Integrality over different paradigms: Card sorting and two-stimulus matching

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Orthogonal interference—indicating the cohesiveness between geometrical dimensions—was examined using two separate tasks: (1) card sorting and (2) two-stimulus matching requiring same/different responses. The card-sorting results of the present experiment were contrasted with the results of our previous research (1977, 1979) which used the two-stimulus matching task. Results were generally similar in that the orthogonal interference and, consequently, the degree of integrality/separability were the same for both tasks. Evidence was found for the emergence of a new nominal dimension. This and other results are only compatible with a weaker form of the global-to-local hypothesis of perceptual processing.

The study of the perceptual relationship between the “attributes,” or “dimensions,” that constitute a stimulus has led to the concepts of integrality and separability (e.g., Garner & Felfoldy, 1970; Lockhead, 1972). The typical test that reveals these concepts invites the observer to focus his attention on the dimension that determines category membership—this dimension is termed the relevant dimension—and, if possible, *not* to attend to any other (irrelevant) dimension. This report examines whether these concepts are equally valid for two separate tasks. The first task, used widely in this field, requires the subject to sort a pile of cards, one stimulus per card. The deck contains, say, 25 cards, and the subject speed-sorts them into two piles or categories. Studies with more technical sophistication do not use actual cards, but, for historical reasons, we prefer the term “card sorting” (cf. Felfoldy, 1974). The second task studied here is known as the two-stimulus matching task. Stimuli are presented in pairs and the subject bases his response on a comparison, or a match, between the stimulus of a pair. We will discuss these two tasks in order.

In card sorting, performance with a critical series of stimuli is contrasted with performance in a baseline-condition series of stimuli. The critical series requires the observer to treat stimuli that differ on the irrelevant dimension as identical. This secondary dimension varies orthogonally; that is, it is not possible to predict the state of the secondary dimension from the state of the relevant dimension, or vice versa. Orthogonal performance—the adjective “orthogonal” will be used to denote the critical series of stimuli in the two-stimulus matching task as well—would

be best when variations in the irrelevant attribute are simply not perceived. The ideal subject would simply focus on the relevant dimension, exclude the rest of the stimulus, and directly filter out the relevant from the whole. Bivalued dimensions reduce the number of effective stimuli with a factor two, since stimuli differing on the irrelevant dimension are then perceived as identical. This reduction in stimulus uncertainty improves performance, and the expectation is that the sorting times are identical to the baseline series in which the irrelevant dimension was kept fixed.

When, however, the subject fails to consistently focus on the relevant dimension, he can still perform the task, since the attentional failure is compensated for by additional processing. It is commonly supposed that the subject is highly motivated to adopt the optimal strategy of focusing on the relevant dimension. But whether or not he will be *able* to do so depends on the perceptual relationship between the dimensions or attributes. Separable dimensions do permit a focusing strategy. They have no “cohesive forces” between them, and the subject can filter out at will. If, on the other hand, the dimensions are integral, the stimulus is initially perceived as a whole (a Gestalt, or a blob; Lockhead, 1972) and the subject must resort to additional processing to overcome the cohesive forces between the dimensions.

It has to be kept in mind that the baseline, or unidimensional, condition with which the orthogonal performance is contrasted, is *not* supposed to be sensitive to the between-dimension relation; in this condition, within a series of stimuli, only the relevant dimension varies and the other dimension is in a fixed state throughout. (It is therefore called a univariate or unidimensional series.) The unidimensional series has thus a smaller number of actual stimuli than the orthogonal series, and the strategy of focusing on the relevant dimension does not reduce the number

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of effective stimuli. Unidimensional performance will consequently always be at its optimum, whether focusing is possible or not.

Now we turn to the two-stimulus matching task, in which every trial presents two stimuli instead of one. Same/different matchings (are the two stimuli similar on the relevant dimension or not?) are used widely, but other matchings exist as well (for example, Dykes & Cooper, 1978). The use of same/different judgments has the advantage that there is a growing body of knowledge about the additional processing resorted to when integrality disables the use of the focusing strategy for "same" responses. Dixon and Just (1978) and others (Besner & Coltheart, 1975, 1976; Bundesen & Larsen, 1975; Larsen & Bundesen, 1978) present evidence that a to-be-matched stimulus pair that is "same" on the relevant dimension but different on the irrelevant dimension—we call this an *orthogonal* "same" pair—is *normalized* before being compared. This process, which compensates for irrelevant disparity, can be considered a form of mental transformation (cf. Shepard, 1975).

