coordinates determine the ordering of points, maintaining tied values, on the dimensions specified. When the physically orthogonal dimensions for this stimulus set, height and length of right side, were used to constrain the configurations, stress increased for M.S. from .06 to .18 and for S.T. from .07 to .17. These large increases in stress indicate that the configurations constrained to be consistent with the values of the triangles on H and R are quite noisy, a poor representation of the dissimilarity judgments. The dimensions used to constrain the configuration were physically orthogonal in this stimulus set. If the stress of the constrained configuration had remained low, it would have been likely that this physical relationship between H and R was




S M.S. H x R Stress = .06




S S.T. H x R Stress = .07

Fig. 3. Multidimensional scaling configurations of stimuli in Experiment Ia.

similar to the perceived relationship between them. The high stress values indicate that the deviation from perceptual orthogonality of the unconstrained configuration was significant. Thus, it is unlikely that the dissimilarity judgments were an additive combination of dissimilarities on the perceptual dimensions corresponding to height and length of right side.

To confirm statistically the presence of dimensional interaction and to assess the variation in interaction within the stimulus set, an analysis of variance was performed on the dissimilarity judgments for pairs of adjacent diagonally related stimuli. While the analysis of variance is not independent of the multidimensional scaling--they are based on the same data--it does evaluate the variability of judgments in a way that multidimensional scaling cannot. The analysis of variance therefore provides a statistical test of the effects graphically demonstrated via multidimensional scaling.

The variable of most interest was the relationship between positively and negatively correlated pairs. In general, if dimensions systematically interact pairs in which the dimensions are positively correlated would be judged consistently more or less dissimilar than pairs with negatively correlated dimensions. The scaling configurations indicated that for this stimulus set positively correlated pairs were judged less dissimilar than negatively correlated pairs. The analysis of variance examined this indicator of interaction, direction of correlation (D).

One goal of Experiment II was to test the correlation between dimensional interaction and interference. This relationship could be

tested within the interacting stimulus set if different groups of four adjacent stimuli within the set varied in amount of interaction. Thus, the second factor in the analysis of variance was group (G).

Figure 4 describes a numbering scheme for the groups within a stimulus set that will be used throughout the experiments. A group consists of four stimuli that are the orthogonal combination of two adjacent values on each of the two dimensions. The pairs of adjacent values on the horizontal dimension will be termed columns and the pairs of values on the vertical dimension will be termed rows. Each group is the intersection of one column and one row. Therefore there are three columns, three rows, and nine groups in a stimulus set. Columns are numbered from left to right in the scaling configuration and rows from bottom to top, corresponding to increasing values on the dimensions. Dimensional interaction in a group is indicated by the difference between judgments for the positively correlated pair, for example the pair (a,d) in Figure 4, and the negatively correlated pair, pair (b,c). A variation in dimensional interaction from group to group will be revealed in the analysis of variance as an interaction between D and G.

The effect of session(S) was also evaluated. The six judgments of each pair within each session were considered to be replications and were used as the error term. The analysis of variance tables for the two subjects are given in Appendix E. All contrasts cited below and in Experiment Ib as significant were computed using 95 percent Scheffé confidence intervals.

Both subjects judged the positively correlated pairs significantly

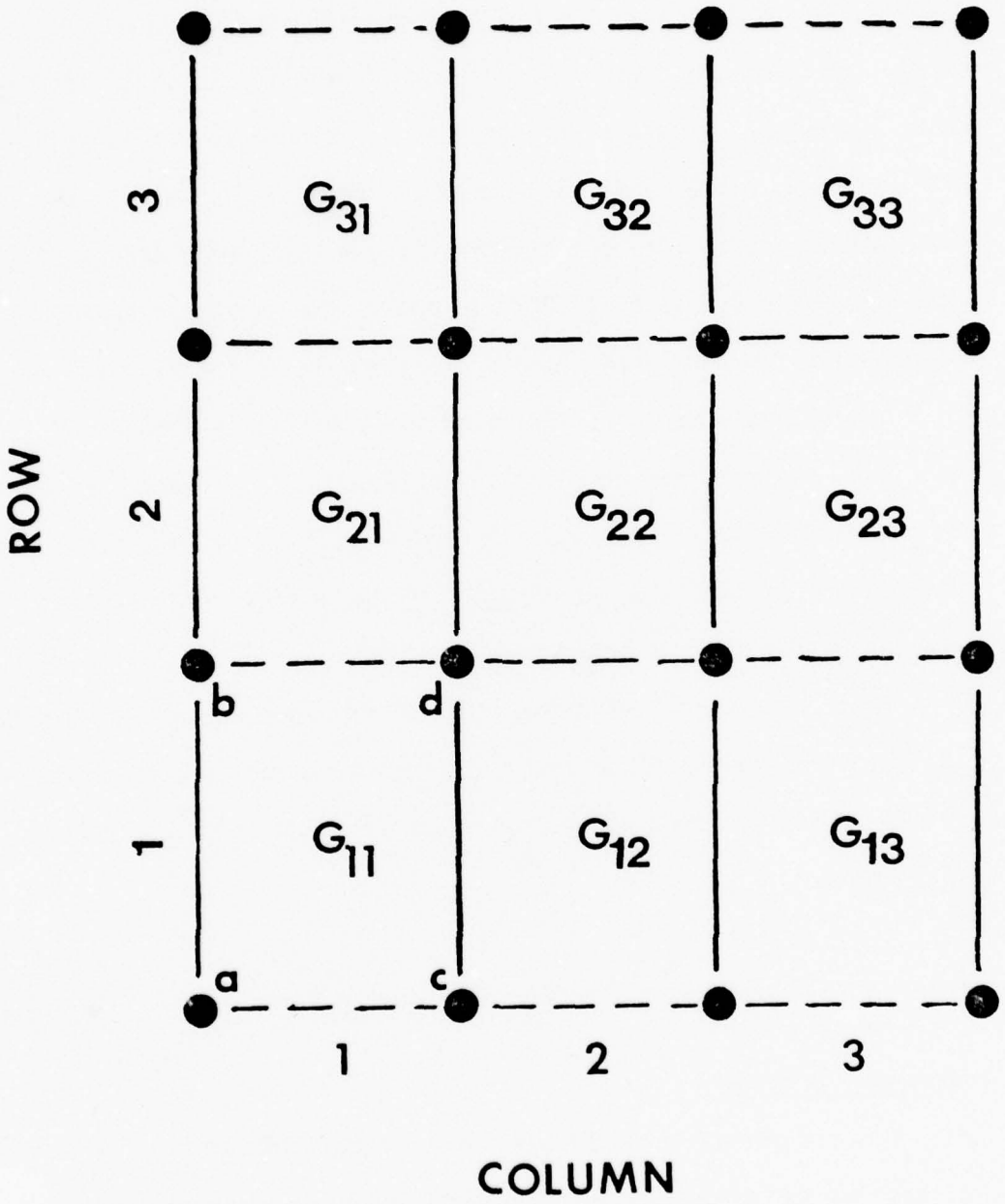



Fig. 4. Numbering scheme for columns, rows, and groups.

less dissimilar than the negatively correlated pairs ($F(1,180)=152.12$, $p<.001$, MSE=.86 for M.S.; $F(1,180)=22.31$, $p<.001$, MSE=.56 for S.T.). For M.S. direction interacted with group ($F(8,180)=3.59$, $p<.001$). The groups in column 3, the highest levels of height, had significantly more dimensional interaction than those in column 1. In addition, the three groups in row 1, the lowest levels of R, had significantly more interaction than those at the higher levels. The main effect of group for S.T. ($F(8,180)=4.76$, $p<.001$) is due to the general decrease in dissimilarity from the lowest levels of R, row 1, to the highest, row 3.

The analysis for S.T. indicated two significant effects of session. The main effect ($F(1,180)=6.47$, $p<.025$) reflected an overall drop in dissimilarity ratings. In addition, session interacted with direction ($F(1,180=4.76$, $p<.05$) so that the effect of direction decreased from session one to session two.

Thus, the major prediction, that H and R perceptually interact, was confirmed for both subjects. In addition, the amount of interaction varied systematically from group to group for M.S., but did not vary for S.T.

## Experiment Ib: Non-interacting Dimensions

### Stimulus Parameters

To discover stimulus dimensions that corresponded to the perceptual dimensions for triangles, a transformation of H and R was sought that would result in orthogonal axes through the psychological space. Figure 5 indicates informally how these perceptual dimensions were converged upon.

Drawing roughly parallel axes connecting stimuli 2 and 8; 1 and 7; 6 and 12; 5 and 16; 10 and 15; 9 and 14 in the configuration of interacting dimensions for M.S. indicates one potential dimension along which members of each of these pairs share a value. This dimension is the size of the lower right-hand interior angle of the triangle ($\alpha$). An axis roughly orthogonal to $\alpha$ in this space is specified by the height of the triangle multiplied by its right side (HR). An examination of triangles varied orthogonally on HR and $\alpha$ indicates that these stimulus dimensions approximately correspond to perceived size and shape. The relationship of HR and $\alpha$ to the psychological space for H and R is shown in Figure 5.

As a first approximation a set of 16 triangles produced by the orthogonal combination of these dimensions was presented to each subject and dissimilarity judgments obtained. The result indicated that for S.T. these did not correspond to independent perceptual dimensions. The two-dimensional multidimensional scaling configuration is shown in Figure 6 (stress = .09). The dimensions are mutually augmenting. As HR increases, constant levels of $\alpha$ perceptually grow; the reverse is also true.

Augmentation can be eliminated by adding a correction factor to $\alpha$ that decreases $\alpha$ slightly as size increases and by slightly decreasing the influence of the right side in the size dimension. By interpolating in the psychological space, exact values for these dimensions were determined. One dimension was $\alpha R^{.2}$. The size dimension became $HR^{.8}$.

Thus, two new stimulus sets were constructed, one for each

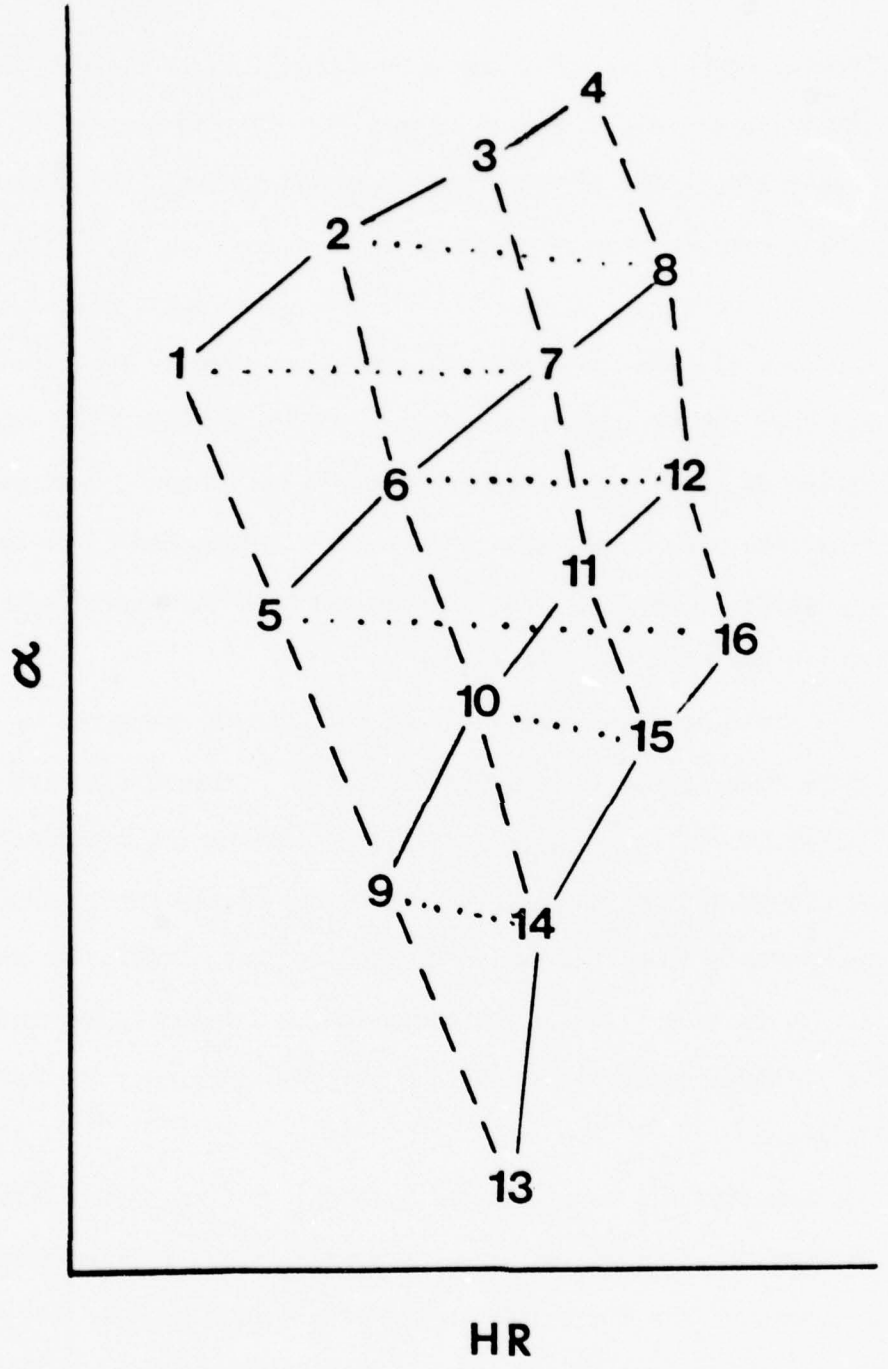



Fig. 5. Relationship between the perception of dimensions H and R and the physical dimensions HR and α. Solid lines connect stimuli of equal H, dashed lines equal R and dotted lines equal α.

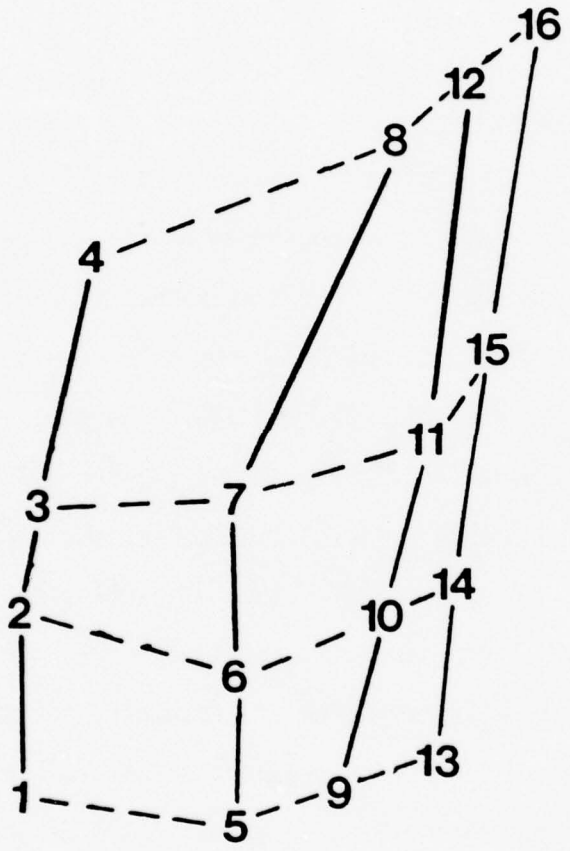



Fig. 6. Multidimensional scaling configuration for stimuli varying orthogonally on HR and $\alpha$ for subject S.T. Stress = .09.

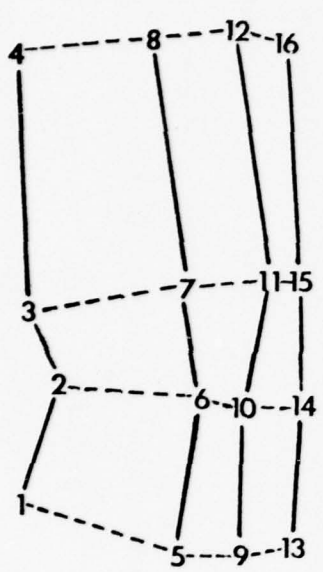
subject. Stimuli in each set varied orthogonally on two dimensions hypothesized to correspond to the perceptual dimensions for the subject. For M.S. the dimensions were HR--values 15.9, 42.2, 68.6, 94.9 cm--and $\alpha$--values 98, 120, 142, 164 deg. For S.T. the dimensions were $HR^{.8}$--values 8.9, 25.4, 44.5, 64 cm--and $\alpha R^{.2}$--values 175, 217, 259, 300 corrected deg. The two stimulus sets are pictured in Appendices C and D.

Results and Discussion

Analysis of dissimilarity judgments paralleled that for the interacting set. Again the Euclidean metric and two-dimensional solutions proved superior. For M.S. stress in one, two and three dimensions was .20, .03, and .03. For S.T. stress in one, two, and three dimensions was .29, .07, and .05. The two dimensional solutions using the City Block metric had stress .13 for M.S. and .21 for S.T.

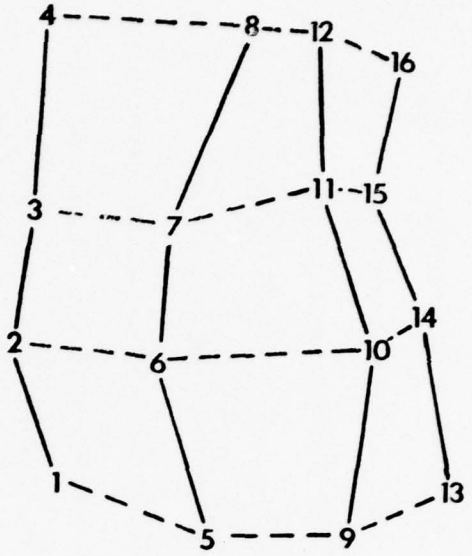
Figure 7 presents the Euclidean two-dimensional scaling configurations for M.S. and S.T. Solid lines connect stimuli of equal HR or $HR^{.8}$ and dashed lines connect stimuli of equal $\alpha$ or $\alpha R^{.2}$. In neither configuration is there evidence of systematic interaction between dimensions. When the points are constrained to lie along perfectly orthogonal axes corresponding to the stimulus dimensions for the set, stress increases slightly, for M.S. from .03 to .05 and for S.T. from .07 to .10.

The analysis of variance tables are given in Appendix F. For M.S. there was a small but significant effect of direction ($F(1,180)= 5.73$, $p<.025$, MSE=.68). There is, however, a clear contrast with the large effect of direction in the previous stimulus set. It is




S M.S. $HR \times a$

Stress = .03




S S.T. $HR^{.8} \times aR^{.2}$

Stress = .07

Fig. 7. Multidimensional scaling configurations of stimuli in Experiment Ib.

possible that dimensional interaction would not be reflected in a main effect of diagonal direction if the amount of augmentation were perfectly symmetric around the central levels of the influenced dimension. Such an interaction would show up as a group by direction interaction. S.T. exhibited such an interaction ($F(8,180)=2.04$, $p<.05$, MSE=.38). Columns 1 and 3 showed opposite effects of direction of correlation. To accept this as evidence of a systematic dimensional interaction requires judgments of $HR^{\cdot 8}$ intervals to systematically increase with increasing $\alpha R^{\cdot 2}$. An examination of multidimensional scaling configuration for this stimulus set does not confirm such a pattern. Rather, it appears that the opposite direction effects in columns 1 and 3 are the result of unequal but unsystematic unidimensional judgments in column 2.

The analyses of variance also revealed significant main effects of group for both subjects (for M.S. $F(8,180)=40.58$, $p<.001$; for S.T. $F(8,180)=6.94$, $p<.001$). For both subjects, judgments in column 1 were significantly larger than those for column 3 groups; that is, as size increased, equal or increasing physical intervals were perceived to be smaller. In addition, for M.S. rows 1 and 2 were narrower than row 3; equal physical differences perceptually increase with increasing $\alpha$. For S.T. row 1 was wider than rows 2 and 3; equal physical differences in $\alpha R^{\cdot 2}$ perceptually decrease with increasing $\alpha R^{\cdot 2}$. Finally, both subjects showed significant but opposite main effects of session.

To summarize, there was little evidence for dimensional interaction in either of these stimulus sets, and a sharp contrast in the amount of interaction with the previous sets. While the dimensions did

not interact, discriminability of adjacent values along each separate dimension varied significantly.

## Experiment Ic: Combined Set

Since the stimulus dimensions of the noninteracting set were derived from orthogonal axes in the psychological space of the interacting set it was assumed that these corresponded to the perceptual dimensions for that set. Nevertheless, a direct test of this assumption was warranted, to test the reliability of the pattern of dissimilarity judgments for each set in the context of the full range of variability provided by a combined set. Thus, the 32 triangles in this combined set consisted of the 16 triangles varying orthogonally on H and R and the 16 triangles varying orthogonally on the psychologically independent dimensions for each subject.

### Procedure

Subjects made seven judgments of each of the 496 possible stimulus pairs for the combined set. To insure a good mix of pairs from the two component sets during a session, the 496 pairs were decomposed into four blocks of 124 pairs. Each block contained 30 pairs of stimuli within each of the two component sets, chosen randomly, and 64 pairs containing one stimulus from each component set, again chosen randomly. Each session consisted of seven blocks, with three blocks presented twice and one block once. Order of blocks within a session was random with two constraints: a block could not follow itself, and each block appeared in each serial position once over the

course of four sessions. Thus, after four sessions each block of stimulus pairs had been presented seven times. Trials within a block occurred in a different random order for each block presentation. In all other respects sessions for the combined set were identical to previous sessions.

Results and Discussion

Since the first block in each session was considered practice, six judgments of each stimulus pair were averaged, and the mean dissimilarity ratings were subjected to nonmetric multidimensional scaling. Figures 8a and 9a are the resulting two-dimensional configurations for the two subjects. For ease of comparison to the configurations of each of the component sets the sixteen stimuli of the non-interacting set are connected by solid lines, and the sixteen stimuli from the interacting sets are connected by dashed lines.

The results both replicate the pattern of judgments made for each set in isolation, and indicate the perceived relationship between the sets. To determine if the configuration was consistent with the value of the 32 stimuli on the stimulus dimensions of the non-interacting set, the configuration was constrained to be consistent with those values. The resulting configurations are shown in Figures 8b and 9b. Stress increased slightly, from .07 to .08 for M.S. and from .13 to .14 for S.T. It is worth noting that these stress values are low given the large number of points, indicating that the configurations have recovered structure in the data and that the data were themselves reliable. By contrast, constraining the configurations according to the values of the stimuli on the psychologically interacting dimensions

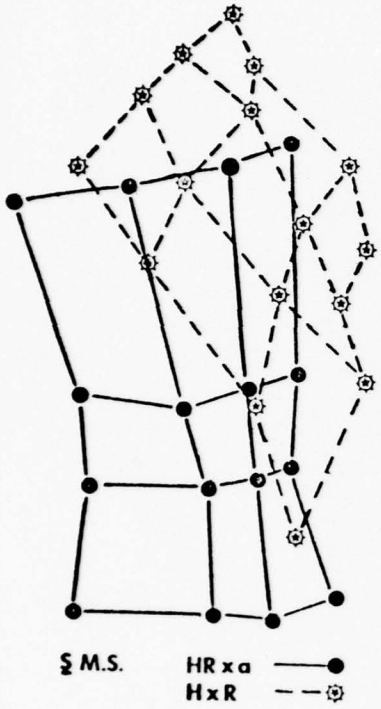



Fig. 8a. Unconstrained configuration. Stress = .07.

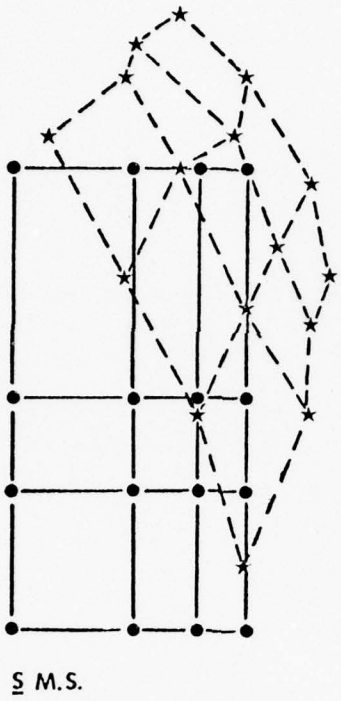



Fig. 8b. Configuration constrained by HR and α. Stress = .08.

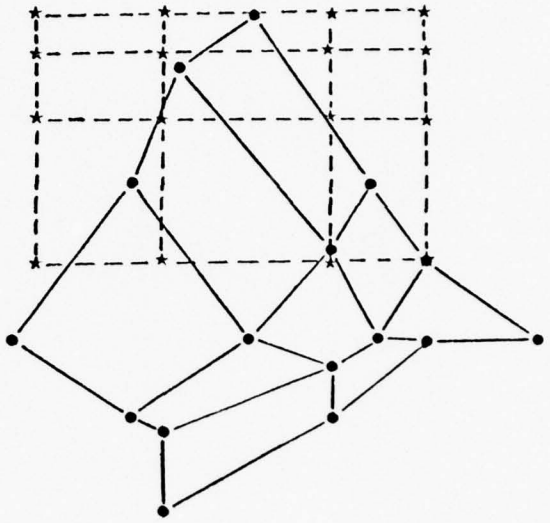


Fig. 8c. Configuration constrained by H and R. Stress = .19.

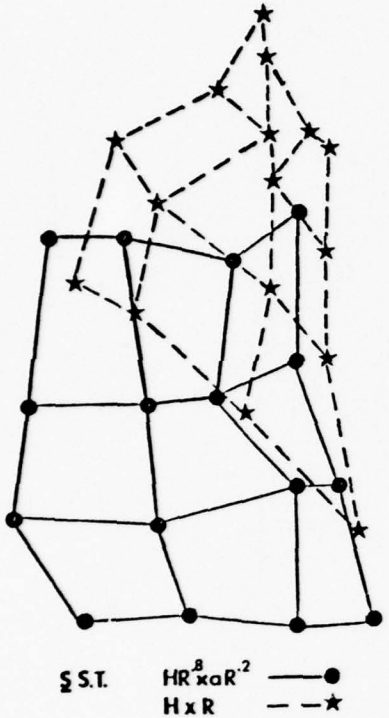



Fig. 9a. Unconstrained configuration. Stress = .13.

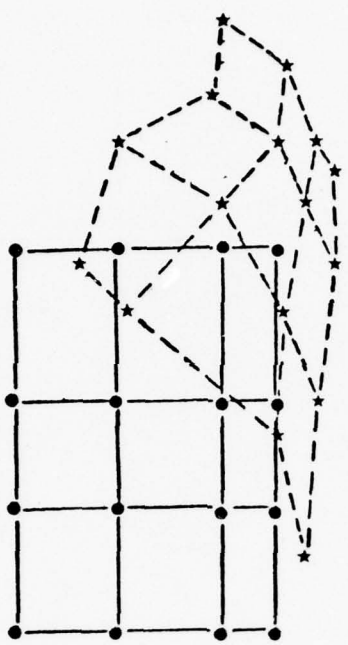



Fig. 9b. Configuration constrained by $HR^{.8}$ and $\alpha R^{.2}$. Stress = .14.

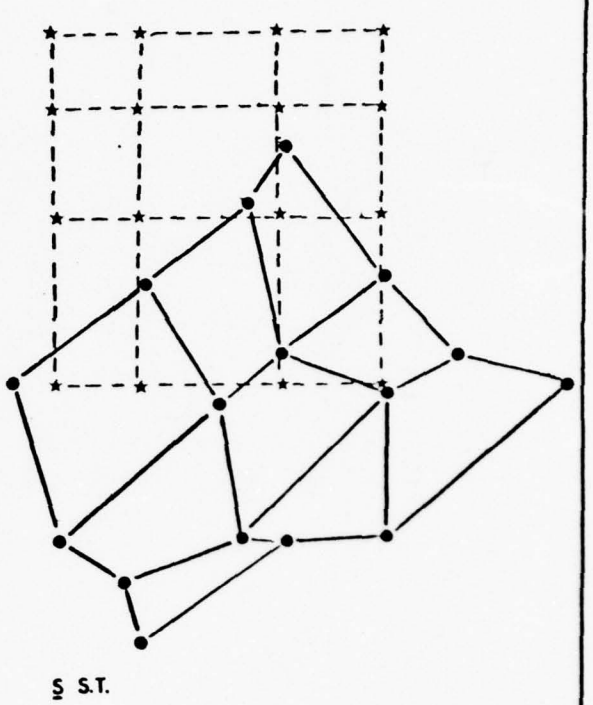



Fig. 9c. Configuration constrained by H and R. Stress = .21.

resulted in the solutions shown in Figures 8c and 9c. Stress is .19 for M.S. and .21 for S.T.

These results clearly indicate that the stimulus dimensions orthogonal in what was called the non-interacting set, dimensions HR and $\alpha$ for M.S. and $HR^{\cdot 8}$ and $\alpha R^{\cdot 2}$ for S.T., were the independent perceptual dimensions for both stimulus sets; the patterns of dissimilarity judgments for both sets were consistent with physical values on these dimensions. Thus, subjects based their dissimilarity judgments of triangles on perceptual dimensions that were inappropriate for one of the stimulus sets. Perceptual dimensions, while not necessarily entirely context-free, depend on a context larger than a particular stimulus set chosen arbitrarily from a larger domain.

# CHAPTER III

# EXPERIMENT II

This experiment tests the speeded classification predictions for the two stimulus sets developed in Experiment I. The predictions are based on the fact that dimensional interaction alters similarity both within a speeded classification response class and between response classes, as compared to the perceived similarity of unidimensionally varying stimuli. If these aspects of similarity are related to classification speed, then dimensional interaction should lead to interference and redundancy gain in speeded classification. By contrast, the non-interacting stimulus set should permit selective attention to the dimension relevant to classification and should not result in redundancy gain. Any interference and redundancy gain in the non-interacting set should be inversely proportional to the relative discriminability of the dimension relevant to classification. In sum, the speeded classification experiments afford a detailed exploration of the relationship between similarity and classification latency with interacting and non-interacting dimensions.

## Method

### Structure of the Experiment

Each of the two stimulus sets contains nine replications of the basic speeded classification experiment, allowing only adjacent values

of a dimension as the alternative classes in a given experiment. These nine replications consist of groups $G_{11}$ through $G_{33}$, as indicated in Figure 10. The perception of H was more influenced by R than vice versa, as indicated by the fact that lines in the scaling configurations connecting stimuli of equal R are parallel. Since the aim of Experiment II was to assess the role of dimensional interaction in speeded classification, H and its non-interacting counterparts HR or $HR^{\cdot 8}$ were used as the dimensions relevant to classification. Each of the nine replications in a stimulus set was based on four stimuli, the orthogonal combination of two adjacent values on each of the two orthogonal stimulus dimensions of a full set.

Associated with each replication or group of four stimuli are five conditions, five types of classification tasks. Consider, as an example, the stimulus group consisting of stimuli labelled a,b,c, and d in Figure 10. The dimension relevant to classification is the horizontal dimension in this figure; a and b are equivalent on this dimension, as are c and d. All four stimuli comprise the "orthogonal" condition of the speeded classification experiment, in which the subject must filter the orthogonally varying irrelevant dimension. There are two "unidimensional" conditions, stimulus a to be sorted from c or stimulus b from stimulus d. There are also two "correlated" conditions, consisting of stimuli a and d or stimuli b and c; here the irrelevant dimension is redundant with the relevant one. The condition using stimuli a and d will be termed positively correlated. The condition in which stimulus b is to be sorted from c will be termed negatively correlated. The distinction parallels the difference found between

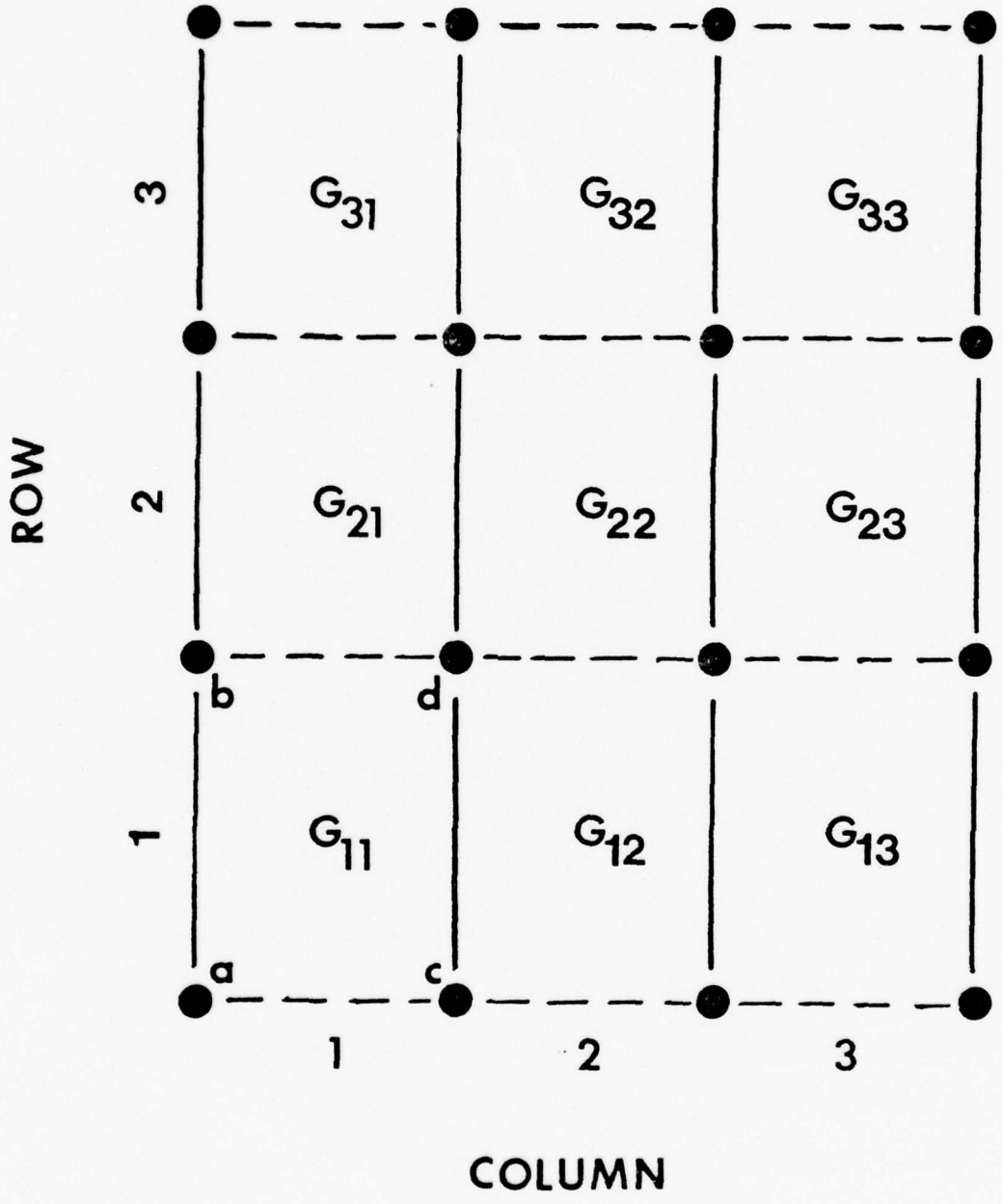



Fig. 10. Numbering scheme for columns, rows, and groups.

dissimilarity judgments for these two types of pairs in the interacting set.

Subjects completed all speeded classification tasks for one stimulus set before starting the second. S.T. classified stimuli of the non-interacting set first and M.S. classified stimuli of the interacting set first. Because he made a larger number of errors in both stimulus sets M.S. completed a second series of sessions for all speeded classification tasks, about one month after completing the first set of sessions. Results from the second series are presented here. Thus, the data from the two subjects differ in that those of M.S. represent extensive experience with both stimulus sets.

A session consisted of all speeded classification tasks for the three groups within a column of one stimulus set. Columns refer to pairs of adjacent values on the horizontal dimension as in Experiment I and as indicated in Figure 10. That is, in any given session stimuli varied on only two values of the relevant dimension and all four values of the irrelevant dimension. A session therefore contained three examples of the orthogonal condition, four unidimensional conditions, three positively correlated conditions, and three negatively correlated conditions, for a total of 13 different speeded classification tasks. The 13 tasks were done in a random order, followed in the same session by a second run of each in a different random order. Each stimulus set, then, took three sessions to complete, one session for each column. The order of the three columns was determined randomly. The orders were: M.S., H x R -- 2,1,3, HR x $\alpha$ -- 2,3,1; S.T., H x R -- 3,1,2, $HR^{.8}$ x $\alpha R^{.2}$ -- 2,3,1.

Procedure

At the beginning of each session, subjects were shown the stimuli to be classified and the response to be made to each. There were two possible responses for each session, corresponding to the two values of the relevant dimension used during a session. Because simply naming the relevant dimension was not thought to be very useful for describing the stimulus classes, subjects were allowed to study all eight stimuli for as long as was necessary for them to feel confident that they could distinguish the classes. They were urged to discover the attribute that the stimuli in a class shared and that distinguished the two classes. When subjects were asked to name this attribute, the typical response was "size." Subjects were also urged not to memorize the specific triangles, but rather to determine for each presentation in the sorting task whether the triangle had the small or large value of the attribute, and to make the appropriate response. Subjects were also specifically told to ignore the second attribute, that which distinguished members of a class, in making their response.

During the actual classification task, stimuli were presented on the CRT and subjects responded by pushing one of two microswitches. The left index finger corresponded to "small" throughout the sessions, and the right index finger corresponded to "large." Prior to each of the 26 tasks run during a session, the two or four stimuli in that condition were presented one at a time on the CRT along with the words "small left" or "large right" to describe the stimulus value and response. Subjects studied the stimuli presented in this way for as long as they wished, then initiated the series of trials. A trial

consisted of the presentation of a small warning dot in the center of the screen for 500 msec, followed by the presentation of a single triangle, also centered on the screen. The presentation of the triangle was terminated by the production of a response. The screen remained blank for 1500 msec and was followed by another trial.

There were 12 practice trials followed by 40 actual trials in a task. Thus, there were ten presentations of each stimulus in the orthogonal condition and 20 presentations of each stimulus in the remaining conditions. Stimuli were presented in a random order. Subjects were cautioned to respond as accurately as possible, and within that limitation as quickly as possible; accuracy was stressed. Subjects took a five minute break between the two halves of a session. A session took approximately 90 minutes.