From these considerations, it follows that the orthogonal series should have an irrelevant disparity (i.e., the irrelevant dimension is "different"), while the unidimensional series should be without an irrelevant disparity. Orthogonal "same" pairs can thus be judged as "same" only when the subject normalizes the irrelevant disparity. The increased processing of the orthogonal series, or the orthogonal interference, within the "same" response of a two-stimulus matching task can thus be considered as an indication of whether the very "cohesive forces" supposed to hamper orthogonal card sorting are operative in opposition to a dimension-wise analysis in two-stimulus matching.

It must be mentioned that in previous research (Boer & Keuss, 1979; Keuss, 1977) we had the irrelevant level fixed for a particular stimulus within the pair. For example, in the orthogonal series, the *left* stimulus of the pair always had irrelevant level x1, while the right stimulus always had irrelevant level x2. Consequently, the irrelevant level for a particular stimulus was completely known in advance of all trials. Fixed presentation of the irrelevant level, rather than nonfixed or varied presentation of the irrelevant dimension, might have prompted selective attention. If so, this procedural detail should actually cause an underestimation of the integrality between relevant and irrelevant dimensions.

By contrast, somewhat less is known about the compensatory processes resorted to in an orthogonal card-sort task. Lockhead and King (1977) have shown that, on first sighting, the stimulus is recognized in terms of similarity to other potential stimuli (or, to use their terms, that the stimulus is located in a psychological, or similarity, space). It is not clear which processing ensues if stimuli occupying different positions in similarity space are assigned the same

response. "There must be additional internal processing to map two (or more) objects into a common response" (Lockhead & King, 1977, p. 442), but the nature of this process is as yet unknown. Comparing results from the card-sort task with results from the two-stimulus matching task might reveal whether the same sort of additional processing for integral dimensions is used in both tasks.

An additional point in need of clarification is that of the fixed serial availability of the dimensions that constitute a particular stimulus, that is, that perceptual processing of one particular dimension is always faster than the perceptual processing of the other dimension. Within the Garnerian system (Garner, 1976), based on card-sorting tasks, there is no provision for this situation, but that this state of affairs seemed to exist was the conclusion of our previous research (Boer & Keuss, 1979; Keuss, 1977). Judging an outline rectangle (the fastest dimension) was *not* interfered with by an inserted line (the slower dimension), while judging an inserted line was interfered with by the outline. The implication is thus an asymmetry in orthogonal interference: The slower dimension can be filtered out when judgment is of the faster dimension, but the faster dimension cannot be filtered out when judgment is of the slower dimension.

A fixed serial availability of dimensions has also some implications for *correlated* card-sort series. The dimensions of such a correlated series are combined with 100% redundancy. This leaves it to the subject to decide how to categorize: by dimension x, by dimension y, or by both. A redundancy gain relative to the unidimensional series is taken as another sign of integrality. Only if the dimensions cannot be used simultaneously will the subject fail to profit by redundancy in the correlated series.¹ This is the case when the dimensions are separable and also when one dimension is always faster than the other dimension, as in a situation of fixed serial availability. This leads to two predictions: (1) a redundancy gain relative to unidimensional series when judging is by the inserted line, and (2) no redundancy gain when judging is by the outline form.

The experiment uses a card-sort task, correlated series included. The results can be compared with the results of previous work in which the to-be-matched pair was presented simultaneously (Keuss, 1977; and the simultaneous condition of Boer & Keuss, 1979). Stimuli are, of course, the same in both paradigms.

METHOD

Subjects

Six university students (one female) participated as paid volunteers.

Stimuli and Apparatus

The subject sat at approximately 50 cm from the screen of a Tektronix 611 display unit, which, except for a 4 × 5 cm space, was covered. The display (P31 coated) was slightly below eye level

and was used in nonstore mode. Stimuli appeared as yellowish-green outlines on a dark-gray background. A stimulus subtended a visual angle of about 1 deg 2 min. Its construction time and refresh rate were 6 msec.

Responses were made by using two conventional response buttons that were connected to microswitches. The buttons were mounted on a panel below the display unit. Depression of either button stopped stimulus presentation. Reaction time was recorded with millisecond accuracy by means of a KW8IE real-time clock. A PDP-8/1 computer controlled the experiment.