## Results and Discussion

Analyses of variance were performed on correct classification latencies and error frequencies separately for the two stimulus sets and the two subjects. Factors in the latency analysis were type of condition (orthogonal vs. unidimensional vs. positively correlated vs. negatively correlated), column (or session), run, group within column, and stimulus (the two or four stimuli in a group). "Group" here refers to the three or four tasks of each type within a column or session. For every condition but the unidimensional, groups correspond to the groups as numbered in Figure 10. Since there are four unidimensional tasks within a column, the unidimensional groups in column 1, for example, would be numbered $G_{11}$ through $G_{41}$. Trials were

treated as replications and used as the error term. Because it was desirable to maintain a constant task length of 40 trials, there were half as many replications per stimulus in the orthogonal condition. Factors in the error analysis were type, column, run, group, and hand (left vs. right). Error frequency for each cell was transformed by $\sqrt{x} + \sqrt{x+1}$ to stabilize the variance, following Freeman and Tukey (1950). Analysis of variance tables appear in Appendix G. Contrasts given below are significant with 95 percent Scheffé confidence intervals, unless otherwise indicated.

Errors

Mean error rates were low, .01 and .02 for M.S. in the non-interacting and interacting stimulus sets, and .03 and .02 for S.T. Analysis of errors in the interacting stimulus set yielded no significant effects for S.T. For M.S., there was a significant type x column x run x hand interaction ($F(6,18)=3.37$, $p<.025$, MSE=.60). There were no significant differences between conditions on run two or in column 1. In columns 2 and 3 more errors were made with the left hand than the right, most markedly in the orthogonal condition. Right-hand errors decreased from column 2 to column 3, while left-hand errors remained high.

In the non-interacting set, S.T. made more errors in the orthogonal condition than the two correlated conditions ($F(3,18)=6.90$, $p<.025$, MSE=.74). A significant column x hand interaction ($F(2,18)=3.69$, $p<.05$) indicates that there were more left-hand errors, most markedly in column 3.

For M.S. there was a significant type x column x hand interaction

($F(6,18)=10.66$, $p<.001$, MSE=.26). Errors were higher for the left hand in column 3, for the orthogonal condition. The column x hand x run interaction ($F(2,18)=6.25$, $p<.01$) is due to a decrease of the effect in run two.

Dissimilarity and Classification Latency

The proposed correlation between dimensional interaction on one hand and interference and redundancy gain on the other was based on the hypothesis that classification latency is directly related to similarity. That hypothesis can be directly tested in this experiment by examining classification latency for the unidimensional condition. To be most applicable to the filtering situation, similarity should be measured along the dimension relevant to classification. Analyzing unidimensional stimuli provides freedom from the assumptions that underlie the derivation of univariate similarity from similarity judgments of bivariate stimuli.

Analysis of the dissimilarity judgments indicated that for both subjects stimulus pairs in column 3 of the non-interacting stimulus set were perceived as less dissimilar than those in column 1. The effect of column of the non-interacting stimulus set on unidimensional latency was significant (M.S., $F(2,887)=111.99$, $p<.001$, MSE=3494; S.T., $F(2,869)=3.68$, $p<.05$, MSE=38827). For both subjects, latency for column 3 was significantly longer than for column 1. Since column is perfectly confounded with session, interpreting these results is less than straightforward. For both subjects, the order of sessions was columns 2,3, and 1. Since a practice effect would also lead to the superiority of column 1 over column 3, the effect of dissimilarity

cannot be isolated.

The role of dissimilarity in the interacting stimulus set is clearer. The effect of dimensional interaction in this stimulus set is to decrease dissimilarity for unidimensional pairs within a column, as the level of R increases. The factor group in the analysis of variance of classification latency evaluates this effect. The effect of group in the unidimensional condition was significant for both subjects (M.S., $F(9,890)=5.24$, $p<.001$, MSE=2799; S.T., $F(9,884)=11.13$, $p<.001$, MSE=48564). Figure 11 presents classification latencies for the four unidimensional pairs, averaged over column for the two subjects. Again, groups are numbered from low values of R (high discriminability) to high values of R. While Figure 11 averages over column for clarity, there was a significant effect of group within each column for both subjects. The first subscript of each group refers to value of R, numbered from low to high. The second subscript refers to column. For M.S., there were significant increases in latency from $G_{31}$ to $G_{41}$, from $G_{32}$ to $G_{42}$, and from $G_{23}$ to $G_{33}$. For S.T., latency increased significantly from $G_{11}$ to $G_{41}$, from $G_{32}$ to $G_{42}$, and from $G_{23}$ to $G_{33}$ to $G_{43}$.

Another aspect of judged dissimilarity in the interacting stimulus set permitted a test of the dissimilarity-latency relationship. There is a difference in perceived dissimilarity between positively and negatively correlated pairs in the interacting set, such that the positively correlated pairs are judged less dissimilar. This is paralleled by a latency difference between these conditions in the speeded classification task for both subjects. For S.T., the posi-

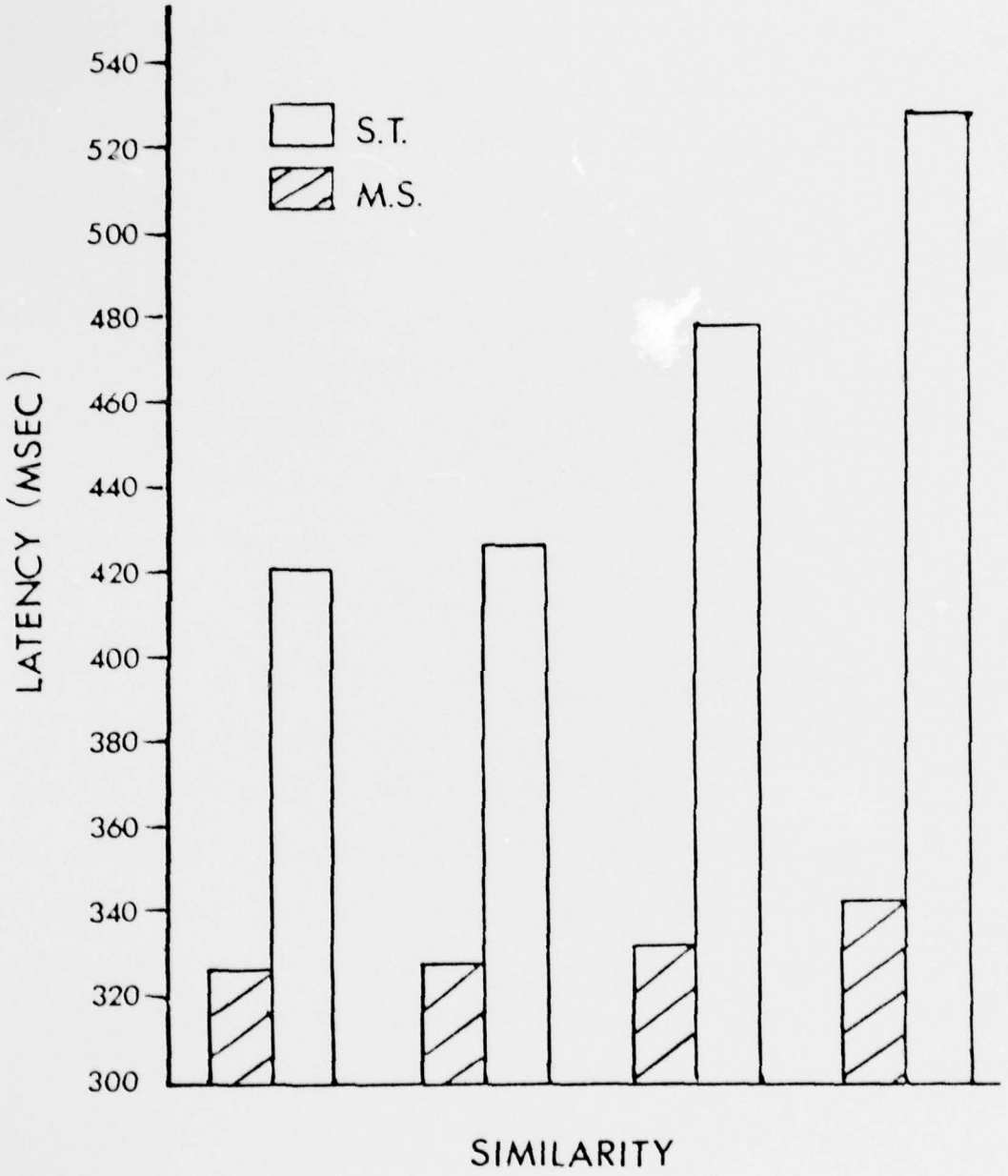



Fig. 11. Latency for the four unidimensional pairs as a function of increasing R, averaged over column. As R increases, similarity increases.

tively correlated condition was longer by 56±28 msec. For M.S., the positively correlated condition was longer by 10±9 msec, $p<.10$. Furthermore, a difference of 16±8 msec between the two correlated conditions in the noninteracting set for M.S. was due to column 1. An examination of the multidimensional scaling configuration for the stimulus set (Figure 7a) indicates that there is a corresponding disproportion of diagonal distances in this column.

Thus, two pieces of evidence strongly support the correlation between classification latency and similarity. As the similarity of unidimensional pairs increased with increasing R in the interacting set, classification latency increased. In addition, the greater similarity of positively correlated pairs as compared with negatively correlated pairs was accompanied by longer latencies.

Interference and Redundancy Gain

Interference is defined as the classification latency for the orthogonal condition minus that for the unidimensional condition. Redundancy gain is defined as the classification latency for the unidimensional condition minus that for the correlated condition. These quantities are evaluated by the type factor in the analysis of variance of classification latency. Since there are two correlated conditions, there are two measures of redundancy gain.

Interacting dimensions. For M.S. the significant effect of type ($F(3,2831)=63.09$, $p<.001$, MSE=4753) was largely due to interference, 42±10 msec. Since the higher latency for the orthogonal condition was accompanied by more errors, there was no evidence of a speed-accuracy tradeoff. Latency for the positively correlated condition was slightly

but significantly higher than the unidimensional condition, by 12±9 msec, consistent with the higher similarity of positively correlated pairs due to dimensional interaction.

Interpreting the lack of redundancy gain with the negatively correlated condition for M.S. is difficult due to the confounding of session and column. Both the increase in interference and the increase in dimensional interaction from column 1 to column 3 suggest that redundancy gain should be most marked in column 3 as well. Unfortunately, column 3 was also the third column presented, so that the subject was most practiced. That practice had an effect is supported by the fact that latency for the unidimensional, as well as that for the negatively correlated condition, decreased from column 1 to column 3; the decrease in discriminability across these columns would predict an increase in latency for the unidimensional condition. A further increase in speed for the negatively correlated condition, which would have resulted in redundancy gain, may have been impossible due to a floor effect created by practice. Latency for the negatively correlated condition in column 3 was 324 msec. That for the corresponding stimuli in the unidimensional condition was 319 msec.

The interaction between type and run for M.S. ($F(6,2831)=17.00$, $p<.001$) was due to a decrease with run in classification time for the orthogonal condition. Interference decreased from 64±15 msec in run one to 22±14 msec in run two.

For S.T. there was a significant effect of type ($F(3,2833)=33.54$, $p<.001$, MSE=38485). Mean interference was 51±28 msec. Redundancy gain when measured by the difference between the unidimensional and negatively correlated conditions was 51±28 msec, but classification latency

for the positively correlated condition was not significantly smaller than the unidimensional condition. "Redundancy gain" for S.T. will therefore refer to the gain in classification speed for the negatively correlated condition.

The effect of type interacted with run for S.T. ($F(3,2833)=4.42$, $p<.005$). Interference decreased with run and redundancy gain increased due to a 58±36 msec increase in the classification time for the unidimensional condition.

Non-interacting dimensions. For M.S. both a significant amount of interference, 41±8 msec, and a significant amount of redundancy gain, 35±8 msec for the positively correlated condition and 51±8 msec for the negatively correlated condition, were found. As before, the high error rate in the orthogonal condition was paralleled by longer latency. The interaction of type with run for M.S. ($F(3,2853)=5.34$, $p<.001$, MSE=3047) was due to increases in latency for the unidimensional and positively correlated conditions with run.

For S.T. the significant effect of type ($F(3,2791)=14.48$, $p<.001$, MSE=29703) was due solely to redundancy gain. Redundancy gain for the negatively and positively correlated conditions did not differ. Mean redundancy gain was 31±26 msec. Differences between type conditions did not vary with run.

## Interaction vs. Relative Discriminability

Evidence that interference and redundancy gain occurred in the speeded classification of both interacting and non-interacting stimulus sets confirms the notion that integrality as defined by speeded classification results is not unitary. Two aspects of interdimensional

relationships, dimensional interaction and discriminability along the relevant dimension as compared to the irrelevant dimension, have been theoretically connected with interference and redundancy gain.

The analysis of variance of dissimilarity judgments in Experiment I indicated that for M.S. column 3 of the interacting set had significantly more interaction than column 1, and row 1 had more interaction than rows 2 and 3. Thus, the effect of dimensional interaction on interference and redundancy gain can be assessed in the analysis of classification latency in the interacting set via the interaction of type with column and with group within column. Similarly, the variation in relative discriminability of the relevant dimension from group to group in the non-interacting set for both subjects allows a test of the effects of relative discriminability via the interaction of type with column and with group in the non-interacting set.

Mean latency in each type condition for each of the nine groups in each stimulus set is given in Appendix H.

Interacting dimensions. For M.S. interaction of type with column was large ($F(6,2831)=41.5$, $p<.001$); interference increased from column 1 to column 3. The effect of group within column was largest in the orthogonal condition ($F(6,610)=7.21$, $p<.001$, MSE=11678). Interference was significantly higher in row 1 than rows 2 and 3, for columns 1 and 2.

The effects of column and group on interference for M.S. suggest that the amount of interference correlates with the amount of dimensional interaction. To test this prediction, a measure of dimensional interaction was computed for each of the nine groups in the interacting

set from the multidimensional scaling configuration, Figure 3a. Basing dimensional interaction on distance rather than the original dissimilarity ratings themselves was more reliable, since the scaled distance between two stimuli is based on the pattern of dissimilarities for the entire stimulus set. Interaction was defined to be the ratio of the distance between members of a negatively correlated pair to that between members of the positively correlated pair.

The correlation between interaction and interference for M.S. was .77, $p<.05$. Figure 12 depicts the relationship between interaction and interference. The points in Figure 12 are labelled with the appropriate group numbers. The lack of redundancy gain for this stimulus set made a test of the correlation between interaction and redundancy gain uninformative.

For S.T. there was also a significant interaction of type with column ($F(6,2833)=10.67$, $p<.001$). Interference and redundancy gain were significantly larger in column 3 than in columns 1 and 2. The variation of interference and redundancy gain from group to group within column 3 is revealed by variation in the effect of group across the different type conditions. The groups in column 3 are labelled $G_{13}$, $G_{23}$, and $G_{33}$, from lowest to highest values of length of right side. Each group was 2 unidimensional conditions. Because the two unidimensional conditions of $G_{23}$ differed significantly from one another (see Figure 11; these conditions are labelled groups 2 and 3), it was difficult to calculate a meaningful indicator of interference and redundancy gain for $G_{23}$. Interference and redundancy gain measured as deviations from the mean unidimensional condition latency for $G_{13}$ were 58 and 6 msec. Interference and redundancy gain for $G_{33}$ were 286

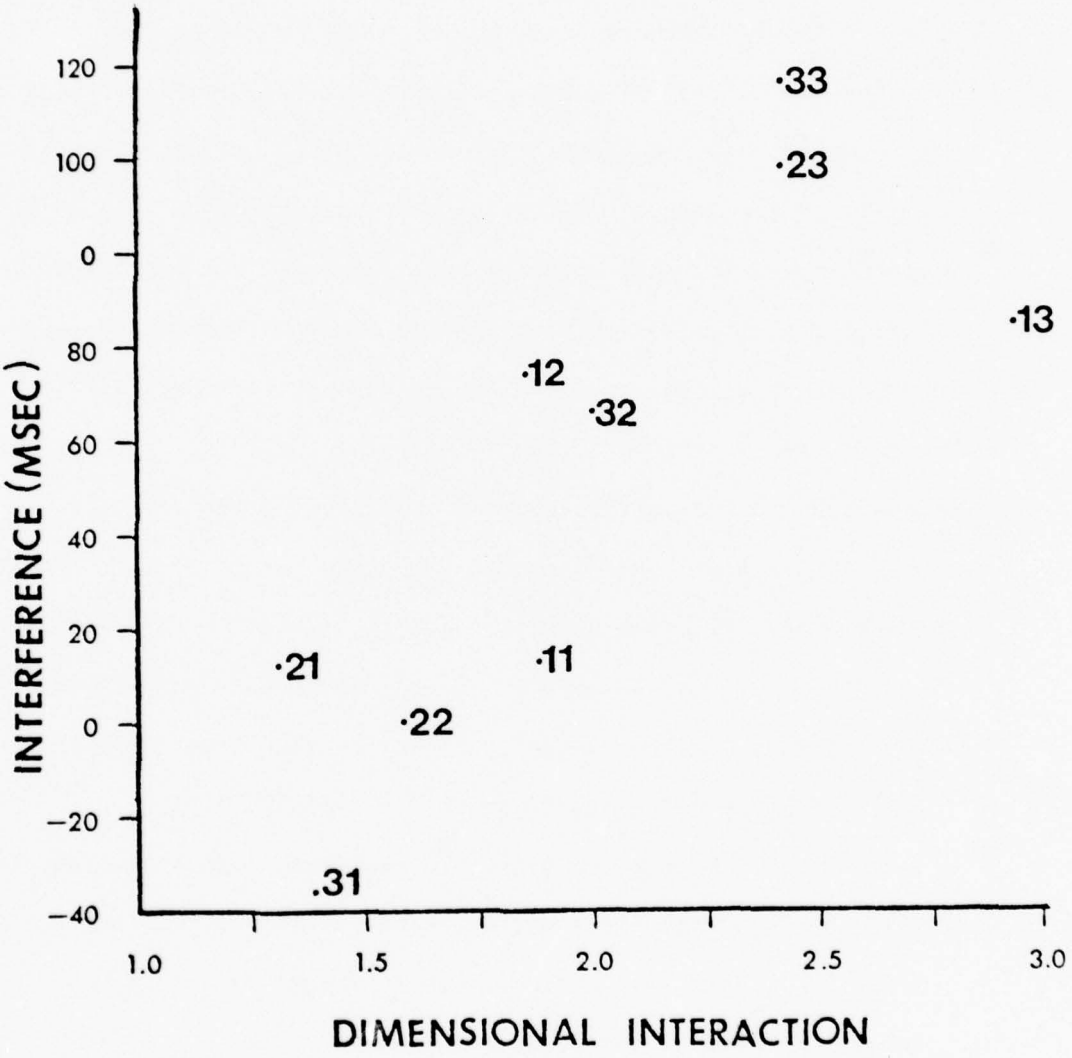



Fig. 12. Interaction and interference for each of the nine stimulus groups of the interacting set, subject M.S.

and 218 msec. Confidence intervals had halfwidth 45 msec.

The variability in dimensional interaction for S.T. from group to group within the interacting stimulus set was much smaller than that for M.S. Thus, a strong test of the interaction-integrality relationship at this detailed level was not possible. The correlation of interaction with interference was .41, with redundancy gain .31, $p > .05$.

The main effect of group on dissimilarity judgments of the interacting set for S.T. suggests that a second factor, relative discriminability of the relevant dimension, may have played a role in determining latency for this stimulus set. However, the low correlation of relative discriminability with interference and redundancy gain for the interacting set, .06 and -.09, argues against this possibility. Furthermore, there were more interference and redundancy gain in column 3 of the interacting set (93 and 114 msec) than in column 3 of the non-interacting set (41 and 51 msec), but these groups of the interacting set had higher relative discriminability. Since higher relative discriminability should lead to lower interference and redundancy gain, it is unlikely that the latency effects in the interacting stimulus set for S.T. are due solely to relative discriminability.

While the correlation between dimensional interaction and interference or redundancy gain was not high within the interacting stimulus set for S.T., there was a significantly larger effect of type in the interacting stimulus set than in the non-interacting set ($W(16,1406) = 2.08$, $p < .025$, where w is the ratio of the two F's, following Bradley and Schumann, 1957). This fact, along with the high correlation between interaction and interference within the interacting set for M.S., supports the dimensional interaction theory of integrality:

interference and redundancy gain in speeded classification are directly correlated with psychological interaction between stimulus dimensions.

Non-interacting dimensions. The occurrence of interference and redundancy gain in the non-interacting stimulus set was proposed to be due to high discriminability of the irrelevant dimension, as compared to the relevant dimension. If latency is a function of the similarity between stimuli to be distinguished in classification, classifying stimuli by attending to the irrelevant dimension will be faster than the unidimensional control on the relevant dimension. It should not be faster than the appropriate control, the unidimensional condition on the more discriminable dimension. Obtaining interference from a highly salient but non-interacting irrelevant dimension is based on the assumption that salience attracts attention to irrelevant information, thus increasing classification time.

For M.S., interference and redundancy gain in the non-interacting set increased from column 1 through column 3 ($F(6,2831)=71.41$, $p<.001$), paralleling both the increase in judged similarity with column found in Experiment I and the increase in classification errors with column. The difference between groups within columns was most marked for the orthogonal condition ($F(6,626)=11.62$, $p<.001$, MSE=5019). Within columns 2 and 3, classification latency increased from group 1 to group 3, with a difference of $63\pm40$ msec in both cases.

For S.T., the interaction of type with column was also significant. ($F(6,2791)=4.82$, $p<.001$). A significant amount of redundancy gain was found only in column 3, paralleling the high error rate for column 3. An analysis of the effect of group indicated that redundancy

gain was largest in group 3 of column 3, at 85±80 msec.

To test the correlation of relative discriminability with interference and redundancy gain, relative discriminability of the relevant dimension was computed for each of the nine stimulus groups in the non-interacting set. To compute discriminability, the interstimulus distance along the relevant dimension for the two unidimensional pairs of a groups were averaged. The result was divided by the mean distance along the irrelevant dimension for pairs at a single level of the relevant dimension.

For M.S. relative discriminability correlated with interference -.82, $p<.01$ and with redundancy gain -.77, $p<.05$. For S.T. there was no interference in the non-interacting set. Relative discriminability correlated with redundancy gain -.80, $p<.01$. Figures 13 through 15 depict the scatter plots for these correlations.

While both dimensional interaction and unequal discriminability of dimensions yielded speeded classification results typical of "integral" stimuli, relative discriminability is far removed from the phenomenological definition of integrality. Given the additional theoretical distinctions that can be drawn between interaction and relative discriminability, the value of the speeded classification task for converging on phenomenological integrality without knowledge of the underlying psychophysics is questionable.

Unlike dimensional interaction, discriminability along a pair of dimensions depends on the particular values chosen on those dimensions, not on the dimensions themselves. If proper values are chosen then the two dimensions are identifiable and neither interference nor redundancy

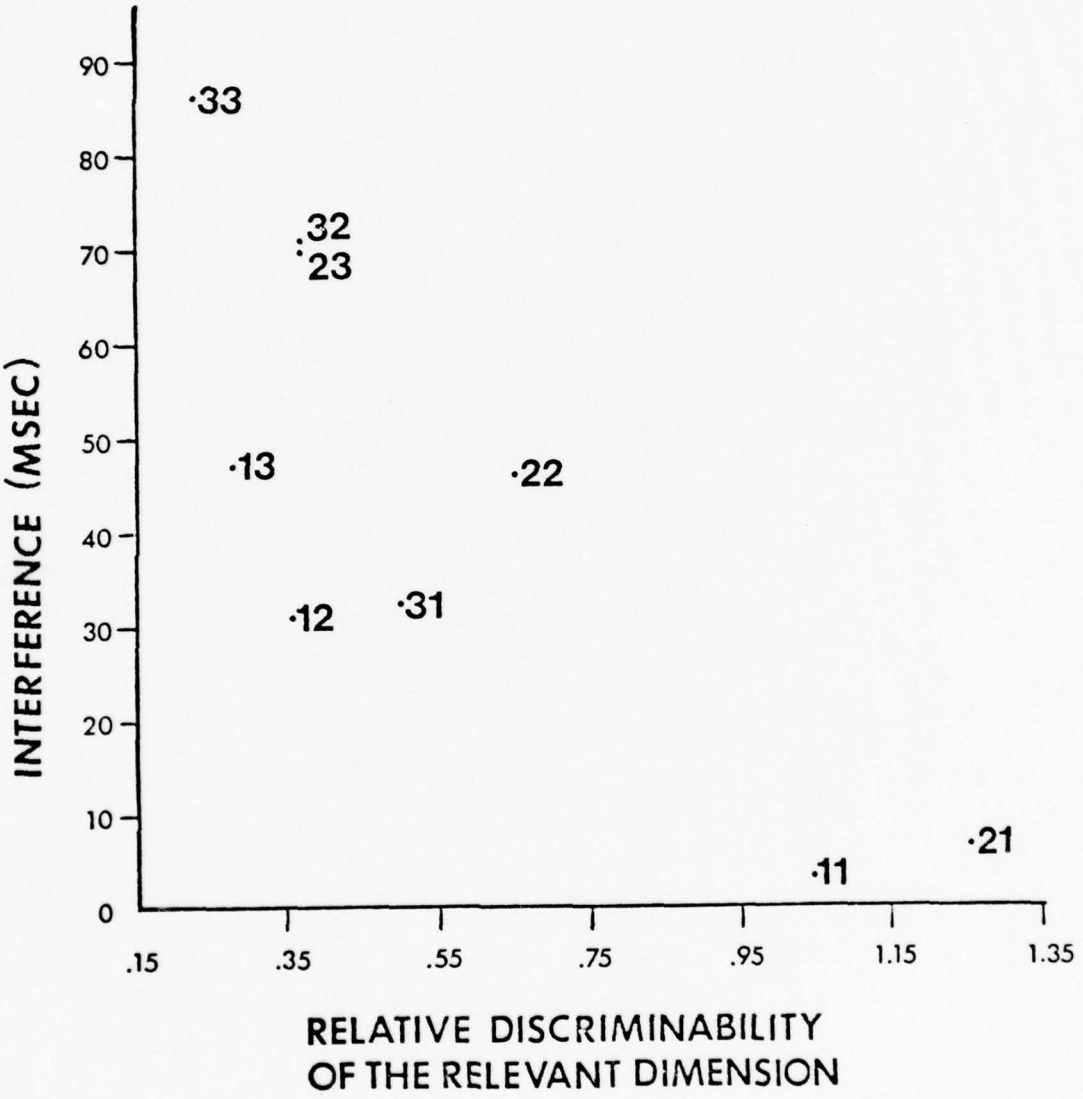



Fig. 13. Discriminability and interference for each of the nine stimulus groups of the non-interacting set, subject M.S.

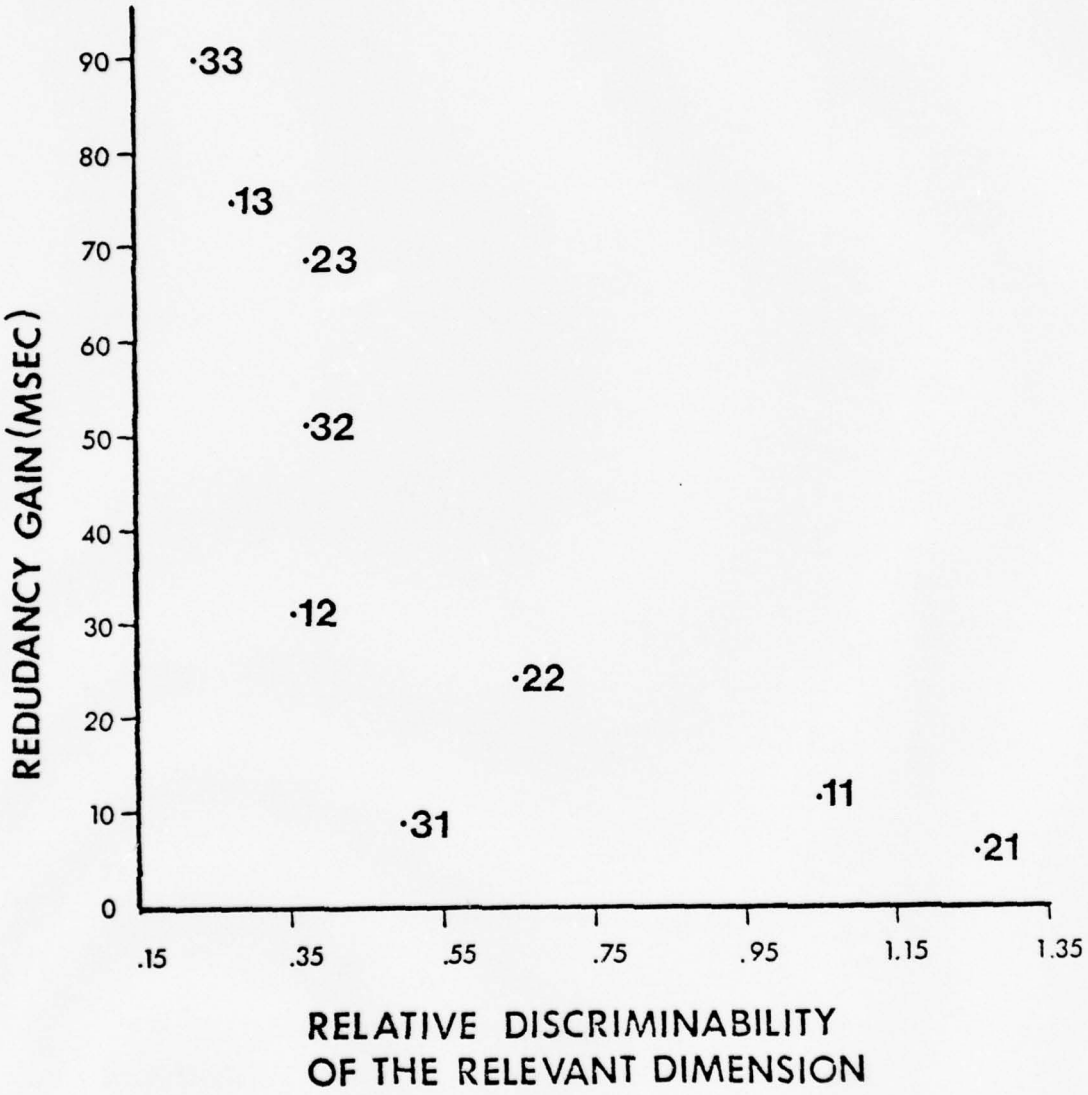



Fig. 14. Discriminability and redundancy gain for each of the nine stimulus groups of the non-interacting set, subject M.S.

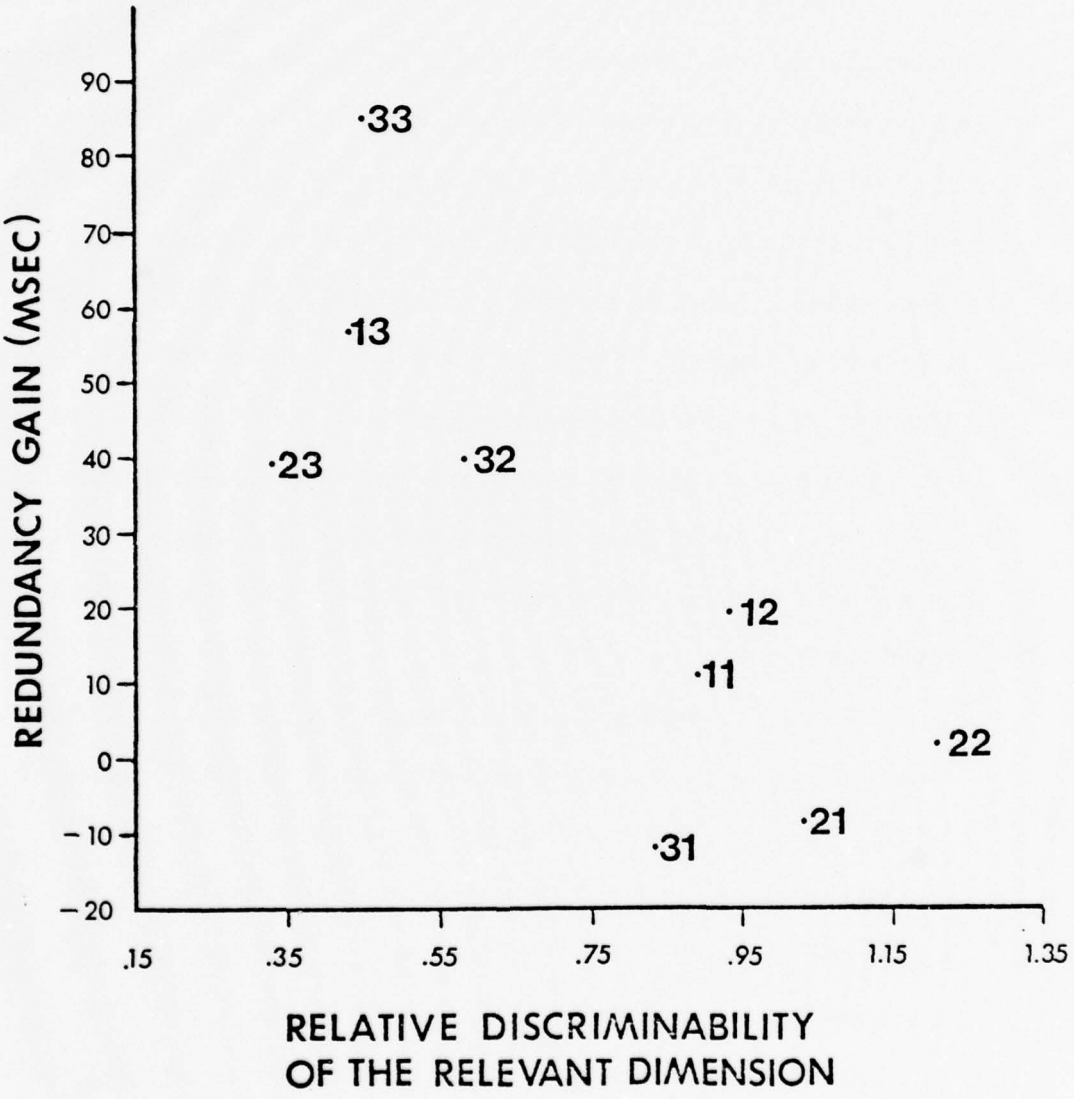



Fig. 15. Discriminability and redundancy gain for each of the nine stimulus groups of the non-interacting set, subject S.T.

gain result. This was true in the non-interacting set for groups of stimuli for which perceived dissimilarity along the two dimensions was equal, that is for groups $G_{11}$ and $G_{21}$ for M.S. and groups $G_{11}$, $G_{12}$, $G_{21}$, $G_{22}$ for S.T. In the case of interaction, dissimilarity judgments reveal that the irrelevant dimension actually alters perceived values along the relevant dimension. Two stimuli that are physically identical on an interacting dimension are not psychologically identical; their difference is systematically influenced by the second dimension. This implies that the two dimensions are not entirely psychologically distinguishable. When dimensions are unequally discriminable but not interacting, however, the orthogonality of psychological axes implies that the dimensions are psychologically distinguishable. The ability of the more salient dimension to distract can be seen through multidimensional scaling as increased dissimilarity between two stimuli along one dimension, while perceived values of the other dimension remain intact.

Thus, two psychophysically different aspects of dimensional relationships implying different underlying psychological processes result in interference and redundancy gain in speeded classification. The consequent ambiguity of those performance patterns in speeded classification diminishes the value of the task as an operation converging on phenomenological integrality. Furthermore, since both factors are based on aspects of the relationship between perceived dissimilarity and classification latency, it is this relationship that is the more parsimonious predictor of results in the speeded classification task.

# CHAPTER IV

## EXPERIMENT III

Since a distinction between unequal discriminability of dimensions and dimensional interaction can be drawn both on theoretical grounds, in terms of the psychological processes involved, and on operational grounds, in terms of dissimilarity judgments, it is of benefit to distinguish the effects of these variables on performance in the speeded classification task.

Furthermore, while it is clear that an imbalance of discriminability in favor of a stimulus dimension irrelevant to classification can lead to both a failure of selective attention and a gain in classification time with correlated dimensions, it is less clear that the interaction of equally discriminable dimensions also results in appreciable interference and redundancy gain: Relative discriminability correlated highly with interference and redundancy gain in the non-interacting stimulus set. Dimensional interaction in the interacting stimulus set also correlated highly with interference for one subject, but there was no redundancy gain. For the second subject interference and redundancy gain were strongest in a stimulus group with fairly low discriminability of the relevant dimension. Experiment III was designed to clarify the roles of dimensional interaction and relative discriminability in speeded classification.

Because the effect of dimensional interaction is to alter discriminability along at least one dimension, the measurement of relative discriminability cannot be exact in a group of four stimuli whose physically orthogonal dimensions psychologically interact. While this experiment varied discriminability and interaction independently in terms of operational definitions given below, functional discriminability and interaction could not be completely controlled. The additivity of these effects, therefore, is not a critical indicator of the distinction between them. Instead, two other indicators are useful. First, changes in each of the factors, interaction and relative discriminability, should influence interference and redundancy gain when the other is held constant, although the absolute size of the influence is not meaningful. Obtaining a significant effect of interaction when discriminability is held constant at a high level will support the dimensional interaction theory for S.T., for whom the results of Experiment II were not conclusive.

The second, more clear-cut demonstration of the distinction is based on the difference between dissimilarity judgments of positively correlated and negatively correlated stimulus pairs. Increasing dimensional interaction for the dimensions used here decreases the distance between positively correlated stimuli and should therefore decrease redundancy gain when measured using this stimulus pair. Redundancy gain measured in terms of the negatively correlated pair should increase with increasing interaction. Decreasing relative discriminability, when there is no dimensional interaction, will increase pairwise distance identically for both types of pairs, and should result in an increase in redundancy gain for both.

## Method

### Stimuli

Discriminability and interaction are operationally defined as in Experiment II. Specifically, consider the four stimuli of a group, a,b,c, and d. In this stimulus group stimuli a and b share a value on the dimension relevant to classification, and a and c share a value on the irrelevant dimension. If d(a,b) is the distance between stimuli a and b as given by the Euclidean distance between them in the multidimensional scaling configuration, the relative discriminability of the relevant dimension is defined for this stimulus group as $\frac{d(a,c)+d(b,d)}{d(a,b)+d(c,d)}$. Interaction for this group is defined as the ratio of the diagonal pair distances, that is, $\frac{d(b,c)}{d(a,d)}$. Values for interaction and discriminability were calculated from the multidimensional scaling configurations of dissimilarity judgments of single stimulus sets, which had lower stress than the combined sets.

New groups of four stimuli were chosen from the stimulus sets of Experiment II to provide groups varying orthogonally in discriminability and dimensional interaction. For M.S. there were six groups of stimuli comprising two levels of interaction and three levels of discriminability. Interaction was varied by using groups in column one vs. column three of the interacting stimulus set. Relative discriminability was manipulated by increasing the distance between stimuli on the irrelevant dimension.

Columns within the interacting stimulus set did not vary as much in interaction for S.T. In order to obtain a clear contrast in amount

of interaction, two high-interaction groups were constructed by selecting stimuli from the interacting set, and two low-interaction groups were constructed by selecting stimuli from the non-interacting set. The groups from the interacting set were equated at a high level of interaction and varied in discriminability so that in one case the dimensions were approximately equal in discriminability and in the other case the irrelevant dimension was more discriminable. The two groups from the non-interacting set were matched as closely as possible with these in relative discriminability, but were low in interaction. Values of discriminability and interaction for the stimulus groups used for each subject are given in Table 1.