All stimuli were rectangles varying dichotomously within any 240-trial series in either one or both dimensions (see Figure 1). During a stimulus series, the upper left corner of the display held the stimulus exemplar(s) belonging to the left-response category. Similarly, the upper-right corner of the display held the exemplar(s) belonging to the right-response category. The exemplars were drawn as black outlines on white index cards and were six times larger than the actual stimuli.

Conditions. The dichotomic dimensions used were size and form of an outline rectangle and orientation of a line inserted in the rectangle. The two levels of the size dimension were small/large, and the two levels of form and orientation were, in order, lying/standing and horizontal/vertical. There were three main conditions: SF (stimulus set: size and form), OF (orientation and form), and OS (orientation and size). Each set consisted of four stimuli. Figure 1 shows them in 2 by 2 matrices. The four stimuli of SF were: small, lying (A); large, lying (B); small, standing (C); and large, standing (D) (the letters A-D refer to the identification labels in Figure 1). The four stimuli of OF were: horizontal, lying (E); vertical, lying (F); horizontal, standing (G); and vertical, standing (H). The four stimuli of OS were horizontal, small (J); vertical, small (K); horizontal, large (L); and vertical, large (M).

Sorting the stimuli of any main condition could be done by each of the constituent dimensions. Stimuli in a different *column* of a 2 by 2 matrix could be mapped to different responses (e.g., A and C vs. B and D) or stimuli in a different *row* could be mapped to different responses (e.g., A and B vs. C and D). Sorting was by size in condition SF and by orientation in conditions OF and OS when *column* membership was critical. Sorting was by form in conditions SF and OF and by size in condition OS when *row* membership was critical.

Any stimulus of a 2 by 2 set for a particular main condition could occur from trial to trial in the orthogonal series of that condition. Sorting was by one of the constituent dimensions, as indicated by the instructions. Only *two* of the set of four stimuli could occur in a particular unidimensional or correlated series. In a unidimensional series, one of the dimensions was held constant while the other dimension was varied. (This excluded one row or one column of the matrix, and sorting was, of course, by the dimension that varied.) There were thus four unidimensional series in each main condition: In condition SF there was an A vs. B series and a C vs. D series (both sorted by size) and an A vs. C series and a B vs. D series (both sorted by form). In a correlated series, both dimensions varied again, but in a perfectly correlated fashion. This excluded either

the major or the minor diagonal of the matrix. There were thus two correlated series in each main condition: for example, an A vs. D series and a B vs. C series. Sorting was by either dimension or by both, as the subject preferred.

Procedure

All subjects were presented all series of the main conditions in different random orders. Each subject ran through nine 1.5-h individual sessions, three per main condition. A three-session block for a particular main condition was completed before another block for another condition was run. The first session of a three-session block was used to familiarize the subject and was not further analyzed.

Each series consisted of 240 trials. A programming device selected the stimuli in a completely random fashion. The least significant two bits of the reaction time (msec) determined the next stimulus. Depression of either button stopped stimulus presentation. The interval between the response and the construction of the next stimulus was .5 sec. This was lengthened to 1.5 sec when an error was made. The lengthened interval began with the sounding of a 200-msec buzzer and ended with an erase-the-screen flash.

The subject was instructed to avoid errors and to react as quickly as possible. Each session began with two warm-up series that were randomly selected from the experimental series. After a 5-min break, the subject began with the eight experimental series (two correlated, four unidimensional, and two orthogonal). One series of 240 items lasted about 3-5 min, on the average. Between series there was 2-min rest. After four experimental series, the rest was lengthened to 20 min. Stimulus-to-response mapping—e.g., press left for the small stimulus and press right for the large stimulus—was reversed for the remaining four series.

RESULTS

Error responses were few: 2.1%. Incidence of errors was tested separately and in parallel with RT. Figure 2 shows, for each main condition (SF, OF, and OS), mean RTs and percent errors of the two correlated, four unidimensional, and two orthogonal series. Within a main condition, there was no RT/error difference between any pair of unidimensional series that were sorted by the same dimension [largest $t(5) = .438$]; neither was there a difference between any pair of correlated series [largest $t(5) = 1.710$]. Data were consequently collapsed across such pairs.