Procedure

A session consisted of two runs of all speeded classification tasks constructed from the stimulus groups at a single level of interaction. Thus, for M.S. three stimulus groups were presented in a session, for a total of 13 tasks composed as in Experiment II. For S.T. there were two stimulus groups per session. The high interaction session consisted of ten tasks, one orthogonal, two unidimensional, and two correlated conditions per group. Since the low-interaction groups shared a unidimensional condition, the low-interaction session contained nine tasks.

With the exception of session length for S.T., procedure within a session was identical to that in Experiment II. Two sessions at each interaction level were run, a total of four sessions per subject. The order of sessions was low interaction, high, high, low.

TABLE 1

STIMULUS GROUPS FOR EXPERIMENT II

Subject M.S.[a]

| Stimuli | Interaction | Discriminability |
|---|---|---|
| 1-4-5-8 | 1.26 | .42 |
| 1-3-5-7 | 1.39 | .61 |
| 2-3-6-7 | 1.26 | 1.18 |
| 9-12-13-16 | 1.83 | .40 |
| 10-12-14-16 | 2.32 | .73 |
| 11-12-15-16 | 2.46 | 1.24 |

Subject S.T.[b]

| Stimuli | Interaction | Discriminability |
|---|---|---|
| 2-4-6-8 | 1.03 | .49 |
| 2-3-6-8 | 1.00 | 1.00 |
| 10-7-14-11 | 2.20 | .55 |
| 3-4-11-8 | 2.00 | 1.07 |

[a]Stimulus numbers for M.S. refer to stimuli in Figure 3a.

[b]Stimulus numbers for low-interaction stimuli for S.T. refer to Figure 7b. Stimulus numbers for high-interaction stimuli for S.T. refer to Figure 3b.

## Results

The analysis of variance of classification latency included error latencies for ease of analysis. Error rates were low: .02 for M.S. and .03 for S.T. Correlation of error latency with mean correct latency across type x interaction x discriminability cells was .73 for M.S. and .72 for S.T. There were five factors in the analysis of latency. The first was type, the difference between the speeded classification conditions. Since a group-by-group examination of results was the target of the analysis, the unidimensional condition was divided into the lower unidimensional and the upper unidimensional condition for each stimulus group, for a total of five types of condition. Other factors were interaction and discriminability. Two practice factors were session (the two sessions of an interaction level) and run. As before, analyses were done separately for each subject, with the 40 trials of each task used as the error term.

The analysis of variance of error frequencies paralleled the latency analysis, with the exception that session and run were combined into a single practice factor and the interaction of practice with the three main factors was used as the error term. Error frequencies were transformed as in Experiment II. Full analysis of variance tables are given in Appendix I. Confidence intervals given below are 95 percent Scheffé confidence intervals.

### Errors

The analysis of error frequencies revealed a significant effect of type for both subjects ($F(4,24)=3.76$, $p<.025$, MSE=.62 for M.S.; $F(4,12)=6.01$, $p<.01$, MSE=.98 for S.T.). More errors occurred in the

orthogonal condition than the remaining conditions, for both subjects. The interaction x practice effect was also significant for both subjects ($F(3,24)=3.82$, $p<.05$ for M.S.; $F(3,12)=4.11$, $p<.05$ for S.T.). For M.S., errors at both interaction levels decreased with practice, but decreased more quickly with high interaction stimulus groups. Error frequencies for the two levels were about equal on the first and last runs. For S.T. there were significantly more errors with the high interaction stimulus groups than the low in every run but the last, where that pattern was reversed.

Interference and Redundancy Gain

The result of most interest with regard to latency is the interaction between type, discriminability, and dimensional interaction. This triple interaction indicates the effects of the two stimulus variables and their interaction on contrasts between the speeded classification conditions.

For M.S. latencies in the two unidimensional conditions of each of the six stimulus groups were not significantly different from one another, so mean unidimensional latency for a group was used to calculate interference. As before, interference refers to the increase in classification latency for the orthogonal condition, where both dimensions vary, over that for the unidimensional condition. The variation of interference with interaction and discriminability differed across sessions and runs. The five-way interaction was significant ($F(8,4680)=5.26$, $p<.001$, MSE=7808). Interference is plotted as a function of interaction and discriminability for the four session-run combinations in Figure 16.

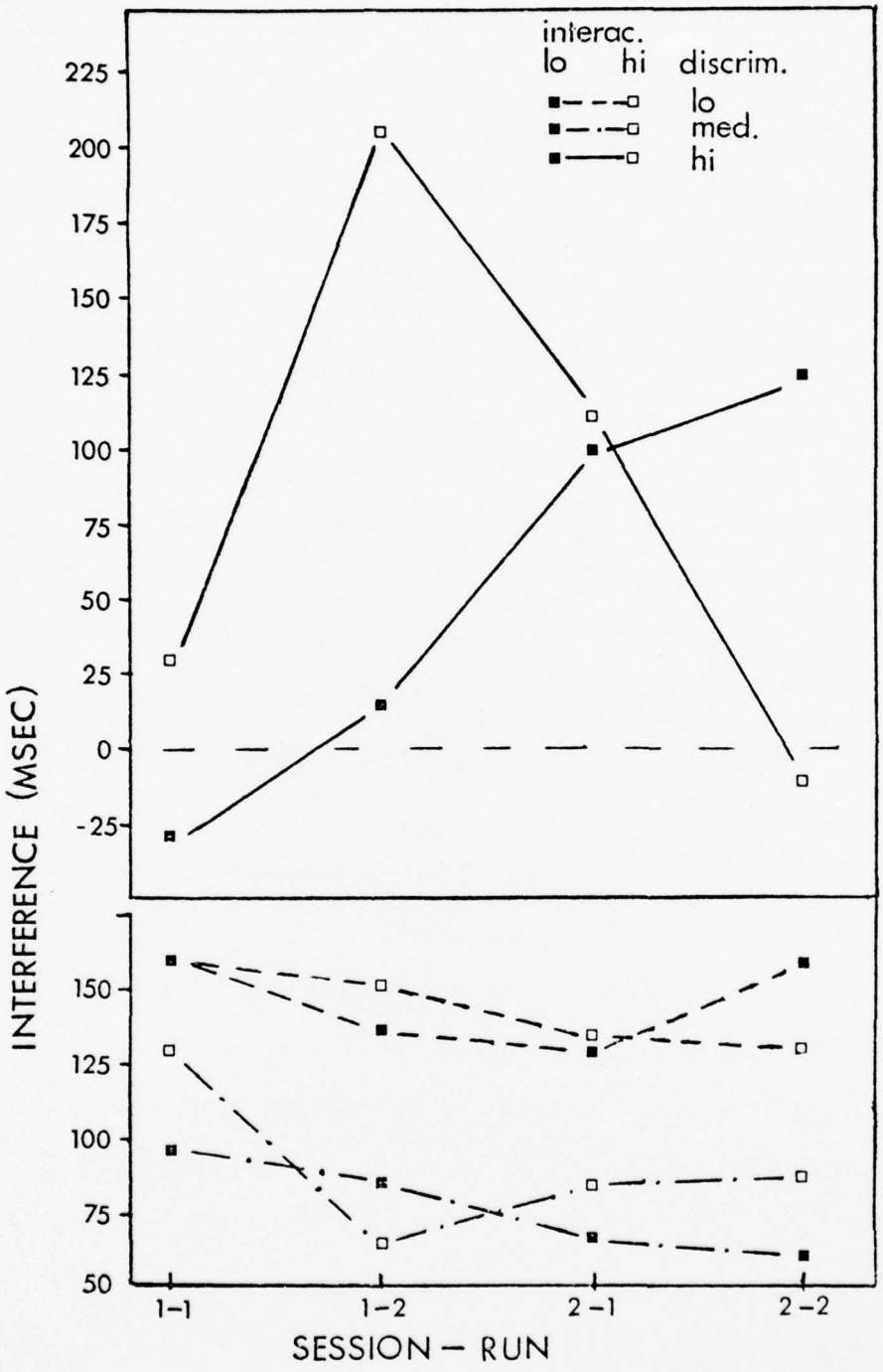



Fig. 16. Interference as a function of dimensional interaction, relative discriminability of the relevant dimension, and practice, subject M.S.

At low and medium levels of discriminability, there was no effect of interaction on interference, and interference decreased significantly as the discriminability of the relevant dimension increased. The only effect of practice was a decrease in interference from Session 1 - Run 1 to succeeding runs with medium discriminability. At the highest level of discriminability, where the relevant dimension was more discriminable than the irrelevant, there was a significant effect of interaction which changed with practice. The effect of interaction increased with run in Session 1, then decreased and eventually reversed with further practice. The results can be summarized in this way: When the dimension irrelevant to classification was more discriminable than the relevant dimension, differences in relative discriminability determined the degree of success in selective attention. When the relevant dimension was more discriminable than the irrelevant, success of selective attention depended on dimensional interaction, but the effect of interaction changed with practice.

There was no significant overall redundancy gain for M.S., measured in terms of either correlated condition. More theoretically relevant, however, is the fact that there were significant changes in redundancy gain of both types with changes in discriminability and dimensional interaction. Figure 17 illustrates redundancy gain as a function of interaction and discriminability for run one, averaged over sessions. There was no significant variation in redundancy gain with any factor in run two in either session. For clarity of presentation, only low and high discriminability groups are shown. Note that

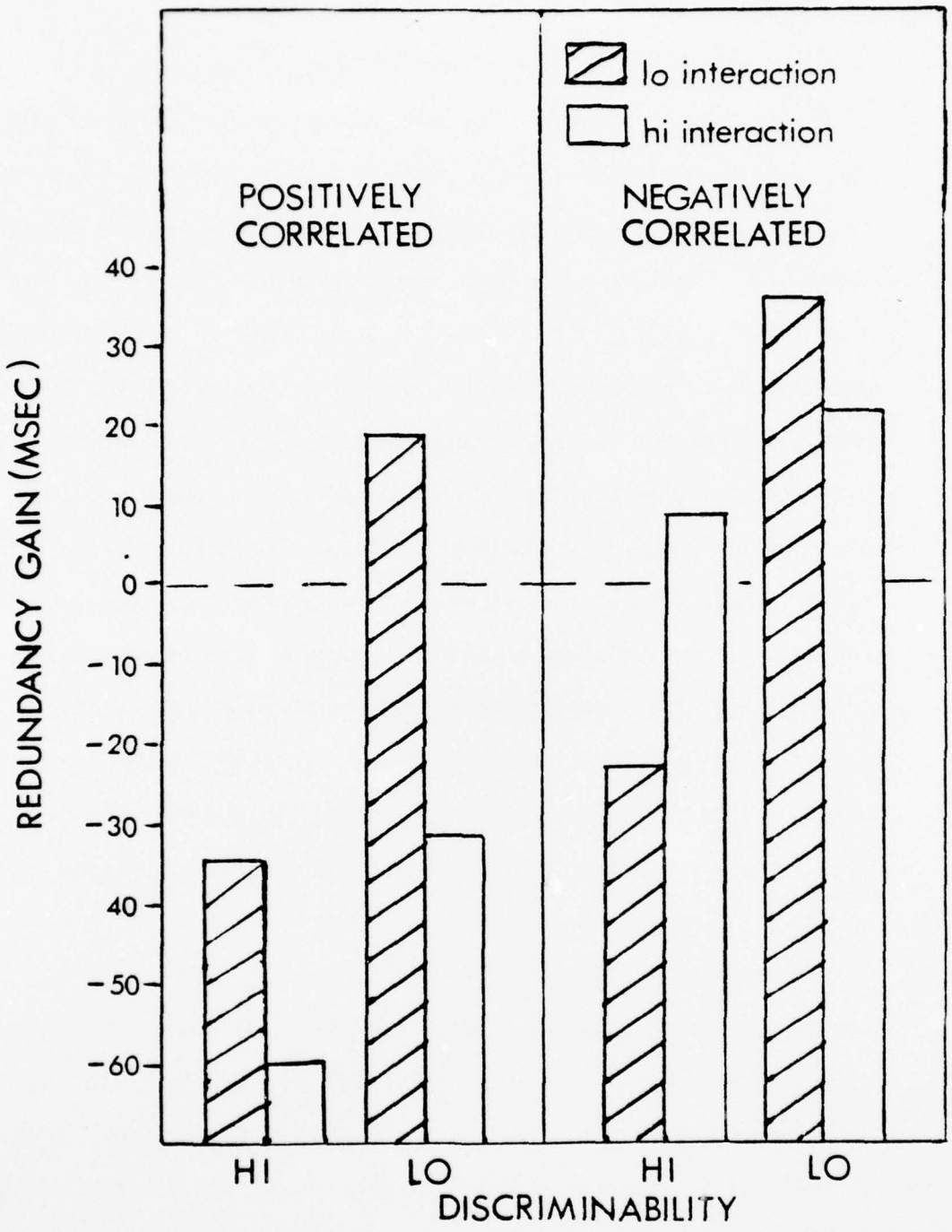



Fig. 17. Redundancy gain as a function of interaction, discriminability, and direction of correlation, subject M.S.

the term redundancy gain is actually a misnomer, for the correlated conditions do not consistently represent a gain in classification speed over the unidimensional condition. Thus, positive numbers on the ordinate indicate a gain in classification speed with redundant dimensions and negative numbers indicate a loss.

When dimensional interaction was low, redundancy gain increased with decreasing discriminability for both the negatively and positively correlated conditions. When dimensional interaction was high, redundancy gain for the positively correlated condition increased slightly with decreasing discriminability. As dimensional interaction increased, redundancy gain for the positively correlated condition decreased, but redundancy gain for the negatively correlated condition remained the same (low discriminability) or increased (high discriminability).

It was not possible to calculate interference and redundancy gain meaningfully for each stimulus group for S.T., due to variability in the unidimensional conditions. When dimensional interaction was high, the lower and upper unidimensional conditions of each stimulus group differed, and did so in opposite directions for the two groups. In the low discriminability group, the lower unidimensional condition was 63 msec slower than the upper unidimensional condition. In the high discriminability group, the upper unidimensional condition was slower by 92 msec. Thus, while there was significant interference, 60$\pm$ 23 msec, and negatively correlated condition redundancy gain, 45$\pm$23 msec, meaningful comparisons of interference and redundancy gain cannot be made between stimulus groups. Figure 18 presents latency for the orthogonal and correlated conditions as a function of interaction and discriminability.

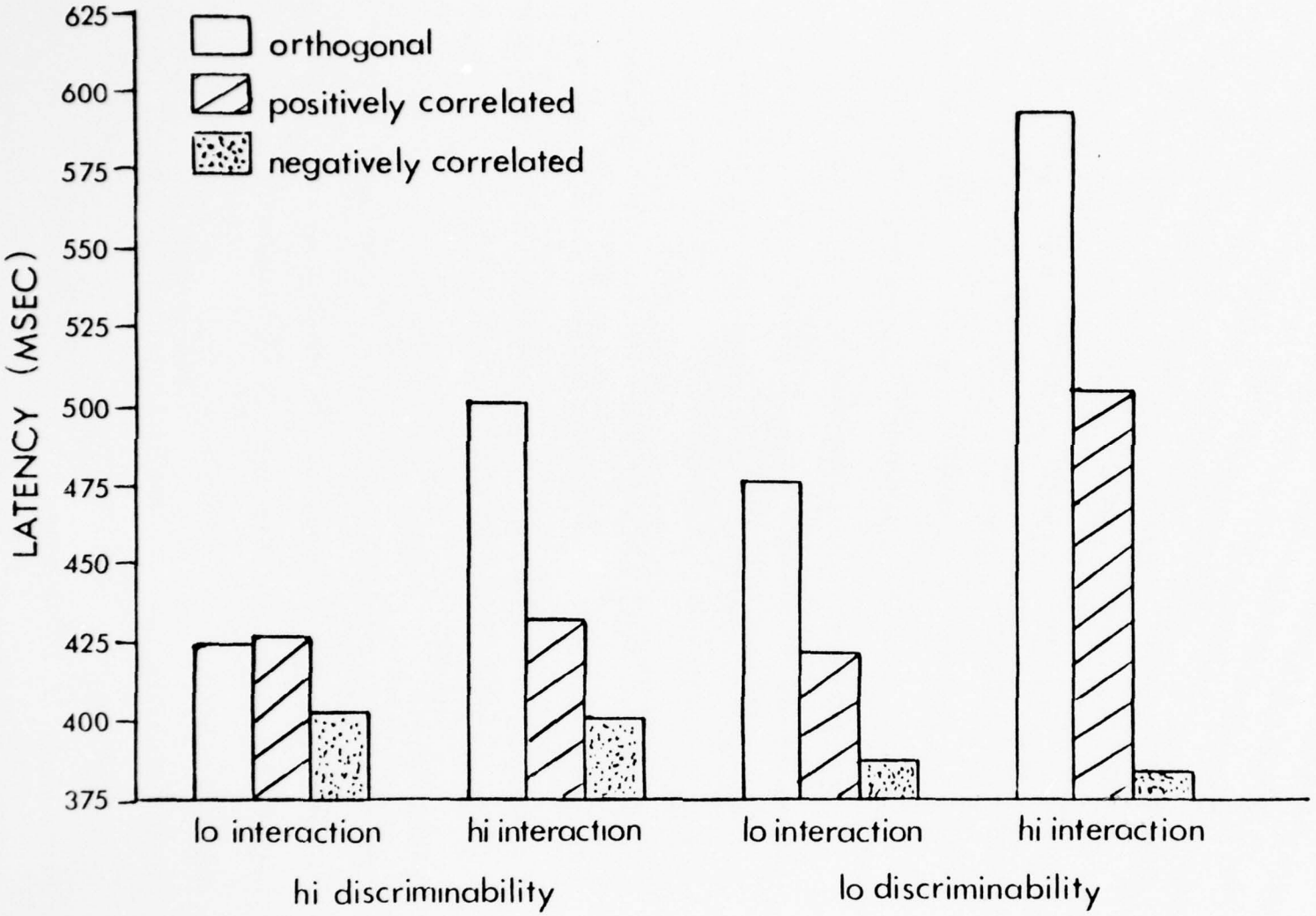



Fig. 18. Latency in three speeded classification conditions as a function of interaction and discriminability, subject S.T.

Classification latency for the unidimensional condition can be thought of as a balance point for variation in performance of the speeded classification task as different combinations of stimuli from a given group are classified. While there is not a clear balance point in two of the stimulus groups for this subject, an idea of the variation in classification latency within a stimulus group as a function of discriminability and dimensional interaction can be obtained by contrasting the orthogonal and negatively correlated conditions. Since results in the previous experiment indicated that for both stimulus sets interference and redundancy gain are roughly symmetrical for this subject, a statistic calculated by subtracting latency in the negatively correlated condition from that in the orthogonal condition is a reasonable measure of departure from a theoretical balance point. With regard to this measure, there is a significant interaction between discriminability and dimensional interaction. Classification latency in the orthogonal condition increases significantly with each factor as the other is held constant. The joint effect of the factors is overadditive.

Figure 18 indicates that neither interaction nor discriminability had significant effects on latency in the negatively correlated condition. Constant latency in this condition does not imply constant redundancy gain, however. With low discriminability, redundancy gain significantly increased as interaction increased, comparing the negatively correlated condition to either unidimensional condition for these groups. The predicted interaction between discriminability, dimensional interaction, and positively vs. negatively correlated

condition latency was significant. This was due solely to the high latency for the positively correlated condition with high discriminability and low dimensional interaction.

Practice effects for S.T. were interactions between type, dimensional interaction, and run ($F(4,3120)=4.15$, $p<.005$, MSE=22975); type discriminability, and run ($F(4,3120)=2.43$, $p<.05$); and type, discriminability, and session ($F(4,3120)=3.64$, $p<.01$). The effect of dimensional interaction tended to increase with practice, while the effect of discriminability decreased.

## Discussion

If it were possible to measure exactly that aspect of relative discriminability that is relevant to speeded classification, then the expected independence of discriminability and interaction would be indicated by the additivity of the effects. For neither subject was additivity obtained: M.S. exhibited evidence of underadditivity; for S.T. the effects on both the orthogonal and positively correlated conditions were overadditive. It is difficult to interpret these results, however, because it is questionable that the relative discriminability of stimulus dimensions that are not psychological is pertinent to classification behavior. The interaction between the two factors, dimensional interaction and discriminability, may be due at least in part to the fact that the nature of the measurement of relative discriminability changes as interaction changes: when interaction is high, mean discriminability along a dimension is different from discriminability as measured by either component of the mean.

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An additional factor in the production of interference is nevertheless suggested by the overadditivity found for S.T. For both subjects, the low interaction stimulus groups were essentially identical in absolute discriminability as well as relative discriminability of the relevant dimension. For S.T. the same was not true of the high interaction groups. Here, the group that was lower in relative discriminability of the relevant dimension was lower in absolute discriminability of that dimension as well. This inequality in absolute discriminability may have contributed to the apparent overadditivity of dimensional interaction and relative discriminability.

One goal of the present series of experiments was to reproduce speeded classification data typical of integral dimensions using interacting dimensions. For S.T. there was some question as to whether the speeded classification results for interacting dimensions in Experiment II could be accounted for by low absolute or low relative discriminability of the relevant dimension, as opposed to dimensional interaction. The 100 msec contrast between the orthogonal and negatively correlated condition in the high interaction, high discriminability stimulus group in the present experiment weighs heavily against this interpretation. While again there is some question about the exact value of relative discriminability for this group, both relative discriminability and the absolute discriminability of each unidimensional pair in this group are as large as that for the low interaction group, where there was a 21 msec effect.

The differential effects of dimensional interaction and discriminability on the positively correlated-negatively correlated condition

contrast for M.S. support the relationship between perceived similarity and classification latency. Increasing dimensional interaction and decreasing relative discriminability had opposite effects on the similarity of positively correlated stimuli, resulting in contrasting redundancy gain effects. The correlation of redundancy gain with perceived similarity has important implications for the nondimensional theory of integrality. The theory assumes that stimuli differing on two dimensions are more discriminable than those varying unidimensionally. If integrality consists of attention to two dimensions, redundancy gain with integral stimuli would be inevitable. Data from Experiment I indicate that the assumption is incorrect: positively correlated stimuli in the interacting set were often judged more similar than unidimensional stimuli. Experiment III confirms the expected relationship: latency for the positively correlated pair in the high discriminability-high interaction group was significantly longer than mean latency for the unidimensional pairs. This "redundancy loss" with integral stimuli is consistent with the dimensional interaction theory of integrality, but is not explainable within the framework of the nondimensional theory.

For S.T. the positively correlated condition was slower than the negative in all groups, even where pairs were judged equally similar in Experiment I. In speeded classification, attention may have switched to a dimension not directly perceived in Experiment I, a dimension on which the positively correlated pairs were more similar. One with this dimension characteristic is $\alpha$. Thus, there is tentative evidence for context dependency of psychological dimensions, at least when the subject is under speed stress.

# CHAPTER V

## GENERAL DISCUSSION

Taken together, these experiments have shown that failures of selective attention to a single dimension of a multidimensional stimulus set occur when the dimensions of the set interrelate in either of two ways: when they interact and when they are not equally discriminable. That the perception of a dimension less discriminable than another is impaired relative to the equidiscriminable case has been noted previously (Egeth & Pachella, 1969; Garner & Felfoldy, 1970). Both the high correlations of relative discriminability of the relevant dimension with interference and redundancy gain in Experiment II and the systematic effect of further decreases in relative discriminability in Experiment III support the applicability of independently obtained dissimilarity judgments as an indicator of discriminability to speeded classification behavior.

Two aspects of the results of Experiments II and III confirm the fact that dimensional interaction is sufficient for the production of "integral" speeded classification behavior. First, for both subjects, interference correlated highly with interaction. For M.S. this was evidenced most strongly in Experiment II, with a correlation between the two factors of .77. For S.T. significant interference occurred in the interacting stimulus set in Experiment II, but did not occur without dimensional interaction. In Experiment III, changes in dimensional

interaction significantly affected latency for S.T. with relative discriminability constant at either level. Secondly, for both subjects and both experiments, classification latency for positively correlated pairs was greater than that for negatively correlated pairs in interacting stimulus groups where positively correlated pairs were consistently judged less dissimilar.

Unequal discriminability of stimulus dimensions can be theoretically distinguished from what is generally meant by integrality, and can be operationally distinguished, as demonstrated by Experiment III, from dimensional interaction. The operational distinction consists of two parts, the differential effects of discriminability and interaction on classification latency for positively correlated and negatively correlated dimensions, and the demonstration that both relative discriminability and interaction have significant effects on interference when the other is held constant.

Since the major goal of the present experiments was to shed light on the dimensional basis of integrality, the discussion will largely be concerned with a consideration of dimensional interaction. The demonstration that perceptual interaction between physically orthogonal dimensions leads to the failure of selective attention in speeded classification originated with a theory regarding the correspondence between stimulus dimensions and psychological dimensions. According to this theory, psychological dimensions are orthogonal, so that when they are varied orthogonally selective attention between them is possible. It has been demonstrated that psychologically orthogonal dimensions, when of equal discriminability, permit selective attention.

Furthermore, the extent of the failure to filter an irrelevantly varying dimension depends on the extent to which dimensional interaction increases the similarity of stimuli to be distinguished, as compared to the unidimensional control.

Nevertheless, the following question must be raised: to what extent does additivity between dimensions as demonstrated by dissimilarity judgments imply that the additive dimensions are unique psychological dimensions for a stimulus domain? If the implication is valid, the techniques developed here can be used to discover the physically specified dimensions that correspond to the perceptual invariants of the domain.

In the strongest sense, a set of unique psychological dimensions for a stimulus domain should be context-free. That is, for all subsets of stimuli drawn from the domain the perceptual description of the stimulus will be written in terms of the same set of dimensions. This is to imply that at least part of the perceptual processing of a stimulus is invariant of the response required of the perceiver, that the perceptual dimensions referred to are aspects of a basic coding system that comes into play regardless of the influence of more cognitive processes.

Some evidence against context independence comes from Tversky (1977), who found that the similarity of schematic faces and names of countries varied according to the diagnosticity of a dimension for partitioning a particular subset of the stimuli. The nature of the stimuli used by Tversky points out a limitation of the sense in which it can be said that psychological dimensions as revealed by similarity

judgments are invariant. For schematic faces a critical dimension for similarity judgments was the degree to which a face was smiling. Even though the stimuli were visual, it is not clear that this dimension is perceptual rather than an experience-based interpretation of a combination of perceptual dimensions. When names of countries were used, the stimuli were semantic, and perception of the name itself is not at all relevant. Thus, the first limitation on the notion of context-free psychological dimensions is that if such dimensions do exist for semantic stimuli, they are not revealed by dissimilarity judgments that are based on semantic features. A distinction can therefore be drawn between psychological dimensions--those that may be the basis of a similarity judgment or other cognitive response--and perceptual dimensions--the initially coded aspects of the stimulus as presented. Tversky's results indicate that the existence of invariant perceptual dimensions for meaningful visual stimuli will have to be demonstrated in a more indirect manner than through simple judgments of similarity.

The stimuli used in the present experiments, and probably geometric forms in general, are not subject to these problems. To what extent is there context-independence in the perceptual dimensions of form? Logically, a dimension is defined by context. Variation from stimulus to stimulus indicates which aspects of a single stimulus are useful for distinguishing it from its fellows. Psychologically, however, the most useful dimensions are not necessarily the ones used. In Experiment I, the dimensions height and length of right side most efficiently partitioned the stimulus set, yet dissimilarity judgments were an additive combination of dissimilarity along other dimensions.

Dissimilarity judgments of the combined set of 32 triangles indicated that the perceptual dimensions for that set were free of the context provided by a particular subset. The use of context-free dimensions might be thought of as the "inference" by the dimensional coding process of the larger domain to which the stimuli presented belong. To the extent that the set of 32 triangles used is considered to be representative of the natural domain of triangles, there are unique perceptual dimensions for triangles.

When the constraints put on the variation of triangles in this set are considered, however, it is clear that the dimensions discovered in Experiment I are not necessarily appropriate to the full domain. Since the triangles were two-dimensional, perfect preservation of shape over changes in size was impossible. Similarly, invariance over rotation in space was also eliminated. Thus, a basic aspect of form perception--shape constancy--was not fully tapped. The transformation of the perceptual dimensions found in these experiments by the addition of new and more varied triangles would be evidence against the existence of unique perceptual dimensions for triangles. While this aspect of the problem has yet to be explored, it is apparent that the generality of perceptual dimensions inferred from interdimensional additivity is limited to the stimulus domain fairly represented by the set used to derive the dimensions.

One potential effect of changes in context provided by the presentation of small subsets of stimuli is attention switching between dimensions from subset to subset. While the number of perceptual dimensions that code a stimulus or differences between stimuli may

equal the number of physical dimensions of the set, the specification of those dimensions may change with the presentation of stimuli. Such a change is suggested by the non-dimensional theory of integrality. If different dimensions are used as the basis of dissimilarity judgments for different stimulus pairs, the judgments will not reveal invariant perceptual dimensions for the full set, or will reveal "average" dimensions, not actual ones. Geometric models of similarity such as those that underlie multidimensional scaling assume that judgments are derived from a stable psychological structure. If dissimilarity judgments are based on a consistent set of dimensions, but performance in subsequent perceptual tasks is not, perceived similarity as revealed by judgments will be of small predictive value for performance in those tasks.

In the present experiments, dissimilarity judgments appeared to be based on consistent dimensions for both subjects; judgments were reliable over sessions and with changes in context, and the resulting multidimensional scaling configurations were of low stress and clearly structured. The speeded classification task, however, involves memory to a greater extent, since a stimulus must be compared to stored criteria for the response classes. Since the criteria change between stimulus groups the use of different dimensions for different groups is encouraged. The consistent, though small, superiority of positively correlated pairs in the non-interacting stimulus set for S.T. in Experiment III is suggestive of such attention switching. Nevertheless, the weight of data in Experiments II and III supports the contention that judged dissimilarity is directly related to classification speed, and therefore that a single set of perceptual dimensions coded stimulus differences in both experimental situations.

This consistency in the use of psychological dimensions supports the dimensional interaction theory with regard to the basis of integrality in speeded classification, but it does not prove that the use of consistent axes in psychological space is necessary to obtain separability. According to the non-dimensional theory of integrality, the use of consistent dimensions is a critical factor that distinguishes separable from integral stimuli. The present results leave open the opposing possibility that the orthogonality of stimulus dimensions in psychological space is a sufficient condition for separability. This position would be supported by the discovery of additional perceptually orthogonal dimensions for triangles that lead to "separable" results in speeded classification. The use of consistent perceptual dimensions in the present experiment may have been due to the similarity between the stimulus sets presented. The presentation of more widely varying stimulus sets from a domain might encourage the development of different pairs of perceptually orthogonal dimensions to encode similarity in different sets.

If there do exist consistent perceptual dimensions for a stimulus domain, it is reasonable to expect these dimensions to be ecologically valid. In a restricted sense, ecological validity can be equated with cue validity as described by Brunswik (1956). The validity of a cue is the degree to which it covaries with a distal stimulus property. The validity of a cue with respect to a stimulus class increases as its association with that class increases and its association with other classes decreases (Rosch et al., 1976). The occurrence of interference in speeded classification with interacting stimulus dimensions indicates that these dimensions are of low cue validity--the perceived

value of a stimulus on one of these dimensions is a poor indicator of its class as defined by the physical value on that dimension. The perceived value is actually determined by a set of dimensions that are high in cue validity, the (non-interacting) perceptual dimensions. Since these dimensions so well describe categories as perceived, they might also satisfy ecological validity in its more general sense, that they are associated with the structure of the stimulus domain in the world. Clearly, attempting to force the psychologically interacting dimensions H and R to be orthogonal does not reflect the natural structure of triangles; in the full stimulus domain the dimensions are correlated, not independent.

The present experiments have demonstrated that the perceptual dimensions that subjects use to code stimuli in a speeded classification task are not necessarily those explicitly varied by the experimenter. One of the most important implications of this finding is that the investigation of behavior cannot proceed in the absence of knowledge about the perception of stimuli. While this point has been noted before (e.g., Gibson, 1960; Garner, 1970), the implicit assumption prevalent in the use of speeded classification to diagnose integrality is that the stimulus set's logical structure is equivalent to its psychological structure. When classification behavior that is implied by this equivalence is not confirmed, it is concluded that the logical structure was not perceived by the subject. As correct as this conclusion might be, the approach encourages the posing of yes-no questions--does the subject perceive these dimensions (i.e., are they separable)--when what is warranted is a quite specific attack on what the subject does perceive. The present experiments have indicated how

such an attack might proceed and what the potential focus of the attack might be.

Searching directly for the perceived structure in a stimulus domain necessitates a reconsideration of the usefulness of the filtering task. The present results indicate that when dimensions interact the analysis of interference and redundancy gain is inappropriate. The use of the unidimensional condition as a baseline derives from the logical structure, not the psychological structure, of the stimuli. When dimensions psychologically interact, the variation in perceived similarity of different unidimensional pairs is accompanied by variation in latency for these pairs. Only when the physical orthogonality within the stimulus set is matched by psychological orthogonality is the unidimensional condition truly unidimensional and therefore meaningful.

Psychologically orthogonal dimensions, that is, perceptual dimensions, are by definition filterable. Thus, it would appear that the problem of selective attention with regard to perceptual dimensions is theoretically uninteresting. In reality, however, many factors can limit the success of selective attention, even when the dimensions to be filtered correspond perfectly to perceptual dimensions. These are factors such as the relative discriminability of dimensions, the amount of speed stress involved in the performance of the task, and the resemblence between stimulus subsets and the domain to which perceptual dimensions apply. The failure of selective attention under the influence of these factors indicates the extent to which perceptual dimensions derived from perceived similarity generalize over changes in

both stimulus and response environment. Conversely, dimensions not originally perceptually preferred may come to be efficient for classification with practice. Thus, while asking whether filtering is possible is not diagnostic per se, the examination of changes in filtering performance as a function of changes potentially relevant to the perception of stimulus structure can reveal not only the nature of perceptual dimensions, but the flexibility of the coding system that utilizes them.

Performance in the speeded classification task, then, provides information about the perceived structure of stimulus sets, when analysis of that performance is accompanied by independent data on the perceived similarity between items to be classified. Patterns of classification performance resulting from dimensional interaction resemble the patterns diagnostic of integrality and are predictable from similarity judgments. However, it is debatable that the notion of perceived structure or dimensional interaction per se resembles the original, phenomenology-based idea of integrality. The major difference between the two concepts of integrality is that perceived structure always refers to a stimulus set or domain, while the appearance of integrality to an observer can refer to a single stimulus presented alone. The contrast is characteristic both of integrality in the sense developed here, as a lack of correspondence between physically orthogonal and psychologically orthogonal dimensions, and in the sense developed by Garner (1974), as an inability to differentiate any dimensions in a stimulus set. Because the operationalization of integrality requires the development of a set of stimuli, the resemblence of the operationalization to the original concept is inevitably questionable. The

question is more critical for the dimensional interaction notion of integrality, however, because the idea that structure is perceived in integral stimuli is counter to the appearance of a single integral stimulus.

It is first necessary to distinguish the appearance of unity or integrality in a single stimulus from the appearance of complexity. A human face for example may seem to be unitary. Nevertheless, faces have properties that are both distinguishable within a given face and common over faces. These include permanent features such as the shape of the face and transitory features such as emotional expression. In many cases subjects are able to make similarity judgments based on one of these features without being influenced by the other (Benjamin, 1978; Somers & Pachella, 1977). These features can be called psychologically emergent; they are not immediately given by simple physical elements of the face. A more useful way to characterize them is to note that they can be specified by higher-order physical variables, combinations of the simple physical elements that are immediately apparent. The single face, therefore, gives the impression of integrality with regard to those simple elements. A search for the higher-order physical variables that correspond to emergent features, however, will reveal separable dimensions.

Integrality is also used to refer to the situation in which dimensions may be perceived for a stimulus pair or group, but change from group to group (Shepard, 1964). In such a case, there are no invariant perceptual dimensions, although the physical domain is multidimensional. While a clear demonstration of a stimulus domain of this type has not

been made, the description of such a domain as integral potentially confuses this aspect of attribute perception with a variety of other situations, one of which has been explored in detail here. The direct investigation of the existence and specification of perceptual dimensions would both clarify the use of the term "integrality" and reorient experimentation toward a description of the physical correspondents of the perceptual world.

The problem that has held back the investigation of attribute perception is that of defining integrality. A single stimulus presented in isolation can appear to be integral. Nevertheless, many aspects of a perceptual situation can direct attention to the component dimensions of a single stimulus. These include experience using that stimulus in a variety of contexts (Gibson, 1966), the spatial separation of dimensions (Hyman & Well, 1967, 1968), and the context provided by a larger set, if only in memory (Garner, 1974). One might ask whether dimensions that come to be distinguishable in this way are integral. Garner (1974) uses integrality to refer to a preferred mode of processing, not a necessary one. In this sense, dimensions that with effort become separable are still integral as a characterization of a preferred mode of operation. However, since most natural objects are seen in context and are usually familiar, the evaluation of integrality in the absence of context and of meaningfulness--for example the use of a color patch--is not necessarily indicative of a preferred processing mode in its true sense. It has yet to be demonstrated, therefore, that the simple characterization of dimensions presented in an isolated experimental situation as integral is a useful description

of normal perceptual behavior. The alternative is a more specific analysis of the correspondence between physical specification and perceptual behavior. Such an approach is the beginning of a direct attack on the nature of attribute perception.

# APPENDICES

# APPENDIX A

## INSTRUCTIONS FOR DISSIMILARITY JUDGMENTS IN EXPERIMENT I

In this experiment I'll show you pairs of triangles, like this one, and ask you to judge how dissimilar the triangles are. You are to rate the degree of dissimilarity of a pair of triangles on a scale of one to ten. If the triangles are almost identical, that is, the dissimilarity between them is very small, give the pair a small number. If the triangles are very dissimilar, give them a high number. For intermediate levels of dissimilarity, give them an intermediate number.

You are to indicate your rating of a pair by pressing the corresponding one of these ten buttons. For a score of one press the button at the far left, for a score of ten, press the button at the far right.