Redundancy Gains

Per main condition, the superiority of correlated xy sorting over unidimensional sorting (or the redundancy gain) was tested twice—once relative to the x-sorted unidimensional data and once relative to the y-sorted unidimensional data. In condition SF, both tests reached significance in the predicted direction [smallest $t(5) = 3.219$, $p < .02$], but in condition OF, both tests failed to reach significance. Correlated sorting even tended to be inferior to sort-by-form unidimensional performance [$t(5) = -1.684$, $p < .15$]. In condition OS, there was a redundancy gain relative to the orientation-sorted unidimensional series [$t(5) = 4.422$, $p < .01$]. The gain relative to the size-sorted series was apparent only in the error frequency, which was significantly less in the correlated series [$t(5) = 3.341$, $p < .02$].

Figure 1. The three groups of four stimuli in the card-sort task. In left-to-right order, the groups were used in conditions SF, OF, and OS. (The labels have been added for identification. All stimuli are drawn on the same scale. The actual sizes of the stimuli were as follows: A and C measure 4.9×7.3 mm; B and D, 7.3×10.8 mm; E-H, 6.0×9.0 mm; J and K, 6.0×6.0 mm; and L and M, 9.0×9.0 mm.)

Figure 2. Reaction time and percent error as a function of the way in which the dimensions of a particular main condition were combined (correlated, unidimensional, or orthogonal).

Orthogonal Interferences

Within a main condition, the x-sorted orthogonal series was compared with the two x-sorted unidimensional series, and the y-sorted orthogonal series was compared with the two y-sorted unidimensional series. All six such tests, two per main condition, showed significant interference [smallest $t(5) = 2.153$, $p < .05$]. In general, more errors were observed in the orthogonal than in the unidimensional series, although significance was reached only in condition OF [smallest $t(5) = 2.162$, $p < .025$]. It appears that in condition SF orthogonal interference was strongest when form instead of size had to be judged [$F(1,5) = 8.17$, $p < .05$]. In condition OF, orthogonal interference was strongest when orientation, rather than form, was to be judged [$F(1,5) = 10.39$, $p < .025$]. In condition OS, orthogonal interference did not depend on the dimension of relevance ($F < 1$).

For both OF and OS, sorting by outline—either size or form—was faster than sorting by orientation [$F_s(1,5) = 37.93$ and 29.27 , respectively; $p < .005$].

Card Sorting vs. Two-Stimulus Matching

Table 1, last column, shows all six orthogonal interferences. They can be compared with previous two-stimulus matching tasks, the results of which are given

in the first two columns. Note that the first two columns agree on the rank order of the interferences and not on strength per se (the probability of obtaining the same order of six combinations twice is 1:720, or less than .0014). Therefore, we prefer to compare rank orders rather than absolute results. The order of orthogonal interference of the present card-sort task was similar to the order obtained with the two-stimulus matching tasks in that the two combinations with strongest interference were, respectively, orientation with irrelevant form and form with irrelevant size (the probability of this agreement is 1:30, which is less than .04). The difference between tasks is that the two combinations of relevant outline (size or form) and irrelevant orientation showed interference only in the card-sort task.

DISCUSSION

There appeared to be considerable agreement between the two-stimulus matching task and the card-sort task. Mutual integrality between size and form was observed in both paradigms. The asymmetric integrality between outline (size or form) and inserted line (orientation) was, to some degree, also observed in the card-sort task. In the two-stimulus matching

Table 1
Orthogonal Interferences (in Milliseconds) Measured in the
"Same" Response of Two-Stimulus Matching Tasks
(Boer & Keuss, 1979; Keuss, 1977) and in the
Card-Sort Task of the Present Experiment

Main Condition	Dimension		Two-Stimulus Matching		Card Sorting
	Relevant	Irrelevant	Keuss	Boer & Keuss	Present Experiment
SF	S	F	65	30	16
	F	S	76	49	40
OF	O	F	79	73	64
	F	O	11	5	34
OS	O	S	26	9	19
	S	O	2	0	12

Note—The stimuli of a to-be-matched pair were always presented simultaneously and side by side. S = size; F = form; O = orientation.

task, irrelevant variation in the inserted line was ignored, whereas irrelevant outline variation could not be ignored. In the card-sort task, on the other hand, this asymmetry was observed in the *amount* of interference: irrelevant variation was harder to ignore in the outline than in the inserted line. This finding could point to a greater sensitivity for interference of the card-sort test. But it could also point to slightly different modes of perceiving, implying that the "cohesive forces" between dimensions depend, to some degree, on the paradigm used. The fact that the individual trial in the one task requires a judgment about a *pair* of stimuli and that the other task requires judgments only about single stimuli may have something to do with the difference in perceptual processing. In the main, however, it can be said that the meaning of integrality is the same over different paradigms.