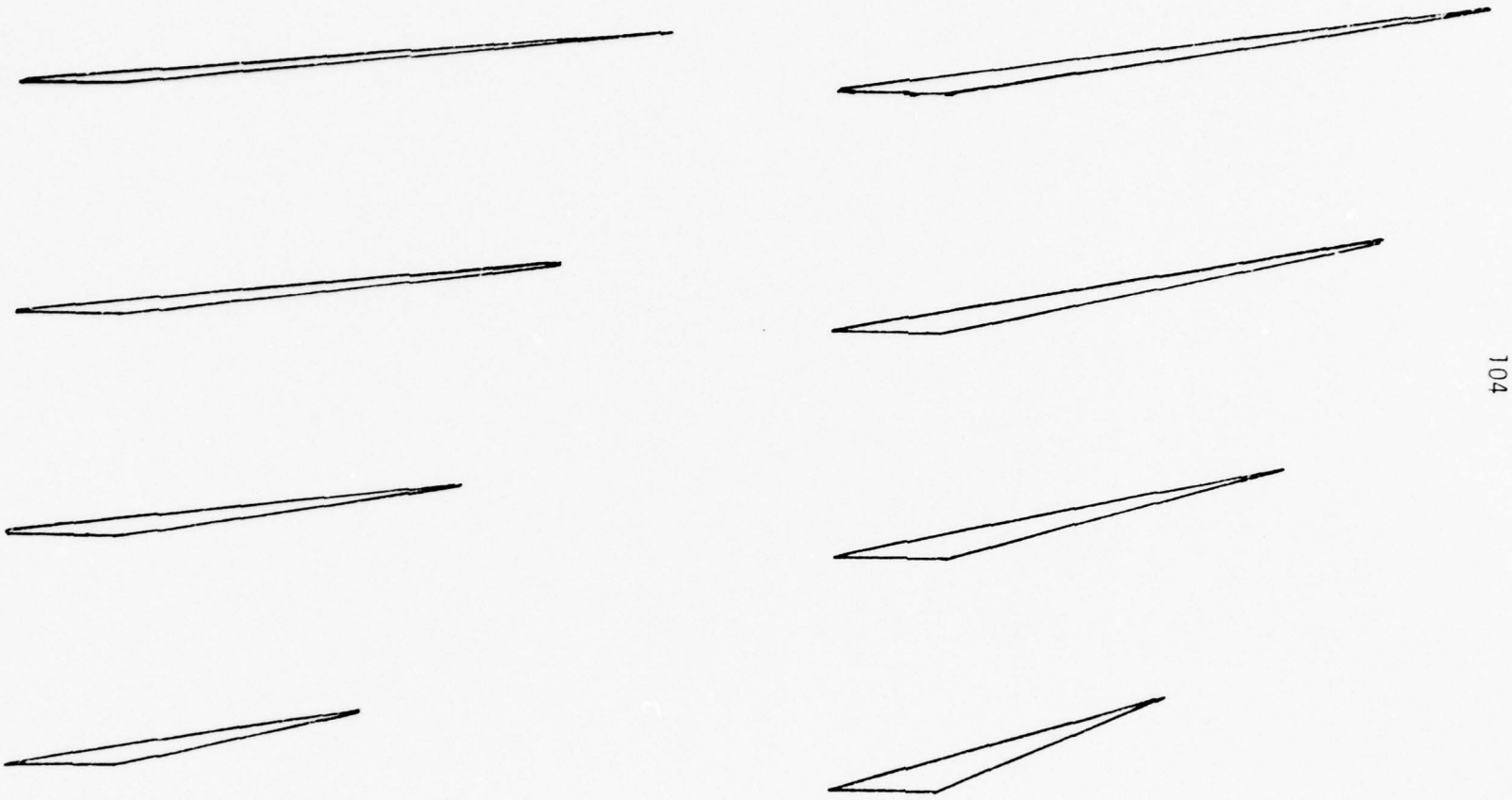
I'm interested in your subjective impression of the degree of dissimilarity between triangles. Thus, there are no correct or incorrect answers. I'm not at all concerned with your ability to do geometry; just look at the pair of triangles for a short time, and press a button corresponding to your general impression of how dissimilar the triangles are. This is not a speeded task, but don't spend a lot of time deliberating. Just press a button corresponding to your impression of the dissimilarity of the triangles.

First, you'll see all of the triangles in the set, one at a time, in a random order, to get an idea of how varied they are. This is one of the triangles. To see the remaining triangles, push any button, and the next triangle will appear. After all of the individual triangles in the set have been displayed, they will start appearing in pairs. When you press a button indicating your dissimilarity rating of the pair, that pair will disappear and the next one will be displayed.

There will be breaks between blocks of 120 pairs.

APPENDIX B

TRIANGLES USED IN EXPERIMENT IA

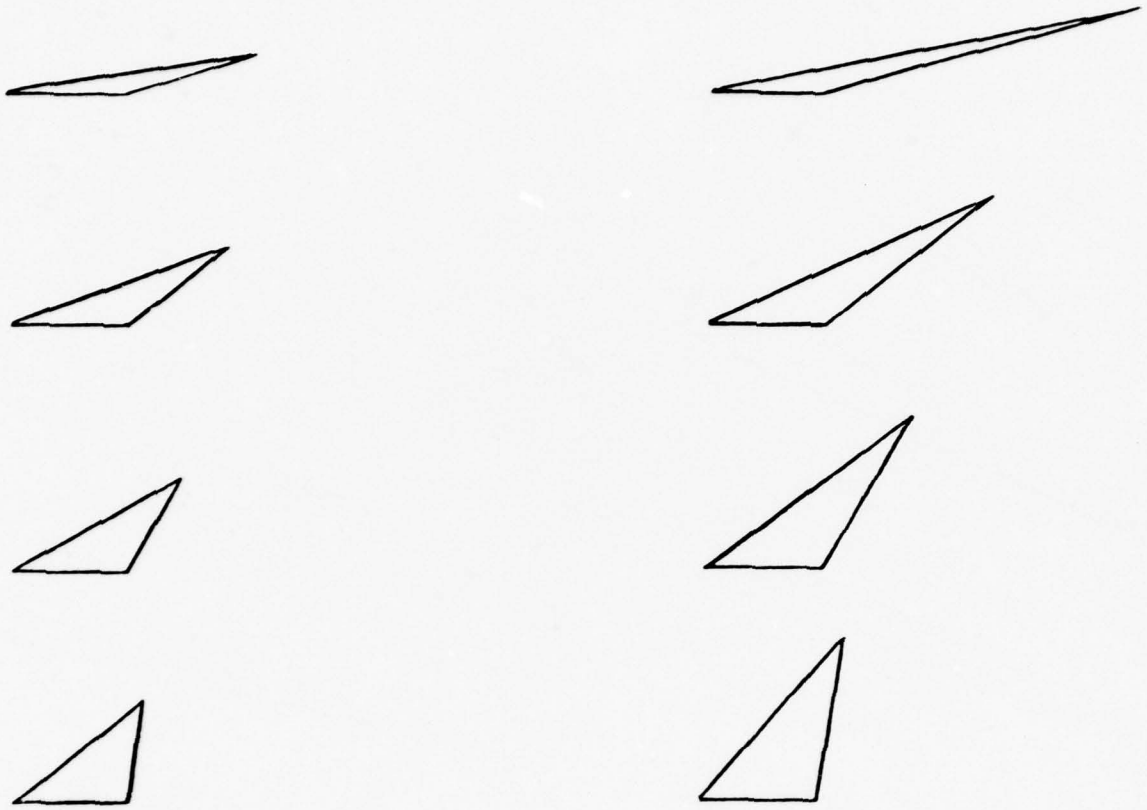



Triangles presented in appendices B, C, and D are .65 original size.

HEIGHT
LENGTH OF RIGHT SIDE

APPENDIX C

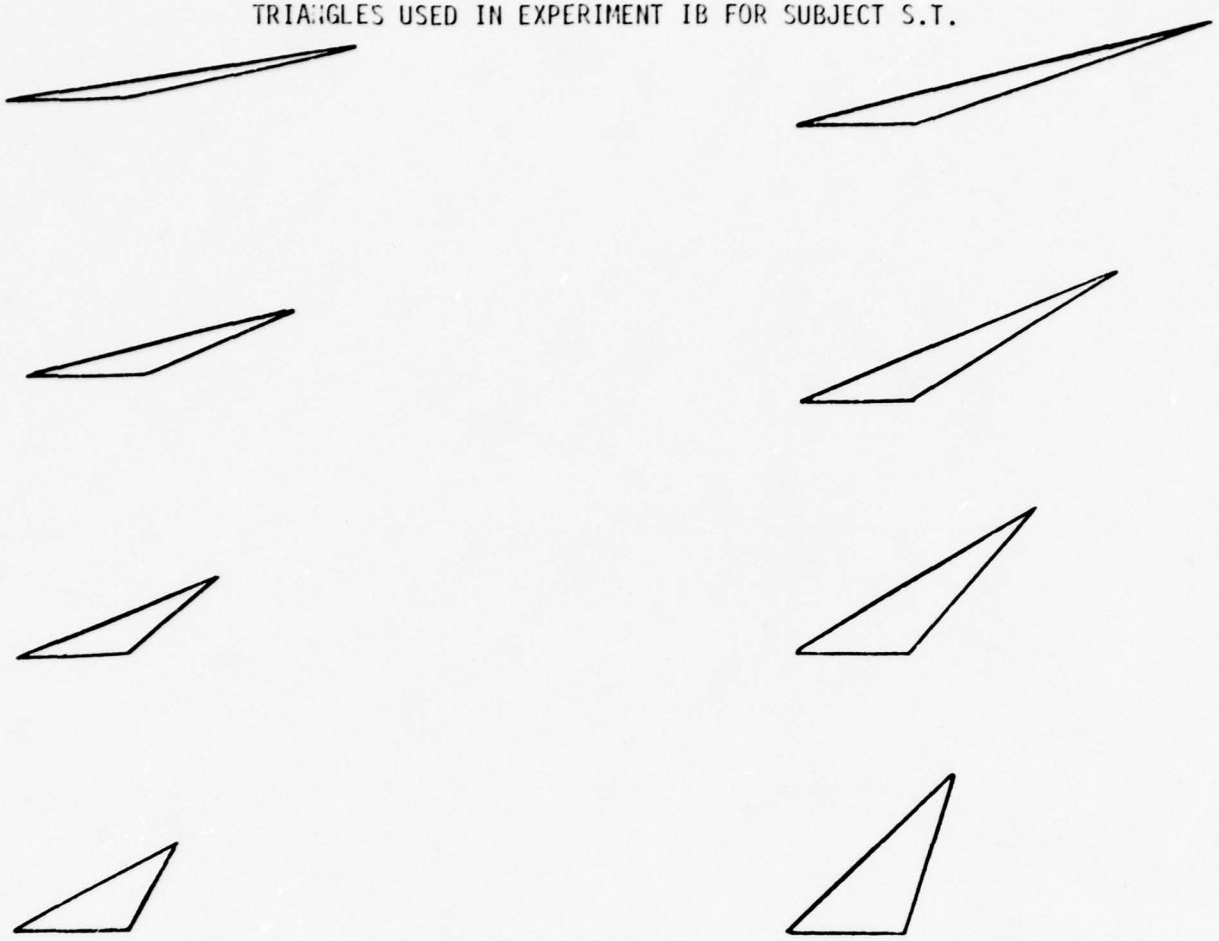
TRIANGLES USED IN EXPERIMENT IB FOR SUBJECT M.S.



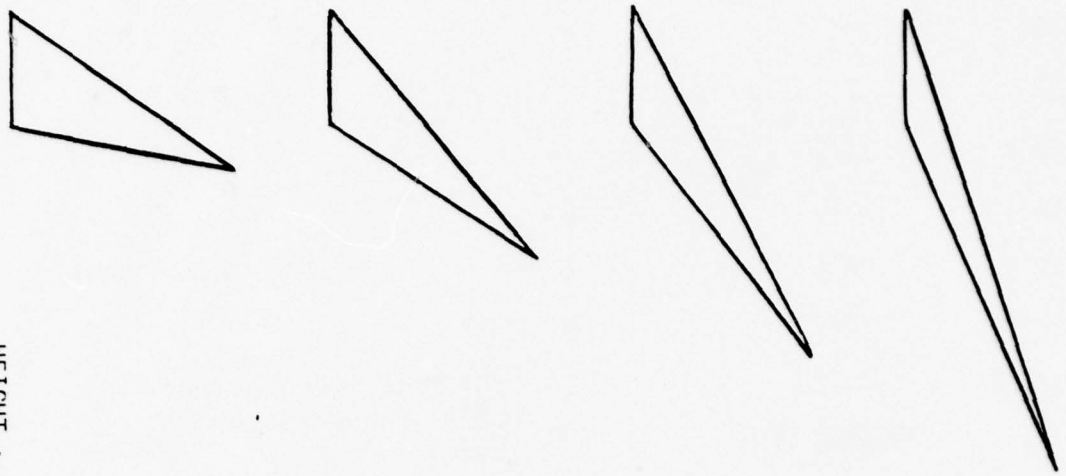
HEIGHT • LENGTH OF RIGHT SIDE
LOWER RIGHT-HAND ANGLE

APPENDIX D

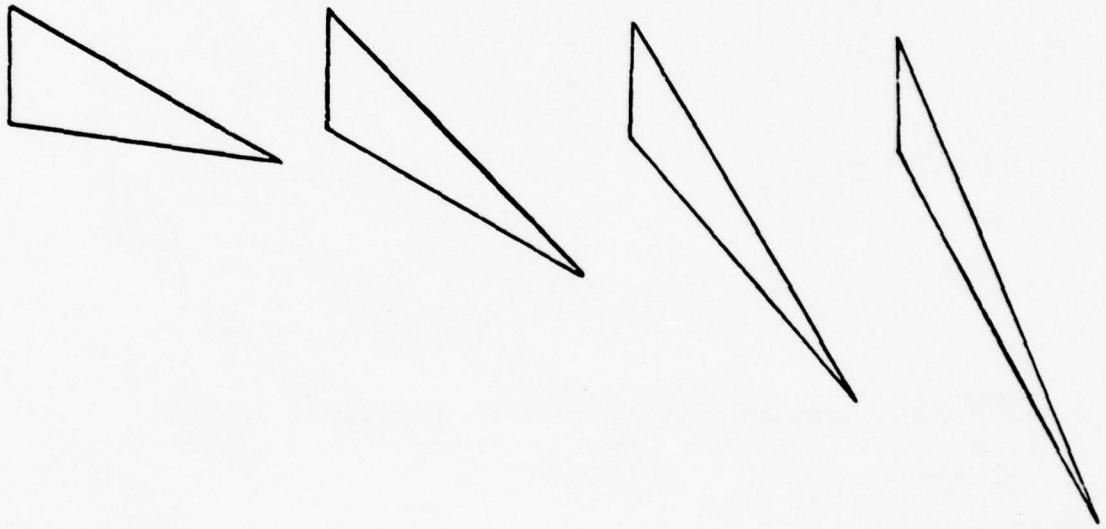
TRIANGLES USED IN EXPERIMENT IB FOR SUBJECT S.T.



LOWER RIGHT-HAND ANGLE · LENGTH OF RIGHT SIDE·$^{2}$



HEIGHT · LENGTH OF RIGHT SIDE·$^{8}$



# APPENDIX E

## ANALYSES OF VARIANCE FOR INTERACTING DIMENSIONS IN EXPERIMENT I

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Direction of correlation (D) | 1 | 130.67 | 152.12 |
| Group (G) | 8 | 10.05 | 11.70 |
| Session (S) | 1 | .07 | .08 |
| D x G | 8 | 3.08 | 3.59 |
| D x S | 1 | 2.67 | 3.11 |
| G x S | 8 | .87 | 1.01 |
| D x G x S | 8 | .29 | .34 |
| Replications within DGS | 180 | .86 | |

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Direction of correlation (D) | 1 | 12.52 | 22.31 |
| Group (G) | 8 | 2.67 | 4.76 |
| Session (S) | 1 | 3.63 | 6.47 |
| D x G | 8 | .59 | 1.05 |
| D x S | 1 | 2.67 | 4.76 |
| G x S | 8 | .29 | .52 |
| D x G x S | 8 | .47 | .84 |
| Replications within DGS | 180 | .56 | |

# APPENDIX F

## ANALYSES OF VARIANCE FOR NON-INTERACTING DIMENSIONS IN EXPERIMENT I

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Direction of correlation (D) | 1 | 3.89 | 5.73 |
| Group (G) | 8 | 27.54 | 40.58 |
| Session (S) | 1 | 10.23 | 15.07 |
| D x G | 8 | .34 | .50 |
| D x S | 1 | 1.04 | 1.53 |
| G x S | 8 | 1.36 | 2.00 |
| D x G x S | 8 | .55 | .81 |
| Replications within DGS | 180 | .68 | |

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Direction of correlation (D) | 1 | .30 | .79 |
| Group (G) | 8 | 2.61 | 6.94 |
| Session (S) | 1 | 6.69 | 17.61 |
| D x G | 8 | .77 | 2.03 |
| D x S | 1 | .07 | .18 |
| G x S | 8 | .32 | .84 |
| D x G x S | 8 | .36 | .95 |
| Replications within DGS | 180 | .38 | |

# APPENDIX G

## ANALYSES OF VARIANCE IN EXPERIMENT II

## Errors

### Interacting Dimensions

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | .48 | .80 |
| Column (C) | 2 | .94 | 1.57 |
| Hand (H) | 1 | .33 | .55 |
| Run (R) | 1 | .86 | 1.43 |
| Group within C (G) | 6 | .30 | .50 |
| TC | 6 | .84 | 1.40 |
| TH | 3 | 1.03 | 1.72 |
| CH | 2 | 2.33 | 3.88 |
| TR | 3 | .31 | .52 |
| CR | 2 | .088 | .15 |
| HR | 1 | .006 | 1.02 |
| TG(C) | 18 | .36 | .36 |
| GH(C) | 6 | 1.00 | 1.67 |
| GR(C) | 6 | .18 | .30 |
| TCH | 6 | .59 | .98 |
| TCR | 6 | .32 | .53 |
| THR | 3 | .33 | .55 |
| CHR | 2 | 1.17 | 1.95 |
| TGH(C) | 18 | .61 | 1.02 |
| TGR(C) | 18 | .69 | 1.15 |
| GHR(C) | 6 | 1.34 | 2.23 |
| TCHR | 6 | 2.02 | 3.37 |
| TGHR(C) | 18 | .60 | |

## Errors

### Interacting Dimensions

### Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | 1.68 | 1.08 |
| Column (C) | 2 | 1.40 | .90 |
| Hand (H) | 1 | 2.28 | 1.46 |
| Run (R) | 1 | .004 | .002 |
| Group within C (G) | 6 | .49 | .31 |
| TC | 6 | .21 | .13 |
| TH | 3 | .34 | .15 |
| CH | 2 | .44 | .28 |
| TR | 3 | .62 | .40 |
| CR | 2 | .02 | .01 |
| HR | 1 | .38 | .24 |
| TG(C) | 18 | .27 | .17 |
| GH(C) | 6 | .45 | .10 |
| GR(C) | 6 | .30 | .19 |
| TCH | 6 | .65 | .42 |
| TCR | 6 | .40 | .26 |
| THR | 3 | .21 | .13 |
| CHR | 2 | .66 | .42 |
| TGH(C) | 18 | .73 | .47 |
| TGR(C) | 18 | .59 | .38 |
| GHR(C) | 6 | .40 | .26 |
| TCHR | 6 | .60 | .38 |
| TGHR(C) | 18 | 1.56 | |