Condition OF offers evidence for a new nominal dimension (cf. Garner, 1976), based on the way in which orientation and form are combined. The main reason to decide upon the new nominal dimension is the "redundancy loss" observed in condition OF. Inferior correlated sorting suggests that the correlated OF stimuli are more similar and, hence, more difficult to discriminate than are unidimensional sort-by-form OF stimuli. This could be caused by the way in which the inserted line was perceived. It can be seen in Figure 1, stimuli E-H, that form and inserted line have something in common inasmuch as the labels horizontal/vertical and lying/standing can, in principle, describe both the form of the rectangle and the orientation of the inserted line. For instance, the line of stimulus E can be said to be consistent with the state of the rectangle, since both dimensions are "horizontal" (or "lying"). Similarly, the line of stimulus H is consistent with the surrounding rectangle, since both are "standing" (or "vertical"). The lines of stimuli F and G are, by contrast, in conflict with their rectangles, since

the position of the line is not the same as that of the rectangle.

It follows that the lines in the correlated pair E/H are similar—both consistent to the rectangle—much as the lines in the other correlated pair E/G are conflicting. This renders discrimination in the correlated series more difficult. A unidimensional pair, on the other hand, with a conflicting line in the one stimulus and a consistent line in the other stimulus, is more easy to discriminate. (An additional indication for the new nominal dimension is observed in the orthogonal OF series. In both series, sorting conflicting stimuli was significantly more difficult than sorting consistent stimuli.³) It should be noted that we do not wish to convey the idea that the subjects actually used verbal labels. This question, interesting as it may be, is beyond the scope of the present study.

There was some evidence for an outline-first availability. Sorting by outline—orthogonal or unidimensional—was faster than sorting the same stimuli by orientation of the inserted line. There are, however, two aspects of the data that are in contrast with outline-first availability: (1) sorting by outline was interfered with by the inserted line, and (2) the emergence of the new nominal dimension, mentioned in the previous paragraph. If relevant outline is perceived first, why should it combine with the interior to form a new nominal dimension?

In Boer and Keuss (1979), we originally suggested that White's (1976) outside-to-inside iconic scanning might be the mechanism behind the outline-first availability. But, as Petersik (1977) suggested, an equally valid explanation is that low spatial frequencies are analyzed before higher frequencies, and an outline has a lower spatial frequency than the interior. A more general theory is that the buildup of perceptual information proceeds from global to local (Bouma, 1971; Eriksen & Schultz, 1978; Navon, 1977), and gross contour information line outline form can be perceived as being global and details such as an inserted line as being local. When judgment about a local aspect is required, the subject has to wait until the "icon" (in the sense of Eriksen & Schultz, 1978) is completed, so the globals are inevitably taken in. On the other hand, when judgment is about a global aspect only, the icon can be used as soon as the global aspects are taken in, which occurs before the moment that the locals are taken in.

Our study thus is only compatible with some weaker form of the global-to-local hypothesis; that is, the global aspects are *usually but not always* taken in before the local aspects are.

Doubts have recently arisen about the generality of the global-to-local hypothesis (Martin, 1979; Pomeranz & Sager, 1975), but caution in interpreting the negative evidence for the global-to-local hypothesis is recommended. When looking for global precedence, one

often tries to show that irrelevant global variation affects local judgments (Kinchla & Wolfe, 1979; Martin, 1979; Navon, 1977). This finding, most clearly visible as an interference effect, indeed indicates that perception of the global aspect did occur. Such interference is, however, not established as the unavoidable consequence of global perception. Separability is consistent with the idea that perception of one aspect can occur without affecting the perception of other aspects. The absence of interference does not guarantee the absence of perception! The researcher who wants to test for global precedence might want to keep this thought in mind.

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NOTES

1. It is implied that a difference along two dimensions will be greater than a one-dimensional difference. Lockhead and King (1977) have shown that this statement is not always true and that a deliberate choice of the dimensions and their levels can result in a situation of near identity of two stimuli that differ along two dimensions. (Of course, the result will be a redundancy loss instead of a redundancy gain.) We think, however, that this is an exception rather than the rule.

2. Further confirmation that conflict stimuli were more difficult to classify was obtained in three follow-up experiments, the subjects of which sorted only the unidimensional and the orthogonal series of condition OF by form [$t(7) = 2.384$, $p < .025$; $t(5) = 4.113$, $p < .005$; and $t(7) = 2.844$, $p < .025$].

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