## Errors

### Non-interacting Dimensions

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | .69 | 2.65 |
| Column (C) | 2 | 1.10 | 4.23 |
| Hand (H) | 1 | .09 | .36 |
| Run (R) | 1 | 3.60 | 13.85 |
| Group within C (G) | 6 | .23 | .88 |
| TC | 6 | .52 | 2.00 |
| TH | 3 | .70 | 2.69 |
| CH | 2 | 1.59 | 6.12 |
| TR | 3 | .05 | .20 |
| CR | 2 | 1.41 | 5.51 |
| HR | 1 | .55 | 2.15 |
| TG(C) | 18 | .56 | 2.19 |
| GH(C) | 6 | .91 | 3.55 |
| GR(C) | 6 | .47 | 1.84 |
| TCH | 6 | 2.73 | 10.66 |
| TCR | 6 | .45 | 1.76 |
| THR | 3 | .45 | 1.76 |
| CHR | 2 | 1.60 | 6.25 |
| TGH(C) | 18 | .41 | 1.60 |
| TGR(C) | 18 | .39 | 1.52 |
| GHR(C) | 6 | .50 | 1.95 |
| TCHR | 6 | .47 | 1.84 |
| TGHR(C) | 18 | .26 | |

## Errors

### Non-interacting Dimensions

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | 5.07 | 6.90 |
| Column (C) | 2 | 11.01 | 14.97 |
| Hand (H) | 1 | 10.78 | 14.56 |
| Run (R) | 1 | .02 | .03 |
| Group within C (G) | 6 | .31 | .44 |
| TC | 6 | 1.64 | 2.23 |
| TH | 3 | .68 | .93 |
| CH | 2 | 2.71 | 3.69 |
| TR | 3 | .22 | .30 |
| CR | 2 | .65 | .88 |
| HR | 1 | 1.50 | 2.04 |
| TG(C) | 18 | 1.13 | 1.54 |
| GH(C) | 6 | .47 | .64 |
| GR(C) | 6 | .85 | 1.16 |
| TCH | 6 | .86 | 1.17 |
| TCR | 6 | .36 | .49 |
| THR | 3 | .15 | .20 |
| CHR | 2 | .10 | .14 |
| TGH(C) | 18 | .52 | .71 |
| TGR(C) | 18 | .74 | 1.01 |
| GHR(C) | 6 | .30 | .41 |
| TGHR | 6 | .58 | .79 |
| TGHR(C) | 18 | .74 | |

## Latency

### Interacting Dimensions

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T)[1] | 3 | 299842 | 63.09 |
| Column (C) | 2 | 57611 | 12.12 |
| Run (R) | 1 | 63872 | 13.44 |
| Group within T x C (G) | | | |
| $G(T_o)$[2] | 6 | 84219 | 7.21 |
| $G(T_u)$ | 9 | 14657 | 5.24 |
| $G(T_p)$ | 6 | 16789 | 5.33 |
| $G(T_n)$ | 6 | 5524 | 2.11 |
| Stimulus within G (S) | | | |
| $S(T_o)$ | 27 | 42724 | 3.66 |
| $S(T_u)$ | 12 | 7874 | 2.81 |
| $S(T_p)$ | 9 | 19156 | 6.08 |
| $S(T_n)$ | 9 | 9800 | 3.74 |
| T x C | 6 | 195545 | 41.15 |
| T x R | 3 | 80798 | 17.00 |
| C x R | 2 | 8421 | 1.77 |
| R x G(T x C) | | | |
| R x $G(T_o)$ | 6 | 62915 | 5.39 |
| R x $G(T_u)$ | 9 | 3304 | 1.18 |
| R x $G(T_p)$ | 6 | 10107 | 3.21 |
| R x $G(T_n)$ | 6 | 2573 | .98 |

[1] Type, and other effects summed across type, were tested using a pooled error term and Fs are therefore approximate in all latency analyses of Experiment II.

[2] $T_o$ is the orthogonal condition, $T_u$ the unidimensional, $T_p$ the positively correlated, $T_n$ the negatively correlated, in all latency analyses of Experiment II.

## Latency

### Interacting Dimensions

### Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| R x S(G) | | | |
| R x S($T_o$) | 27 | 10270 | .88 |
| R x S($T_u$) | 12 | 6380 | 2.28 |
| R x S($T_p$) | 9 | 4601 | 1.46 |
| R x S($T_n$) | 9 | 4504 | 1.72 |
| T x C x R | 6 | 18422 | 3.27 |
| Trials within Stimulus (E) | | | |
| E($T_o$) | 610 | 11678 | |
| E($T_u$) | 890 | 2799 | |
| E($T_p$) | 664 | 3149 | |
| E($T_n$) | 667 | 2622 | |

## Latency

### Interacting Dimensions

### Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | 1290870 | 33.54 |
| Column (C) | 2 | 2461708 | 63.96 |
| Run (R) | 1 | 1002281 | 26.04 |
| Group within T x C (G) | | | |
| $G(T_o)$ | 6 | 1872096 | 37.70 |
| $G(T_u)$ | 9 | 540400 | 11.13 |
| $G(T_p)$ | 6 | 77436 | 2.09 |
| $G(T_n)$ | 6 | 17558 | 1.06 |
| Stimulus within G (S) | | | |
| $S(T_o)$ | 27 | 212288 | 4.27 |
| $S(T_u)$ | 12 | 205500 | 4.23 |
| $S(T_p)$ | 9 | 148032 | 4.00 |
| $S(T_n)$ | 9 | 39630 | 2.41 |
| T x C | 6 | 410669 | 10.67 |
| T x R | 3 | 170173 | 4.42 |
| C x R | 2 | 199427 | 5.18 |
| R x G(T x C) | | | |
| $R \times G(T_o)$ | 6 | 135379 | 2.72 |
| $R \times G(T_u)$ | 9 | 53817 | 1.10 |
| $R \times G(T_p)$ | 6 | 31983 | .86 |
| $R \times G(T_n)$ | 6 | 10529 | .64 |
| R x S(G) | | | |
| $R \times S(T_o)$ | 27 | 48708 | .98 |
| $R \times S(T_u)$ | 12 | 118779 | 2.45 |
| $R \times S(T_p)$ | 9 | 89438 | 2.41 |
| $R \times S(T_n)$ | 9 | 22662 | 1.37 |
| T x C x R | 6 | 118044 | 3.07 |

## Latency

### Interacting Dimensions

### Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Trials within Stimulus (E) | | | |
| $E(T_o)$ | 614 | 49660 | |
| $E(T_u)$ | 884 | 48564 | |
| $E(T_p)$ | 665 | 36996 | |
| $E(T_n)$ | 670 | 16425 | |

## Latency

### Non-interacting Dimensions

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | 1183838 | 388.49 |
| Column (C) | 2 | 598980 | 196.56 |
| Run (R) | 1 | 101002 | 33.15 |
| Group within T x C (G) | | | |
| $G(T_o)$ | 6 | 58339 | 11.62 |
| $G(T_u)$ | 9 | 17734 | 5.08 |
| $G(T_p)$ | 6 | 11632 | 6.25 |
| $G(T_n)$ | 6 | 3418 | 1.90 |
| Stimulus within G (S) | | | |
| $S(T_o)$ | 27 | 14112 | 2.81 |
| $S(T_u)$ | 12 | 8944 | 2.56 |
| $S(T_p)$ | 9 | 12072 | 6.49 |
| $S(T_n)$ | 9 | 2432 | 1.35 |
| T x C | 6 | 217617 | 71.41 |
| T x R | 3 | 16287 | 5.34 |
| C x R | 2 | 46273 | 15.19 |
| R x G(T x C) | | | |
| $R \times G(T_o)$ | 6 | 23795 | 4.74 |
| $R \times G(T_u)$ | 9 | 9603 | 2.75 |
| $R \times G(T_p)$ | 6 | 3037 | 1.63 |
| $R \times G(T_n)$ | 6 | 5266 | 2.93 |
| R x S(G) | | | |
| $R \times S(T_o)$ | 27 | 4017 | .80 |
| $R \times S(T_u)$ | 12 | 2667 | .76 |
| $R \times S(T_p)$ | 9 | 2172 | 1.17 |
| $R \times S(T_n)$ | 9 | 1833 | 1.02 |
| T x C x R | 6 | 18606 | 6.11 |

## Latency

### Non-interacting Dimensions

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Trials within Stimulus (E) | | | |
| $E(T_o)$ | 626 | 5019 | |
| $E(T_u)$ | 887 | 3494 | |
| $E(T_p)$ | 666 | 1861 | |
| $E(T_n)$ | 674 | 1800 | |

## Latency

### Non-interacting Dimensions

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 3 | 429961 | 14.48 |
| Column (C) | 2 | 174184 | 5.86 |
| Run (R) | 1 | 114675 | 3.53 |
| Group within T x C (G) | | | |
| $G(T_o)$ | 6 | 155617 | 3.89 |
| $G(T_u)$ | 9 | 129030 | 3.23 |
| $G(T_p)$ | 6 | 56967 | 3.88 |
| $G(T_n)$ | 6 | 8593 | .36 |
| Stimulus within G (S) | | | |
| $S(T_o)$ | 27 | 110858 | 2.77 |
| $S(T_u)$ | 12 | 156062 | 4.02 |
| $S(T_p)$ | 9 | 53073 | 3.62 |
| $S(T_n)$ | 9 | 32805 | 1.38 |
| T x C | 6 | 143285 | 4.82 |
| T x R | 3 | 50823 | 1.71 |
| C x R | 2 | 250489 | 8.43 |
| R x G(T x C) | | | |
| R x $G(T_o)$ | 6 | 42247 | 1.06 |
| R x $G(T_u)$ | 9 | 24880 | .64 |
| R x $G(T_p)$ | 6 | 73945 | 5.04 |
| R x $G(T_n)$ | 6 | 80295 | 3.39 |
| R x S(G) | | | |
| R x $S(T_o)$ | 27 | 79549 | 1.99 |
| R x $S(T_u)$ | 12 | 86365 | 2.22 |
| R x $S(T_p)$ | 9 | 26167 | 1.79 |
| R x $S(T_n)$ | 9 | 16633 | .70 |
| T x C x R | 6 | 102744 | 3.46 |

## Latency

### Non-interacting Dimensions

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Trials within Stimulus (E) | | | |
| $E(T_o)$ | 592 | 39969 | |
| $E(T_u)$ | 869 | 38827 | |
| $E(T_p)$ | 665 | 14667 | |
| $E(T_n)$ | 665 | 23679 | |

# APPENDIX H

## LATENCY (IN MSEC) FOR TASK-GROUP COMBINATIONS IN EXPERIMENT II

### Interacting Dimensions

Subject M.S.

| Group (Row/Column) | Orthogonal | Mean Unidimensional | Positively Correlated | Negatively Correlated |
|---|---|---|---|---|
| 1 1 | 345 | 332 | 352 | 334 |
| 2 1 | 343 | 331 | 341 | 326 |
| 3 1 | 313 | 349 | 332 | 347 |
| 1 2 | 433 | 344 | 343 | 337 |
| 2 2 | 339 | 340 | 349 | 341 |
| 3 2 | 342 | 336 | 341 | 339 |
| 1 3 | 390 | 306 | 317 | 315 |
| 2 3 | 442 | 318 | 353 | 323 |
| 3 3 | 461 | 325 | 360 | 335 |

Subject S.T.

| | | | | |
|---|---|---|---|---|
| 1 1 | 479 | 419 | 451 | 426 |
| 2 1 | 490 | 448 | 404 | 444 |
| 3 1 | 522 | 474 | 467 | 452 |
| 1 2 | 417 | 427 | 418 | 374 |
| 2 2 | 418 | 389 | 433 | 375 |
| 3 2 | 466 | 419 | 444 | 412 |
| 1 3 | 483 | 425 | 434 | 419 |
| 2 3 | 487 | 519 | 490 | 420 |
| 3 3 | 934 | 648 | 514 | 430 |

Non-Interacting Dimensions

Subject M.S.

| Group (Row/Column) | Orthogonal | Mean Unidimensional | Positively Correlated | Negatively Correlated |
|---|---|---|---|---|
| 1 1 | 355 | 359 | 354 | 340 |
| 2 1 | 362 | 355 | 369 | 330 |
| 3 1 | 388 | 356 | 363 | 332 |
| 1 2 | 368 | 337 | 296 | 313 |
| 2 2 | 396 | 350 | 330 | 297 |
| 3 2 | 431 | 360 | 315 | 304 |
| 1 3 | 449 | 402 | 327 | 327 |
| 2 3 | 477 | 407 | 341 | 335 |
| 3 3 | 511 | 425 | 347 | 323 |

Subject S.T.

| | | | | |
|---|---|---|---|---|
| 1 1 | 444 | 452 | 458 | 424 |
| 2 1 | 451 | 425 | 423 | 443 |
| 3 1 | 454 | 426 | 455 | 420 |
| 1 2 | 436 | 448 | 397 | 461 |
| 2 2 | 475 | 460 | 446 | 469 |
| 3 2 | 559 | 505 | 472 | 458 |
| 1 3 | 548 | 448 | 377 | 404 |
| 2 3 | 471 | 448 | 413 | 405 |
| 3 3 | 498 | 500 | 404 | 425 |

# APPENDIX I

## ANALYSES OF VARIANCE IN EXPERIMENT III

### Errors

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Interaction (I) | 1 | .62 | 1.0 |
| Discriminability (D) | 2 | 1.08 | 1.74 |
| Practice (P) | 3 | 1.70 | 2.74 |
| Type (T) | 4 | 2.31 | 3.73 |
| ID | 2 | .57 | .92 |
| IP | 3 | 2.35 | 3.79 |
| DP | 6 | .20 | .32 |
| IT | 4 | .22 | .35 |
| DT | 8 | 1.40 | 2.26 |
| PT | 12 | .87 | 1.40 |
| IDP | 6 | 1.08 | 1.74 |
| IDT | 8 | .32 | .52 |
| IPT | 12 | 1.56 | 2.52 |
| DPT | 24 | .50 | .81 |
| IDPT | 24 | .62 | |

## Errors

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Interaction (I) | 1 | 1.77 | .90 |
| Discriminability (D) | 1 | .21 | .11 |
| Practice (P) | 3 | 1.12 | .57 |
| Type (T) | 4 | 5.87 | 2.97 |
| ID | 1 | 3.40 | 1.72 |
| IP | 3 | 4.02 | 2.03 |
| DP | 3 | .44 | .22 |
| IT | 4 | 2.06 | 1.04 |
| DT | 4 | .88 | .45 |
| PT | 12 | .87 | .44 |
| IDP | 3 | .55 | .28 |
| IDT | 4 | .41 | .21 |
| IPT | 12 | .71 | .36 |
| DPT | 12 | .63 | .32 |
| IDPT | 12 | .98 | |

## Latency

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 4 | 1925520 | 246.62 |
| Interaction (I) | 1 | 179231 | 22.96 |
| Discriminability (D) | 2 | 10968 | 1.40 |
| Session (S) | 1 | 399182 | 51.13 |
| Run (R) | 1 | 110084 | 14.10 |
| T x I | 4 | 24231 | 3.10 |
| T x D | 8 | 161267 | 20.65 |
| T x S | 4 | 25480 | 3.26 |
| T x R | 4 | 4905 | .63 |
| I x D | 2 | 69106 | 8.85 |
| I x S | 1 | 23369 | 2.99 |
| I x R | 1 | 137 | .02 |
| D x S | 2 | 57638 | 7.39 |
| D x R | 2 | 8439 | 1.08 |
| S x R | 1 | 80565 | 10.37 |
| T x I x D | 8 | 22336 | 2.86 |
| T x I x S | 4 | 42760 | 5.48 |
| T x I x R | 4 | 5944 | .76 |
| T x D x S | 8 | 23270 | 2.98 |
| T x D x R | 8 | 26621 | 3.41 |
| T x S x R | 4 | 48955 | 6.27 |
| I x D x S | 2 | 22498 | 2.88 |

## Latency

Subject M.S.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| I x D x R | 2 | 12191 | 1.56 |
| I x S x R | 1 | 221639 | 28.39 |
| D x S x R | 2 | 18322 | 2.35 |
| T x I x D x S | 8 | 57190 | 7.32 |
| T x I x D x R | 8 | 12746 | 1.63 |
| T x I x S x R | 4 | 28168 | 3.61 |
| T x D x S x R | 8 | 52220 | 6.69 |
| I x D x S x R | 2 | 22663 | 2.90 |
| T x I x D x S x R | 8 | 41032 | 5.26 |
| Trial within TIDSR | 4680 | 7808 | |

## Latency

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| Type (T) | 4 | 893250 | 38.88 |
| Interaction (I) | 1 | 1942223 | 84.54 |
| Discriminability (D) | 1 | 631857 | 27.50 |
| Session (S) | 1 | 4343 | .19 |
| Run (R) | 1 | 191086 | 8.32 |
| T x I | 4 | 210458 | 9.16 |
| T x D | 4 | 290611 | 12.60 |
| T x S | 4 | 26534 | 1.15 |
| T x R | 4 | 14898 | .65 |
| I x D | 1 | 434498 | 18.90 |
| I x S | 1 | 53481 | 2.33 |
| I x R | 1 | 3728 | .16 |
| D x S | 1 | 131636 | 5.73 |
| D x R | 1 | 198261 | 8.63 |
| S x R | 1 | 6012 | .26 |
| T x I x D | 4 | 148490 | 6.46 |
| T x I x S | 4 | 38446 | 1.67 |
| T x I x R | 4 | 95409 | 4.15 |
| T x D x S | 4 | 83705 | 3.64 |
| T x D x R | 4 | 55773 | 2.43 |
| T x S x R | 4 | 61984 | 2.70 |
| I x D x S | 1 | 138364 | 6.02 |

## Latency

Subject S.T.

| Source | D.F. | Mean Square | F |
|---|---|---|---|
| I x D x R | 1 | 33891 | 1.48 |
| I x S x R | 1 | 7116 | .31 |
| D x S x R | 1 | 211608 | 9.21 |
| T x I x D x S | 4 | 44838 | 1.95 |
| T x I x D x R | 4 | 53553 | 2.37 |
| T x I x S x R | 4 | 39781 | 1.73 |
| T x D x S x R | 4 | 37660 | 1.64 |
| I x D x S x R | 1 | 2934 | .13 |
| T x I x D x S x R | 4 | 53553 | 2.33 |
| Trial within TIDSR | 3120 | | |

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This paper describes and tests a new psychological theory of dimensional integrality. Integrality refers to the phenomenon of physically independent dimensions appearing fused into a single perceptual attribute such that the physically separable dimensions are not perceptually separable. The theory proposes that all stimuli are perceived as combinations of perceptually independent dimensions, but that for integral stimulus sets the perceptual dimensions do not correspond to the physically independent dimensions. (CONT'D)

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20. (cont'd)

Integrality is demonstrated psychophysically by interaction in psychological similarity space between physically independent dimensions.

Interactive and non-interactive stimulus sets from the same stimulus domain were developed. Similarity judgments indicated that observers perceived both sets using the same pair of perceptual dimensions.

The theory's predictions on speeded classification of interactive and non-interactive stimulus sets were tested. Interacting dimensions produced results in speeded classification tasks typical of phenomenal integrality. First, when compared to the baseline of unidimensional classification, reaction time increased in a "filtering" task, a task requiring selective attention to one dimension as the stimuli varied independently on two dimensions. Amount of interference correlated highly with degree of interaction. Second, observers gained in speed in a task requiring discrimination between two stimuli which differ from each other on two dimensions. Reaction time was directly related to perceived similarity between stimuli -- the more similar the pair, the slower the response. This relationship was demonstrated by a difference between speed gain for positively correlated and negatively correlated pairs, consistent with the form of the dimensional interaction.

With non-interacting dimensions, interference in "filtering" and speed gain in classification of correlated pairs correlated highly with the degree to which the dimension irrelevant to classification was more discriminable than the relevant dimension.

It was concluded that speeded classification performance is best predicted by the psychophysical structure of the stimulus set. The demonstrated relationship between classification reaction time and both interaction and relative discriminability of the dimensions suggested that the study of integrality can be beneficially redefined as a direct analysis of the psychophysics of dimensions.